Ptolemaeus
Arabus et Latinus

PTOLEMY'S COSMOLOGY IN GREEK AND ARABIC: THE BACKGROUND AND LEGACY OF THE *PLANETARY HYPOTHESES*

Paul Hullmeine

BREPOLS

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Ptolemaeus Arabus et Latinus

Texts

Volume 4

PAL Ptolemaeus Arabus et Latinus

Ptolemaeus Arabus et Latinus (PAL) is a project of the Bavarian Academy of Sciences and Humanities and the University of Würzburg. As part of the Academies' Programme, PAL is jointly funded by the Federal Republic of Germany and the Free State of Bavaria.

PAL is sponsored by the Union Académique Internationale (UAI).

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An earlier version of this book was accepted as a doctoral dissertation at the Ludwig-Maximilians-Universität in Munich on 9 July 2021.

Cover design by Hilde Verhelst, T'Hi, Lier, Belgium.

Cover illustrations:

Woodcut (detail) from *La geografia di Ptolemeo Alessandrino*, Venice, 1548. Copy from Munich, Bayerische Staatsbibliothek. Gemini (detail) from al-Ṣūfī's *Book of Constellations* (Arabic), MS Paris, Bibliothèque nationale de France, arabe 5036, fol. 126v.

D/2024/0095/219

ISBN 978-2-503-60717-7

Printed on acid-free paper.

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Abbreviations

Bibliographical details of the editions of the following works that are abbreviated in the notes are provided in the bibliography.

(ps.-)Aristotle

An. Post.	*Posterior Analytics* (ed. Ross)
An.	*On the Soul* (ed. Ross)
Cael.	*On the Heavens* (ed. Moraux)
Gen. Anim.	*On the Generation of Animals* (ed. Lulofs)
Gen. et Corr.	*On Generation and Corruption* (ed. Rashed)
Inc. Anim.	*On the Progression of Animals* (ed. Jaeger)
Metaph.	*Metaphysics* (ed. Ross)
Meteor.	*Meteorologica* (ed. Fobes)
Mot. An.	*On the Movement of Animals* (ed. Primavesi)
Part. Anim.	*On the Parts of Animals* (ed. Louis)
Phys.	*Physics* (ed. Ross)
Spir.	*On Breath* (ed. Jaeger)

Philoponus

In Meteor. Commentary on Aristotle's *Meteorology* (ed. Hayduck)

(ps.-)Plato (ed. Burnet)

Epin.	*Epinomis*
Leg.	*Laws*
Phd.	*Phaedo*
Phil.	*Philebus*
Rep.	*Republic*
Tim.	*Timaeus*

Proclus

In Rep.	Commentary on Plato's *Republic* (ed. Kroll)
In Tim.	Commentary on Plato's *Timaeus* (ed. Diehl)

Ptolemy

Plan. Hyp.	*Planetary Hypotheses* (ed. in the present volume)

Simplicius

In Cael.	Commentary on Aristotle's *On the Heavens* (ed. Heiberg)
In Phys. I–IV	Commentary on the first four books of Aristotle's *Physics* (ed. Diels)
In Phys. V–VIII	Commentary on the last four books of Aristotle's *Physics* (ed. Diels)

Acknowledgments

This study is a revised version of my PhD dissertation, written at Ludwig-Maximilians-Universität, Munich. First and foremost, I want to express my gratitude to my supervisors Peter Adamson and Dag Nikolaus Hasse, who encouraged and supported me throughout the past years, taking care of many details as well as the wider picture of my argument. I could not ask for better supervisors, and for this I will always remain grateful. I am also delighted to thank Kärin Nickelsen who joined the committee of my defense rather spontaneously and provided me with valuable references to Copernicus.

I wrote my thesis under the aegis of *Ptolemaeus Arabus et Latinus*, hosted by the Bavarian Academy of Sciences and Humanities. I want to thank the research leaders Benno van Dalen and David Juste, both for their help whenever I encountered some problems in my research as well as for making the offices of *PAL* such an amazing place to work. In particular, Benno van Dalen offered detailed criticism on earlier versions of my translation and led me through the technical aspects of publishing my thesis. José Bellver guided me in the first steps of my dissertation, and his successor as postdoctoral researcher, Pouyan Rezvani, was always there for me when I had a question on an obscure Arabic passage (mostly in works by our shared friend al-Bīrūnī).

I also benefitted a lot from the many seminars, reading groups, workshops, and conferences held at the *Munich School of Ancient Philosophy* (LMU Munich). I want to thank especially Rotraud Hansberger for continuously improving my knowledge of Arabic. I also had the privilege to visit the *Warburg Institute* in London, where I had the most pleasant stay and profited from the rich and fascinating collection of its library. I had the opportunity to show my early work on the edition and translation to Charles Burnett, who provided me with many valuable comments and much encouragement. Shortly before the submission, Jan P. Hogendijk offered his help on the edition and translation and came back to me only after two weeks with many corrections and most helpful suggestions. Abdurrahman Ali Mihirig took the burden upon himself to revise my English translation and Claudia Dorl-Klingenschmid agreed to take a close look at the bibliography; both of them saved me from many errors and inaccuracies. In addition, I thank Tommaso Alpina and Damien Janos for providing me with pre-publication versions of their articles, and Guillaume Loizelet and Sajjad Nikfahm-Khubravan for sharing their dissertations with me. I also thank Megan Foster, who took it upon herself to proofread the entire book.

Such a long-term work would also not have been possible without the support of my friends and family. Especially my sisters and parents were a constant source of support whenever I needed it. I want to thank them for enduring long lessons of Latin and Greek with me and for teaching me how to correctly pronounce Sartre. I cannot fully express the gratitude I feel for Martina, who made me feel at home in Munich from the first day. Without her love, patience, and belief in me when I was in doubt, I could never have finished this work. It is my greatest pleasure to dedicate this book to my entire family.

I: Introduction

There are many facets of the important status of Claudius Ptolemy (fl. second century AD) in the history of science and philosophy. Still to this day, he is well-known for his works on mathematical astronomy, astrology, geography, optics, and harmonics. For many centuries and throughout various cultures and societies, he was one of the main authorities in these fields. The *Planetary Hypotheses* cover a further aspect of ancient science within his œuvre, namely the question of how to conceive of celestial motions in physical terms. Ptolemy tackles the arrangement of the celestial spheres, their number, and the way in which they interact with each other. In doing so, he dives deeply into questions that are not so much the object of mathematical astronomy, but rather fall under what is usually called cosmology. As far as we know, in the time before him, these questions had been studied in works on natural philosophy or metaphysics, which is nicely illustrated by the fact that Ptolemy refers in Book II to both Plato's *Republic* and Aristotle's *Metaphysics*. This connection between the astronomical theories from the *Almagest*, on which Ptolemy relies in the *Planetary Hypotheses*, and accounts from natural philosophy and metaphysics is unique within Ptolemy's works, with the exception perhaps of the first chapters of the *Almagest*.[1] When we acknowledge that Ptolemy indeed turns to cosmological issues, we might wonder what he thinks is the method of these issues: is it still observation and mathematical calculation, as in the *Almagest*, or does one have to rely on further methods and principles that are already known from other sciences as well? This question of the approach towards cosmological issues will be one of the most important aspects of the present study.

A project on Ptolemy's cosmology needs to rely on an established text of the *Planetary Hypotheses*. Despite previous partial editions and translations, we still lacked a complete edition of the Arabic text until now, which is the only complete witness, since only the first part of Book I has survived in Greek. This is also the reason why there is yet no detailed account of the theories presented in Book II in particular, which is arguably the most complicated part of this treatise. Therefore, this study contains a critical edition and modern translation of the *Planetary Hypotheses*. The English translation is accompanied by a number of brief notes that mainly serve the purpose of providing references to other ancient and medieval works. My commentary on the edition and translation has the purpose of offering a more detailed analysis of the content, especially of chapters that are not discussed in detail in Chapters II and III. I divide the chapters into thematic groups and briefly discuss their content and previous modern scholarship. I pay special attention to the purpose of each

[1] For the scanty biographical evidence and an overview of his writings, see Feke and Jones, 'Ptolemy', and Jones, 'The Ancient Ptolemy'. For previous assessments of Ptolemy's cosmology, see, most importantly, Taub, *Ptolemy's Universe*, Murschel, 'Structure and Function', and Feke, *Ptolemy's Philosophy*, especially pp. 176–200.

section within Ptolemy's argument. In this way, the commentary is expected to help the reader to understand the line of arguments throughout the entire work. Of course, I also devote sections to an explanation of especially difficult passages. Although it is not the main focus of the present study, in this commentary, I refer to explanations of Ptolemy's mathematical calculations and critical assessments of the parameter values we find in the Greek and Arabic versions in previous modern research.[2] Unlike these previous studies, my focus lies on the epistemological and physical accounts discussed and applied by Ptolemy.

Thus, this study contains not only the edition and translation, but also provides an interpretation of the transition from Ptolemy's mathematical theories to a cosmological account. In the process of editing, translating, and commenting, it became clear that there are two subjects that deserve special attention, not only because they are fundamental to an understanding of Ptolemy's cosmological project, but also because it is through these two subjects that we can follow the later reception of the *Planetary Hypotheses*. The first is a methodological and epistemological issue. In the beginning of Book II, Ptolemy distinguishes between the mathematical and the physical sciences and devotes some of the following chapters to the latter. Ptolemy here leaves the ground of mathematical and geometrical calculations from the *Almagest* and elaborates on different arguments from natural philosophy in order to arrive at a possible physical explanation of his mathematical models. The discussion has strong epistemological implications when we read it together with *Almagest* I.1, where Ptolemy claimed that only mathematics provides us with certain knowledge and that physics is inferior to it because it deals with ever-changing objects and thus offers merely conjectural knowledge. This distinction resurfaces in the *Planetary Hypotheses* whenever Ptolemy alludes to arguments from natural philosophy, most obviously in his discussion of planetary distances and sizes in Book I and the cosmological issues in Book II such as the shape of the spheres. This is why Chapter II of the present study deals with Ptolemy's epistemology and with his theories of nested spheres and sawn-off pieces.

The second main issue is Ptolemy's dynamic theory: how do celestial motions come about? How do planets, stars, and spheres interact with each other? Are the spheres mechanically connected with each other or is there another means of transmission at work that uses philosophical concepts such as soul, nature, and desire? Ptolemy addresses these questions in the first chapters of Book II. Although this investigation takes its starting point from the question of the shape and number of celestial bodies, it has a different context from the arguments of the epistemological discussion that I address in Chapter II. Ptolemy's main idea is the analogy of the planetary systems and birds, in which the planet takes the position of the bird's heart as the origin of an impulse to move, and the spheres are compared to the bird's limbs that perform these motions. The background of this

[2] Most importantly, these studies are Neugebauer, *A History*, pp. 900–17, Swerdlow, *Ptolemy's Theory*, and Duke, 'Mean Motions'.

theory is formed by discussions on the natural motion of the fifth element, aether, and of motions that are induced by souls, both in the sublunar as well as in the supralunar world. I investigate this second main issue in Chapter III. In this way, the *Planetary Hypotheses* serve as the main point of reference for Chapters II and III, which contain an investigation of its cosmological doctrines and, in the next step, of their reception in later traditions, most importantly Greek authors in late antiquity and Arabic works from the Middle Ages.

In what follows, I provide separate introductory remarks to the main parts of my study. First, I briefly give an outline of the history of the text and previous modern research before I add some remarks concerning the Arabic version and its relation to the extant Greek fragment, and lay out the principles of my edition. I conclude the introduction by presenting the scope of Chapters II and III, which cover the late ancient and medieval reception of the *Planetary Hypotheses*.

The *Planetary Hypotheses*

History of the Text and its Authenticity

We know virtually nothing about the exact circumstances of the composition of the *Planetary Hypotheses*. In addition to the ascription to Ptolemy, which can be defended on textual grounds, we only know that Ptolemy wrote it at a comparatively late stage of his career, as it contains back-references to the *Almagest*.[3] On the other hand, there is much more to say about the history of the extant versions and their reception until modern times. The extant Greek manuscripts break off in the middle of Chapter I.14, and thus the last part of Book I as well as the entire Book II are missing. Of these missing parts, we only have short Greek fragments from Chapters I.17 and II.12 in Proclus' commentary on the *Timaeus* and in Simplicius' commentary on *On the Heavens*.[4] These passages correspond closely to the extant Arabic version and thus confirm its authenticity. In some Greek manuscripts, however, the text continues until the end of Chapter I.14. This additional part is a literal copy from the analogous section of the previous Chapter I.13, with the exception that the mathematical values were omitted. According to Fabio Acerbi, it is 'very likely' that this revision was made by John Abramius in the 14th century AD.[5] All three medieval Latin

[3] On the dating and chronology of Ptolemy's works, see Feke and Jones, 'Ptolemy', pp. 198–201, and Jones, 'The Ancient Ptolemy', pp. 25–27. See also the table on Ptolemaic language in Jones, 'The Ancient Ptolemy', p. 21.

[4] Proclus, *In Tim.*, Vol. 3, pp. 62:24–63:11, and Simplicius, *In Cael.*, p. 456:22–27 (and p. 506:16–20 for a paraphrase of a part of Chapter II.6). See also Jones, 'The Ancient Ptolemy', pp. 20–22.

[5] See Acerbi, 'Byzantine Recensions', p. 172, with reference to Pingree, 'The Astrological School', p. 202. On the basis of this revision, Heiberg initially distinguished between two families of Greek manuscripts. See his editorial preface in Ptolemy, 'Hypotheseōn', pp. clxvi–clxxiv.

translations depend on this revised Greek version. While the two earlier translations from the 16th century AD also omit the values for the part added by John Abramius, John Bainbridge, in his edition of the Greek text and his Latin translation from AD 1620, added these values from an unknown source, possibly just providing the results of his own calculations.[6] Perhaps Bessarion (d. AD 1472) played a role in this story, as he was in possession of three Greek manuscripts containing the *Planetary Hypotheses*, which he presumably took with him from Byzantium to Italy in the 15th century AD and thus roughly a century before the first two Latin translations were made.[7] Be that as it may, we can clearly see that the entire extant Greek and Latin tradition relies on one truncated version of the *Planetary Hypotheses* that made its way to Byzantium, while the complete version was extant in the Middle Ages only in the Islamic world and through the Arabic–Hebrew translation by Kalonymus ben Kalonymus (early 14th century AD) in medieval France.[8]

Modern Research

The modern history of research on the *Planetary Hypotheses* saw some surprising turns. At the beginning of the twentieth century, an edition of the Greek text was published by Johan L. Heiberg, which was accompanied by a German translation by Ludwig Nix that was finished after his death by Frants Buhl and Poul Heegaard.[9] This German translation, however, also covers all of Book II because it is based on the two Arabic manuscripts and not the Greek text. It tends to be a very literal rendering of the Arabic version, with the downside of being sometimes even harder to follow than the original Arabic text. Apparently, Buhl and Heegaard did not notice that Nix's initial translation lacked the second half of Book I, which is, in fact, one of the most important parts of the *Planetary Hypotheses*, namely a discussion of planetary distances and sizes. Thus, this part remained unstudied for another six decades. Bernard R. Goldstein noted this omission after previous findings on the reception of Ptolemy's parameters in al-Bīrūnī by Willy Hartner. Finally, in 1967, Goldstein published an English translation of this missing part (Chapters I.15–21 in the present edition), together with a facsimile edition of one of the two complete manuscripts and the variant readings from the other.[10] Apart

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[6] On the Latin versions, see David Juste's entries on the website of *Ptolemaeus Arabus et Latinus*: David Juste, 'Ptolemy, *Planetary Hypotheses*' (update: 19.12.2020), *Ptolemaeus Arabus et Latinus* at https://ptolemaeus.badw.de/work/141 (last consulted on 7.1.2021).

[7] See Shank, 'Regiomontanus versus George of Trebizond', p. 338 n. 105. Two of these copies (MS Venice, Biblioteca Nazionale Marciana, gr. Z. 323 and 324) contain Abramius' version, whereas the third one (gr. Z. 314) was apparently copied from MS Vatican, Biblioteca Apostolica Vaticana, gr. 1594 and only contains the shorter version. See Acerbi, 'Byzantine Recensions', p. 163.

[8] Through an inventory of his personal library, we know that Gersonides owned a copy of this Hebrew translation. See Glasner, 'Gersonides on Simple and Composite Movements', p. 568 n. 132.

[9] See Ptolemy, 'Hypotheseōn', especially pp. ix–x for the circumstances of the German translation.

[10] See Hartner, 'Medieval Views', and Goldstein, 'The Arabic Version'.

from a complete Spanish translation published by Eulalia Pérez Sedeño,[11] the next important publication was Régis Morelon's edition and French translation of Book I of the Arabic text, for which he also consulted the Hebrew version.[12] The present edition and translation benefitted much from this edition. The main reason why I include a new edition of Book I is to have the Arabic text of both books and thus the fullest version of the *Planetary Hypotheses* finally printed and studied in its entirety in one publication.

Recently, the *Planetary Hypotheses* became apparently irresistible to PhD students, as four doctoral theses (including the present one) have been devoted to this text since 2011. Elizabeth A. Hamm made a new English translation of the Greek version that is accompanied by a thorough commentary.[13] The Arabic reception of the *Planetary Hypotheses* was studied by Guillaume Loizelet, who focused on the chapters on planetary distances and sizes, and Sajjad Nikfahm-Khubravan, who dealt with Ptolemy's latitude theory and even appended a critical edition of the Arabic text of Chapters I.10–15.[14]

The Arabic Translator(s)

Regarding the Arabic translation of the *Planetary Hypotheses*, we do not have much information on the date or translator. In the Leiden manuscript (MS Leiden, Universiteitsbibliotheek, Or. 180, f. 2^r), Ṯābit ibn Qurra is credited as the author of the revision extant in this witness. This ascription receives even more importance in light of the fact that the earliest known reference to the *Planetary Hypotheses* comes, in fact, from Ṯābit ibn Qurra and thus from the ninth century AD. In his work on the visibility of the lunar crescent, Ṯābit refers to the *Planetary Hypotheses* under the following title: *Fī Uṣūl ḥarakāt al-kawākib al-mutaḥayyira* (*On the Principles of the Motions of the Wandering Planets*).[15] This title differs significantly from the title used in subsequent times. In later authors, the work appears either as *Kitāb al-Iqtiṣāṣ* (*Book of the Report*) or as *Kitāb al-Manšūrāt* (*Book of the Sawn-off Pieces*).[16]

[11] See Ptolemy, *Las hipótesis*; cf. the critical remarks in Toomer, 'Review: Las hipótesis'.

[12] Ptolemy, 'La version arabe du *Livre des Hypothèses*'. In addition, Chapter I.21 was edited and translated into French by Roshdi Rashed (see Rashed, 'Fūthīṭos (?) et al-Kindī', pp. 558–59), and a part of Chapter II.12 by Roshdi Rashed and Erwan Penchèvre (see Rashed and Penchèvre, 'Ibn al-Haytham', pp. 120–26).

[13] Hamm, *Ptolemy's Planetary Theory*.

[14] See Loizelet, *Mesurer et ordonner*, and Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories*, especially pp. 565–81 for the partial Arabic edition.

[15] See Ṯābit ibn Qurra, *Œuvres d'astronomie*, p. 104:4–5. On the different titles in the Arabic tradition, see Morelon's introduction in Ptolemy, 'La version arabe du *Livre des Hypothèses*', pp. 8–9.

[16] The latter of these two refers to Ptolemy's theory of sawn-off pieces (*manšūrāt* in Arabic) from Book II; the former is an abbreviation of the more complete title that one finds in the Arabic manuscripts, namely *Kitāb fī Iqtiṣāṣ ǧumal ḥālāt al-kawākib al-mutaḥayyira* (*Book on the Report of the Summaries of the States of the Wandering Planets*) in the Leiden manuscript, and *Kitāb fī l-Hay'a al-musammā bi-l-iqtiṣāṣ* (*Book on the Configuration, called the Report*) in the London manuscript.

In the tenth century AD, Ibn al-Nadīm's *Fihrist* knows it as *Kitāb al-Iqtiṣāṣ aḥwāl al-kawākib* (*Book on the Report of the States of the Planets*).[17] In fact, the title given by Ṯābit is closer to the title we find in the Greek manuscript tradition, namely *Klaudiou Ptolemaiou hypotheseōn* (*tōn planōmenōn*) (*Ptolemy's Hypotheses of the Planets*), and Proclus and Simplicius knew it under the short title *hypotheseis*.[18] In the very first sentence of the *Planetary Hypotheses*, the Greek *hypotheseis* is translated into Arabic as *uṣūl*, which is the same translation as in the title given by Ṯābit. The fact that Ṯābit's title is closer to the Greek than the other later ones indicates that Ṯābit had access to an alternative title by the initial translator, or that he was familiar with the original Greek title of the *Planetary Hypotheses* and revised the Arabic translation on the basis of it. What can be established through Ṯābit's reference, however, is that the *Planetary Hypotheses* had already been translated by the ninth century AD.

Ṯābit's involvement in the extant version of the text has been doubted on account of the allegedly poor quality of the translation.[19] A detailed comparison of the extant part of the Greek text and its corresponding Arabic version does not confirm this impression. In the following, I highlight some of the most important results of such a comparison. Needless to say, this comparison is based on the extant truncated version of the Greek text, which means that Ptolemy's version might have looked different. Nevertheless, the correspondence between the two versions suggests the general stability of the text. However, these results may merely be of a provisional nature. For example, in order to confirm whether Ṯābit ibn Qurra was involved in the translation process, we would need to have a better idea of the revisions he made for his version of the translation of the *Almagest* by Isḥāq ibn Ḥunayn. We still lack complete editions of the surviving Arabic versions of the *Almagest*.[20] The following observations on the translation of the *Planetary Hypotheses* can therefore serve as another small step towards a better understanding of the way in which the translators worked.

I take a closer look at Chapter I.1 of the *Planetary Hypotheses* as an example of the translator's method. For a better orientation, I divided the text into four sections. Passages in the Greek and Arabic versions that are more extensive than, or are not found in, the other version have been underlined in the text as well as the translation.[21]

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[17] Ibn al-Nadīm, *Kitāb al-Fihrist*, p. 268:11.

[18] On the Greek title, see Swerdlow, *Ptolemy's Theory*, pp. 20–21.

[19] See, for example, Murschel, 'Structure and Function', p. 34.

[20] This will soon change thanks to the effort of the *Ptolemaeus Arabus et Latinus* team. For the different versions of the Arabic *Almagest*, see Kunitzsch, *Der Almagest*, pp. 15–82 and, more recently, Grupe, 'Thābit ibn Qurra's Version'.

[21] Greek text cited following Ptolemy, 'Hypotheseōn', pp. 70:3–72:5 (cf. the English translation in Hamm, *Ptolemy's Planetary Theory*, pp. 44–45). For the Arabic text, see below *Plan. Hyp.* I.1, pp. 222:4–224:6.

[1] Τὰς ὑποθέσεις, ὦ Σύρε, τῶν οὐρανίων φορῶν ἐν μὲν τοῖς τῆς μαθηματικῆς συντάξεως ὑπομνήμασιν ἐφωδεύσαμεν διὰ λόγων ἀποδεικνύντες καθ’ ἑκάστην τό τε εὔλογον καὶ τὸ πανταχοῦ πρὸς τὰ φαινόμενα σύμφωνον πρὸς ἔνδειξιν τῆς ὁμαλῆς καὶ ἐγκυκλίου κινήσεως, ἣν ἀναγκαῖον ἦν ὑπάρχειν τοῖς τῆς ἀϊδίου καὶ τεταγμένης κινήσεως κεκοινωνηκόσιν καὶ κατὰ μηδένα τρόπον τὸ μᾶλλον καὶ τὸ ἧττον ἐπιδέξασθαι δυναμένοις·

إنّا قد وصفنا الأصول التي عليها مبنى الحركات السماوية يا سوري في الأقاويل التي وضعناها في الأمور التعليمية وأتينا في ذلك بقياس برهاني وبيّنّا الشيء الذي يجب أن يكون كلّ واحد منها موافقًا فيه لما يظهر لنا والشيء الذي لا يوافقه فيه لنبيّن بهذا أمر الحركة المستديرة اللازمة ضرورة للأشياء التي تعمّها الطبيعة الثابتة على حال واحدة المستوية النظام وإنّه لا يمكن فيها قبول الزيادة والنقصان بنوع من الأنواع البتّة

We have described the principles on which the heavenly motions rely, oh Syrus, in the account laid down by us about the mathematical issues [i.e. the *Almagest*]. In this course, we have brought forward a demonstrative proof and we have shown the aspect in which each of the [motions] is necessarily in agreement with what is apparent to us, and the aspect in which it is not in agreement, in order to show by this the case of the circular motion that necessarily belongs to the things to which the nature is common that stays in one condition and is regularly arranged. For it is not possible that [these things] receive an increase or decrease in any way.

[2] ἐνταῦθα δὲ προήχθημεν αὐτὸ μόνον ἐκθέσθαι κεφαλαιωδῶς καὶ ὡς ἂν μάλιστα προχειρότερον κατανοηθεῖεν ὑπό τε ἡμῶν αὐτῶν καὶ τῶν εἰς ὀργανοποιΐαν ἐκτάσσειν αὐτὰ προαιρουμένων, ἐάν τε γυμνότερον διὰ χειρὸς ἑκάστης τῶν κινήσεων ἐπὶ τὰς οἰκείας ἐποχὰς ἀποκαθισταμένης τοῦτο δρῶσιν, ἐάν τε διὰ τῶν μηχανικῶν ἐφόδων συνάπτωσιν αὐτὰς ἀλλήλαις τε καὶ τῇ τῶν ὅλων.

وأمّا في كتابنا هذا فإنّ غرضنا أن نضع فيه جمل هذه الأشياء التي ذكرناها فقط ليكون تصوّرها في أوهامنا وأوهام من أراد أن يعمل لها الآلات سهلًا وكذلك إن أراد مريد أن يحسب باليد فيعلم الموضع الذي انتهت إليه كلّ واحدة من الحركات وكذلك إن أراد أيضًا أن يجمع الحركات بعضها إلى بعض وإلى حركة الكلّ بمذهب المخانيقي وهي الحيل

In this treatise, it is our aim to lay down only a summary of these things that we mentioned so that it is simple to imagine them in our minds and the minds of those who want to construct instruments for them, both if someone wishes to calculate by hand to know the position in which each of the motions comes to an end, as well as if one wants also to join **the motions** with each other and with the motion of the universe by the mechanical approach, which is [the approach] of devices.

[3] Οὐ μὴν ὃν εἰώθασι τρόπον σφαιροποιεῖν· ὁ γὰρ τοιοῦτος καὶ χωρὶς τοῦ διημαρτῆσθαι τὰς ὑποθέσεις τὸ φαινόμενον παρίστησι μόνον καὶ οὐ τὸ ὑποκείμενον, ὥστε τῆς τέχνης καὶ μὴ τῶν ὑποθέσεων γίνεσθαι τὴν ἔνδειξιν·

ليس بأن يعمل كرة على المثال الذي جرّت به العادة فإنّ هذا النوع من الأكر مع ما فيه من المناقضة لما قد وضع وقيل في الحركات فإنّما يتبيّن فيه ظاهر الشيء فقط وليس يظهر فيه الوضع الحقيقي حتّى أنّه إنّما يكون به ظهور الصناعة ليس ظهور الوضع بالحقيقة

[This would not result] from constructing a sphere in the customary way. For in this kind of the spheres — in addition to the fact that some of it is in contradiction to what is laid down and said regarding the motions — rather only the appearance of the thing becomes evident and the true hypothesis does not become apparent, so that through this, rather the artefact and not the hypothesis in truth becomes apparent.

[4] ἀλλὰ καθ’ ὃν ἥ τε τάξις ὁμοῦ καὶ ἡ διαφορὰ τῶν κινήσεων ὑπ’ ὄψιν ἡμῖν μετὰ τῆς διὰ τῶν ὁμαλῶν καὶ ἐγκυκλίων παρόδων ὑποπιπτούσης τοῖς ὁρῶσιν ἀνωμαλίας, κἂν μὴ πάσας οἷόν τ’ ᾖ τῆς εἰρημένης προθέσεως ἀξίως συμπλέκειν, ἀλλὰ χωρὶς ἑκάστην οὕτως ἔχουσαν ἐπιδεικνύειν.

لكن بأن يعمل ذلك بنوع يقع تحت البصر نظام الحركات وفصولها والاختلاف الذي يرى لها بنظر الناظرين إليها وهي تتحرّك حركة مستوية مستديرة وإن كان لا يمكننا أن <u>نركّب الحركات كلّها تركيبًا موافقًا</u> لغرضنا الذي قصدنا له لكنّا <u>نبيّن بهذا النوع من العمل حال كلّ واحد منها بانفراد</u>

But [it would result] from constructing it in such a way that before our eyes, there occurs the arrangement of the motions and their divisions and the anomaly, which is seen for them by observing them, whereas they [i.e. the motions] move regularly and circularly, even if we are not able <u>to assemble all of the motions in accordance</u> with our intended aim, but <u>we show by this kind of construction the condition of each of them separately</u>.

Since the underlined parts represent the differences between the Greek and the Arabic versions, it can be clearly seen that the majority of Chapter I.1 is stable in both versions and that there is more additional material in the Arabic than in the Greek version. Again, it should be noted that this might stem from a more extensive Greek version that is now lost. However, there are also some other instances in which the Arabic translator clearly made some changes in order to provide a comprehensible text. Take, for example, ‘the motions’ in Section 2, which are shown in bold in the English translation. Although the Greek here only reads *autas* (a simple pronoun referring to ‘them’), the Arabic translator chose to reiterate the word *ḥarakāt* to which the pronoun refers back. This occurs throughout the Arabic text, mostly concerning motions and specific circles.[22] Similarly, the Arabic translator apparently rendered the Greek *houtōs* (‘in this way’) as *bi-hāḏā l-nawʿ min al-ʿamal* (‘by this kind of construction’) right at the end of Section 4. Another illustration of the translator’s attempt to provide a comprehensive Arabic version is his double addition of *ḥaqīqī* or *bi-l-ḥaqīqa* (‘true, real’ or ‘in reality’) in Section 3. In this way, the translator highlights the distinction he thinks Ptolemy has in mind between the phenomena (*phainomena*) and the ‘underlying’, i.e. the hypotheses or model (*hypokeimenon*). More examples can be found in the remaining chapters, such as at the end of Chapter I.3, where the Greek expression *kata tēn ekkeimenēn periphoran* (‘according to the established revolution’) is translated as *fī ḥarakat al-kull* (‘regarding the motion of the cosmos’).[23] Here again, the translator replaces the unspecific back-reference with the motion to which Ptolemy actually referred. Throughout Chapters I.10–13 of the Arabic version, one comes across the addition of the expression *bi-ḥarakati-hī* whenever a circles moves another inner circle ‘by its own motion’, which is never written in the Greek.[24]

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[22] See for example *Plan. Hyp*. I.8, p. 234:17.

[23] *Plan. Hyp*. I.3, p. 228:6.

[24] For example, see *Plan. Hyp*. I.10, p. 242:19, and I.11, p. 246:4.

All these examples indicate that the translator attempted to get rid of possibly ambiguous expressions. Of course, this opens up the possibility that, in some instances, the Arabic text is not always true to the original meaning intended by Ptolemy. However, judging from the cases discussed above, the translator had a good understanding of the text.[25] Similar to these efforts, in both complete Arabic manuscripts, we find headings for the chapters on the planets, such as 'the condition of the circles of the Moon' (*ḥāl aflāk al-qamar*) in Chapter I.9. Obviously, these headings could have made their way into the Arabic text through manuscript scribes. Nevertheless, we find similar attempts to further structure the text in Chapters I.10–14, where the Arabic version has additional instances of *ayḍan* ('also') when introducing another circle.[26]

From a comparison of the terminology used in this translation versus other translations, no clear picture about the identity of the translator has emerged.[27] However, a large amount of the terminology used here is shared by works that are known to have been translated by Ṯābit ibn Qurra, such as his translation of Nicomachus' *Introductio Arithmetica*. Here is a brief list of examples from only Chapters I.2 and 3: *ekthesis — waḍ'*; *tōn kata meros — ašyā' ǧuz'iyya*; *autōn hekaterōthen — 'an ǧanbatay-himā*; *antikeimenon — muqābila*.[28] This means that we should seriously consider Ṯābit's involvement in the translation from a terminological perspective at the present state of research.

I want to conclude the comparison by highlighting some of the most interesting aspects of this translation. Throughout the entire text, in relative clauses, the Arabic version omits the pronoun that refers back to the relative pronoun in sentences as the following: '[things] that we have mentioned' (*allatī ḏakarnā* instead of *allatī ḏakarnā-hā*). In the case of *allatī* or *allaḏī*, this omission is not as usual as in the case of *mā*. Most often, this concerns cases in which the subject is in the first person singular or plural, and therefore when it is clear that the relative pronoun must be the accusative object of the relative clause. Since this can be seen throughout both main witnesses, this was apparently the decision of an adaptor earlier than the witnesses or even by the translator himself.

[25] This is mostly true for the entire text for which we have the Greek version. One exception, however, can perhaps be found in Chapter I.2: see below, p. 225 n. 4. One must note again that this deviation might also go back to a different Greek original.

[26] For example, see *Plan. Hyp*. I.10, p. 242:15, and I.14, p. 258:6.

[27] I have mostly made use of the online database *Glossarium Graeco-Arabicum* (Ruhr-Universität Bochum), available at https://glossga.bbaw.de/. In addition, I have consulted the online transcriptions of the two extant Arabic versions of the *Almagest* made by Josep Casulleras (for the Ḥaǧǧāǧ version) and by Pouyan Rezvani (for the Isḥāq/Ṯābit version) for *Ptolemaeus Arabus et Latinus*, available online at https://ptolemaeus.badw.de/works_arabic. The terminology of the Arabic version of the *Planetary Hypotheses* is accessible in the online glossary of *Ptolemaeus Arabus et Latinus* (see https://ptolemaeus.badw.de/glossary (beta version)).

[28] See *Plan. Hyp*. I.2, p. 224:7, 8; I.3, p. 228:2, 4. For the corresponding expressions in Nicomachus' *Introductio*, I rely again on the entries of the *Glossarium Graeco-Arabicum* (see https://glossga.bbaw.de/).

In two cases, the Arabic version transliterates a Greek term, and in both cases, it is followed by its Arabic equivalent. In Chapter I.1, *mēchanikōn* is given as *al-miḫānīqī wa-hiya al-ḥiya*, and in Chapter I.2, *tē Syntaxei* (the Greek title of the *Almagest*) is given as *Kitāb al-Sinṭakīsīs wa-huwa al-Maǧisṭī*.[29]

There are also some terms that are translated in more than one way:

ametastatos ('unmoving'): at its first appearance in Chapter I.3, it is translated as *ġayr muntaqila*. In Chapter I.9, however, the Arabic has *lāziman li-hāḏā l-falak ġayr zā'il 'an-hū* (literally: 'adhering to this circle and not departing from it'). Afterwards, this word comes up twice in every chapter. First, it indicates that the inclined circle in every model is in a fixed position with respect to the main homocentric circle. In these instances, the Arabic uses *ġayr zā'il 'an-hū*. Second, when it comes to the description of eccentric circles, the Arabic uses the longer form *ġayr zā'il wa-lā mutaḥarrik*. These expressions remain mostly unaltered throughout Chapters I.10–14.[30]

Derivatives of *hypotithēmi* (literally 'to place below, under'): for the noun *hypothesis*, derivatives of *waḍ'* are mostly used, except in Chapter I.1, where *aṣl* is used. As described above, this expression also comes up in Ṯābit ibn Qurra's citation of the work's title.[31]

hē ek tou kentrou ('radius'): at its first appearance in Chapter I.8, the Arabic uses a very complicated description that imitates the Greek: *al-ḫaṭṭ al-ḫāriǧ min markazi-hā ilā al-ḫaṭṭ al-muḥīṭ bi-hā* (literally: 'the line that passes from its [with reference to a circle] centre to its circumference'). However, in what follows, the translator started using the technical term for 'radius', which is *niṣf quṭr*.[32]

epipedos ('plane'): sometimes given as *saṭḥ* and sometimes as *basīṭ*.[33]

peristrophē ('revolution, course [of stars]'): translated as *'awda*, *dawr* or *dawarān*. In the later chapters on the planetary circles, when this term is used to signify diurnal rotation, the translator uses *al-nāḥiyya allatī yataḥarriku ilay-hā al-'ālam* (literally: 'the direction into which the world moves').[34]

These different translations might indicate the involvement of different translators in the process or refinement of the vocabulary used by one translator in the process of translating, but at the present state of research, this is far from certain. It is also worth considering the translation of *ekballō*, which is in the passive and means 'to be drawn', referring to lines, as *ḫaraǧa*, as is the case in both Arabic versions of

[29] *Plan. Hyp.* I.1, p. 222:12–13, and I.2, p. 224:7–8.
[30] *Plan. Hyp.* I.3, p. 226:12; I.9, p. 236:15. As an example for the following chapters, see *Plan. Hyp.* I.11, p. 246:5, 10–11.
[31] For the exception, see *Plan. Hyp.* I.1, p. 222:4.
[32] *Plan. Hyp.* I.8, p. 234:12; for the later usage, see I.9, p. 236:17 for example.
[33] For *saṭḥ*, see, for example, *Plan. Hyp.* I.3, p. 226:10; for *basīṭ*, I.10, p. 242:16.
[34] For *'awda*, see, for example, *Plan. Hyp.* I.4, p. 228:14; for *dawr*, I.4, p. 228:8; for *dawarān*, I.4, p. 228:16; and for *al-nāḥiyya allatī yataḥarriku ilay-hā al-'ālam*, see I.10, p. 242:17.

Almagest I.6 that I consulted (by al-Ḥaǧǧāǧ and Isḥāq/Ṯābit). In the *Planetary Hypotheses*, it is mostly translated by *yaǧūzu*, which means (actively) 'to pass, go through'.[35]

One of the most interesting translations is that of the Greek *hoiōn*. Ptolemy uses this word mostly in sentences such as the following: 'this angle contains 45 degrees, by which one right angle is 90 degrees.'[36] The Arabic in the *Planetary Hypotheses* always renders this term as follows: *bi-l-miqdār allaḏī yakūn bi-hī*. We find exactly the same translation in al-Ḥaǧǧāǧ's version of the *Almagest*, throughout nearly the entire text (with the exception of Chapter I.14). On the other hand, the Isḥāq/Ṯābit-version reads *bi-l-aǧzāʾ allatī bi-hā*.[37] This might be the first textual indication that al-Ḥaǧǧāǧ was the first translator of the *Planetary Hypotheses*, as I have not found al-Ḥaǧǧāǧ's way of translating *hoiōn* anywhere else.

Another indication that also points in the direction of al-Ḥaǧǧāǧ is an allusion to the process of turning in Chapter II.17, Arabic *ḫarṭ*.[38] One can compare this passage to Ptolemy's description of the construction of astronomical instruments in the *Almagest*. Four times in that context, Ptolemy uses the term *torneuein* ('to turn on the lathe') in order to describe a precise method of producing regular rings.[39] In two of these four instances, al-Ḥaǧǧāǧ translates *torneuein* with expressions that include derivatives of *ḫarṭ*, whereas one cannot find that in the Isḥāq-Ṯābit-version.[40] Supposing that behind the term *ḫarṭ* in *Planetary Hypotheses* II.17 is also the Greek *torneuein*, this would be another term which the translation of the *Planetary Hypotheses* shares with al-Ḥaǧǧāǧ's *Almagest*-translation.

The most important conclusion that one should draw from this comparison is to acknowledge that the Arabic translation is a literal witness of the Greek text available to us today, but with some additions. It is certainly true that the Arabic *Planetary Hypotheses* is quite difficult to understand at times, and the exact reasons for these

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[35] See, for example, *Plan. Hyp.* I.8, p. 234:13; cf. the versions of *Almagest* I.6 by al-Ḥaǧǧāǧ in MS Leiden, Universiteitsbibliotheek, Or. 680, f. 4^{v}:34, and by Isḥāq/Ṯābit in MS Tunis, Dār al-kutub al-waṭaniyya, 7116, f. 4^{v}:12.

[36] For example, see *Plan. Hyp.* I.3, p. 226:14–15, and I.8, p. 236:1–2.

[37] Take a look, for example, at *Almagest* I.9 (Ptolemy, *Syntaxis*, I.9, Vol. 1, pp. 34–35): for the version of al-Ḥaǧǧāǧ, see MS Leiden, Universiteitsbibliotheek, Or. 680, ff. 6^{r}:37–38 and 6^{v}:3–4. For the corresponding occurrences in the Isḥāq/Ṯābit-version, see MS Tunis, *Dār al-kutub al-waṭaniyya*, 7116, f. 7^{r}:5–7, 12–13. In later times, however, al-Battānī and al-Bīrūnī used this Arabic expression in a similar way. See, for example, al-Battānī, *Opus Astronomicum*, Vol. 3, p. 80:3, and many occurrences in al-Bīrūnī, *Chronologie*, pp. 183–84.

[38] See *Plan. Hyp.* II.17, p. 344:19.

[39] See Ptolemy, *Syntaxis*, I.12, Vol. 1, pp. 64:13 and 66:19; V.1, Vol. 1, p. 351:12; VIII.3, Vol. 2, p. 180:23.

[40] For the important passages in al-Ḥāǧǧāǧ's translation, see MS Leiden, Universiteitsbibliotheek, Or. 680, ff. 10^{v}:31 and 128^{r}:34.

difficulties cannot be determined with certainty.[41] The part of the *Planetary Hypotheses* that is extant in Greek is, in fact, only less than a third of the entire text. In addition, this part only covers one thematic aspect that is very much related to the content of the *Almagest*. Although this remains rather speculative, one idea would be that the translator of the *Planetary Hypotheses* was mostly proficient in mathematics and in the *Almagest* specifically (or perhaps even translated the *Almagest* himself, which would be the case for al-Ḥaǧǧāǧ). However, the *Planetary Hypotheses* then proceeds with many optical remarks in the second half of Book I and with the metaphysical and physical discussion on the shape of the spheres in the first half of Book II. These are the parts that offer the most problems. Afterwards, the planetary models from the latter part of Book II are quite clear, to the degree that one can reconstruct the described diagrams without major problems.[42] These issues will surely be better understood once editions of the Arabic versions of the *Almagest* are available (for which there is one main advantage in comparison with the *Planetary Hypotheses*, namely that we know the translators). The present study and the preceding brief comments are clearly not intended to be a definitive statement but are intended to stimulate further research.

Editorial Principles

The Arabic version of the *Planetary Hypotheses* is extant in three manuscripts:

B: MS London, British Library, Add. 7473, ff. 81ᵛ–102ᵛ: this manuscript is written in one clear main hand. It is dated to May AD 1242 (f. 172ᵛ). There are some notes in a single second hand, namely a note of collation on f. 92 at the end of Book I and marginal corrections. Of the five diagrams in the second part of Book II, only three were drawn in spaces left empty by the scribe of the text (ff. 96ᵛ, 98ᵛ, and 99ʳ; empty spaces are left on ff. 100ᵛ and 101ᵛ), but they lack most of the points described in the text. The manuscript contains works from a wide range of fields, mostly mathematics and astronomy, but also philosophy. A considerable part of the manuscript has a direct connection to Ṯābit ibn Qurra. Besides some of his own mathematical works, the manuscript contains Ṯābit's translation of Nicomachus' *Introduction to Arithmetic* next to a fragment from Apollonius' *Conics*, parts of the Arabic version of which are also ascribed to Ṯābit.[43] In addition, the philosophical works include treatises by al-Kindī, as well as two treatises on psychology, namely those by Bakr al-Mawṣilī and by Avicenna.[44] This is worth mentioning insofar as the combination of mathematical

[41] This was already stated by Régis Morelon, among others, in his edition of the Arabic version of Book I. See Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 9.

[42] This was recently done by Roshdi Rashed and Erwan Penchèvre, see Rashed and Penchèvre, 'Ibn al-Haytham', pp. 120–26.

[43] See Sezgin, *Geschichte des arabischen Schrifttums V*, pp. 139 and 165.

[44] For the work by Avicenna, see Gutas, *Avicenna and the Aristotelian Tradition*, pp. 80–86.

with philosophical — and especially psychological — issues in the *Planetary Hypotheses* is mirrored by the contents of this collection.[45]

L: MS Leiden, Universiteitsbibliotheek, Or. 180: apart from the *Planetary Hypotheses*, this manuscript contains only some sketchy astrological notes and was apparently copied for personal use. It can perhaps be dated roughly to the 12th or 13th century AD. The script is not as careful as that in B. The folios are not in the correct order, and one must read them in the following order instead: ff. 1^{v}–21^{v}, 25^{r}–27^{v}, 22^{r}–24^{v}, 28^{r}–44^{r}.[46] There are empty spaces and even entire folios left for the diagrams, which, however, are all missing (ff. 32^{v}, 36^{r}, 37^{v}, 41^{v}). It seems that one sheet between ff. 39^{v} and 40^{r} was lost, which contained the end of the text on the model of Mercury (Chapter II.15) and the supposedly empty space for the corresponding diagram. The title page (f. 2^{r}) contains a note that this is the revised version (*iṣlāḥ*) by Ṯābit ibn Qurra.[47] This makes the inclusion of much material connected to Ṯābit in B even more intriguing.

C: MS Cairo, Dār al-kutub, riyāḍa Taymūr 238: this fairly recent manuscript (early 20th century AD) contains only the beginning of the *Planetary Hypotheses* and is clearly dependent on B. It is written in a very nice and careful ductus with red rubrications.[48]

Since C is only a fragment and obviously dependent on B, the major witnesses are B and L. Both show a number of gaps that can all be explained by scribal misreadings that led to the skipping of a number of words or even lines. There is nothing to be added to the stemma by Régis Morelon.[49] I have not included the medieval Hebrew translation by Kalonymus ben Kalonymus in my edition, which, according to Morelon, is closer to L than to B and is extant in two manuscripts, only one of which contains the complete text.[50] On the other hand, I have compared my edition with the edition of Book I by Régis Morelon, which I include as another witness (**m**). I note the few differences between m and the present edition in the critical apparatus so that the reader knows when to turn to Morelon's text for a different reading. Despite the statement of collation in B, L turned out to be slightly more reliable than B.[51] This means that in cases in which one cannot rely on grammatical

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[45] I rely on the description by José Bellver for *Ptolemaeus Arabus et Latinus*, available online at https://ptolemaeus.badw.de/ms/664 (last consulted on 17.01.2021), which should be consulted for more details. See also the remarks by Régis Morelon in Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 9.

[46] Already established by Bernard R. Goldstein, see Goldstein, 'The Arabic Version', p. 5.

[47] See again José Bellver's description online at https://ptolemaeus.badw.de/ms/667 (last consulted on 18.01.2021), and Morelon's overview in Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 9.

[48] See José Bellver's description online at https://ptolemaeus.badw.de/ms/679 (last consulted on 18.01.2021), and Morelon's overview in Ptolemy, 'La version arabe du *Livre des Hypothèses*', pp. 9–10.

[49] Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 11.

[50] The complete text is extant in MS Paris, Bibliothèque nationale de France, hébr. 1028, ff. 54^{v}–81^{r}, and only a small fragment in MS Halle, Universitäts- und Landesbibliothek, YB 4° 5, ff. 54^{r}–56^{v}.

[51] As noted earlier by Morelon in Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 9.

arguments or the context, I often relied on the reading of L. As an example, this happens in cases such as the difference between *wa-* and *fa-*.

Numerous quotes from the *Planetary Hypotheses* are contained in Ibn al-Hayṯam's *Doubts about Ptolemy*. This work was written before AD 1038, while one of the extant manuscripts (Oxford, Bodleian Library, Arch. Seld. A. 32) has been dated to the time before AD 1235–1236.[52] Thus, this witness predates at least B, which might tempt one to include these fragments in the edition. Most of the differences between the fragments in *Doubts about Ptolemy* and the main witnesses B and L are either differences concerning diacritical points or explanatory additions clearly by Ibn al-Hayṯam himself, for example in order to explain to which circle or sphere Ptolemy refers in a sentence that Ibn al-Hayṯam takes out of the context of the passage. In addition, these fragments do not consistently confirm one of the two main witnesses. In Chapter II.3, for example, Ibn al-Hayṯam's fragment reads similar to B, and in Chapter II.12 similar to L.[53] I only provide references to the fragments in the notes to the English translation for the orientation of the reader.

In the critical apparatus, the following abbreviations and symbols are used:

add (*additur*): an addition;
corr (*corrigitur*): a visible correction by a scribe;
del (*deletur*): words that are mistakenly deleted, i.e. crossed out, by a scribe;
mg (*in margine*): an addition or correction in the margin;
om (*omittitur*): an omission;
sl (*supra lineam*): an addition above the line;
†: uncertain readings, mostly concerning damaged parts of the manuscript.
[...]: used in the English translation for additions by myself.
|...|: division of the text into sections. For example, |2:3| signifies the beginning of Chapter 2, Section 3.

As for the corrections in the main hand, I only provide the form to which the words are corrected. I also do not note whenever the scribe crossed out mistakenly added words. On the other hand, I highlight the deletion of words in case they are crossed out by mistake. As for the way in which the numbers are written, both witnesses B and L mostly use spelled numbers. In my edition, I follow this manner and I standardize the utilization of long vowels without specifying when the witnesses have, for example, *ṯalaṯa* instead of *ṯalāṯa* for Arabic 'three'. There are only some exceptions to these general rules. In Chapters I.6–7, B gives some numbers in Hindu-Arabic numerals and others in *abjad*-notation (ff. 82^{v}:25–83^{r}:17). At the ends of Chapters I.9, I.13 as well as I.14, B gives in total seven values in *abjad*-notation (ff. 84^{r}:13, 87^{r}:17–21, and 87^{v}:25–88^{r}:1), and Hindu-Arabic numerals are also used in Chapter I.18, however

[52] See Rashed, 'The Celestial Kinematics', p. 10. For a description of the Oxford manuscript, see https://ptolemaeus.badw.de/ms/962 (last consulted on 18.01.2021).

[53] Compare *Plan. Hyp.* II.3, p. 290:4 with Ibn al-Hayṯam, *al-Šukūk*, p. 46:3, and *Plan. Hyp.* II.12, p. 320:12 with Ibn al-Hayṯam, *al-Šukūk*, p. 60:13.

again only in B (f. 90^{v}:3). In all these cases, I follow the example of L and the rest of B and provide the numbers in their spelled form.

Apart from these exceptions concerning corrections and numbers, I include every single variant from the three manuscripts in the critical apparatus. This implies that I even note minor variant readings for example concerning diacritical points (which are substantially given in both B and L), case endings in spelled numbers, or missing overlines for the points in diagrams. Since there are only two complete witnesses, it is particularly important to provide full variants from both, while at the same time the apparatus does not become overly confusing. Indeed, the minor variants that I include do affect the reading of the text from time to time. Let me give two examples that should be well-known to Arabists. The diacritical points that distinguish between the letters *ya-* and *ta-* differentiate between the subject or the form of a verb. An example that comes up quite frequently is the verb with the root *ya/ta-ḥ-r-k*. By adopting *ya-*, this verb most often means that 'a sphere moves another sphere' in the second form in the present tense, whereas reading *ta-* makes the verb intransitive in the fifth form in the past tense, which simply means that 'a sphere moves'. In the chapters on the planetary models of Book II, the points, lines, and circles for the diagrams are given with overlined letters. On some occasions, the scribe apparently forgot to add these overlines. In the case of a line from point Ḥ/Ḫ to Ṭ, these two letters can also be read as *ḫaṭṭ* (the Arabic term for 'line') and thus the meaning changes from '[the line from] Ḥ/Ḫ to Ṭ' in the original version to 'line'. This works, of course, also the other way round when the scribe accidentally added an overline to the Arabic word *ḫaṭṭ*. To give another example, the '[line from] K to L' can be changed to *kull*, the Arabic term for 'each'.[54] It is therefore clear that even some of these minor variants affect the content of the text and should be included in a critical apparatus.

There is one feature that deserves some additional clarification. Whenever the subject of a relative clause in Arabic is not the relative pronoun, a pronoun needs to be appended to the verb that refers back to the relative pronoun and thus to the object of the verb. This rule is usually followed, though with the curious exception when the verb of the relative clause is in the first singular plural, as in the following example: '[the circle] that we have mentioned.' In most of these cases, both witnesses B and L omit the pronoun, and in some cases, either B (nine times, most of them towards the beginning of the text) or L (only once) adds it, sometimes even in the wrong numerus. It seems that the original version did not include the pronoun in these fixed sentences, and sometimes, a scribe at a certain point added it here or there. In each case, I decided to follow the manuscript that does not write the pronoun because it might go back to the translator himself. Of course, the variant is still given in the apparatus.

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[54] Examples of such occurrences can be found in Chapter II.15.

For the first part of Book I, I add a second apparatus below the Arabic one. There, I note a selection of variants from the Greek version as printed in the edition by Heiberg (**H**). I include Greek variants in two cases: first, when they enhance the understanding of the Arabic version, and second, when there are omissions or additions either in the Greek or in the Arabic version. In some cases, this might lead us to make changes in the Arabic text. However, I have remained true to the Arabic version as extant in B and L, and I only add a brief note to the translation when the Greek helps us, for example, in structuring the train of thought. We should also keep in mind that some additional sentences we find in the Arabic were either added by later Greek or Arabic scholars, or were not transmitted in the Greek text like the rest of Book I and all of Book II. Some mistakes in the Greek text were already noted and corrected by John Bainbridge, some of which are confirmed by the Arabic text.[55]

As for the diagrams in Book II, only three of them are contained in B, though not in a complete fashion. There are previous reconstructions in the German translation by Nix, Buhl, and Heegaard, and, more recently, a reconstruction of the model of Saturn was made by Roshdi Rashed and Erwan Penchèvre.[56] Because of the lack of reliable diagrams in the manuscripts, I reconstructed the diagrams from the description in the text. In this process, these previous reconstructions have been of help.

As for the division of the text into chapters, my edition and translation follows the text by Nix, Buhl, and Heegaard as I saw no reason to introduce major changes that would mess with the established ways of referencing. I also adopted Goldstein's division for the second part of Book I and simply continued the count of chapters. Furthermore, the text is subdivided into sections (indicated by vertical strokes in the English and Arabic texts). This is a system applied by Ptolemaeus Arabus et Latinus in order to enhance the comparison of a text in different versions (i.e., Greek, Arabic, Latin) and is used especially for the glossaries, both online and — concerning the *Planetary Hypotheses* — in the present volume.[57]

I added full-stops to the Arabic text in accordance with the punctuation in the English translation in order to facilitate the parallel reading of the English and Arabic. These full-stops are omitted in the Arabic occasionally, for example when I decided to split up a long sentence in my English translation although the Arabic sentence clearly goes on.

Two Notes on the English Translation: 'Hypothesis' and 'Sphere'

As there are some difficulties translating the Greek term *hypothesis*, the same is true for its Arabic counterpart, *waḍʿ*. Following the remarks by Gerald J. Toomer in his

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[55] For Bainbridge's list of corrections, see Ptolemy, *De planetarum hypothesibus*, p. 52.

[56] See Ptolemy, 'Hypotheseōn', pp. 123, 126, 132, 134, 139, and Rashed and Penchèvre, 'Ibn al-Haytham', p. 126.

[57] For a *beta*-version of the online glossary of *PAL*, see https://ptolemaeus.badw.de/glossary.

English translation of the *Almagest*, I decided to translate *waḍʿ* in most cases as 'hypothesis'.[58] The reader must know that the meaning of this term shifts depending on the context. In Book I Ptolemy intends to refer to what has been 'laid down', so to speak, in geometrical terms, whereas in Book II he uses this term to devote the physical models of planetary motions instead. Although this is true in most cases, there is at least one instance, namely in Chapter I.9, where *waḍʿ* translates the Greek *thesis*, which should instead be translated as 'position'.[59] Following this example, I have chosen to translate the term *waḍʿ* as 'position' whenever it seems preferable with respect to the context.

I have previously written about the different translations of the Greek terms for 'circle' (*kyklos*) and 'sphere' (*sphaira*). Although the translation of Arabic *kura* as 'sphere' is uncontroversial, the two terms *dāʾira* and *falak* share the meaning of 'circle', but the latter can also mean 'sphere' and thus can translate both Greek *kyklos* as well as *sphaira*. For part of Book I, I made use of the extant Greek in order to decide when to translate *falak* as 'circle' or as 'sphere', whereas the terms *kura* and *dāʾira* are always translated as 'sphere' and as 'circle', respectively. This means that I do not make a terminological difference between *kura* and *falak* when translated as 'sphere' or between *dāʾira* and *falak* when translated as 'circle'.[60]

Ptolemy's Cosmology in the Medieval Arabic Tradition

As already outlined before, Chapter II of the present study deals with the epistemological status of astronomy and its relation to other sciences, and Chapter III with Ptolemy's theory of celestial dynamics. Nevertheless, both chapters follow a similar structure. In the beginning of each chapter, I try to explain Ptolemy's accounts within the wider context of his time. Quite naturally, the important points of departure are the two dominant figures of Plato and Aristotle, and I show in some detail how Ptolemy relies on them, from Plato's myth of Er in the *Republic* to Aristotle's *On the Movement of Animals*, *On the Heavens*, and *Metaphysics*. Before I approach the reception of Ptolemy's cosmology in the Arabic tradition, I devote some pages to the Hellenistic and late ancient reception of the issues discussed by Ptolemy for two main reasons. First, a comparison with the way in which other Greek authors dealt with the relationship between physics and astronomy or with celestial dynamics enhances our understanding of what Ptolemy might have had in mind, since his own account is not as detailed as one would hope. Second, there are other Greek cosmological works that decisively influenced medieval Arabic philosophy. Take, for example, *On the Cosmos* by Alexander of Aphrodisias or Theophrastus'

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[58] See Toomer's remarks in Ptolemy, *Almagest*, pp. 23–24; see also Moureau, 'Note', and Bowen, 'Hypothesis'. In the first chapter of the *Planetary Hypotheses* only, the Greek word *hypothesis* has been translated differently, namely as *aṣl*, for which see the commentary on Chapter I.1 below (p. 353).

[59] See *Plan. Hyp.* I.9, p. 238:7.

[60] For more details, see Hullmeine, 'Was there a Ninth Sphere', especially pp. 83–89.

On First Principles, both of which were translated into Arabic. The influence of Alexander's cosmology on thinkers such as al-Kindī has already been the subject of modern research, and the present study should not fail to acknowledge such lines of transmission.[61] One must especially keep Alexander in mind, as he was active around the same time as Ptolemy and tackled the question of celestial dynamics in a remarkably similar way. This means that in order to avoid a false conclusion on the afterlife of Ptolemy's theories, one must first set out the specific details by which one can distinguish Ptolemy from other authors that have been read in the Middle Ages. Especially for the late ancient authors such as Simplicius and Proclus, we do not have as much evidence as we do for Alexander that their works were available in the Islamic world. However, I include some remarks about their cosmological theories, as they are the first figures in the history of philosophy in whose works we can detect the influence of the *Planetary Hypotheses*.

As for the reception of Ptolemy's cosmology in the medieval Islamic world, the framework of such an investigation is given by the following list of authors who refer to the *Planetary Hypotheses* by name or even quote from it:

– **Ṯābit ibn Qurra** (d. AD 901, active in Ḥarrān and Baġdād),
– **Ibn al-Hayṯam** (d. around AD 1040, Baṣra and Cairo),
– **al-Bīrūnī** (d. around AD 1050, Ḫwārazm and Ġazna),
– al-Ǧūzǧānī (fl. in the first half of the 11th century AD, various locations in modern Iran),
– Ibn al-Ṣalāḥ (d. AD 1154, Baġdād and Damascus),
– **Averroës** (d. AD 1198, al-Andalus),
– **al-ʿUrḍī** (d. around AD 1266, Marāġa),
– Bar Hebraeus (d. AD 1286, Marāġa),
– Quṭb al-Dīn al-Šīrāzī (d. AD 1311, Marāġa and Anatolia),
– Gersonides (d. AD 1344, South France).

This is a rather wide framework, given that these authors range from the ninth to the fourteenth centuries AD, and from the Islamic East to al-Andalus in the West. Although I will at least briefly mention each one of these authors, I put the strongest emphasis on the authors that are highlighted because they deal with the *Planetary Hypotheses* in more detail than the others.[62] I also consider further authors, most importantly al-Kindī, al-Fārābī, Avicenna, and Naṣīr al-Dīn al-Ṭūsī in the East, and Maimonides and Ibn Bāǧǧa in the West. The first reason to include these other thinkers is that an investigation of their works helps us understand the different developments in the reception of Ptolemaic cosmology in their proper context. Second, it also turns out

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[61] See, for example, Fazzo and Wiesner, 'Alexander of Aphrodisias'.

[62] An exception is perhaps Gersonides, who seems to have much to say about the *Planetary Hypotheses* in his commentaries on Aristotle and Averroës written in Hebrew, and thus surely deserves more attention. However, my focus lies on Arabic works. See Janos, 'The Reception of Ptolemy's Theory' for Gersonides' reception of the *Planetary Hypotheses*.

that although they do not refer explicitly to the *Planetary Hypotheses*, they nevertheless more or less clearly depend on it (either directly or indirectly).

Therefore, by considering all these different authors from different times and places, and discussing some in more detail than others, I hope to provide a comprehensive overview of the reception of Ptolemy's astronomy and cosmology in general, and his *Planetary Hypotheses* more specifically. According to my findings, these developments can very roughly be divided into different stages. There are the early philosophical and astronomical engagements in the ninth and tenth centuries AD in the Islamic East when there was not yet an established tradition of a thorough critical reflection of Ptolemaic cosmology, although it pops up in different centres like Damascus, Baġdād, and Aleppo. The discussion of planetary distances and sizes is the most discussed topic from the *Planetary Hypotheses* in this period, both in smaller treatises devoted solely to this issue as well as in astronomical handbooks. A clear shift can be observed with some of the key figures in the history of Arabic philosophy and astronomy, namely al-Fārābī, Avicenna, Ibn al-Hayṯam, and al-Bīrūnī in the tenth and eleventh centuries AD. In their philosophical and astronomical works, they turn to a critical assessment of Ptolemy's cosmological theories, with a special emphasis on Ptolemy's method and on the question whether astronomy needs to rely on natural philosophy. The influence of these towering figures can easily be detected in one of the most important schools in the history of Arabic science, namely the group of scholars around Naṣīr al-Dīn al-Ṭūsī working at the observatory in Marāġa in the 13th century AD. In their works, one can detect the connection between the innovative astronomical activities at the observatory and the influence of earlier scientists and philosophers such as al-Fārābī, Ibn al-Hayṯam, and Avicenna. Finally, there is the quite different tradition in al-Andalus, where Peripatetic philosophers such as Ibn Bāǧǧa and Averroës urged a development that has been called a 'revolt against Ptolemaic astronomy', and the *Planetary Hypotheses* are an important piece in this 'revolt'.[63] Surely, all of these authors had their own approach towards Ptolemy's cosmological theories within the context of their own interests. What connects all of these schools and authors is that they use not only Ptolemy as their starting point for cosmology, but also Aristotelian natural philosophy. Thus, Chapter II deals heavily with this tension between Ptolemaic astronomy and Aristotelian physics. Ptolemy's cosmology left later authors with questions as to which of these two sciences was superior to the other in epistemological terms, and whether the non-homocentric and non-spherical celestial bodies violated Aristotelian physics or not. Ptolemy's theory of celestial dynamics, as can be seen in Chapter III, was compared with other dynamic systems that had their origin in a variety of sources, although the question whether the planets move on their own or are carried by a sphere touches upon Aristotelian natural philosophy. In sum, Chapters II and III look at the way in which Ptolemy's *Planetary Hypotheses* influenced and challenged medieval Arabic cosmology.

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[63] Sabra, 'The Andalusian Revolt'.

As explained before, the commentary in Chapter VI does not engage in detail with planetary models or mathematical calculations. My focus explicitly lies on the philosophical problems just outlined. However, I refer from time to time to some parameters concerning planetary distances and sizes whenever such a reference is useful for tracking a possible influence of the *Planetary Hypotheses*. In this way, the present study will establish, for the first time, the philosophical implications of the *Planetary Hypotheses* with respect to Ptolemy's general epistemology, and it will demonstrate its previously underestimated importance for the whole later tradition of cosmology in the Islamic world.[64] In doing so, I will look at a number of different works: commentaries on or paraphrases of the *Almagest*, astronomical compendia and introductory works, and philosophical works on metaphysics and physics. Although there is yet much research to be done on most of these works, I connect them through the overarching question of the reception of the *Planetary Hypotheses*.

[64] Simultaneously to the present study, Damien Janos worked on the reception of Ptolemy's celestial dynamics in Arabic works. See, most importantly, Janos, 'The Reception of Ptolemy's Theory', which develops some ideas already published in Janos, *Method, Structure*, and Janos, 'Moving the Orbs'.

II: Astronomy, Natural Philosophy, and the Physical Reality of the Celestial Bodies

Ptolemy's Methodology and Epistemology in the *Almagest* and *Planetary Hypotheses*

A thorough understanding of the *Planetary Hypotheses*, its agenda, and outcome builds not only upon the content of this work itself but also upon Ptolemy's general methodology and division of sciences as presented in the first chapter of the *Almagest*. Thus, although *Almagest* I.1 has been the subject of much modern research, it is nevertheless necessary to present its most important implications.[1] Let us take Chapter II.3 of the *Planetary Hypotheses* as an example: in order to settle the question of how the celestial spheres are shaped, Ptolemy claims that this can be tackled by two approaches, the mathematical and the physical. Thereby, he alludes to two of the three theoretical sciences he distinguishes in *Almagest* I.1. One therefore needs to go back to the *Almagest* in order to understand the philosophical consequences of this claim.

In the first sentences of the *Almagest*, Ptolemy distinguishes practical from theoretical philosophy.[2] Despite this distinction, he holds that mathematics, the highest of the theoretical parts of philosophy, contributes significantly to practical philosophy such as ethics, because studying mathematics is an essential part of a good life.[3] Apart from that, practical philosophy does not play a role in the *Almagest* or the *Planetary Hypotheses*, so we can jump to the next division Ptolemy sets forth in the *Almagest*.[4] He divides theoretical philosophy into three disciplines, namely physics, mathematics, and theology. His criteria are whether their objects are perceptible and moving. As for theology, he states that it deals with the first cause of motion, which itself is invisible and motionless.[5] Physics is its counterpart, for it deals with perceptible qualities and its objects are 'ever-moving'.[6] After providing examples of the quantifications with which mathematics deals, Ptolemy claims that mathematics is in the middle of the first two divisions for two reasons. First, one can conceive of

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[1] Among others, one should primarily refer to Boll, *Studien*, pp. 66–75; Pedersen, *A Survey*, pp. 26–32; Taub, *Ptolemy's Universe*, pp. 19–37, Feke, *Ptolemy's Philosophy*, pp. 10–51.

[2] Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 4:7–9.

[3] This is one of the main claims made by Liba Taub and Jacqueline Feke; see Taub, *Ptolemy's Universe*, pp. 19–21 and 135–38, and Feke, *Ptolemy's Philosophy*, especially Chapter 4. See also Boll, *Studien*, pp. 70–71.

[4] In Ptolemy, *Die Harmonielehre*, III.6, Ptolemy also differentiates between three practical sciences, namely ethical, domestic, and political. See Feke and Jones, 'Ptolemy', p. 208.

[5] See Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 5:13–16. For the question as to whether this means that Ptolemy supposes the existence of the Prime Mover like Aristotle, see Chapter III of the present study.

[6] See Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 5:19–24.

mathematical objects both with and without sense-perception. Second, it quantifies both the ever-changing things as well as the unchanging aethereal ones.[7]

Ptolemy himself provokes the question of the influence of Aristotle, since he writes at the beginning that Aristotle 'fittingly' (*emmelōs*) divided theoretical philosophy into these three kinds.[8] In his next step, however, Ptolemy abandons the Aristotelian example. For Aristotle, theology is clearly the highest of these three theoretical sciences, because it deals with the most honourable being, God.[9] In Ptolemy's *Almagest*, the division of theoretical philosophy depends on the perceptibility and motion of the subject matters, and the rank of each discipline depends on the epistemological status of these criteria. Ptolemy states this straightforwardly:

> From all this, we concluded that the first two divisions of theoretical philosophy should rather be called guesswork (*eikasia*) than knowledge (*katalēpsis epistēmonikē*), theology because of its completely invisible and ungraspable nature, physics because of the unstable and unclear nature of matter; hence there is no hope that philosophers will ever be agreed about them; and that only mathematics can provide sure and unshakeable knowledge to its devotees, provided one approaches it rigorously. For its kind of proof proceeds by indisputable methods, namely arithmetic and geometry.[10]

Theology and physics are differentiated from each other by the fact that theology deals with the imperceptible, immobile, and thus never-changing God, whereas physics deals with perceptible qualities. In Ptolemy's view, this is also what makes them only conjectural sciences, namely that it is impossible to perceive its subject properly, as in the case of theology, or that they are subject to constant change, as in the case of physics. Mathematics, on the other hand, is a better (or even the only) guide to sure knowledge for two reasons. First, it makes use of arithmetic and geometry, tools that offer 'indisputable' proofs.[11] Second, mathematical objects are not changing (as in theology) but are still perceptible (as in physics). This becomes especially clear in the case of astronomy. It studies the divine celestial bodies, which are perceptible and move unceasingly and in an orderly fashion, and thus he singles

[7] See Ptolemy, *Syntaxis*, I.1, Vol. 1, pp. 5:25–6:11.

[8] For the details of Ptolemy's division and its relationship to the different Aristotelian texts, see especially Boll, *Studien*, pp. 71–75; Feke, *Ptolemy's Philosophy*, pp. 15–25; and (most recently) Bowen, 'Hypothesis', pp. 73–78 and 85–88. Feke, for example, concludes that 'although Ptolemy's definitions of the sciences are not Aristotle's, they are still Aristotelian' (p. 19). The tripartition of theoretical philosophy by Aristotle can be found in *Metaph*. VI.1, 1026a6–22, XI.7, 1064b1–6, and *Phys*. II.2, 193b22–35, among others.

[9] See, for example, *Metaph*. VI.1, 1026a18–23.

[10] Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 6:11–21, tr. by Toomer in Ptolemy, *Almagest*, p. 36, slightly modified.

[11] As highlighted by Feke, *Ptolemy's Philosophy*, pp. 115–16, Ptolemy apparently does not consider them as mathematical sciences themselves, for they are used as instruments in astronomy, harmonics, and optics.

out astronomy (and, since it is a part of mathematics, also mathematics itself) as the part of theoretical philosophy that leads us onto the best path to secure knowledge.[12] That Ptolemy puts mathematics as the highest science and degrades theology to a conjectural discipline of philosophy is a fundamental break with Aristotle. However, Aristotle in his *Metaphysics* also makes the degree of exactness dependent on motion. He claims that the greatest exactness is when there is no motion, which puts theology in the place of the science that offers the highest possible degree of certainty. Next, however, is the science that deals with the primary, simplest kind of motion, which is the regular circular motion of the heavens, whereas the sublunar motions and changes discussed in physics do not fall under this category. In this way, Aristotle seems to foreshadow Ptolemy's view that physics is, compared with astronomy, of an inferior epistemological status. On other occasions, however, Aristotle sorts the sciences on epistemological grounds but ends up with a different order. There is the famous passage in *On the Parts of Animals* I.5, in which Aristotle emphasizes that there is less insight into celestial than into sublunar things because we have much more contact with animals than with the stars and planets. A similar point is made twice in *On the Heavens*, namely that not all of the celestial attributes are perceivable through the senses. This has the consequence that, in some cases, one should be content with just a small amount of insight.[13]

Looking superficially over the content of the *Almagest*, this first chapter seems only of minor significance for actual mathematical discussions.[14] Nevertheless, it is not only the case that this chapter serves as a justification for studying astronomy. By assigning the highest epistemological rank to mathematics, Ptolemy does not claim that mathematics and astronomy *always* provide us with sure knowledge about every phenomenon. A telling and quite famous example comes from Book III of the *Almagest*, in which Ptolemy presents two possible theories for the motion of the Sun. Both of them can be constructed so that they conform to the phenomena. To put it differently, astronomical observation tells us *that* the Sun's motion is such, but since there are at least two ways to represent it, it does not tell us *why*, namely whether the Sun is carried by an eccentric sphere or an epicycle. His choice of an eccentric sphere for the Sun's motion relied on his principle of explaining the phenomena by the simplest possible theory.[15] In Ptolemy, this principle of

[12] See the analyses in Boll, *Studien*, pp. 71–75; Bowen, 'The Demarcation', pp. 349–55; Feke, 'Meta-mathematical Rhetoric'; and Feke, *Ptolemy's Philosophy*, pp. 26–29.

[13] *Metaph.* XIII.3, 1078a9–14; *Part. Anim.* I.5, 644b22–25; *Cael.* II.3, 286a3–7 and II.12, 291b24–28 and 292a14–17. See also Pellegrin, 'The Argument for the Sphericity', pp. 168–69; and Feke, *Ptolemy's Philosophy*, pp. 28–29. One could also point to the pseudo-Platonic *Epinomis*, in which astronomy is appointed the highest rank of the sciences for its closeness to the divine, see *Epin.* 989a1–990b4 and 992c6–d3, but with no connection to its epistemological status.

[14] As suggested in Boll, *Studien*, p. 70.

[15] Proclus writes that already the Pythagoreans (or even Pythagoras himself) strived for the 'fewest and simplest hypotheses' (*ex elachistōn kai haploustatōn hypotheseōn*). See Proclus, *Hypotypōsis*, p. 18:5–9 and van der Waerden, 'Die Erkenntnistheorie', pp. 238–39.

simplicity is related to the divine nature of the celestial realm and the assumption that the heavens are made out of a correspondingly divine element, aether.[16] Ptolemy establishes the existence and nature of aether in *Almagest* I.1, but without a specific demonstration.[17] Admittedly, he provides proofs that only spherical motions can account for the phenomena in *Almagest* I.3. At the end of this chapter, he writes that one comes to the same conclusion 'from certain physical considerations'. Basically, the argument rests on the uniform nature of aether, which is, in its entirety, shaped in the most regular possible way: the sphere. Ptolemy sums up this short passage by claiming that it is 'for this reason [...] reasonable (*eulogon*)' that the surrounding aether is spherical and has a uniformly circular motion.[18] Again, this underlines that physical arguments can be convincing and reasonable, but are not demonstrative as mathematical proofs. Nevertheless, a proper proof for the existence of aether in the first place along the lines of Aristotle's *On the Heavens* is missing from the *Almagest*.

The importance of *Almagest* I.1 can also be detected later when Ptolemy makes it clear that if we have a mathematical proof for a phenomenon, it is not necessary to look for the cause. This assertion can be found in *Almagest* I.7, which establishes that the Earth does not have locomotion on the basis of the mathematical proofs from Chapter I.5 of the central position of the Earth in the cosmos. Ptolemy then writes:

> Hence I think it is idle to seek for causes for the motion of objects towards the centre, once it has been so clearly established from the actual phenomena that the Earth occupies the middle place in the universe, and that all heavy objects are carried towards the Earth.[19]

In Ptolemy's view, the observed phenomena provide us with certain proofs that the Earth is always in the centre of the cosmos and cannot be outside of the centre (*Almagest* I.5) and that the heavy elements (earth and water) move towards the centre of the cosmos (I.7). Accordingly, he considers it superfluous to ask why the heavy elements move towards the centre. Of course, in Aristotle's *On the Heavens*, the downward motion of the heavy elements is the cause of the central position of the Earth. Ptolemy, on the other hand, does not indicate the same rationale. Rather, it seems that he considers two observed facts, namely (a) the observed phenomena of the celestial motions and (b) the downward motion of earth and water, as equally proving *that* the Earth must be the centre of the cosmos. At the end of

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[16] Regarding the Sun's model, see Ptolemy, *Syntaxis*, III.4, Vol. 1, p. 232:5–17. For Ptolemy's account of his principle of simplicity, see Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 201:18–22 and XIII.2, Vol. 2, pp. 532:12–534:6.

[17] See Jones, 'Ptolemy's Mathematical Models', p. 31.

[18] Ptolemy, *Syntaxis*, I.3, Vol. 1, pp. 13:21–14:16. The English terminology is taken from Toomer's translation (see Ptolemy, *Almagest*, p. 40). For a more detailed analysis, see Taub, *Ptolemy's Universe*, pp. 45–60. She focuses on the relation of Ptolemy's account of aether in *Almagest* I.3 and its relationship to Aristotle's proofs of the circularity of the heavens, but not so much on the epistemological status of the arguments. She also shows that Ptolemy's account of aether is similar to Aristotle's.

[19] Ptolemy, *Syntaxis*, I.7, Vol. 1, p. 21:14–19, tr. by Toomer in Ptolemy, *Almagest*, p. 43.

Almagest I.7, he addresses the question that the Earth might be at the centre but nevertheless rotates diurnally in its place. He also rejects this theory from observed phenomena such as the motion of clouds. Thus, Ptolemy highlights all arguments in this chapter as originating from observed phenomena. Only once does he refer to a causal explanation, though marking it as superfluous.

In this short example, it seems that there is Aristotle's distinction of *hoti-* (that) and *dihoti*-demonstrations (why) at work in the background of Ptolemy's distinction of physics and mathematics. In the *Posterior Analytics*, Aristotle distinguishes these two kinds of demonstration and makes the point that the science which shows the fact is of a lower rank than the science which proves the cause and thus why something is.[20] Ptolemy's position is quite contrary: if a science shows that the heavens move circularly and that the Earth is in the centre of the cosmos, there is no need to further ask why that is so. Of course, one still can find further confirmation by looking at possible causes for a phenomenon, just as Ptolemy does in *Almagest* I.3, but these do not have the necessary status as astronomical proofs, i.e. proofs from observation.[21]

Although Ptolemy is not too explicit about the consequences of this methodological framework for the following proofs in *Almagest* I.3–8, there are, nevertheless, brief glimpses in this direction. As just seen, Ptolemy uses the word *eulogon* ('reasonable') for the supporting evidence from physics in *Almagest* I.3 that the heavens are spherical. Strikingly similarly, he uses the same term in *Almagest* III.1 in the definition of a solar year, but only in its comparative form *eulogōteron*. He argues that both the mathematical and the physical approach imply that one should take the equinoxes and solstices as the points that define a solar year. For the physical approach, he writes that no alternative way of defining it is 'more reasonable'.[22] Another example can be found in *Almagest* III.4. Given that both the theory of an epicycle and of an eccentric sphere could account for the phenomena of the single anomaly of the Sun, Ptolemy asserts that it would be 'more reasonable' to assume the simpler of the two theories.[23] For Ptolemy, the word *eulogos* thus seems to indicate evidence that is not gained from observation or mathematical reconstruction of the phenomena, but builds on premises alien to mathematics such as the nature of aether and the principle of simplicity, the latter of which is closely connected to the Aristotelian claim that 'nature does nothing in vain'.[24]

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[20] There are a couple of noteworthy passages: *An. Post.* I.13, 78b34–79a16 establishes that different subordinate sciences investigate the fact and the cause, I.14 shows that the syllogistic figure that demonstrates the cause is the most scientific, and I.27, 87a31–37 shows that knowledge of the fact and the cause is 'more accurate and prior'. See Kullmann, *Wissenschaft und Methode*, pp. 204–12.

[21] Briefly indicated in Bowen, 'The Demarcation', p. 353.

[22] Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 193:7.

[23] Again, see Ptolemy, *Syntaxis*, I.3, Vol. 1, p. 13, and III.4, Vol. 1, p. 232:14.

[24] One can compare this use of *eulogos* to the Aristotelian usage (see Bolton, 'Two Standards'). A nice parallel is Simplicius' reading of *Metaphysics* XII.8, 1074a:14–17, where Aristotle depicts his account of the number of unmoved movers as 'reasonable' (*eulogon*). For Simplicius, this usage

When Ptolemy labels the investigation of the causes as 'idle' (*perissōs*), he speaks from the point of view of the mathematician, as opposed to the natural philosopher, who aims at a proper understanding of the causes. This way of distinguishing between mathematics and physics is not original to Ptolemy. There is the famous fragment in Simplicius' commentary on *Physics* II.2. The history of this report is quite complicated: Simplicius quotes the commentary by Alexander of Aphrodisias, who, in his turn, quotes Geminus' (fl. roughly first century BC) abridged commentary on Posidonius' work on meteorology.[25] This testimony from Geminus' commentary confirms that physics and astronomy were indeed distinguished from each other by the kind of their proofs. Physics and astronomy, as the fragment reads, have the same aim — namely to prove theses such as 'the Earth is spherical' — but they follow different methods. The natural philosopher is concerned with substances, capacities, or generation and corruption, and thus often with the causes, whereas the astronomer deals only with the quantitative aspects and extrinsic properties, and thus not with the underlying causes.[26] A little later, the report confronts the philosopher with the question of which astronomical hypothesis one should follow if more than one is able to 'save the appearances'. The correct method, according to Simplicius' report, is to gather all the astronomical hypotheses and to pick the one that conforms best with the causal theory (*aitiologia*).[27] As I am about to show, this is actually exactly what Ptolemy does in Book II of the *Planetary Hypotheses* when he describes the possible shapes of the celestial spheres and explains at length why sawn-off pieces better fit the physical principles. As parallel as the descriptions of physics and astronomy are in Simplicius' report and, rather implicitly, in Ptolemy, astronomy is certainly not considered as the highest science in the former. On the contrary, Simplicius' report rather states that astronomy has to take its first principles from physics and there is no trace of an epistemological difference.[28]

Obviously, Geminus or Posidonius and Ptolemy are not the only ancient authors who were concerned with the issue of the relationship between physical and astronomical proofs.[29] The combination of this distinction with a strong

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demonstrates Aristotle's 'uncertainty' (*endoiasmon*) about that question; see Simplicius, *In Cael.*, p. 506:7–8.

[25] Simplicius, *In Phys. I–IV*, pp. 291:21–292:31. Although much of the report thus goes back to Posidonius, modern scholars treat this report as consistent with what Geminus wrote in his *Introduction to the Phenomena* and therefore as a possible witness for Geminus' views as well. See Bowen, 'The Demarcation', pp. 330–31. James Evans and J. Lennart Berggren, the translators of Geminus' *Introduction to the Phenomena*, discuss this passage as evidence for Geminus' view on realism; see Geminus, *Introduction*, pp. 53–58.

[26] Simplicius, *In Phys. I–IV*, p. 292:3–15.

[27] Simplicius, *In Phys. I–IV*, p. 292:15–20.

[28] For the claim that astronomy takes its first principles from physics, see Simplicius, *In Phys. I–IV*, p. 292:26–29. For further discussions of this report, see the introduction by Evans and Berggren in Geminus, *Introduction*, pp. 53–58, and Bowen, 'The Demarcation', pp. 335–44.

[29] Incidentally, see Ian Mueller's article on a number of other authors (Mueller, 'Remarks on Physics and Mathematical Astronomy').

epistemological emphasis is very curious in Ptolemy and, as I have just described in some detail, these different epistemological values of the sciences indeed have an impact on the theories presented in the *Almagest*, although in a rather obscure way. In the following, I want to argue that this ranking of the sciences is even more important for understanding the *Planetary Hypotheses*, to the extent that *Almagest* I.1 provides a crucial methodological background for understanding the project of the *Planetary Hypotheses*.

The *Planetary Hypotheses* starts as a reprise of the *Almagest*. The first half of Book I deals with the simple returns of the celestial bodies and geometrical models for the five wandering planets, the Sun, and the Moon, which have been updated in comparison with the *Almagest*. This is the first step that Ptolemy promises in the outset of his work (Chapter I.2). Afterwards, the second half of Book I already reveals Ptolemy's wish to give a coherent picture of how the cosmos can be conceived in actuality. He had addressed the exact order of the planets already in the *Almagest*, finishing, however, at a dead end. Because of the lack of clear observations, Ptolemy claimed that the middle position of the Sun (with the Moon, Mercury, and Venus below, and Mars, Jupiter, and Saturn above) is 'more plausible' (*pithanōtera*).[30] This term can best be understood along the lines of *eulogos* discussed above, implying that Ptolemy is aware that he is leaving demonstrative grounds. Only with the introduction of two new criteria in *Planetary Hypotheses* I.16 is Ptolemy able to infer the order and distances of the planets, departing from the few values for the Moon and the Sun from the *Almagest*. These two new criteria are, first, that the ratios of the relative distances from the geometrical models concerning the perigee and apogee of the planets are like the true ratios, and, second, that there cannot be any void in the cosmos and thus the maximum distance of a planet must be like the minimum distance of the upper planet.[31] After he has seemingly established the order and corresponding distances of the planets, he notes that this is only the 'most likely' account (*ašbah al-umūr*). Besides the strong connection with the epistemological value of physics in *Almagest* I.1, for which I argue in this chapter, one should nevertheless also have Plato's *Timaeus* in mind, for the interlocutor Timaeus also labels his cosmological account as 'likely'.[32] One can find the same hesitation at the end of *Planetary Hypotheses* I.19 regarding planetary sizes: the values given in this

[30] Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:13–22. For the parallel between *pithanos* and *eulogos* in the *Almagest*, see Proclus, *In Tim.*, Vol. 3, p. 62:18, and the discussion of this passage above (pp. 55–58).

[31] See *Plan. Hyp.* I.16. For Ptolemy's method, see the commentary on Chapters I.16–19 and the summary in Goldstein and Swerdlow, 'Planetary Distances', pp. 138–43. One could argue that these chapters on the order and distances of the planets are directed towards instrument makers, whom Ptolemy addresses in *Plan. Hyp.* I.1. The fact that he transfers the relative values into actual stades tells us that Ptolemy goes beyond that and has a description of the physical cosmos in mind.

[32] *Tim.* 29d2. This was already suggested in Taub, *Ptolemy's Universe*, p. 167 n. 15. Cf. Feke, *Ptolemy's Philosophy*, p. 188. Perhaps the *Phaedo* is also relevant, in which Socrates expresses his doubt about attaining knowledge in natural philosophy (see *Phd.* 96a6–c2). For the terminological correspondence to *Almagest* I.1, compare the Isḥāq-Ṯābit-version, in which 'guesswork' (*eikasia*) is

chapter are only true, as Ptolemy admits, if the values for the distances are correct. If, on the other hand, a void exists in the cosmos (for example, between the main spheres of each planet), the distances have to be adapted and accordingly the sizes. The difference between the values for the Sun and the Moon from the *Almagest* and the remaining ones from the *Planetary Hypotheses* is the further addition of two premises. In the language of *Almagest* I.1, the former values are derived from mathematical calculations and thus from indisputable proofs. The two additional premises, however, are not derived from similar calculations and thus their result is only called 'most likely'. If these additional premises stem from physics, it would nicely draw a connection between *Almagest* I.1 and their status as providing only likely results. Concerning the first premise that the relative ratios are like the true ratios, this might not be the case at first sight, for the true ratios still deal with measuring the never-changing aethereal realm that Ptolemy defined as the subject matter of mathematics and astronomy in particular. Here, it simply might be the case that the mathematician is not able to provide sufficient proof from observation and calculation, and thus, although this premise is strictly not taken from physics either, its result is not certain. This would somehow correspond to the case of the anomaly of the Sun in *Almagest* III.4; indeed, the premise of corresponding ratios is the simplest possibility. In the case of the non-existence of a void, the connection to physics is clearer. Aristotle discussed it not only in *On the Heavens* but also in his *Physics*, and since the void cannot be measured in any way, it would be rather strange to call the investigation into void mathematical. In addition, the principle that nature does nothing in vain is about natural philosophy and thus occurs in Aristotle's *On the Heavens* and his biological treatises such as *On the Progression of Animals*.[33]

In summary, whenever Ptolemy leaves clear mathematical proofs, he labels the result as 'reasonable' or 'most likely', regardless of whether we call the other premises physical or not. In the second book of the *Planetary Hypotheses*, however, Ptolemy finally makes things much clearer by explicitly dividing his investigation of the shapes of the spheres into a mathematical and a physical approach. He starts with the latter and gives a version of his account of elementary motions that is slightly more detailed than that in *Almagest* I.1. Again, the ever uniformly moving aether is brought in opposition to the sublunar elements.[34] Ptolemy then turns to his subject matter of Book II, namely the shape of the spheres, and starts with the mathematical approach.

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translated as *aš'bah wa-aḥrā*, 'most likely and appropriate'; see MS Tunis, Dār al-kutub al-waṭaniyya, 7116, f. 2ʳ:9. I consulted the transcription by Pouyan Rezvani, available on the website of *Ptolemaeus Arabus et Latinus* at: https://ptolemaeus.badw.de/text/M971 (visited on 20 January 2021).

[33] See, for example, *Phys.* IV.6–9 for the discussion of void; for the statement that nature does nothing in vain, see *Cael.* I.4, 271a32–33, and *Inc. Anim.* 2, 704b15.

[34] The important additional assumptions in *Planetary Hypotheses* II.3 are that the celestial motions of aether are voluntary and that certain powers inherent in the planets play a role. See *Plan. Hyp.* II.3 and Chapter III of the present study.

He claims that there are two options, namely that all celestial spheres are complete orbs or that some of them are not complete but sawn-off, for the planets are only seen to move in a certain area above and below the annual path of the Sun. From the mathematical data, Ptolemy explains that both of these options are possible, because it does not make a difference to the resulting planetary motion whether the planet is carried by a complete sphere or a ring.[35] This claim strongly resembles *Almagest* III.4 on the equivalence of the eccentric and epicyclic theory for explaining the anomaly of the Sun.[36] Although, in the latter case, he was satisfied by adducing his principle of simplicity as a strong indication of the eccentric theory, in the context of the shape of the spheres, however, this is apparently not enough for Ptolemy, even though he uses this principle as well at the end of the *Planetary Hypotheses* in arguing for sawn-off pieces. Nevertheless, he spends the following chapters providing the reader with arguments against complete spheres and for sawn-off pieces.

It is quite noteworthy that Ptolemy refers to Plato and Aristotle explicitly by name in his discussion of the shape of the spheres. In the case of these slices of spheres, Ptolemy compares the solid slice to a tambourine and the hollow slices to belts and bracelets, and, most interestingly, to Plato's whorls.[37] This is the only explicit reference to Plato in Ptolemy's extant works. It goes back to the so-called myth of Er in *Republic* X.[38] Within this account of Er's near-death experience, Plato includes the following description of the cosmos: it is dependent upon the spindle of Necessity, whereas the celestial spheres are the whorls. In a normal spindle, there was just one disc-shaped whorl. In the case of the cosmos, however, this whorl is subdivided into a total of eight nested whorls (one for the fixed stars and one for each Sun, Moon, and the five wandering planets), all of them hollow. The shaft goes through the hole in the inner whorl.[39] Thus, Ptolemy borrows the idea of hollow

[35] *Plan. Hyp.* II.4.

[36] As discussed by Feke, *Ptolemy's Philosophy*, pp. 191–92.

[37] *Plan. Hyp.* II.4, p. 292:8. The Arabic term for the Greek *sphondylos* is *falka* or *filka* (see Lane, *An Arabic-English Lexicon*, Vol. 6, p. 2444), which should not be confused with *falak*, 'sphere' or 'circle'. On the Arabic terminology, see also Hartner, 'Falak', pp. 761–62.

[38] The cosmological description is at *Rep.* X.616b2–617d1.

[39] cf. Knorr, 'Plato and Eudoxus', p. 316, for an attempt to interpret this myth in a more elaborate astronomical way. He argued that, in this myth, the three goddesses of fate together generate the diurnal rotation of the cosmos and the complex planetary motions. There has been a debate about Plato's astronomical theories and how his accounts from *Republic* and *Timaeus* can be interpreted, especially in comparison with the theories of other astronomers of his time, the most important being Eudoxus and, later, Callippus and Aristotle. Besides the article by Knorr just cited, see, among others, Heath, *Aristarchus of Samos*, pp. 134–224; Vlastos, *Plato's Universe*, pp. 23–65; Goldstein and Bowen, 'A New View'; and Gregory, 'Eudoxus, Callippus'. See also Halliwell, *Plato: Republic 10*, pp. 17–21 for Plato's astronomical sources and especially for the connection of this myth to the rest of the *Republic*.

spheres that are stacked into each other from Plato, and subsequently connects it with his more advanced astronomical system.[40]

Ptolemy then criticises Aristotle explicitly. Although I deal with the details of his arguments in the commentary on Chapters II.5–6, this is a suitable place for a summary of these arguments, as whoever dealt with the *Planetary Hypotheses* in later traditions obviously had to face these arguments. In *Planetary Hypotheses* II.5, Ptolemy first criticises the idea that celestial motions are transmitted from one sphere to the next sphere inside of it by celestial poles, an idea that he ascribes to Aristotle. The idea behind this critique is pretty obvious: if he wants to argue for the existence of sawn-off pieces, which move independently from the part of the heaven near the poles, he first needs to show that the poles and thus this area is indeed 'without meaning', as he puts it in Chapter I.18, i.e. without any function for celestial dynamics. The most important argument builds upon the difference between sublunar and supralunar physics, as presented in *Planetary Hypotheses* II.3. The celestial element (aether) is always moving uniformly, without any change or alteration. According to Ptolemy, it should not be compared with the sublunar realm, where different physical bodies influence each other in their movements. The same would be the case for celestial poles, which are somehow distinct from the sphere and, since they are attached to the upper sphere, cause the inner sphere to move with it. This leads to another set of problems, as Ptolemy wonders whether the celestial poles should be considered as bodies or points. He dismisses the latter option immediately, as mathematical points lack physical existence, and what is not bodily cannot be connected to a body. This straightforward argument had been brought forward already by Aristotle in *On the Motion of Animals* 3, where he argues that even the cosmos needs an external immovable point by which it is supported.[41] Ptolemy, however, goes on to explain that the celestial poles cannot be bodies either. This assertion would lead either to (a) that they are of the same substance as the surrounding element (i.e. aether) or (b) that they would differ from the aether of the spheres. Option (a), then, begs the question of what makes them different from the rest of the spheres, so that one could ascribe to these points the capacity of moving the rest of the sphere. For dismissing (b), Ptolemy goes back to his theory of elementary motions. If the poles were not made out of aether, their natural place would be different from that of the surrounding aether and thus they could not stay in the aethereal realm.[42] Thus, this set of arguments ultimately ends with the claim that the assumption of celestial poles as distinct

[40] Incidentally, the whorl also shows up in Strabo's *Geography*, where he uses it to describe the area between the equator and the Arctic circle; see Strabo, *Geographica*, II.5.6, Vol. 1, p. 150:19–27. This shows that Ptolemy was not the only one to follow Plato in using the whorl as an example of a ring-shaped area taken out from a spherical object.

[41] *Mot. An.* 3, 699a20–24.

[42] See *Plan. Hyp.* II.5, pp. 294:21–296:17.

physical entities with the capacity to move the aethereal spheres is not conceivable in the heavenly realm.

Another line of argument again starts with a comparison with sublunar physics and is probably another direct reply to Aristotle. Ptolemy makes the point that even on Earth, round objects (balls, globes) do not necessarily need an unmoved external pole, and he refers to rolling motions as an example. His idea seems to be that if we observe a ball rolling on the floor, it does not have a physical body on which it is fixed and around which it rotates. The way he puts it is highly illuminating, for he says that the rolling spheres 'do not depend on any one external thing', and he goes on to say that 'it is not possible for something fixed to be the cause of motion, but rather, the cause must be something other than these points.'[43] Contrary to Aristotle in *On the Motion of Animals*, Ptolemy apparently denies the necessity of an external resting support on which the spheres depend for their motion or at least that these leaning points induce the spheres' motion, and indicates that the circular motion arises from the inside of the sphere itself.

Ultimately, this rejection of celestial poles as transmitters of motion also implies that Aristotle's counteracting spheres, which Ptolemy mentions twice in this context, become superfluous. If the motion of an upper sphere is not mechanically transmitted through the poles to the inner one, the complex motions of the upper planet do not influence the motion of a lower planet and thus do not need to be cancelled. This is what Ptolemy tries to establish with his alternative theory of celestial dynamics that rests on the idea that certain capacities connected to souls induce the celestial motions. While the details of this theory will be discussed in the next chapter, it should be clear by now that Ptolemy has two main reasons for opening up this argument. First, he must argue that the poles and thus the entire regions around them are indeed superfluous for an explanation of planetary motions, which allows us to assume sawn-off pieces. Second, by identifying the mechanical transmission of motions via poles and Aristotle's theory of counteracting spheres, he uses the same arguments against these unrolling spheres that oppose his economical theory of celestial motions that uses as few spheres as possible.

This last principle is first laid out in *Planetary Hypotheses* II.6. Ptolemy claims that in the case of sawn-off pieces, they are in direct contact with each other and with a certain area of the aether that imparts diurnal rotation to each of them. Ptolemy explains why one needs fewer spheres in the case of sawn-off pieces in more detail later when he presents the planetary models. However, to put it very briefly here, the area of the parts of the spheres that have been abandoned is now filled with aether or, as Ptolemy puts it, 'the rest of aether'. This aether moves naturally in the diurnal direction and is in direct contact with the main sphere of *each* planet below it, not only with the one next to it, due to the ring shape of the sawn-off pieces. Moreover, the parecliptic shells, which are the result of an eccentric complete sphere rotating

[43] *Plan. Hyp.* II.5, pp. 294:6–9.

within another complete sphere, do not occur anymore, because a ring rotating within another ring does not divide that ring into two unconnected parts.[44]

Chapters II.5–6 are therefore of special interest to the historian of astronomy as well as philosophy. It is true that Ptolemy does not tell us very much about the astronomical system of Aristotle and his predecessors.[45] He simply ascribes to him and other 'natural philosophers' the theories of celestial poles that transmit motion and of counteracting spheres, although it is not entirely certain whether this is actually a fair presentation of Aristotle's cosmology, given that unmoved movers also play a crucial role in it.[46] Although Ptolemy directly opposes what he at least considers as Aristotle's position, he apparently wants to place himself within the Platonic tradition when he compares his sawn-off pieces with Plato's whorls. A similar move is known from Dercyllides' *On the Spindle and Whorls in Plato's Republic*, a fragment of which is preserved in Theon of Smyrna's *Mathematics Useful for Reading Plato*. Whereas the former is roughly dated to the first century AD, the latter lived only slightly before Ptolemy at the beginning of the second century AD.[47] Theon reports that Dercyllides

> accuses all those philosophers who, as if unifying inanimate celestial bodies, introduce multiplications of spheres to the spheres and the circles of the celestial bodies, as Aristotle thinks it right to do, and among the mathematicians Menaechmus and Callippus, who introduced some spheres to carry the stars and some to unwind (*anelittousais*) the other spheres.[48]

Although Dercyllides' work is not extant in its entirety and we thus do not know what exactly Dercyllides had to say about Plato's whorl, the fragment in Theon testifies that Dercyllides saw himself in line with Platonic astronomy and argued that celestial bodies choose their motions.[49] Theon himself also claims that — after citing the entire myth of Er in *Mathematics Useful for Reading Plato* — he had written a commentary on Plato's *Republic*, in which he had discussed the myth of

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[44] For the details, see the commentary on Chapters II.11–16.

[45] Since, apart from these cosmological arguments, Ptolemy does not discuss homocentric planetary theories, I refrain here from a proper analysis and comparison, and also because it has been the subject of much research already. See the literature cited in the commentary on Chapters II.5–6 and also below (pp. 151–52 n. 4).

[46] I will deal with this question briefly in Chapter III.

[47] The dating of Theon of Smyrna depends on a bust that apparently stems from the Hadrianic time. However, Theon of Smyrna should not be confused with the Theon to whom Ptolemy refers in his *Almagest*. See Jones, 'Translating Greek Astronomy', pp. 467–68.

[48] Theon of Smyrna, *Expositio*, 201:22–202:2, tr. by Richard Sorabji in Sorabji, 'Adrastus', p. 586.

[49] The entire passage in question is at Theon of Smyrna, *Expositio*, 198:9–202:7. See van der Waerden, 'The Earliest Form', p. 183, and Zhmud, *The Origin*, pp. 234–35. For possible sources of Dercyllides' account, see van der Waerden, 'Die Erkenntnistheorie', pp. 229–34. Richard Sorabji suggested that the fragment in question is not from Dercyllides but from Adrastus, whom Theon had indeed cited before he mentions Dercyllides; see Sorabji, 'Adrastus', pp. 584–86. Against that, see Petrucci, 'Il *Commento*', p. 14, n. 49.

Er, and even that he attempted to construct a model analogous to the description in the myth.[50] Alexander Jones argued that we find Platonic as well as Aristotelian elements in Theon's cosmology and that Theon even tried to interpret Aristotle's *Metaphysics* XII and Plato's myth of Er as allowing for the existence of non-homocentric spheres.[51]

In addition, there is the evidence of two Peripatetic philosophers, Adrastus and Sosigenes (both fl. second century AD). The former is cited extensively by Theon of Smyrna and Sosigenes, whereas the latter was the teacher of Alexander of Aphrodisias and thus an older contemporary of Ptolemy. Like Theon of Smyrna later, Adrastus also dealt with astronomy within a commentary on a Platonic work. In Adrastus' case, however, the commentary was on the *Timaeus*. Although this commentary is not extant, many fragments survive in later authors.[52] Through these citations, we know that Adrastus devised a physical theory for the planets that made use of epicycles and that he thought that epicycles had already appeared in Plato and Aristotle.[53] Nevertheless, he is still considered as a Peripatetic due to his overall agreement with Aristotle on issues of natural philosophy; indeed, the claim has been made that Adrastus considered Aristotle's astronomical theories as a necessary development of Plato's *Timaeus*.[54]

The same is valid for Sosigenes, of whom Simplicius preserves a lot in his commentaries on Aristotle's works. We know that Sosigenes wrote an astronomical work that included a discussion 'on the counteracting spheres' (*en tois peri tōn anelittousōn*), as reported by Proclus in his *Exposition of Astronomical Hypotheses*.[55] It should be mentioned as a side note that the Greek term *anelittousai* does not necessarily denote the counteracting spheres added by Aristotle exclusively, but is often used more generally of the homocentric spheres of Eudoxus and Callippus.[56]

Like Adrastus before him, Sosigenes apparently was not satisfied with the astronomical theories of Eudoxus, Callippus, and Aristotle. As Simplicius testifies, Sosigenes complained that 'the [spheres] of the Eudoxans do not in fact save the

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[50] See Theon of Smyrna, *Expositio*, pp. 143:7–146:5, as briefly pointed out in Jones, 'Translating Greek Astronomy', p. 467.

[51] See Jones, 'Translating Greek Astronomy', pp. 475–78. As a minor point, it is interesting to note that it is 'out of place' (*atopos*) that the 'mathematicians' argue whether the Sun moves on an epicycle or an eccentric circle; see Theon of Smyrna, *Expositio*, p. 154:12–17.

[52] See Moraux, *Der Aristotelismus. Zweiter Band*, pp. 296–99, and Petrucci, 'Il *Commento*', especially pp. 14–25 for the astronomical part.

[53] See Moraux, *Der Aristotelismus. Zweiter Band*, pp. 305–13, and Sorabji, 'Adrastus', pp. 581–84.

[54] As argued in Petrucci, 'Adrastus on Aristotle'.

[55] See Proclus, *Hypotypōsis*, p. 130:18–19. It is not entirely certain whether this should be considered as the actual title of this treatise, since it is otherwise (for example, in Simplicius) not attested. See Bowen, *Simplicius on the Planets*, pp. 249–50.

[56] See Moraux, *Der Aristotelismus. Zweiter Band*, pp. 344–47, and Bowen, *Simplicius on the Planets*, p. 135 n. 113.

phenomena'.[57] Because of the difficulty of exactly determining where the citations of Sosigenes end in Simplicius' commentary, it is not easy to extract a complete picture.[58] In any case, Simplicius at least makes it clear that Sosigenes raised some doubts about the theory of eccentric spheres and epicycles, the most obvious one being that such spheres contradict Aristotle's teaching that every celestial body should move around the centre of the cosmos.[59] In Sosigenes, we thus find the two main worries the Peripatetics had to face in this period. The first was that the new astronomical tools (epicycles and eccentric spheres) could account better for the apparent celestial motions than the homocentric theory of Eudoxus, Callippus, and finally Aristotle. The second was that this alternative astronomy might conflict with Aristotle's natural philosophy.

In summary, Ptolemy's attack against Aristotle in *Planetary Hypotheses* II.5–6 is placed in a time of merging and debating various Platonic, Aristotelian, and recent astronomical elements. There is enough evidence of philosophers who critically engaged with Aristotle's astronomy, often within a Platonic frame, though still subscribing to fundamental Aristotelian positions such as the existence of aether. Providing an explanation of Plato's whorls in connection with a working astronomical theory seems to have been an important motivation for a number of authors in this time. Against this backdrop, one can understand why Ptolemy compares his sawn-off pieces to Plato's whorls. The appearance of the Platonic whorls in other astronomical works strongly suggests that Ptolemy does this not only because he strives for an authoritative philosophical justification for his sawn-off pieces, but even to show that he does not consider his theory as his own new one. On this account, we can read *Planetary Hypotheses* II.4, in which Ptolemy presents the two theories of complete spheres and sawn-off pieces, as a brief introduction into recent discussions on Plato's and Aristotle's astronomical accounts. An illustration of the importance of Plato and Aristotle for this first half of Book II of the *Planetary Hypotheses* is the fact that Ptolemy refers to both of them, and not to other philosophers, in

[57] Simplicius, *In Cael.*, p. 504:17–18, tr. by Alan C. Bowen in Bowen, *Simplicius on the Planets*, p. 165. The expression 'saving the phenomena' goes back the famous story by Sosigenes, as cited by Simplicius, that Plato set this as the astronomers' task, namely to find an astronomical theory with only uniform circular motions that fitted the celestial appearances. See Simplicius, *In Cael.*, p. 488:21–24. There is copious literature on this report and its historicity. See, among others, Duhem, *Σῴζειν τὰ φαινόμενα*; Mittelstrass, *Die Rettung*; the comments by James Evans and J. Lennart Berggren in the introduction to Geminus, *Introduction*, pp. 49–58; Bodnár, 'Sozein ta phenomena'; and Bowen, *Simplicius on the Planets*, pp. 251–59.

[58] As an example, it has been argued that at 505:23–27 of Simplicius' commentary on *On the Heavens*, Sosigenes makes an attempt to show that even Aristotle had recognized some problems with this theory, whereas Alan C. Bowen argued that this part does not belong to the citation from Sosigenes anymore. See Schramm, *Ibn Al-Haythams Weg*, pp. 46–47; Moraux, *Der Aristotelismus. Zweiter Band*, p. 354; and Bowen, *Simplicius on the Planets*, p. 165 n. 268.

[59] See Simplicius, *In Cael.*, p. 509:19–28; Schramm, *Ibn Al-Haythams Weg*, pp. 55–63; and Moraux, *Der Aristotelismus. Zweiter Band*, 355–57.

Chapters II.4–5. Ptolemy's main aim in Book II of the *Planetary Hypotheses* then is not only a defence of his own, new theory on the shape of celestial bodies but also an attempt to combine Plato's whorls, Aristotelian natural philosophy, and more recent inventions such as epicycles and eccentric spheres.

What distinguishes Ptolemy's discussion, however, from (at least some of) his predecessors is the context in which he discusses the Platonic and Aristotelian heritage. His agenda was not to harmonise Aristotle's homocentric theory with the appearances or the theories of epicycles and eccentric spheres, because, supposedly, he thought that his reconstructions from the *Almagest* had sufficiently established that they work better. Thus, Aristotle's homocentric theory is not discussed with respect to the question whether it fits the appearances but instead whether it is coherent from the physical point of view.

In addition to refuting Aristotle's complete spheres, Ptolemy also explains at length why his theory of sawn-off pieces, in his eyes, should be preferred. Nevertheless, in Chapters II.11–16, he finally presents the planetary models in both ways, namely, if we adopt complete spheres and if we adopt his sawn-off pieces. One reason why he does that is obviously the attempt to prove that his new theory indeed needs fewer spheres than any system involving complete spheres, even if one does not follow Aristotle's idea of counteracting spheres. Still, there is a lack of a final statement, something along the lines that 'since I have proven now that we indeed need fewer spheres in the case of sawn-off pieces, this is how the cosmos is constituted'. As I have argued in this chapter so far, here again, we can detect Ptolemy's caution concerning indications deriving from physical arguments. As he said in the beginning of Book II, there is no mathematical reason definitely proving that one of the two theories is correct or incorrect. Thus, all the physical arguments in the following chapters and his demonstration that his own theory is more economic are not necessary proofs. This is the second reason why Ptolemy provides two versions for each planetary model and this again highlights how the epistemological distinction of the three theoretical sciences in *Almagest* I.1 permeates the entire *Planetary Hypotheses*. This interpretation has the obvious downside that many results from the *Planetary Hypotheses* have to be considered as only conjectural in Ptolemy's own terminology. In this context, one can point to Ptolemy's description of his principle of simplicity in *Almagest* XIII.2. There, Ptolemy makes the point that although his planetary models might seem rather complicated, they still could be characterised as simple, for simplicity in the terrestrial world might be completely different from simplicity in the celestial realm. Alexander Jones described this as a 'dangerous (and perhaps desperate) move [...] since one might wonder whether it leaves any place for simplicity arguments in astronomy.'[60] Since Ptolemy uses this principle of economy in the *Planetary Hypotheses* despite these general reservations

[60] Jones, 'Theon of Smyrna and Ptolemy', p. 95, with reference to Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:12–534:6.

about its demonstrable status, one could wonder about the actual agenda and aim of this work, and one could be worried about how seriously he takes the results of his own work.

Fortunately, Ptolemy also wrote a work called *On the Kriterion and the Hegemonikon*, in which he lays out his epistemological principles. Although the authenticity of this work has been doubted, Jacqueline Feke, in her account of Ptolemy's philosophy, has shown how *On the Kriterion* is consistent with the philosophical doctrines from his other works.[61] As the title suggests, this work is divided into two parts. The first deals with Ptolemy's criterion of truth, the second with the ruling part of the soul. Of interest to the present question is the first part, in which Ptolemy discusses the way in which knowledge is generated. Ptolemy introduces us to this topic by providing an analogy with a law court. This leads him to say that if truth is the goal, sense perception is the instrument by which the intellect, the agent of judgment, judges. Reason is the means by which the intellect is able to judge the perceived things.[62] After distinguishing body and soul, Ptolemy compares two capacities of souls with respect to their activity, namely sense perception and thought. He describes that first the senses perceive things, then *phantasia* transmits what is perceived to the intellect, and that thought comes into play here and makes judgements about them. The difference between sense perception and thought, according to Ptolemy, is not the object. Instead, the senses only deal with things while they are perceiving them. In doing so, they are independent from intellect. The intellect, on the other hand, needs sense perception, at least in the beginning, for without the signal from the senses, there is nothing to which it could apply thought.[63] Although this sounds like a straightforward empiricist statement, Ptolemy argues in the following that one should not favour intellect over sense perception or vice versa, for they both play a necessary role in generating certain knowledge. Next, Ptolemy acknowledges that both are liable to deception, for example, when things affect more than one sense at a time. Whenever the senses, however, perceive simple things, their judgments get at least as close to truth as humans can ever get.[64] This first part closes with Ptolemy's distinction between opinion and knowledge. He describes this distinction and transition as follows:

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[61] See Feke, *Ptolemy's Philosophy*, especially pp. 144–63, and previous studies in Boll, *Studien*, pp. 77–93, and Long, 'Ptolemy *On the Criterion*', including discussions on the question of its authenticity. Since these studies discuss *On the Kriterion* and its influences in detail, I restrict myself to a couple of notes that might be helpful for understanding what Ptolemy means by certain assertions regarding the soul, intellect, and volition.

[62] Ptolemy, 'Peri Kritēriou', pp. 5:4–14. I made use of the English translation by the Liverpool–Manchester Seminar on ancient Greek philosophy, published with a revised text in Huby and Neal, *The Criterion of Truth*, pp. 179–230.

[63] Ptolemy, 'Peri Kritēriou', p. 13:3–14:3.

[64] Ptolemy, 'Peri Kritēriou', pp. 15:5–16:7.

> When the internal *logos* of thought combines with these simple and non-inferential *kriteria*, even *logos* can still only form opinions if it concentrates exclusively on its immediate object. But when it makes clear scientific distinctions, it at once enters the state of knowledge. This involves separating and combining the differences and non-differences between actual things, and moving up from particulars to universals and on to the genera and species of the objects before it.[65]

What does this epistemological framework mean for Ptolemy's astronomy? First, the relative importance of sense perception is mirrored by Ptolemy's downgrading of theology, since its object cannot be properly perceived, and elevation of astronomy, since the motions of the stars can be perceived and never change, which makes it easier to go from particular observations to universal planetary models, for example. This is what Ptolemy does in the *Almagest* and he thus can label the result as solid knowledge according to his criteria from *On the Kriterion*. Nevertheless, astronomy, one could add, is not always as certain as *Almagest* I.1 seems to suggest, for Ptolemy notes later in III.1 and IX.2 that observations might be inaccurate because of imprecise methods or having only a small number of observations.[66] This means that even in astronomy, there is room for some uncertainties. One can only be as certain as humans can get, as Ptolemy expressed it in *On the Kriterion*, in light of the quality of the empirical observations. In this context, then, theology and physics should not be seen as pseudo-sciences without any value but simply as sciences leaving more room for ambiguity than a mathematical science such as astronomy. These uncertainties of astronomical science, however, do not result from a general human incapability to grasp certain objects of the cosmos. Instead, they arise from occasional observational imprecisions that can have a negative impact on the exactness of our astronomical knowledge. This means that ongoing observations and a refinement of astronomical instruments can generate better astronomical theories, as is the case with Ptolemy and his predecessors, or with the earlier *Almagest* and the later *Planetary Hypotheses*. In the same way, further application of thought and a more and more skillful analysis can disprove one physical opinion after the other to finally reach a firmer opinion that is more likely than the previous ones.

The sources of Ptolemy's epistemology have already been extensively discussed. In summary, they all amount to the conclusion that he indeed borrows notions from different traditions, most importantly Aristotelian, Platonic, and Stoic elements, though there are differences as to which of these sources might have been the most

[65] Ptolemy, 'Peri Kritēriou', p. 18:9–17, tr. from Huby and Neal, *The Criterion of Truth*, p. 1205. See also Ptolemy, 'Peri Kritēriou' p. 6:9–11, where opinion and knowledge are introduced. For similar summaries of Ptolemy's epistemology from *On the Kriterion*, see Boll, *Studien*, pp. 77–87; Long, 'Ptolemy *On the Criterion*', pp. 162–65; Feke, *Ptolemy's Philosophy*, pp. 35–37.

[66] See Feke, *Ptolemy's Philosophy*, pp. 131–34.

important.[67] From these previous studies, it becomes clear that Ptolemy was able to draw from a huge variety of sources regarding scientific truth and conjecture. More illuminating might be the comparison to his contemporary Galen, who is famous for his critique of speculative philosophy, for example, concerning questions such as the eternity of the world and the existence of a void outside of our cosmos.[68] In his view, these are good examples of questions on which philosophers cannot actually come to a final agreement, which is very much the same attitude Ptolemy exhibits concerning theological or physical questions in general. Like Ptolemy, Galen also emphasizes the important role of both reason and sense perception in attaining truths. Finally, we can use Galen's notion of 'approximating the truth' to better understand what Ptolemy could mean by 'conjecture'. As Riccardo Chiaradonna argued, in Galen, one finds the distinction between what is merely persuasive and what approximates the truth. As opposed to the former, which simply states that an argument is persuasive, but does not entail any epistemological value beyond that, the latter can indeed be described as likely to be true.[69] For our present investigation, this means that the relationships among truth, probability, and persuasion were the subject of ongoing discussions, and probability or conjecture did not generally have the simple meaning of making an unfounded guess.

Let us turn back to *Almagest* I.1. Before Ptolemy distinguished among the three theoretical sciences, he distinguished theoretical philosophy in its entirety from practical philosophy, claiming that 'it is impossible to achieve theoretical understanding of the universe (*tēs de tōn holōn theōrias*) without instruction'.[70] Notably, this claim comes before the separation of mathematics and astronomy from the other theoretical sciences, and thus he plans to 'devote most of our time to intellectual matters, in order to teach theories, which are so many and beautiful, and especially those to which the epithet "mathematical" is particularly applied.'[71] This means that Ptolemy considers mathematics as probably the most important of the theoretical sciences for a thorough understanding of the cosmos, but apparently not the only one. Although it is certainly true that the *Almagest* mostly deals with mathematics, there are certain aspects of the cosmos that need physical arguments, of which we have seen examples throughout the present chapter. These physical arguments may not be as certain as mathematical proofs, but Ptolemy shows

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[67] See Boll, *Studien*, pp. 77–93, for the identification of Aristotelian elements; Lammert, 'Eine neue Quelle', and Lammert, 'Eine neue Quelle. Zweites Kapitel', on the Stoic context; and, recently, Feke, *Ptolemy's Philosophy*, Chapter 3 for its closeness to philosophical handbooks e.g., by Alcinous. See also Long, 'Ptolemy *On the Criterion*', pp. 163–65.

[68] For these two examples, see Adamson, 'Galen on Void', and Koetschet, 'Galien, al-Rāzī'. For the following brief comparison of Ptolemy's epistemology to that of Galen, I rely on Chiaradonna, 'Galen on What is Persuasive'. Ptolemy had already been compared to Galen by Anthony A. Long. See Long, 'Ptolemy *On the Criterion*', pp. 165–71.

[69] See Chiaradonna, 'Galen on What is Persuasive', especially pp. 80–88.

[70] Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 4:14, tr. by Toomer in Ptolemy, *Almagest*, p. 35.

[71] Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 5:4–7, tr. by Toomer in Ptolemy, *Almagest*, p. 35.

in the *Planetary Hypotheses* that some physical theories are preferable to others, whereas yet others are already excluded by mathematics. Speaking in more general epistemological terms, in these cases where mathematics is not decisive because what has been perceived by the senses is not enough to judge the underlying causes, reason steps in and qualifies some of the possibilities as less or more reasonable than others. Moreover, as we have seen, astronomical observations are not completely free from any doubt.

In addition, Ptolemy offers a further reason why one should engage with physics, although it has an inferior epistemological status to astronomy. Theoretical philosophy in general, and within it mathematics in particular, also has an important ethical value for Ptolemy. Just as Plato did in the *Timaeus*, Ptolemy connects the study of the celestial motions with the orderly state of the human soul and the direction of actions towards what is good:

> With regard to virtuous conduct in practical actions and character, this science, above all things, could make men see clearly; from the constancy, order, symmetry and calm which are associated with the divine, it makes its followers lovers of this divine beauty, accustoming them and reforming their natures, as it were, to a similar spiritual state. It is this love of the contemplation of the eternal and unchanging which we constantly strive to increase, by studying those parts of these sciences which have already been mastered by those who approached them in a genuine spirit of enquiry, and by ourselves attempting to contribute as much advancement as has been made possible by the additional time between those people and ourselves.[72]

These passages nicely underline the description of the *Almagest* as a pedagogical work that has been made by some modern scholars.[73] As a last point on the nature of the *Planetary Hypotheses*, I want to suggest that Ptolemy follows the same methodology as in the *Almagest*. All these instances of a continuation from the *Almagest* to the *Planetary Hypotheses* might not be too surprising, since Ptolemy

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[72] Ptolemy, *Syntaxis*, I.1, Vol. 1, pp. 7:17–8:6, tr. by Toomer in Ptolemy, *Almagest*, pp. 36–37. For detailed analyses of Ptolemy's theory of the ethical value of theoretical philosophy, see Taub, *Ptolemy's Universe*, pp. 135–38; Feke, *Ptolemy's Philosophy*, Chapter 4. In *Tim*. 47b5–c4, Plato describes how God provided humans with sensation to perceive the celestial motions so that they can harmonize their souls accordingly. Compare this also with Ptolemy's description of the goal of astronomy as approaching the divine in Ptolemy, *Syntaxis*, IV.9, Vol. 1, p. 328:3–11.

[73] Among others, see Bernard, 'In What Sense', pp. 98–99, and, most recently, Kremer, 'Experience and Observation', p. 215. This is also confirmed by the way in which the *Almagest* was indeed used in late antiquity, for example, as well as in the medieval Arabic tradition, where philosophers themselves or biographers claim to have studied Ptolemy's *Almagest* and, through it, astronomy in general. See Pingree, 'The Teaching', and Jones, 'Uses and Users', for the late ancient tradition. In Avicenna's autobiography, Avicenna first describes how he studied the *Almagest* after mastering Euclid. Then his pupil, al-Ǧūzǧānī, continued the biography, and when he describes how Avicenna finished the *The Cure* in Isfahan, he simply uses 'Almagest' as an equivalent to astronomy. See Avicenna and al-Ǧūzǧānī, *The Life*, pp. 22:5–24:6 and 64:5–66:4.

himself connects the two works in the preface of the *Planetary Hypotheses*.[74] As an example of Ptolemy's methodology in the *Almagest*, one can look at how Ptolemy unfolds his theory of Moon, as Alexander Jones has already done.[75] Ptolemy does not simply provide a final model for the Moon's motion and shows how it conforms with the observational data. Rather, he shows a way to get to this correct model and how this process is properly done, although this includes making a mistake on the way that has to be corrected in the end. The same methodology can be observed in the *Planetary Hypotheses* on different occasions. For example, in *Planetary Hypotheses* I.19, he takes us through the various steps for calculating the volumes of the planets. Here again, he first gives values for the diameters under the condition that all diameters form the same apparent angle at their mean distance, which facilitates the calculation in the first place, despite being only approximations. Thus, in the next step, he shows how to correct that and how to derive the correct values for the relative diameters.[76] Alternatively, let us take a look at how he unfolds the setup of the cosmos in Book II. He not only claims that his theory of sawn-off pieces is more economical in general terms, but he also explains, for each planetary model, how many complete and how many sawn-off pieces we would need and why that is so, after their compliance with the previously established principles of physics has been secured. If we adopt the notion that Ptolemy teaches his readers in the *Almagest* how mathematical astronomy should be done, they now learn in the *Planetary Hypotheses* how to properly connect these astronomical theories with physical arguments, even though they might not provide us with the same degree of certainty. The doubts he usually connects with his arguments concerning the non-existence of the void or that nature does nothing in vain simply pick up his lament from *Almagest* I.1 that philosophers may never agree about theological or physical issues. Thus, Ptolemy shows in the *Planetary Hypotheses* how a theoretical philosopher, as part of his or her path towards ethical well-being, can study astronomy and physics and arrive at some degree of probable knowledge.

Ptolemy's Epistemology and Astronomy in Late Antiquity

In the next chapter, I will draw a picture of how these different issues concerning the relationship between physics and mathematics, their different epistemological values, and the consequences of this relationship for statements about the physical nature of astronomical models were treated in the medieval Arabic tradition. First, however, this is the place for some brief notes about the reception of the Ptolemaic tradition during late antiquity. Although this is not the main aim of the present investigation, the reception of these topics and of Ptolemy's *Planetary*

[74] A point made already by Régis Morelon, see Morelon, 'Le Livre des hypothèses', p. 99.
[75] Jones, 'Ptolemy's Mathematical Models', pp. 28–29.
[76] *Plan. Hyp.* I.19, pp. 278:14–280–21.

Hypotheses in particular can help us understand which problems authors saw in Ptolemaic astronomy and cosmology. In fact, when we are talking about late antiquity, we are roughly talking about the time between Ptolemy and the translation of Greek philosophical and scientific texts into Syriac and Arabic. Thus, an attempt to cast light on astronomy and philosophy in this period can establish certain lines of transmission. For example, we know that Neoplatonic works were a prominent part of this translation movement and thus had a huge impact on Islamic philosophers.[77] Even if it is not always possible to determine this transmission, we will still get a better idea of the problems at which we are going to look in the next chapter.

Undoubtedly, Ptolemy and, most famously, the *Almagest* have attracted wide interest by astronomers and philosophers equally.[78] Two centuries after Ptolemy, Pappus and Theon of Alexandria wrote commentaries on Ptolemaic works. Of the former's commentary on the *Almagest*, only the comments on Books V and VI have survived. Theon of Alexandria wrote two commentaries on the *Handy Tables* as well as (with editorial help by his daughter Hypatia) a commentary on the *Almagest*, which is preserved nearly in its entirety.[79] Concerning the topics discussed in this chapter, these two commentaries, although they were subsequently quite influential, do not add new discussions. Given that we only have Books V and VI of Pappus' commentary, this is natural in Pappus' case. Theon's commentary to Ptolemy's epistemological framework from *Almagest* I.1 is a straightforward presentation without any critical or approving remarks.[80] In addition, there is no explicit reference to the *Planetary Hypotheses* in the four books of Theon's commentary that have been edited so far.

This last point changed with the Neoplatonic commentators, especially Proclus (d. AD 485) and Simplicius (fl. sixth century AD), who refer to the *Planetary Hypotheses* by its title and even quote parts *verbatim*. This development is surely no coincidence, for several philosophers connected to the Neoplatonic school in

[77] As an example, see the various articles in D'Ancona, *The Libraries*.

[78] On the decreasing number of astronomers and astrologers after the second century AD, however, see Thomann, 'The Second Revival', pp. 909–13.

[79] See the editions by Adolphe Rome in Pappus, *Commentaires* (on Books V–VI of the *Almagest*), Theon of Alexandria, *Commentaire sur les livres 1 et 2* (on Books I and II of the *Almagest*), Theon of Alexandria, *Commentaire sur les livres 3 et 4* (on Books III and IV of the *Almagest*). For an overview, see Bernard, 'The Alexandrian School'. Ibn al-Nadīm's *Fihrist* knows both authors, but only a work by Theon on the *Almagest*. This is mentioned as the 'Introduction to the *Almagest* in an old translation' (*Kitāb al-Mudḫal ilā l-Majisṭī bi-naql qadīm*), which might point at an otherwise unknown Arabic translation. See Ibn al-Nadīm, *Kitāb al-Fihrist*, Vol. 1, p. 268:29 (and also Kunitzsch, *Der Almagest*, pp. 118–19 n. 17); for Pappus' entry, see p. 269:8–10. Franz Rosenthal identified that al-Kindī depends on Theon's commentary in his own paraphrase of the first eight chapters of the *Almagest*, proving that al-Kindī had direct access to (at least a partial version of) Theon's commentary (see Rosenthal, 'Al-Kindī and Ptolemy', pp. 446–53).

[80] See the text in Theon of Alexandria, *Commentaire sur les livres 1 et 2*, pp. 319–24, and similarly Mansfeld, *Prolegomena Mathematica*, p. 77.

Athens are known to have written astronomical works: Syrianus wrote an astronomical work that is perhaps comparable with the commentaries by Pappus and Theon. Of his successor as leader of that school, Proclus, we have his astronomical compendium *Exposition of Astronomical Hypotheses* (*Hypotypōsis tōn astronomikōn hypotheseōn*). Ammonius, a pupil of Syrianus, wrote a work on the astrolabe, as did his pupil John Philoponus, and Simplicius includes much astronomical material in his commentary on Aristotle's *On the Heavens*.[81] Of these, Proclus was the first to cite the *Planetary Hypotheses* in his commentaries on Plato's *Timaeus* and *Republic*. Although Proclus is thus an important figure for the reception of Ptolemy's cosmology, I will restrict myself to a couple of remarks, since none of the works in question were (fully) available in Arabic, as it seems.[82] In general, Proclus argues against Ptolemaic astronomy and its use of eccentric and epicyclic spheres on various occasions. At the end of the *Exposition of Astronomical Hypotheses*, Proclus wonders whether the eccentrics and epicycles are only conceived in the mind (*epinoeisthai*) or whether they actually exist (*hypostasin exein*) in the spheres to which they are attached:

> If they are only conceived, they [viz. the astronomers] have moved from physical bodies to mathematical notions and explain from things that do not exist in reality the causes for physical motions, without [even] being aware of it. [...] But if they have actual existence, they destroy the continuity of the spheres in which the circles are, these separately moving [circles] and those separately moving [spheres], not uniform to each other, but rather contrary to each other; [and they do this,] confounding their distances to each other, as if they are sometimes brought together and become in one plane, and sometimes they depart from each other or cut each other. [...] Besides these [problems], the transmission of these constructed hypotheses appears arbitrary. Why does the eccentric behave as it does in each case, being fixed or moved, and the epicycle in this way, whereas the star is moved in the opposite or the same direction? They do not talk at all about what the causes are of these planes and distances, I certainly mean the true causes [...]. However, while they [viz. the astronomers] advance in the reverse order, they do not conclude from the hypotheses the next [things], as the other sciences, but from the conclusions, they try to form the hypotheses from which one [actually] needs to show them.[83]

[81] See Goulet and Luna, 'Syrianus d'Alexandrie', pp. 704–05 for Syrianus; Proclus, *Hypotypōsis*; Philoponus, 'De usu astrolabii', especially p. 129:9 for the reference to Ammonius. Also see Pingree, 'The Greek Influence', pp. 32–34. For Simplicius, see Bowen, *Simplicius on the Planets*.

[82] On the Arabic fragments from his commentary on the *Timaeus*, see Arnzen, 'Proclus on Plato'. These do not include the passages that are important for the present study. Ibn al-Nadīm mentions a Syriac version of a commentary on the tenth book of the *Republic* (see Ibn al-Nadīm, *Kitāb al-Fihrist*, p. 252:21). Detailed analyses of Proclus' astronomy have been offered in Segonds, 'Proclus: Astronomie', and Siorvanes, *Proclus*, pp. 262–316.

[83] Proclus, *Hypotypōsis*, pp. 236:18–238:20; my English translation has been made with reference to the facing German translation by Karl Manitius.

In this passage, Proclus questions the value of the theories that include epicycles and eccentrics for physical and metaphysical investigations. If the astronomers use them only as mathematical entities, they do not provide any explanation for the causal relations of the spheres. However, if they are considered as physical entities, Proclus finds it problematic to explain their different motions within a coherent setup of the cosmos. In addition, he complains that the astronomers fail to explain why all these different spheres move exactly how they need to move in order to agree with the phenomena. One could wonder whether this is actually a fair point, especially with Ptolemy's *Planetary Hypotheses* in mind. Proclus himself opts for an independent motion of the planets themselves, which is rather close to Ptolemy's suggestion of freely moving planets within a set of spheres.[84] The last point of attack might go back to Ptolemy's own confession that he sometimes does not arrive at certain theories from previously established principles.[85] Still, Proclus admits in the last passage of his *Exposition* that the Ptolemaic astronomical hypotheses that he had presented before and that included eccentric and epicycles are indeed 'the simplest and most fitting to divine bodies'.[86] In short, Proclus argues that these theories might be helpful for an investigation of the planets' circuits, but that this is not sufficient for proper Platonic astronomy, as Plato demanded that the philosopher should go beyond the celestial objects that can be perceived through sight and instead attempt to reach the true forms that can be grasped by reason and thought.[87]

On the other hand, Proclus also opposes earlier Platonists who, as we have just seen, tried to read epicycles into Plato's myth of Er in *Republic* X. In a number of passages in his commentaries on Plato's *Timaeus* and *Republic*, he emphasizes that he does not consider epicycles as part of Plato's astronomy. To be clear, he also speaks of celestial spheres as whorls, but he does not identify these whorls with epicycles.[88] In some of these passages, he argues not only against the theory of eccentrics or epicycles, but also against those who employ 'counteracting spheres' (*anelittousai*). His main worry with these theories is that they undermine Plato's

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[84] For an evaluation of Proclus' view on celestial dynamics, see Siorvanes, *Proclus*, pp. 271–84. On Ptolemy's view on this issue, see Chapter III of the present study.

[85] Ptolemy, *Syntaxis*, IX.2, Vol. 2, p. 212:3–5.

[86] Proclus, *Hypotypōsis*, p. 238:23, and also Proclus, *In Tim.*, p. 148:23–30.

[87] As stated for example in *Rep.* 529c6–530a2. Compare this with Proclus' own distinction at the outset of his work, which offers an explanation why he deals with Ptolemaic and not Platonic astronomy (Proclus, *Hypotypōsis*, p. 2:1–13). For an evaluation of the passages discussed here, see Lloyd, 'Saving the Appearances', pp. 204–11; Segonds, 'Proclus: Astronomie', pp. 331–33; and Opsomer, 'Mathematical Explanation', pp. 95–104. For Proclus' reception of Plato's demand for an astronomy that goes beyond the sensible objects, see again Segonds, 'Proclus: Astronomie', pp. 324–25.

[88] Most straightforwardly at Proclus, *In Tim.*, Vol. 3, p. 146:14–17, and also (among others) pp. 56:25–57:4 and 96:19–21, and Proclus, *In Rep.*, Vol. 2, pp. 214:6–13 and 227:23–228:9. For a summary of Proclus' reconstruction of Platonic astronomy, see Opsomer, 'Mathematical Explanation', pp. 86–95.

demand for regular circular motions. In another passage of his commentary on the *Republic*, he explains further his worry with the counteracting spheres:

> Some will say on the basis of mathematics that they use hypotheses of this sort [that include epicycles] in order to save the appearances. But those who are devoted to the philosophical Muse should insist that nothing happens without reason. Nothing happens randomly or by chance, but everything according to reason … For the rallying-cry of the Pythagoreans was the task of ordering the apparent irregularity of the motions of the heavens into evenness and order using the simplest possible hypotheses. However, those who use counteracting spheres (*anelittousai*)[89] by no means accomplish this, since they multiply their hypotheses far beyond even the complexity of the appearances, and they create incredible spheres and construct an entire complex universe just to contrive the single order of one star. Moreover, the cause they identify is not suitable for the creation of multiplicity and variety. Additionally, the hypotheses themselves have been refuted by later [astronomers] on the grounds that they do not actually save all of the phenomena nor do they even adequately explain the ones they do save. This is what Ptolemy treated in the books of the *Hypotheses*.[90]

The first part goes nicely with the passage above. The reference at the beginning goes back to a previous discussion of epicycles, so Proclus claims — as in the *Exposition* — that philosophers should not be content with these theories because they lack an explanation of the causes behind celestial motions. The first point of his attack on the counteracting spheres is the same already made by Ptolemy in *Planetary Hypotheses* II.6, namely that in this system, there are more spheres than are actually needed to account for the planetary motions. The following point regarding the cause is not as obvious as the previous one, but it might also go back to the same chapter in Ptolemy, in which Ptolemy argued that fixed bodies cannot be the source of motion.[91] Another argument made by Ptolemy is that the counteracting spheres would somehow be responsible for the motions of the upper spheres. This argument is also preserved by Simplicius, who writes that they make, according to Ptolemy, the inner spheres the 'causes' of the revolutions of the upper spheres.[92] It is possible that Proclus also has this argument in mind, which, however, also comes from the

[89] Pass (see the following note) translates *anelittousai* as 'extra circles', arguing that Proclus does not mean the homocentric system used by Eudoxus and Aristotle, but rather the Ptolemaic system. I argue that Proclus indeed here (and also in the other instances cited above) alludes to Aristotle's system; otherwise, his reference to Ptolemy's *Planetary Hypotheses* that I discuss here would not make as much sense. Moreover, if Proclus' critique that this system is far too complicated really addressed Ptolemy's astronomy, this would contradict his assertion at the end of the *Exposition* that the system of epicycles and eccentrics is the simplest possible. Pass, 'Platonism and Planetary Motion', p. 383, explains this last point by a development in Proclus' writings.

[90] Proclus, *In Rep.*, Vol. 2, pp. 229:26–230:15, tr. by David Blair Pass in Pass, 'Platonism and Planetary Motion', pp. 385–86, with a few of my own modifications.

[91] See *Plan. Hyp.* II.6, p. 300:3–5.

[92] See Simplicius, *In Cael.*, p. 506:16–22, and the discussion of Simplicius, see below pp. 58–61.

Planetary Hypotheses. This is why Proclus refers to the *Planetary Hypotheses*, and he surely has Ptolemy in mind again when he claims that the counteracting spheres have also been rejected for astronomical reasons.

This seems to be a safe reason to believe that Proclus indeed had access to the *Planetary Hypotheses*. Despite that, there is some debate about whether Proclus really knew the entire *Planetary Hypotheses* directly or whether he became acquainted with it (or parts of it) at a later stage of his career.[93] When Proclus discusses the order of the planets, he makes seemingly odd assertions about Ptolemy's *Almagest* and *Planetary Hypotheses*:

> While Ptolemy does indeed say in the *Syntaxis* that if one follows [the criterion of] 'the reasonable' (*tō eulogō*) or 'the probable' (*tō pithanō*), then it is fitting to place the Sun in the middle position among the seven [planets] in order that, among the five planets, those that are entirely and completely set apart from it might be prior to the Sun, while those that accompany the Sun and go before or flank it might come after. However, in the *Hypotheses*, he is not entirely insistent (*diateinomenos*), nor does he draw a conclusion (*syllogizetai*) in these hypotheses about them [i.e., the planets and their order] from the distances.
>
> 'It follows from what has been shown in the *Syntaxis* that — taking the unit as the [distance] from the centre of the Earth — the closest distance for the Moon is 33 [Earth radii], while the furthest is 64 [radii] (leaving off the fractions in order that we may have the ratios expressed in whole numbers). Furthermore, the shortest distance between us and the Sun is 1076[94] [Earth radii], while the greatest is 1260 [radii]. Now since the ratio that is posited between Mercury's nearest distance and its furthest is approximately that of 34 to 88, and since[95] it is clear that the furthest distance of the Moon coincides with the least distance of Mercury, the greatest distance for the latter will be 166 while the closest is 64. Furthermore, since,[96] in the case of Venus, the ratio of the closest distance to the furthest distance is approximately that of 16 to 104, and since[97] it is clear that the furthest distance of Mercury coincides with the closest distance of Venus, the greatest distance of Venus will be 1079 [Earth radii] and the closest about 166 [radii].'
>
> As a result, since the closest distance of the Sun is 1076, there will be a remainder of a certain size [between it] and the furthest distance of Venus, which would be unaccounted for according to these assumptions. It is obvious that the sphere of Venus and that of Mercury must be arranged between the sphere of the Moon and that of the Sun, for the greatest distance of the Moon [from the Earth] coincides with the closest distance for Mercury, while the furthest distance for Mercury coincides with the closest distance

[93] See Neugebauer, *A History*, pp. 918–19; Segonds, 'Proclus: Astronomie', p. 329 n. 32; and Bowen, *Simplicius on the Planets*, p. 212.
[94] See Swerdlow, *Ptolemy's Theory*, pp. 134–35.
[95] In *Plan. Hyp.* I.17, p. 270:11: 'if' (*in*).
[96] In *Plan. Hyp.* I.17, p. 270:13: *fa-inna*.
[97] In *Plan. Hyp.* I.17, p. 270:14: 'if' (*in*).

> for Venus, and in the case of the latter, the greatest is quite close to the nearest distance for the Sun. But it is necessary that there be no void. Ptolemy concludes on the basis of such arguments that the Sun is in the middle of the seven planets. But of the specialists [i.e., the astronomers], little account [need be taken] as they argue from plausibility (*pithanologountōn*).[98]

The account of the planetary distances should be compared with the nearly identical text in the Arabic version of the *Planetary Hypotheses*.[99] I have added the quotation marks to indicate the passage where both versions show nearly literal correspondence. In addition, I have indicated every discrepancy between the Greek text preserved by Proclus and the Arabic version by underlining. These discrepancies are mostly limited to conjunctions the meanings of which have been altered in the translation process. It is important to highlight that the second reference to the *Almagest*, which might be misleading, since it could make one think that the citation stems from the *Almagest*, is actually already present in the *Planetary Hypotheses* itself. The last passage is a paraphrase of Ptolemy's proof that only Mercury and Venus fit into the space between the Moon and the Sun but not the upper planets (Mars, Jupiter, and Saturn). In fact, Proclus does not talk about the upper planets at all. That there cannot be a void in the cosmos is only explained by Ptolemy at the end of I.18 (namely, a little bit after the cited passage) but apparently, Proclus felt the need to add this point here in order to explain why Ptolemy wants to bring together the smallest and greatest distances of the planets.

While this clearly shows that Proclus was able to quote the *Planetary Hypotheses* literally, one might wonder what Proclus means by his introduction that Ptolemy was not 'entirely insistent' in the *Planetary Hypotheses*. A helpful explanation has been offered by Dirk Baltzly in his note to the sentence in question. According to Baltzly, Proclus criticises Ptolemy for not inferring the planetary order from the calculated distances, but that he uses the order that he finally establishes to calculate the distances of Mercury and Venus. Only after that Ptolemy notices that there is actually only place for Mercury and Venus between the Sun and the Moon, and thus deems it a good argument for the correctness of his planetary order.[100] If this is true, it would be similar to Proclus' complaint in the *Exposition* that the astronomers draw their hypotheses from the conclusions and not the other way round. Although Proclus is not very explicit about that point, which is why this sentence is hard to interpret, we should not read it as if Proclus believes that Ptolemy did not engage with planetary order or distances in the *Planetary Hypotheses* at all, as is obvious from the following *verbatim* quote. Despite this difficult issue, Proclus'

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[98] Proclus, *In Tim.*, Vol. 3, pp. 62:17–63:21, tr. by Baltzly in Proclus, *Commentary on Plato's* Timaeus. Vol. V, pp. 125–27. Slight modifications, Greek terminology, quotation marks and underlinings were added by me.

[99] See *Plan. Hyp.* I.17, p. 270:5–16.

[100] See Baltzly's note in Proclus, *Commentary on Plato's* Timaeus. Vol. 5, p. 126 n. 238, and his introduction on p. 21.

labelling of Ptolemy's arguments as 'reasonable' (*eulogos*) or 'plausible' (*pithanon*) seems to be more crucial. The latter expression is found exactly in the passage on the order of the planets in *Almagest* IX.1.[101] We have already seen Ptolemy's use of *eulogos* in other instances when he refers to non-astronomical or non-mathematical arguments. Proclus, therefore, simply underlines Ptolemy's own disclaimer from the *Almagest* regarding the value of his arguments. The same is true for the *Planetary Hypotheses*, where Ptolemy admits that his calculation of the distances is 'most likely' (*ašbah al-umūr*), although here, he seems to refer only to the distances and not the order.[102] This is the point of Proclus' attack after the citation, for he questions the values of those probable accounts set forth by mathematicians. He makes the same move in the *Exposition*, where he speaks about the order of the planets twice.[103] In the first instance, he only evaluates the strategy from the *Almagest* and ascribes it explicitly to Ptolemy. Proclus writes that Ptolemy relied on 'the plausible rather than on the necessary' (*pithanon mallon ē anagkaion*), and goes on that he had no 'proof' (*apodeixis*) of it. He closes this first discussion by claiming that he is going to show 'how one could plausibly (*pithanōs*) find a proof (*apodeixin*) for the order of these planets from their hypotheses'.[104] Apparently, he thus has a passage towards the end of the *Exposition* in mind, where he again addresses the order of the planets. Although he describes the same method from the *Planetary Hypotheses* that he quoted *verbatim* in his commentary on the *Timaeus*, there are two main differences between these two accounts. First, he does not mention Ptolemy here anymore but only writes that 'some' (*tines*) used the described method. Second, he does not use the values from the *Planetary Hypotheses* but apparently uses the basic values from the *Almagest* to calculate the distances for Mercury and Venus himself, and thus these values are different from the ones found in the *Planetary Hypotheses*, in which Ptolemy adjusted some of the parameters compared with the *Almagest*.[105] These differences are not easy to explain, but attempts have been made to find here an indication of the chronology of Proclus' works, as the Proclus of the *Exposition* did not know yet the *Planetary Hypotheses* directly, but the Proclus of the commentaries did so.[106] Against this, his commentary on the *Timaeus* is usually considered (following Proclus' biographer Marinus) as an early writing and the *Exposition* as being rather late.[107] This suggests that Proclus decided to calculate the planetary distances according to the method found in the *Planetary Hypotheses*,

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[101] Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:13–22.

[102] See *Plan. Hyp*. I.18, p. 276:11–12.

[103] See the discussion in Hartner, 'Medieval Views', pp. 258–61.

[104] Proclus, *Hypotypōsis*, pp. 140:26, 142:5, and 144:25–26.

[105] The entire section can be found in Proclus, *Hypotypōsis*, pp. 220:18–224:16. On the different values for Mercury and Venus, see Hartner, 'Medieval Views', pp. 266–73; Goldstein, 'The Arabic Version', pp. 9–10; and Carman, 'Rounding Numbers', pp. 227–28.

[106] See Segonds, 'Proclus: Astronomie', p. 329 n. 32.

[107] See Manitius' remarks in Proclus, *Hypotypōsis*, pp. 279–80, and Siorvanes, *Proclus*, pp. 5–6.

but on the basis of the values from the *Almagest*, and that he left the reader in the dark about the reasons for that.[108]

As a last point on this discussion, which could easily be expanded in much more detail, Proclus seems to be a bit more favourable toward calculating planetary distances and thus arriving at their order in the *Exposition* than in his commentary on the *Timaeus*. Despite his critical assessment in the latter treatise, he does not criticise such calculations again in the *Exposition*. Instead, at the end of the first mention of the order of the planets, he promises another method of 'how one could plausibly (*pithanōs*) find a proof (*apodeixin*) for the order of these planets from their hypotheses' (as quoted already above).[109] Earlier, Proclus had distinguished between the necessary and plausible account of Ptolemy, which lacked a proper proof. This characterization of the method, however, includes both terms, which seems to indicate that Proclus indeed favours the method from the *Planetary Hypotheses* over the one from the *Almagest*. Nevertheless, it remains unclear whether this proof is demonstrative enough for Proclus.[110]

Proclus' relationship with Ptolemy is thus ambiguous. On the one hand, he acknowledges that Ptolemy offered the simplest model for celestial motions and he explicitly refers to the *Planetary Hypotheses* for his attack on Aristotle's counteracting spheres. On the other hand, he leaves no doubt that Ptolemy's project is, in his view, insufficient, because Ptolemy turns to merely plausible arguments. In addition, Ptolemy and the other astronomers leave open the question of the underlying causes of celestial motions. For answering that question, Proclus relies completely on voluntary motions by the planets, which are to be understood as being independent from the spheres. This, however, is actually pretty close to what Ptolemy suggests in the *Planetary Hypotheses*, although Ptolemy still makes use of eccentrics and epicycles.

The other Neoplatonic commentator who shows direct knowledge of the *Planetary Hypotheses* is Simplicius. His commentary on Aristotle's *On the Heavens* is interspersed with discussions on the history and current developments of astronomy. Ptolemy was, in Simplicius' view, an important authority to refer to in these matters. In his comments on Chapter II.8 of *On the Heavens*, Simplicius tries to harmonize Aristotle with Plato. Although Aristotle argues in this chapter against any motion for the planets and stars, Simplicius claims that both of them admitted that they indeed rotate around their own axes in addition to being carried along by their spheres.[111] To this, he adds a citation from *Planetary Hypotheses* II.2:

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108 cf. Swerdlow, *Ptolemy's Theory*, pp. 135–36.

109 Proclus, *Hypotypōsis*, p. 144:25–26.

110 Despite such reservations, he follows what he thinks is Plato's order of the planets, namely that Mercury and Venus are above the Sun. See Segonds, 'Proclus: Astronomie', pp. 325–26 and 329, and Siorvanes, *Proclus*, pp. 307–10.

111 See Simplicius, *In Cael.*, pp. 454:23–456:22.

> One should also pay attention to Ptolemy, the best of the astronomers, when he says in the second book of his *Hypotheses*: 'Consequently, it is quite reasonable that, because this is both a capacity and an activity of theirs, each of the heavenly bodies moves, to be sure, in its own place, that is, [each moves] smoothly and in a circle back around its own centre, since it is right that this [moving in its own place], which also secures [each heavenly body] in the structures containing it, belong to it first.'[112]

Simplicius does not further develop on this citation and he does not indicate that Ptolemy does not in fact talk about mere rotation in place. Instead, Ptolemy suggests that he could eliminate the last carrying sphere if the planets had simple circular locomotion on their own account. This is not what Simplicius argues for in his attempt to harmonize Plato and Aristotle. It is not entirely clear whether he is silent about Ptolemy's opposition to Plato and Aristotle because he does not fully understand Ptolemy's account or because he wants to use Ptolemy's authority as evidence for independent planetary motions, despite understanding that Ptolemy goes beyond his own account. Of course, Simplicius was generally more inclined to highlight agreement among the ancient authorities, so he might have similar motivation here. Nevertheless, contrary to Proclus' statement that the astronomers did not properly deal with the causes of celestial motions, Simplicius shows that the *Planetary Hypotheses* were used to discuss the sources of planetary motions.

Simplicius also refers to Ptolemy in the context of the planetary order, the topic with which Proclus was so deeply concerned. In a reference to Alexander of Aphrodisias, he assumes that either a scribal error or adherence to Plato's *Republic* was responsible for the statement that Mercury is above Venus. Against this, Simplicius writes that it was proven on the basis of the planetary distances that Mercury is below Venus, referring, however, not to Ptolemy's *Planetary Hypotheses* but to the *Almagest*.[113] This reference is odd, since he lays out the theory of contiguous nested spheres, namely that the greatest distance of Mercury is like the smallest distance of Venus, which Ptolemy only introduces in the *Planetary Hypotheses*. Nevertheless, this can easily be explained, for Ptolemy himself writes in the beginning of his presentation of this method that it is based on what he had calculated in the *Almagest*. We have just seen that Proclus included this reference in his citation, so this is also the case here in Simplicius, although he just gives a summary. The citation given above shows that Simplicius had access to the *Planetary Hypotheses* independently from Proclus, for Proclus did not provide the same citation. Thus, it is possible, but not very likely, that Simplicius did not know that the material on the nested cosmos actually stemmed from the *Planetary Hypotheses*.[114]

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[112] Simplicius, *In Cael.*, p. 456:22–27, tr. by Bowen in Bowen, *Simplicius on the Planets*, p. 32, slightly modified. See the Arabic version at *Plan. Hyp.* II.12, p. 320:19–322:2.

[113] See Simplicius, *In Cael.*, p. 474:14–28.

[114] cf. Bowen, *Simplicius on the Planets*, pp. 211–13.

Another interesting parallel between Simplicius and Proclus can be observed in Simplicius' long discussion of astronomical hypotheses. In *On the Heavens* II.12, Aristotle addressed the question why there is only one planet for the lower spheres, but a huge number of fixed stars for the outermost one.[115] Simplicius' subsequent discussion of Aristotle's astronomy and post-Aristotelian trends stands in the context of a wider defence of Aristotle's cosmology against attacks undertaken by authors such as John Philoponus.[116] In short, Simplicius admits the problems that arise in Aristotle's homocentric theory, most obviously the lack of any explanation of the varying distances of the planets to the Earth. Of special interest in terms of his usage of Ptolemy are some arguments against the counteracting spheres that were taken from the *Planetary Hypotheses*:

> Ptolemy too criticises them [the counteracting (*anelittousai*) spheres][117] on the grounds that they introduce a great multitude of spheres for the sake of the joint return of the seven planets in relation to the rotation of the fixed [sphere] alone, as well as for saying that [the spheres] contained by the containing [spheres], that is, the innermost [spheres], are causes of the joint return for the [spheres] above them, although nature always makes higher things causes of motion for things that are lower. Certainly, even in human beings, it is from on high, that is, from our ruling part, that the impulses for motion are distributed through the nerves to all our organs.[118]

Simplicius refers to two arguments that he claims to have stemmed from Ptolemy, although he does not say from which work he took them. The identification of the arguments with material from the *Planetary Hypotheses* is, however, straightforward. The first argument, namely that the number of counteracting spheres is larger than actually needed for complex planetary motions, appears very similarly in *Planetary Hypotheses* II.5. There, Ptolemy described why Aristotle had to add the counteracting spheres in the first place, namely because each planet needed to partake in the daily rotation of the sphere of the fixed stars but not interfere with the motions of the other planets.[119] Not only does Simplicius paraphrase Ptolemy's critique but he also preserves — by his addition 'for the sake of the joint return of the seven planets in relation to the rotation of the fixed [sphere]' — the reason that led Aristotle to their conception. The second argument is put forward by Ptolemy in *Planetary Hypotheses* II.6. There, Ptolemy ridicules the idea that the counteracting spheres, which are posited below the sphere that carries the planet, are nevertheless to be

[115] See *Cael.* II.12, 292b25–293a12.

[116] Simplicius' discussion of these astronomical hypotheses can be found — with some interruptions — in Simplicius, *In Cael.*, pp. 488:3–510:35. For discussions of this text that were the basis for the following summary, see Bowen, *Simplicius on the Planets*, pp. 37–72, and especially pp. 27–33 for the identification of Philoponus as a major opponent.

[117] This was added by myself.

[118] Simplicius, *In Cael.*, p. 506:16–22, tr. by Bowen in Bowen, *Simplicius on the Planets*, pp. 169–70.

[119] *Plan. Hyp.* II.5, p. 292:16–294:1.

counted among the group of spheres of that planet. He makes the sarcastic claim that by this reasoning one could also claim that the Moon has a share in the motion of Saturn.[120] Simplicius compares this second argument with how decisions to act are made by humans and how the body reacts to these decisions. The main idea is the following: the ruling part sends out impulses through the body and these impulses are transmitted via the nervous system and arrive at the different organs. In *Planetary Hypotheses* II.7, Ptolemy uses the exact same scheme as an illustration of how the planets direct the motions of their surrounding spheres. Admittedly, here, Simplicius could draw on sources other than Ptolemy for this analogy. He also uses it in a slightly different context, as Ptolemy does not add it to his rejection of counteracting spheres but describes what he imagines to be the cause of celestial motions. Nevertheless, it is rather likely that Simplicius got the idea of the analogy of the human nervous system to the celestial motions from Ptolemy, and one can highlight once again that he did so independently from Proclus, who does not allude to this analogy.[121]

On the basis of such doubts about the homocentric theory, Simplicius concedes that theories involving eccentrics and epicycles better represent celestial motions, and they do so by using fewer spheres and thus simpler models.[122] We see that the criterion of the simplicity of celestial motions resurfaces here, and it is again used against Aristotle's calculation from *Metaphysics* XII.8. On the other hand, Simplicius is also hesitant to consider these newer astronomical hypotheses as reflecting the causes of celestial motions. Earlier, in one of the passages where he writes that they save more phenomena than the homocentric theory, he had added that they do not save all of them. At the end of the corollary on homocentric astronomy, Simplicius comes back to the problems that Aristotle had set out in *On the Heavens* II.12 and concludes this discussion by stating that Sosigenes (who lived around Ptolemy's time) had put forward more astronomical arguments against eccentrics and epicycles.[123]

We can infer from these passages that Ptolemy was indeed an important authority for the late ancient commentators of Plato and Aristotle. Although both Simplicius and Proclus still have serious reservations about the physical or metaphysical consequences of Ptolemy's astronomical theory, they acknowledge its advantages over previous homocentric theories and especially over Aristotle's counteracting spheres. They explicitly use Ptolemy's *Planetary Hypotheses* in their rejection of these counteracting spheres, as well as in the context of self-moving planets. Another example

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[120] *Plan. Hyp.* II.6, pp. 300:8–11. Cf. Bowen, *Simplicius on the Planets*, pp. 278–83.

[121] The fact that these three parts of the rejection come from different chapters in Book II of the *Planetary Hypotheses* indicates that he is well informed about the contents of the *Planetary Hypotheses*. If we take this together with the *verbatim* quote noted earlier, there is no reason to doubt that he had direct access to at least the entire Book II.

[122] Simplicius, *In Cael.*, pp. 506:8–10 and 509:16–19.

[123] Simplicius, *In Cael.*, pp. 506:10 and 509:19–510:31.

of Simplicius' usage of Ptolemy is a citation from the *Almagest* in his commentary on Aristotle's arguments for the sphericity of the cosmos. Simplicius preserves doubts about some of Aristotle's arguments that had previously been made by Alexander of Aphrodisias concerning possible other shapes of the spheres, such as lentil- or egg-shaped. Simplicius acknowledges that Alexander is right in arguing — against Aristotle — that a lentil or an egg can rotate around poles without creating void spaces, provided that one choses the correct pair of poles.[124] After admitting that there are indeed such reasonable doubts about the arguments used by Aristotle, Simplicius tries to emphasize that there is nevertheless no other possible shape for the cosmos than a sphere and cites two arguments from *Almagest* I.3.[125] Arguably, this again highlights the high esteem in which Ptolemy is held by Simplicius (note that he referred to Ptolemy as the 'best of the astronomers' in the citation above). He then goes further by claiming that Ptolemy not only agrees with Aristotle on the spherical shape of the cosmos but also with Plato. This illustrates the different agendas of Proclus and Simplicius. Whereas Simplicius tries to harmonize the Platonic with the Aristotelian accounts (and, in this respect, even with Ptolemy), Proclus turns his attention more to Plato and speaks of planetary spheres as 'whorls', allowing for neither Aristotle's homocentric cosmos nor for eccentrics and epicycles.

In addition to Simplicius' and Proclus' usage of Ptolemaic material from the *Planetary Hypotheses* on the order of the planets, and in order to further illuminate their attitude towards Ptolemy, one could also point to their stance on precession, for they disagree on that point. While Proclus rejects it, Simplicius accepts the idea of a starless sphere above the fixed stars that accounts for the precession of the equinoxes. Simplicius further connects this discovery with Ptolemy and informs us that his teacher Ammonius confirmed Ptolemy's observation.[126] In their case, I have already pointed briefly to the fact that the works investigated here were not (fully) translated into Arabic.[127] This is different for Simplicius' contemporary John Philoponus, whose works arguing against the eternity of the world, directed against Aristotle and Proclus, were both available in Arabic. We have an amazing report by al-Bīrūnī on how he became acquainted with the belief that Ptolemy introduced a ninth sphere to his cosmos. He wrote that he found this remark in Philoponus' *Against Proclus On the Eternity of the World*, but he was unable to find the corresponding passage in Ptolemy. In fact, Philoponus makes the assertion that Ptolemy introduced the ninth sphere due to the discovery of the precession not only

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[124] See *Cael.* II.4, 287a11–22, and Simplicius, *In Cael.*, pp. 409:32–410:8. The exact same criticism of Aristotle's argument reappears in the medieval Arabic tradition in the correspondence between al-Bīrūnī and Avicenna, and I will discuss it in more detail in that context (see pp. 87–88 below).

[125] See Simplicius, *In Cael.*, p. 411:3–9, and Ptolemy, *Syntaxis*, I.3, Vol. 1, pp. 13:11–12, and 13:22–14:4.

[126] See Proclus, *Hypotypōsis*, p. 234:7–23, and Simplicius, *In Cael.*, p. 462:12–31.

[127] For Proclus, see above p. 52 n. 82. For Simplicius' commentary on the *On the Heavens*, see Peters, *Aristoteles Arabus*, p. 36.

in *Against Proclus On the Eternity of the World*, but also in *On the Creation of the World* and his commentary on Aristotle's *Meteorology*. In a previously published article, I have shown that al-Bīrūnī is a valuable witness for how the ninth sphere was ascribed to Ptolemy and then entered the Arabic tradition.[128]

In order to complement the picture of the treatment Ptolemy and his astronomy received from the Platonic and Aristotelian commentators, one can also add here that Philoponus' attitude is ambiguous. For his refutation of Aristotle's aether in his *Against Aristotle On the Eternity of the World*, he gladly refers to eccentrics and epicycles as contradicting Aristotle's demand for simple circular motions, and he writes that Alexander followed Aristotle's theory.[129] Moreover, in the passages on the ninth sphere from *On the Creation of the World* just cited, his worry is to show that the Biblical report of a starless sphere is in agreement with recent astronomy, and in that respect, he considers Ptolemy a more trustworthy authority than Plato or Aristotle, who did not allude to such a sphere. On the other hand, in the same passage, Philoponus shows some reservations about the astronomical models and their reliability. Although calling Ptolemy the 'most exact' (*akribestatos*), Philoponus deems astronomical hypotheses unprovable, for they all contradict each other constantly.[130] This attitude by Philoponus puts him into a similar tradition to Proclus and Simplicius, namely in identifying Ptolemy's theories as the best possible ones and in using them in order to reject certain Aristotelian teachings (homocentrism in the case of Proclus and Simplicius, and aether in the case of Philoponus) but still remaining hesitant about their insight into the truth of the heavens. In this respect, they differ from other commentators such as Alexander of Aphrodisias and Themistius, who apparently still followed Aristotle's astronomy and did not show any critical engagement with his homocentric theory.[131]

This summarizing account has shown how Ptolemy in general and his *Planetary Hypotheses* more specifically were received and used in late antiquity. With Simplicius and Proclus, we have two influential authors who quote from the *Planetary Hypotheses verbatim*, thus showing that people considered it as a valuable source for arguments

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[128] See Hullmeine, 'Was there a Ninth Sphere'. For the primary texts, see Philoponus, *De aeternitate mundi contra Proclum*, p. 537:7–10; Philoponus, *De opificio*, pp. 15:17–16:8 and 113:15–116:17; and Philoponus, *In Meteor.*, p. 110:14.

[129] This fragment is preserved by Simplicius. See Simplicius, *In Cael.*, p. 32:1–11.

[130] Philoponus, *De opificio*, pp. 114:24–116:17.

[131] For Alexander, see again the fragment from Philoponus' *Against Aristotle On the Eternity of the World* in Simplicius, *In Cael.*, p. 32:1–11. A fragment preserved by Averroës and translated in Freudenthal, 'Die durch Averroes erhaltenen Fragmente', p. 111 n. 33, states that both Alexander and Themistius followed the homocentric theory (on the authenticity of these fragments, see Di Giovanni and Primavesi, 'Who wrote Alexander's Commentary?'). For a modern evaluation, see Bodnár, 'Alexander of Aphrodisias', and Meyrav's comments to his edition of the Hebrew text of Themistius' commentary on *Metaphysics* XII (see Themistius, *Paraphrase of Aristotle's Metaphysics 12*, pp. 455–56). I will deal with Alexander in more detail in Chapter III, as he will be more important in the topic of celestial dynamics.

against Aristotle's homocentric astronomy. Other important issues arising from this work were the order of the planets, the number of spheres, and the cause of celestial motions. These topics have in common that either Plato and Aristotle are placed in opposition to each other, or that Plato or Aristotle are challenged by recent astronomical models. In these cases, Ptolemy was used to exemplify the recent astronomy and, as we have just seen, he was held in high esteem. This does not mean that the commentators happily discard Aristotelian philosophy in light of new theories such as epicycles and eccentrics, for they still attempted to mediate between natural philosophy and astronomical models. Nevertheless, simply the fact that they engaged with this question, including thinking about the value of such astronomical hypotheses in the search for true reality, shows that they recognized that these more accurate hypotheses were able to question fundamental ideas from natural philosophy. We see Ptolemy at the outset of a tradition that discusses the difference between some parts of astronomy that can be or have been proven by necessary demonstrations and other parts that are merely accepted because they seem more plausible than others.

It is striking that there is no sign whatsoever of an engagement with Ptolemy's sawn-off pieces in any of the late ancient commentators, although both Proclus and Simplicius, for example, quote from *Planetary Hypotheses* II.5–6, the chapters in which Ptolemy argues against complete spheres and for sawn-off pieces, and although they both consider the simplest one to be the best possible astronomical account, which is exactly what Ptolemy tries to achieve with his sawn-off pieces. In fact, the sawn-off pieces could easily be compared with Plato's whorls, as did Ptolemy himself. This would therefore be a good opportunity to highlight the agreement between these two major authorities. In the case of an Aristotelian such as Simplicius, this lack of reception is more understandable, since whorls were not part of Aristotle's cosmology anymore. It had already taken Simplicius much effort to excuse Aristotle's homocentric theory and to harmonize different aspects of *Metaphysics* XII and *On the Heavens* with Plato and more recent developments in astronomy. Although Ptolemy himself does not deem the spherical shape of the cosmos and the sawn-off shape of the inner bodies to be problematic (since he fills the remaining parts with diurnally rotating aether), Aristotelians could see yet another problem in the contradiction between these slices on the one hand, and among Aristotle's *On the Heavens* II.4, Ptolemy's *Almagest* I.3, and the theory of a fifth element obviously propagated by both of them on the other hand. Moreover, since there is no indication of sawn-off pieces in the much more influential *Almagest*, they might have found it safer to consider the *Almagest* as the work in which Ptolemy laid down his true astronomical theories, whenever they came across an apparent contradiction in his works. Whereas Simplicius was not eager to highlight a disagreement between Aristotle and Ptolemy on the shape of the spheres, Proclus in fact adopted the notion of whorls in his commentaries on *Timaeus* and *Republic*. Although he criticised astronomers such as Ptolemy for stopping at the sensible celestial objects and not going beyond them to the intelligible realm, he stills holds Ptolemy in high esteem. Why did he not refer to the fact that Ptolemy apparently agreed with Plato? The reason is that also

Plato conceived of perfect celestial spheres despite describing them as whorls in the myth of Er. After all, Plato describes in the *Timaeus* that the cosmos has the shape of a perfect sphere, since it is the most perfect of all spheres and is best suited to imitate intellect.[132] In his commentary on the passage in question, Proclus follows Plato and defends his arguments for the spherical shape of the cosmos. He first gives Plato's demonstration, which he thinks is superior to others, since it gives the reason and not just the fact. Afterwards, he adds the 'physical' proofs of Aristotle and 'mathematical' proofs, suggesting that the overwhelming majority of thinkers followed Plato.[133] The main idea of the whorls in Plato, on the other hand, was to present hollow spheres that are stacked within each other and not to suggest a shape such as that of Ptolemy's sawn-off pieces. Admittedly, these arguments draw mostly on the shape of the entire cosmos. Nevertheless, as Plato's presentation suggests, each part of the celestial cosmos resembles the whole and thus each inner celestial body should have the same shape as the entire cosmos. In the end, the sawn-off pieces posed major philosophical problems for both Aristotelians and Platonists.

The Arabic Tradition

The previous chapter has mainly revolved around the relationship between mathematics and natural philosophy, both in the context of their value for generating knowledge as well as in the specific context of the harmonization of physical laws and planetary models. In the medieval Arabic tradition, this dichotomy has been addressed in philosophical as well as astronomical contexts. It is a common feature of works that belong to the tradition usually called *ʿilm al-hayʾa* ('science of configuration') that they contain chapters on the structure of the cosmos, for example on the planetary distances. As F. Jamil Ragep has argued in his presentation of al-Ṭūsī's *Memoir on Astronomy* (*Taḏkira fī ʿilm al-hayʾa*), one model for such works was the *Planetary Hypotheses* (although he admits that there are some differences between the *Planetary Hypotheses* and the tradition of *ʿilm al-hayʾa* as well).[134] On this basis, one interesting aspect will be to identify specific traces of the *Planetary Hypotheses* left in the medieval Arabic tradition. For this purpose, it will be useful to define some original Ptolemaic claims as fingerprints in order to identify the texts that draw on the *Planetary Hypotheses*, whether this happened directly or indirectly. The major underlying theme is Ptolemy's characterization of physics as conjectural. Ptolemy strictly follows this idea in both the *Almagest* and the *Planetary Hypotheses*. Needless to say, Ptolemy was not the main authority on the division of sciences, but we will certainly see

[132] See *Tim.*, 33b1–7 and 34a1–4.
[133] Proclus, *In Tim.*, Vol. 3, pp. 68:6–81:11.
[134] See Ragep's introduction in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 27–29; also see Ragep, *Jaghmīnī's Mulakhkhaṣ*, pp. 44–46.

how medieval authors construed the thematic and epistemological distinction between mathematics or astronomy and physics. Ptolemy's distinction finds its echo in the other original topics discussed in the *Planetary Hypotheses*, namely the planetary order, distances, and sizes, as well as the shape of the spheres. As I have argued previously, Ptolemy follows his basic methodology not only in the *Planetary Hypotheses*. I have shown that he already had the physical arrangement of the cosmos in the *Almagest* in mind but only extended this discussion in the *Planetary Hypotheses*. I have identified instances in the *Almagest* in which Ptolemy reflects on the validity of some of his arguments, such as in the cases of the difference between epicyclic and eccentric models, the argument of simplicity, and the planetary order. On this basis, sure fingerprints of the *Planetary Hypotheses* are his famous sawn-off pieces (*manšūrāt*), his method and values of planetary distances and sizes, and the connection between these issues and discussions on their epistemological status. While I stick to these topics because they are essential parts of Ptolemy's cosmology, I will also consider authors who do not directly refer to Ptolemy but nevertheless have interesting things to say about these issues in order to follow the way in which they were treated in different traditions. This investigation will cast more light on the recipients of the *Planetary Hypotheses* and their broader scientific environment.

Early Astronomers in the Ninth and Tenth Centuries AD[135]

Let us begin the present investigation of medieval Arabic cosmology with a very important figure of early Arabic astronomy. Ṯābit ibn Qurra (d. AD 901) played a major role as a translator of Ptolemaic works. He revised Isḥāq ibn Ḥunayn's translation of the *Almagest* and, as outlined in the introduction, possibly also the anonymous translation of the *Planetary Hypotheses*. He is the first Arabic author who refers to the *Planetary Hypotheses*. In *On the Calculation of the Visibility of the Crescent Moon*, he briefly reports that in his book 'on the principles of the motions of the wandering planets' (*Fī Uṣūl ḥarakāt al-kawākib al-mutaḥayyira*), Ptolemy determined two different values for the visual angles of Venus as seven and five degrees, information that stems indeed from *Planetary Hypotheses* I.20.[136]

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[135] The story of early Arabic astronomy has already been presented in much more detail, for which see works such as Saliba, *Islamic Science*. My focus lies, as outlined before, on the reception of ideas that can be traced back to Ptolemy. The reception of Ptolemy's theory of planetary distances and sizes in the Arabic tradition is also the subject of Guillaume Loizelet's PhD dissertation, see Loizelet, *Mesurer et ordonner*, Chapters 6–9.

[136] Edited and translated into French by Régis Morelon in Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 93–112. See also Morelon's introduction on pp. cxiii–cxv. For Loizelet's assessment of the question whether Ṯābit had direct access to the *Plaentary Hypotheses*, see Loizelet, *Mesurer et ordonner*, pp. 300–09. See especially pp. 308–09, where Loizelet discusses this reference to the *Plaentary Hypotheses* in more detail, concluding that Ṯābit could also rely here on another source that cited the *Planetary Hypotheses*.

Ṯābit wrote a number of treatises on specific aspects of the *Almagest*, including geometrical discussions, for example, in the treatise cited above on the visual angle of the crescent Moon. Besides such specific technical treatises, he is also famous for a short introduction into astronomy entitled *Simplification of the Almagest* (*Tashīl al-Maǧisṭī*), which became very influential through its Latin translation by Gerard of Cremona (*De hiis que indigent expositione antequam legatur Almagesti*).[137] After introducing the general astronomical terms, Ṯābit describes the cosmos in a way similar to Ptolemy, though very condensed. Although he does not give a definition of the term *falak* ('sphere' or 'circle'), he explains that the planets move within these *aflāk* ('spheres') and are sometimes closer to the Earth and sometimes farther away. He subscribes to Ptolemy's theory of nested spheres when he writes that the lowest position within the sphere of Mercury is in contact with the farthest position within the sphere of the Moon, and that, accordingly, this principle holds true for the remaining planets as well.[138] This indicates that he clearly construes these spheres as three-dimensional entities. Embedded in these main spheres, so to speak, are the eccentric sphere of the Sun and the eccentric spheres as well as epicycles for the other planets.

Only at the end of the treatise, Ṯābit counts the number of anomalies for each planet and explains on this basis which of the planets are moved by which spheres, namely eccentric spheres and/or epicycles.[139] The summary of the anomalies of each planet is very similar to the summary offered by Ptolemy in *Planetary Hypotheses* I.15. The best evidence that Ṯābit indeed made use of the *Planetary Hypotheses*, however, is his usage of Ptolemaic values for the distances and sizes.[140] Without much ado, Ṯābit lists rounded values for first the sizes and then the distances of the planets. Most of them agree perfectly with the values from the *Almagest* (for the Sun and the Moon) and the *Planetary Hypotheses*. The two divergences can easily be explained. First, Ṯābit gives the size of Venus as 1/37 of the size of the Earth, whereas in the *Planetary Hypotheses*, it is 1/44. There is, though, already within the *Planetary Hypotheses* the oddity that the values of the diameter of Venus do not conform to this calculation. Further, Ptolemy lists Venus as larger than the Moon, which is not the case with Ptolemy's own value of 1/44. To make a long story short, Ṯābit might simply have recognized this problem and adopted the value of 1/37 that would actually conform to the calculation by Ptolemy himself and would make sure that Venus actually was larger than the Moon. Either Ṯābit did this calculation by himself, or he drew on an earlier set of planetary distances, namely those by al-Farġānī, whom

[137] Morelon edited and translated the Arabic version in Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 1–17, and the Latin was edited by Francis J. Carmody (see Carmody, *The Astronomical Works*, pp. 131–39).

[138] Ṯābit ibn Qurra, *Œuvres d'astronomie*, p. 5:9–13.

[139] Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 6:6–8:4 and 15:9–17:6.

[140] See Swerdlow, *Ptolemy's Theory*, pp. 141 and 175–76, and Americo, *An Analysis of Ninth-Century Reception*, pp. 254–55 and 257–58.

I discuss below.[141] In fact, three centuries after Ṯābit, this problem was indicated by Ibn al-Ṣalāḥ (d. AD 1154), who writes in his commentary on the star table of the *Almagest* that Ptolemy, in the *Planetary Hypotheses*, gives the value of 1/44, whereas the correct ratio should be 1/37.[142] Second, the reader of the *Planetary Hypotheses* faces the problem that Ptolemy states that there is no void in the cosmos, and thus the smallest and greatest distances agree with each other. However, he calculates that Venus' greatest distance is 1079 Earth radii, whereas the Sun's smallest distance is 1160 Earth radii. Ṯābit simply drops the latter value, stating that the Sun's smallest distance is the same as Venus' greatest distance.[143] He does not even hint at the problem in Ptolemy. Perhaps Ṯābit feels that a longer discussion of this discrepancy would be out of place in his small introductory treatise on astronomy. In summary, these two divergences are not enough to doubt that Ṯābit indeed used the *Planetary Hypotheses*.[144] As a side note, there is a curious detail in one of the extant manuscripts of Ṯābit's *Simplification of the Almagest*, namely in MS London, British Library, Or. 4104. Régis Morelon discovered that this Judaeo-Arabic witness includes some glosses that were copied into the main text, and that one of them is, in fact, a quote (though not a literal quote in comparison to the extant main witnesses) from *Planetary Hypotheses* I.19 on the order of the planetary sizes.[145] Even if we do not want to argue that this gloss goes back to Ṯābit himself, it shows that Ṯābit's text was read against the *Planetary Hypotheses* at some point.

Although his cosmos looks similar to Ptolemy's, Ṯābit does not provide the reader with the principles that form the basis of this cosmos. He only briefly touches on the apparently irregular planetary motions, although they should indeed be considered as regular, and he seems to adhere to the view that the planets are carried by the

[141] See the commentary on Chapers I.16–19, and Goldstein, 'The Arabic Version', p. 12; Swerdlow, *Ptolemy's Theory*, p. 176; Carman, 'Rounding Numbers', pp. 229–32.

[142] See Kunitzsch's edition and translation in Ibn al-Ṣalāḥ, *Zur Kritik der Koordinatenüberlieferung*, p. 150:15–18 (Arabic) and p. 48 with n. 50 (German translation and Kunitzsch's comment).

[143] Ṯābit ibn Qurra, *Œuvres d'astronomie*, p. 14:12–13.

[144] There is a Latin work entitled *On the Magnitude of the Stars and Planets and the Ratio of the Earth* (*De Quantitatibus stellarum et planetarum et proportio terre*) ascribed to Ṯābit ibn Qurra (edited by Francis J. Carmody in Carmody, *The Astronomical Works*, pp. 145–48). In this work, one finds a set of values different from those in the *Planetary Hypotheses* but in agreement with al-Farġānī's values. For a recent discussion, see Americo, *An Analysis of Ninth-Century Reception*, pp. 247–58, who concludes on p. 258 that the author of the Latin *On the Magnitude* is not the same as the one of the *Simplification of the Almagest*, namely Ṯābit. Even stronger evidence comes from the fact that the Latin work cites Ǧābir ibn Aflaḥ's *Iṣlāḥ al-Maǧisṭī*. Since Ǧābir ibn Aflaḥ lived in the 12th century AD, this text cannot be dated to the ninth century. This was indicated already by Heinrich Hermelink in his review of Carmody's edition, see Hermelink, 'Review of: Francis J. Carmody, *The Astronomical Works*', p. 502. The citation of Ǧābir can be found at Carmody, *The Astronomical Works*, pp. 145:35–146:9.

[145] See Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. xl and 14 (note to line 4 in the Arabic apparatus). Cf. *Plan. Hyp.* I.19, p. 282:7–10.

spheres and do not move freely.[146] He does not explain why the planetary spheres are in touch with each other or why there cannot be any void between them, or his method of calculating the distances. Accordingly, this means that he does not discuss cosmological or physical principles and their relationship to mathematical astronomy. This might be due to the introductory style of this short work. In another work on the planetary models, Ṯābit ibn Qurra elaborates at least a little bit more on such cosmological principles. This work, entitled *On the Spheres, their Constitution, the Number of their Motions and the Size of their Path* (*Fī Ḏikr al-aflāk wa-ḫalqi-hā wa-ʿadad ḥarakāti-hā wa-miqdār masīri-hā*), is as concise as the *Simplification of the Almagest*. Ṯābit aims to provide brief presentations of the spheres (*aflāk*) that are embedded in the main spheres (*kurāt*) of the planets and are responsible for their apparent motions.[147] Although the introduction is kept again rather brief, Ṯābit gives an outline of the entire cosmos. As in his *Simplification of the Almagest*, he adopts Ptolemy's nested spheres that are in direct contact with each other and he further adds the sublunar elements that are arranged 'like a sphere' (*ka-l-kura*) as well. The Earth is situated in the centre of the cosmos, being circular like a sphere. In comparison with the sphere of the fixed stars, the Earth is only as big as a point, and there are two primary motions in the heavens.[148] These principles, which go back to both Aristotle's *On the Heavens* and Ptolemy's *Almagest*, are not mentioned in the *Simplification of the Almagest*. Nevertheless, this second treatise also lacks proper arguments for the truth of these principles.

There are a couple of factors that can explain why we do not have a more elaborate discussion of physical principles and their relationship to mathematics in Ṯābit's works. It is clear that Ṯābit was also interested in philosophical issues, as is evident from the medieval lists of his works and, for example, from the extant *Concise Exposition of Aristotle's Metaphysics* (*Talḫīṣ mā atā bi-hī Arisṭūṭālīs fī kitābi-hi Fī-mā baʿd al-ṭabīʿa*).[149] Other philosophical works in which we could expect Ṯābit to have discussed the sciences and perhaps even their relationship to each other or epistemology such as his *On the Order of Reading the Sciences* (*Fī Marātib qirāʾat al-ʿulūm*) are lost.[150] As emphasized above, the two cosmological treatises that are extant aim to provide a brief introduction. Another explanation comes from Régis Morelon, who labelled Ṯābit's role as the 'mathematization of astronomy'. By this, he meant that Ṯābit attempted to prove geometrically some of the statements for which Ptolemy relied on empirical arguments. Morelon saw him as an important figure for establishing mathematical

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[146] Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 6:12–14, 7:11–12, and 15:4–8, where he briefly defines what he understands by regular motion.

[147] See the edition and French translation by Régis Morelon in Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 18–25.

[148] Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. 19:4–20:16.

[149] See the edition and translation by David C. Reisman and Amos Bertolacci, Reisman and Bertolacci, 'Thābit ibn Qurra's Concise Exposition'.

[150] Listed in al-Qifṭī, *Taʾrīḫ al-ḥukamāʾ*, p. 118:4.

astronomy in ninth century Baġdād.[151] That Ṯābit indeed wrote about the interaction of physical spheres is reported by Maimonides, who claims that Ṯābit posited a body between two independently moving spheres. This testimony, taken together with the mere fact that Ṯābit followed the nested cosmos from Ptolemy's *Planetary Hypotheses*, demonstrates his interest in the relationship between mathematical astronomy and the underlying physical principles. Morelon used this fragment from Maimonides, among others, to argue that Ṯābit tried to introduce terrestrial physics to the celestial realm, something against which Ptolemy explicitly argued in the *Almagest* as well as in the *Planetary Hypotheses*.[152] It is most unfortunate that the work to which Maimonides refers seems to be lost, so there is nothing more to add.

As just seen, Ṯābit ibn Qurra included a discussion of planetary distances in his short introduction to astronomy. In fact, the ninth and tenth centuries saw a number of works that dealt exclusively with planetary distances and sizes. These authors include Ḥabaš al-Ḥāsib (d. around AD 870), Abū Ǧaʿfar al-Ḫāzin, al-Qabīṣī, and al-Saġānī (all three lived in the tenth century AD).[153] This topic was indeed so popular that it became an essential part of many works of the later *ʿilm al-hay'a* tradition.[154] From the fragments of Yaʿqūb ibn Ṭāriq (eigth century AD) that are preserved in al-Bīrūnī's *India*, we also know about the transmission of Indian parameters for the planetary distances into the Islamic world.[155] Another sign of its popularity is the fact that the chapters on the planetary distances that were originally part of a larger *hay'a* work were also copied into manuscript collections detached from the rest of the original work. For example, one finds al-Ṭūsī's section on the planetary distances from his *Memoir on Astronomy* in a manuscript held in the Chester Beatty Library, Dublin (Arabic 5254). This manuscript, dated to the 16th century AD, also contains al-Qabīṣī's treatise on planetary distances and is therefore a valuable witness of the popularity of this topic even in the later period.[156]

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151 See Morelon, 'Ṯābit b. Qurra and Arab Astronomy'.

152 For the fragment in Maimonides, see Maimonides, *The Guide*, Vol. 2, p. 325. For Morelon's analysis, see Morelon, 'Ṯābit b. Qurra and Arab Astronomy', pp. 125–30 and 136–38. Loizelet, *Mesurer et ordonner*, pp. 350–51, argues that this is a misattribution and Maimonides actually refers to the *Liber de orbe* (for which see Mimura, 'The Arabic Original').

153 The text by Ḥabaš al-Ḥāsib, entitled *Book of the Bodies and Sizes* (*Kitāb al-Aǧrām wa-l-abʿād*), has been edited by Tzvi Langermann (see Langermann, 'The Book of Bodies and Distances'). Al-Ḫāzin's work is lost (see Sezgin, *Geschichte des arabischen Schrifttums V*, p. 299), but traces of it have been identified and discussed by Jan P. Hogendijk in his edition of al-Saġānī's treatise, entitled *Treatise on the Distances and Sizes* (*Maqāla fī l-Abʿād wa-l-aǧrām*) (see Hogendijk, 'al-Ṣaghānī's Treatise'). Hogendijk also edited and translated al-Qabīṣī's work on planetary distances and sizes (*Risāla fī l-Abʿād wa-l-aǧrām*), for which see Hogendijk, 'al-Qabīṣī's Treatise'.

154 See Ragep, *Jaghmīnī's Mulakhkhaṣ*, p. 46.

155 The fragments are gathered and discussed in Pingree, 'The Fragments of the Works of Yaʿqūb ibn Ṭāriq', especially pp. 105–09. See also Loizelet, *Mesurer et ordonner*, Chapter 2 for a recent overview on the issue of planetary distances in Indian astronomy, and pp. 341–61 for the tradition around Yaʿqūb ibn Ṭāriq.

156 See the online description on the website of *Ptolemaeus Arabus et Latinus*: https://ptolemaeus.badw.de/ms/916 (last consulted on 28.07.2022). The excerpt from al-Ṭūsī's *Memoir* is on ff. 154r–161r.

However, by the ninth century AD, the topic of planetary distances and sizes was already part of a larger and very influential work, namely al-Farġānī's *Summary of Astronomy* (*Ǧawāmiʿ ʿilm al-nuǧūm*), which became known in the Latin translation as *Elementa astronomica*.[157] This work differs from the other treatises that only deal with planetary distances, as well as from the two introductory works by Ṯābit in an important aspect. In Chapters 2–5, al-Farġānī presents the cosmological principles which also Ptolemy set out at the beginning of the *Almagest*: the cosmos is spherical (Chapter 2 = *Almagest* I.3), the Earth is also spherical (Chapter 3 = *Almagest* I.4), the Earth is situated at the centre of the cosmos and only has the size of a point in comparison with the entire cosmos (Chapter 4 = *Almagest* I.5–6), and there are two primary motions in the celestial realm (Chapter 5 = *Almagest* I.8). These chapters nicely illustrate al-Farġānī's dependence on Ptolemy's *Almagest*, as the observational arguments for these principles are basically the same. One curious exception, however, is Ptolemy's physical argument for the sphericity of the cosmos. As mentioned above, Ptolemy concludes *Almagest* I.3 with further 'physical considerations' that concern the nature of aether. Al-Farġānī drops this argument and does not mention aether as a constituent of the cosmos at all.

In Chapter 12, al-Farġānī presents the basic outline of his cosmology, similar in style to what we have seen in Ṯābit ibn Qurra. Given the prominent story of Ptolemy's ninth sphere to which we have already pointed in the context of John Philoponus' influence on the Arabic tradition, it is interesting to note that al-Farġānī here explicitly speaks of eight spheres. In this context, he uses the words *falak* and *kura* interchangeably for the main spheres of each planet and the fixed stars, in which the eccentric spheres and epicycles are embedded. Most importantly, these main spheres are nested into each other according to the perigees and apogees of their planets, without any discussion of empty spaces between them.[158] The last chapters to which I want to draw attention here are Chapters 21 and 22 on planetary distances and sizes. Al-Farġānī opens up this topic with the following claim:

> Ptolemy demonstrates in his book only the extent of the distance of the Sun and the Moon and we do not find him mentioning the distances of the other planets, except that he demonstrated what we have presented of the distances of the centres of the spheres from the centre of the Earth and the extents of the epicycles.[159]

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[157] It was edited by Jacobus Golius in the 17th century (see al-Farġānī, *Elementa Astronomica*). For a similar investigation of possible traces of the *Planetary Hypotheses* in al-Farġānī, see Loizelet, *Mesurer et ordonner*, pp. 291–300.

[158] See al-Farġānī, *Elementa Astronomica*, especially pp. 45:13–46:6 (Arabic part). For the ascription of the ninth sphere to Ptolemy in the Arabic tradition, see Hullmeine, 'Was there a Ninth Sphere', pp. 80–82.

[159] al-Farġānī, *Elementa Astronomica*, p. 80:5–10 (Arabic part).

Given that Ptolemy indeed calculates only the distances of the Sun and the Moon in his *Almagest* and the others in the *Planetary Hypotheses*, this passage indicates that al-Farġānī was not familiar with the *Planetary Hypotheses*. He gives the same account regarding the sizes of the planets in Chapter 22.[160] What is curious, however, is that in order to infer the remaining distances, he uses the same method as Ptolemy does in the *Planetary Hypotheses*:

> [1] If we make the farthest distance of the Moon from both its spheres combined (I mean the eccentric sphere and the epicycle) [corresponding to] the closest distance of Mercury, and [2] if we apply these aforementioned ratios and if we do the same for Mercury and Venus, we find that the farthest distance of Venus from both spheres combined is the closest distance of the Sun, which Ptolemy had demonstrated. We conclude from this that there is no empty space between the spheres.[161]

Al-Farġānī supposes two conditions on which he builds the calculation of the distances, and these are the same as those one finds in the *Planetary Hypotheses*: [1] the greatest distance of a lower planet equals the smallest distance of the next upper planet; [2] the ratios of the relative distances as calculated in the *Almagest* are applied. While Ptolemy relied on partially new calculations, al-Farġānī only made use of the values from the *Almagest*, which he also uses in the next chapter for the calculation of the sizes.[162] Nevertheless, he concludes with the same finding as Ptolemy in the *Planetary Hypotheses*, namely that Mercury and Venus nicely fit into the space between the Moon and the Sun, and that this is good evidence that there is no empty space in the cosmos. Al-Farġānī's cosmos looks the same as Ptolemy's, and he even transfers the distances from Earth radii into miles, just as Ptolemy did. It is evident that al-Farġānī followed Ptolemy in supposing that the mathematical models of the *Almagest* give us an idea of how the cosmos is actually arranged. This means that al-Farġānī was familiar with Ptolemy's theory of nested spheres without knowing that this material stems, in fact, from the *Planetary Hypotheses*, thus showing no direct acquaintenance with this treatise.[163] In addition, we find again no discussion of the origin or transmission of celestial motions, nothing about why he strives to avoid empty space between the Moon and the Sun, and no insight into his opinion on other principles from natural philosophy such as the existence of aether.

Let us take a brief look at the other treatises on planetary distances and sizes already mentioned above. As Tzvi Langermann concluded, the treatise by Ḥabaš ibn al-Ḥāsib is mostly focused on the astronomical activities conducted in the early ninth century AD. He only reports the distances and sizes for the Moon and the

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[160] See al-Farġānī, *Elementa Astronomica*, p. 83:4–8 (Arabic part).
[161] al-Farġānī, *Elementa Astronomica*, p. 80:11–17 (Arabic part).
[162] For a recomputation, see Swerdlow, *Ptolemy's Theory*, pp. 138–40 and 174–75.
[163] In this conclusion, I follow Loizelet, *Mesurer et ordonner*, pp. 299–300.

Sun from the *Almagest*.[164] More relevant to the present discussion is al-Qabīṣī, who worked at the court of Sayf al-Dawla in Aleppo, and of whom we know that he also wrote a commentary on al-Farġānī's *Summary of Astronomy*.[165] He repeats the same statement cited above from al-Farġānī, namely that 'Ptolemy only demonstrated the magnitude of the Sun and the Moon and their distances by a proof, but he did not discuss (the size and distance of) the other celestial bodies'.[166] Al-Qabīṣī introduces his work with certain 'principles' (*awāʾil*). These are the same that we find in *Almagest* I.3–8 and in al-Farġānī, and al-Qabīṣī only names the principles without any sort of proof or argument.[167] In al-Saġānī's treatise, we find again the remark that Ptolemy in the *Almagest* only treated the distances and sizes of the Sun and the Moon, and in his own presentation of the remaining distances, he does not show any direct knowledge of the *Planetary Hypotheses*.[168] As argued by Jan P. Hogendijk, for his treatise, al-Saġānī relied on two lost works, one by Ṯābit ibn Qurra and another by al-Ḫāzin, and Hogendijk further shows that al-Ḫāzin must have known the calculations from the *Planetary Hypotheses*.[169] To this list, one can easily add more names, such as al-Battānī, whose *zīǧ* also contains a chapter on planetary distances and who probably did not use the *Planetary Hypotheses* directly.[170]

From this summary, no clear picture of the dissemination of the *Planetary Hypotheses* emerges. While there are some hints that it was known to and used by Ṯābit ibn Qurra, who worked in Baġdād until his death in AD 901, and al-Ḫāzin, who lived at the court of Rukn al-Dawla in Rayy and died around AD 970, other 10th-century authors like al-Qabīṣī, who worked at the court of Sayf al-Dawla in Aleppo, and al-Saġānī, who lived in Baġdād just a century after Ṯābit, do not show any sign of direct acquaintance.[171] The dissemination of these astronomers across a number of political centres should be seen in the light of the establishment of more powerful local rulers from the end of the ninth century onwards. Johannes Thomann labelled the period from the middle of the tenth century AD as the 'second revival of

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[164] See Langermann, 'The Book of Bodies and Distances', pp. 109–10.

[165] See Hogendijk, 'al-Qabīṣī's Treatise', pp. 171–72.

[166] Following the edition and English translation by Jan P. Hogendijk in Hogendijk, 'al-Qabīṣī's Treatise', pp. 177 (translation) and 207:7–9.

[167] For the Arabic text, see Hogendijk, 'al-Qabīṣī's Treatise', pp. 207:21–208:2.

[168] Al-Saġānī's statement concerning the *Almagest* can be found in Hogendijk, 'al-Ṣaghānī's Treatise', p. 24:16–17.

[169] See Hogendijk's commentary in Hogendijk, 'al-Ṣaghānī's Treatise', pp. 10–19.

[170] Following Swerdlow, *Ptolemy's Theory*, pp. 143–46. See also Loizelet, *Mesurer et ordonner*, pp. 310–11.

[171] Regarding the biographical details, see for Ṯābit ibn Qurra see Morelon's introduction in Ṯābit ibn Qurra, *Œuvres d'astronomie*, pp. xi–xii; for al-Ḫāzin, see Rashed, *Les mathématiques infinitésimales*. Vol. 1, pp. 738–39; for al-Qabīṣī, see Thomann, 'The Second Revival', p. 921; for al-Saġānī, see Sezgin, *Geschichte des arabischen Schrifttums V*, p. 311.

astronomy' after a comparable decline in the previous century.[172] Despite the fact that apparently some authors did not use or even know the *Planetary Hypotheses* directly until at least the tenth century, Ptolemy's theory of nested spheres in combination with his calculation of the planetary distances nicely illustrates that the *Planetary Hypotheses* indeed influenced Arabic cosmological treatises. This influence can be detected across all these different centres of astronomical activity. All of the authors that were discussed in this chapter go beyond the simple presentation of geometrical models and transfer these into a physical account of cosmology, but without going into much detail about the origin and transmission of motion.

Usually, Ptolemy is credited with the introduction of this theory of a nested cosmos, by both modern as well as medieval authors.[173] What are, in sum, the details of Ptolemy's nested cosmos? Firstly, it consists of an awareness that astronomers not only deal with circles and lines and thus abstract representations, but also think about the planets and their spheres and thus the composition of the cosmos in a three-dimensional way. Secondly, the theory of compactly packed spheres, i.e. spheres that are in touch with each other, is connected both by Ptolemy and later by Arabic authors with the computation of planetary distances. As becomes apparent in *Planetary Hypotheses* I.17, Ptolemy introduces two criteria in order to be able to calculate those distances that he was not able to calculate in the *Almagest* solely on the ground of observations. These two criteria are the non-existence of void spaces and the correlation of relative distances with their actual distances. The influence of Ptolemy's theory cannot be seen in authors simply using one of those aspects. For example, the non-existence of void was an important part of Aristotelian natural philosophy and therefore, in itself, does not provide us with an argument for claiming a Ptolemaic influence. When one finds in later authors the combination of all of these aspects together in a cosmic theory, then one can make a solid argument that there must be some Ptolemaic influence at work, as this combination of a three-dimensional cosmos, nested spheres, and the calculation of planetary distances is original in Ptolemy's *Planetary Hypotheses*.[174]

Carlo Alfonso Nallino, in his edition of al-Battānī's *zīǧ*, pointed to al-Bīrūnī's statement in his *India*, where al-Bīrūnī compares Ptolemy with the Indian table of distances he found in Yaʿqūb ibn Ṭāriq:

> This teaching [the one reported by Yaʿqūb ibn Ṭāriq] is contrary to that on which Ptolemy built the discussion of the distances in his *Planetary Hypotheses* [*Kitāb al-Manšūrāt*] and which the ancients and the moderns followed. For their principle concerning [the distances] [builds] upon the fact that the farthest distance of each planet [corresponds

[172] See Thomann, 'The Second Revival', pp. 916–18.

[173] See for example Ragep, *Jaghmīnī's Mulakhkhaṣ*, p. 44, and Goldstein and Hon, 'The Nesting Hypothesis', pp. 209–11.

[174] Loizelet singles out seven criteria for judging whether a later author knew the *Planetary Hypotheses*, or at least the part on the planetary distances and sizes. See Loizelet, *Mesurer et ordonner*, p. 159.

> to] the closest distance of [the planet] above it, while there is no space devoid of action between both their spheres. According to this teaching, there is between the two spheres a space free of them, in which there is [something] holding [it] like an axis, around which there is revolution, as if they think of aether as something with a weight so that it needs [something] holding the inner sphere in the middle of the outer [sphere].[175]

Al-Bīrūnī shows here his knowledge of Ptolemy's theory of nested spheres from the *Planetary Hypotheses* and actually states that this system comes from this book. Another indication of Ptolemy being the main source for the theory of nested spheres is al-Farġānī, even though he was himself not aware of this source. Nevertheless, he not only presents the same theory as Ptolemy, but even uses, as we have seen, the same method for this system, which enables him to calculate the distances, and he was followed by every author at whom we have just looked. This strongly indicates that this idea had already reached the Arabic astronomers at a comparative early stage, probably together with the translation of the *Almagest*. In some cases, we have seen that the authors adopted the nested cosmos unaware of its source. Given that late ancient philosophers and astronomers such as Proclus also discussed this theory, there might even be other channels of transmission, which, however, in their turn, go back to the *Planetary Hypotheses*.[176]

Apart from tracing the impact of the *Planetary Hypotheses* concerning the way in which medieval Arabic astronomers presented the cosmological setup, I have pointed out that they apparently did not take physical considerations into account.[177] On the other hand, one must bear in mind that the treatises discussed above are only introductions to astronomy or deal with the planetary distances exclusively. As it seems, the 'genre' of planetary distances and sizes in the ninth

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[175] al-Bīrūnī, *Kitāb fī Taḥqīq mā li-l-hind*, pp. 400:1–401:2. This passage has already been referred to and translated by Nallino in al-Battānī, *Opus Astronomicum*, Vol. 1, pp. 287–88, and by Willy Hartner (see Hartner, 'Medieval Views', pp. 257–58). Al-Bīrūnī's presentation of this Indian system has been translated and discussed by David Pingree (Pingree, 'The Fragments of the Works of Yaʿqūb ibn Ṭāriq', pp. 105–09). The fragment itself, as cited by al-Bīrūnī, does not mention spheres. In the table of distances, one finds the empty spaces discussed by al-Bīrūnī. However, they correspond, in nearly every case (with the exception of the space between Saturn and the fixed stars), to the diameters of the planets. As Pingree notes (Pingree, 'The Fragments of the Works of Yaʿqūb ibn Ṭāriq', p. 107), this could indicate that the greatest distances 'are to the nearest points on circumferences of the planets', which would leave open the possibility that we are faced here with a system of nested spheres as well. The few remarks made by Tzvi Langermann on account of Ibn Hibintā are along similar lines (see Langermann's introduction in Ibn al-Hayṯam, *On the Configuration*, p. 29). However, al-Bīrūnī may have drawn on more information from Yaʿqūb ibn Ṭāriq's book.

[176] Loizelet, *Mesurer et ordonner*, Chapter 8 argues that there are at least four different traditions on planetary distances that can be detected in Arabic treatises of the tenth century, which more or less depend on indirect or direct knowledge of the *Planetary Hypotheses*.

[177] An exception is al-Battānī, who at least briefly mentions the distinction between the four sublunar elements that are the causes of generation and corruption on the one hand, and aether on the other hand, which is described as follows: 'Above them is a fifth nature, about which no truth is said, which the senses do not grasp, and the quality of which the intellect (*ʿaql*) does not comprehend.' See

and tenth centuries excluded such concerns, as did an explicit introduction to astronomy such as al-Farġānī's *Summary of Astronomy*. This might explain the lack of any discussion about the consequences of these systems for natural philosophy, and the same authors perhaps addressed such issues in other works. Unfortunately, a more complete view of the cosmology of these authors is prevented by a loss of sources that could presumably cast more light on these issues. For example, al-Qabīṣī refers in his work *On the Testing of Those Who Call Themselves Astrologers* (*Risāla fī mtiḥān al-munajjimīn mimman huwa muttasim bi-ḥāḏā l-ism*) to another work of his entitled *Doubts about the Almagest* (*Šukūk fī l-Maǧisṭī*).[178] This makes him a precursor of Ibn al-Hayṯam's *Doubts about Ptolemy* (*al-Šukūk ʿalā Baṭlamyūs*), in which the author indeed discusses topics such as the relationship between physical and mathematical proofs or the transmission of celestial motions within aether. In fact, there is a large number of commentaries on the *Almagest* from the ninth and tenth centuries. Unfortunately, some of these are lost, such as *The Purposes of the Almagest* (*Kitāb Arġāḍ al-Maǧisṭī*) by Ibrāhīm ibn Sinān, the grandson of Ṯābit ibn Qurra. Others are only concerned with mathematical aspects and not with Book I of the *Almagest*, in which Ptolemy laid out his methodology. At least we have a fragment from al-Ḫāzin's commentary on Book I, but in this, al-Ḫāzin is mostly concerned with the trigonometrical section and not with the first chapters.[179] In addition, al-Bīrūnī transmits al-Ḫāzin's attempt to replace Ptolemy's eccentric solar model with a homocentric one. As far as we can tell from al-Bīrūnī's reports, al-Ḫāzin's motivation was not a return to an Aristotelian cosmology and we have no reason to believe that behind his model stands a critique from the physical point of view (as we can observe later in al-Andalus).[180]

Luckily, there is some evidence that this is only valid for these genres and not for astronomical research in the ninth century in general. In one of his works, Quṭb al-Dīn al-Šīrāzī gives a long citation from a work on the motions of the eighth and ninth sphere and ascribes it to Muḥammad ibn Mūsā, the eldest of the three Banū

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al-Battānī, *Opus Astronomicum*, Vol. 3, p. 182:7–8; this element is explicitly called *ayṯar* on p. 182:1, where he writes that the stars move (*taǧrī*) in it. The reference stems from Tzvi Langermann in Ibn al-Hayṯam, *On the Configuration*, p. 27.

[178] See Sezgin, *Geschichte des arabischen Schrifttums VI*, p. 210. In the introduction of *On the Testing of the Astrologers*, al-Qabīṣī distinguishes between perfect astrologers and astronomers on the one hand, and those who lack this perfection. He puts an emphasis on the fact that true astrologers make use of rational demonstrations, whereas the others do not know such demonstrations. See Burnett, 'The Certitude', pp. 203–04, and Thomann, 'The Second Revival', pp. 923–28. This indicates that al-Qabīṣī did consider, at least in an astrological context, methodological and epistemological questions.

[179] For an overview, see Thomann, 'Ein al-Fārābī zugeschriebener Kommentar', pp. 40–48. For Ibrāhīm ibn Sinān, see Sezgin, *Geschichte des arabischen Schrifttums VI*, p. 195, and for al-Ḫāzin, see again Thomann, 'Ein al-Fārābī zugeschriebener Kommentar', p. 42, and Morelon, 'Eastern Arabic Astronomy', p. 50.

[180] The fragments are translated and discussed in Samsó, 'A Homocentric Solar Model'.

Mūsā who were active in ninth century Baġdād. This fragment has even more relevance to the present study if one considers that it was Muḥammad ibn Mūsā himself who brought Ṯābit ibn Qurra to Baġdād.[181] Since the source of this citation apparently stems from the ninth century AD, the significant differences in comparison with the other treatises discussed above are worth being highlighted briefly.[182] In the beginning of al-Šīrāzī's citation, Muḥammad ibn Mūsā first makes an allusion to the Aristotelian Unmoved Mover. He then quotes from *Almagest* I.1 on the ungraspable nature of God and its claim that astronomy has to be considered as the most excellent science, as it offers the best path to theology.[183] These references to the divine Prime Mover and to Ptolemy's division of theoretical philosophy stand out among the other astronomical treatises of that time. In addition, they signify that Muḥammad ibn Mūsā considered himself in the tradition of the *Almagest* when he argued against the existence of a sphere outside that of the fixed stars. For this, as al-Šīrāzī tells us, was the purpose of Muḥammad ibn Mūsā's treatise 'on the unsoundness of the ninth [sphere]'.[184]

In a nutshell, Muḥammad ibn Mūsā first describes that it is indeed possible that an outer sphere moves an inner sphere if it has a different centre and moves around another axis. The problem for the existence of a ninth sphere, then, is that it is assumed to have the same centre as the inner sphere which is supposed to move along with it. To drive his argument home, he also excludes the possibility that the outer and the inner sphere are not circular.[185] As already stressed by George Saliba, Muḥammad ibn Mūsā stays within an account of how motion is transmitted in the sublunar realm and he does not allude to the possibly different nature of the aethereal heavens.[186] As we have seen, this was actually the main point of critique of Ptolemy against the theory of poles that transmit the motions. It seems that Muḥammad ibn Mūsā also thinks in the way criticised by Ptolemy, without, however, adducing a theory that poles impart motion to the inner sphere.

To avoid the problem, Muḥammad ibn Mūsā turns to the theological explanation that 'this eastern motion is due to a mover which is not a body, nor does it have a nature, nor does it move when it moves [something].'[187] This description is the same as the one attributed to the 'wise philosophers and ancient astronomers'

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[181] This story is repeated quite often. See, for example, Rashed, 'Thābit ibn Qurra, Scholar', pp. 3–4.

[182] The complete citation was edited, translated, and discussed by George Saliba (see Saliba, 'Early Arabic Critique') and, before him, was mentioned by F. Jamil Ragep in al-Ṭūsī, *Memoir on Astronomy*, pp. 389–90.

[183] Saliba, 'Early Arabic Critique', p. 130, Arabic p. 2:5–10. On the question of which translation of the *Almagest* he used, see Saliba, 'Early Arabic Critique', pp. 126–29.

[184] Saliba, 'Early Arabic Critique', p. 130, Arabic p. 2:1–2, tr. by Saliba on p. 131.

[185] For the main geometrical argument, see Saliba, 'Early Arabic Critique', pp. 132–136, Arabic pp. 3:7–8:9.

[186] See Saliba's introduction, Saliba, 'Early Arabic Critique', pp. 121 and 125–26.

[187] Saliba, 'Early Arabic Critique', p. 130, Arabic p. 2:11–13, tr. by Saliba on p. 131. See also at the end, on p. 136, Arabic p. 8:8, that there is no 'circular body' around the sphere of the fixed stars.

at the beginning of al-Šīrāzī's citation and surely goes back to Aristotle's Prime Mover, which, as Muḥammad ibn Mūsā apparently thinks, is in agreement with Ptolemy's *Almagest* I.1. Thus, Muḥammad ibn Mūsā is able to confirm Ptolemy's statement that astronomy indeed is a suitable path towards theological knowledge. He has proven that there cannot be a working astronomical model for a bodily sphere moving the sphere of the fixed stars, from which he infers that the mover of this sphere cannot be bodily and in motion itself. As far as one can tell from the state of modern research, this intermingling of astronomy and theology, and this reception of Aristotle's Prime Mover and Ptolemy's division of the sciences is unique in the context of the astronomical writings of the ninth century. One has to emphasize here, however, that Muḥammad ibn Mūsā's aim is not to prove God's existence. His main interest, judging from the fragment preserved by al-Šīrāzī, is to prove that there cannot be a concentric ninth sphere moving the eighth accidentally by its motion. In a next step, he makes the transition to the theological explanation of how God acts on the eighth sphere. This is the reason why he alluded to Ptolemy's single theological statement from the *Almagest* at the outset of his discussion.

In this section, I have focused more narrowly on the aspect of cosmology from the *Planetary Hypotheses* that had the greatest success in the first three centuries of the Islamic region, namely the cosmos as consisting of solid spheres which are nested into each other and embedded, in which the different minor spheres are responsible for moving the planets. The calculation of the distances and sizes of the planets presupposes that the authors accepted that (a) there is no void in the cosmos, and (b) that the relative distances of the perigee and apogee of each planet, as they are calculated on the basis of the geometrical models in the *Almagest*, can be translated into physical reality. Furthermore, I addressed the problem that we do not have much information on whether the astronomers from the ninth and tenth centuries also took considerations from natural philosophy into account, in a similar way to Ptolemy in the *Almagest* and the *Planetary Hypotheses*. At the present state of research, the evidence from Muḥammad ibn Mūsā and Ṯābit ibn Qurra stands out as an exception, although there might be more discoveries to be made that could challenge that view. In this light, one must refer to Ibn al-Hayṯam's complaint in the introduction to his *Configuration of the World*. According to him, his predecessors failed to describe a physical explanation of the motions from Ptolemy's geometrical models within solid bodies. Given our lack of sources from this period, it remains unclear whether this is a generally fair critique.[188] With the astronomers from the time around AD 1000, there is an evident change insofar as more works are extant in which the relationship between physics and mathematics

[188] I thus follow F. Jamil Ragep's hesitance to accept Ibn al-Hayṯam's self-depiction (see al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 30–33) and also Tzvi Langermann's analysis in Ibn al-Hayṯam, *On the Configuration*, pp. 25–29.

or astronomy was addressed, and which thus contained more philosophical material. However, before we take a closer look at authors such as Ibn al-Hayṯam, al-Bīrūnī, and Kūšyār ibn Labbān, let us see how the early philosophers from the *falsafa* tradition dealt with the Ptolemaic heritage.

Ptolemaic Astronomy in falsafa*: al-Kindī, al-Fārābī, and Avicenna*

So far, I have focused more narrowly on cosmological works by authors who are mostly known for their mathematical and astronomical works. However, the same period witnessed the rise of *falsafa*, philosophy taking its roots from the ancient Greek tradition. Three of its most prominent proponents, namely al-Kindī, al-Fārābī, and Avicenna, also wrote works in the tradition of Ptolemy's *Almagest*.

As for al-Kindī (d. around AD 870), his engagement with Ptolemy is mostly evident through a commentary on the armillary sphere described in Book V of the *Almagest* (*Risāla fī Ḏāt al-ḥalaq*),[189] and through his paraphrase of the first eight chapters of the *Almagest*.[190] In this paraphrase, he includes much additional material from the commentary by Theon of Alexandria. As Rosenthal notes, al-Kindī indicates that he at least intended to continue this paraphrase of the rest of the *Almagest*. Rosenthal also concluded that al-Kindī does not provide much original engagement and closely follows the *Almagest* itself and the commentary by Theon of Alexandria.[191] Nevertheless, there is one interesting aspect right at the beginning that should be highlighted. In the dedication to his son Aḥmad ibn Yaʿqūb,[192] al-Kindī states that the *Almagest* poses some difficulties for the reader, since one not only needs to have mastered arithmetic and geometry but also to have a good grasp of physics and theology or metaphysics. He then adds that although Ptolemy 'prioritizes an account that is superior to the physical account', Ptolemy later makes use of this 'physical account' in the chapter on the shape and motion of the cosmos.[193] Though al-Kindī's choice of the indeterminate usage of 'account' (*qawlan*) is not unambiguous (provided that the extant text is not corrupt), we can be sure that he has Ptolemy's epistemological distinction between mathematics and physics in mind. Despite Ptolemy's claim that physics is only conjectural in opposition to mathematics, al-Kindī maintains that the reader of the *Almagest* still needs to have a proper understanding of natural philosophy as well, and al-Kindī

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[189] See the edition and Italian translation by Giuseppe Celentano in al-Kindī, *L'epistola di al-Kindī sulla sfera armillare*.

[190] First described in detail in Rosenthal, 'Al-Kindī and Ptolemy', modern edition by ʿAzmī Ṭāhā al-Sayyid Aḥmad in al-Kindī, *Kitāb fī l-Ṣināʿa al-ʿuẓmā*.

[191] See Rosenthal, 'Al-Kindī and Ptolemy', pp. 437–38 and 446–55.

[192] As reported in the apparently later appended table of contents (see Gannagé, 'Al-Kindī, Ptolemy', p. 84).

[193] See al-Kindī, *Kitāb fī l-Ṣināʿa al-ʿuẓmā*, p. 118:12–18. This was briefly pointed out in Rosenthal, 'Al-Kindī and Ptolemy', p. 440.

refers to the arguments in *Almagest* I.3 that Ptolemy himself had labelled as 'physical'. It is quite interesting that al-Kindī points to this possible misunderstanding even before introducing Ptolemy's division of the sciences. In fact, this might indicate that al-Kindī was worried that students could take Ptolemy seriously and not study natural philosophy (and neither theology) anymore because it provided them only with conjectural knowledge. This does not mean, however, that al-Kindī departs significantly from Ptolemy. In his paraphrase, al-Kindī stays along the lines of Ptolemy and his commentator Theon when he claims that mathematics provides certain knowledge, physics deals with ever-changing objects, and the object of theology is ungraspable by the senses.[194] One might also refer to Peter Adamson's reading of al-Kindī's methodological introduction to the discussion of the eternity of the world in his *On First Philosophy* (*Fī l-falsafa al-ūlā*). There, al-Kindī first emphasizes the different means of perceiving things that do not change (the intellectual perception of universals) and of things that do change (the sensual perception of particulars). He goes on to explain that the correct method of investigating immaterial things is mathematical, whereas this mathematical method should not be applied to ever-changing physical objects.[195] In his cosmological picture, al-Kindī also follows Ptolemy, though not exclusively. Other main sources are Aristotle and Alexander of Aphrodisias. Al-Kindī adopts both the Aristotelian elemental theory and the physical principles from *Almagest* I.3–8. However, since he connects these topics with other issues such as God's providence and celestial dynamics, I will discuss al-Kindī's cosmology in more detail in Chapter III.

At this point, it remains to say that we do not have any sign that could make us believe that al-Kindī had knowledge of the *Planetary Hypotheses.* It is different for al-Fārābī (d. AD 950), as it has previously been argued that al-Fārābī knew about the content of the *Planetary Hypothesis* and was influenced by it in his own cosmology.[196] Since this evidence comes from al-Fārābī's theory of celestial dynamics, it will be discussed in the next chapter. In the context of the present chapter, there are a couple of things to say concerning al-Fārābī's views on the status of astronomy.

I have already briefly mentioned that al-Fārābī wrote a commentary on the *Almagest*. Johannes Thomann was able to identify parts of that commentary in two manuscripts in Tehran that, unfortunately, only cover a part of Book IX and

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194 See al-Kindī, *Kitāb fī l-Ṣināʿa al-ʿuẓmā*, p. 127:1–15, discussed in detail in Gannagé, 'Al-Kindī, Ptolemy', pp. 91–94.

195 See Adamson, *Al-Kindī*, pp. 33–37 and 88–90; for an English translation of this methodological introduction, see Adamson and Pormann, *The Philosophical Works*, pp. 14–18. Emma Gannagé has also previously argued that al-Kindī follows the view that mathematics is the best path to sure knowledge in other works (see Gannagé, 'Al-Kindī, Ptolemy'). On the place of mathematics and especially geometry in al-Kindī's thought, see Endress, 'Mathematics and Philosophy', especially pp. 127–35, and Gutas, 'Geometry and the Rebirth'.

196 See, for example, Janos, *Method, Structure*, pp. 347–48.

Books X–XIII.[197] The parts that would be most interesting to have, namely on *Almagest* I.1–8, are therefore not extant as far as we know. Nevertheless, Thomann has already highlighted a quite interesting statement concerning Ptolemy's account of the simplicity of nature from *Almagest* XIII.2. In reply to Ptolemy's remark that we cannot really judge about what is simple in the celestial realm, al-Fārābī quickly dismisses this statement in his commentary because one would need to consider it in terms of physics or metaphysics, stating that it is 'outside of the kind of mathematics' (*ḫāriǧ ʿan ǧins ʿilm al-taʿlīm*).[198] In light of this statement, it becomes even more urgent to get a look at his commentary on *Almagest* I.1.

However, we know much about his division of the sciences from other works, and his stance on astronomy in relation to natural philosophy and metaphysics has been studied in detail by Damien Janos.[199] While al-Fārābī follows the division of the sciences that he could find in Ptolemy as well as in other ancient or late ancient Greek authors, he certainly does not follow Ptolemy's epistemology. In his work on music (*Kitāb al-Mūsīqā al-kabīr*), al-Fārābī holds, contrary to Ptolemy, that astronomy deals with the observed appearances and natural philosophy with the essential features of bodies and the underlying causes for these appearances. The astronomer must turn to physical arguments to prove the causes of his observations. In addition, he uses Aristotle's distinction of *hoti* and *dihoti* proofs (*innī* and *limmī* in Arabic) to put metaphysics at the highest position among the theoretical sciences, as it is the science *par excellence* that provides us with proofs of the cause.[200] I have argued above that we find the same elements in Ptolemy as well as in other authors, as is evident, for example, from the fragment on Geminus reported by Simplicius to which Janos also refers as a forerunner of al-Fārābī.[201] The main difference between Ptolemy and other ancient sources lies in his epistemological consequences: since physics and theology are only conjectural, their epistemological value is inferior to that of mathematics and astronomy; nor is it necessary to go back to them in order to look for the causes when we have certain knowledge of the observed phenomena. In this, Ptolemy is not only in opposition to Aristotle and Simplicius' report on Geminus and Posidonius, but also to al-Fārābī, who does not doubt the need for astronomers to start from certain physical and metaphysical principles.

Again, we do not know what al-Fārābī had to say about Ptolemy's epistemology from *Almagest* I.1, since that part of his commentary does not seem to be extant.

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[197] See Thomann, 'Ein al-Fārābī zugeschriebener Kommentar', Thomann, 'Al-Fārābīs Kommentar', and Thomann, 'Terminological Fingerprints'.

[198] See Thomann, 'Ein al-Fārābī zugeschriebener Kommentar', pp. 58–59. The passage can be found in MS Tehran, Kitābḫāna-yi Maǧlis-i šurā-yi Islāmi, 6531, f. 188r:1–12 (following the foliation written in pencil on the *recto* pages; Thomann gives f. 191r).

[199] In the following, I rely on two of Janos's contributions, namely Janos, 'Al-Fārābī on the Method', and Janos, *Method, Structure*, pp. 43–84, which is mostly based on the former.

[200] Janos, 'Al-Fārābī on the Method', pp. 255–56 and 260–62.

[201] See Janos, 'Al-Fārābī on the Method', pp. 258–59.

Given the evidence of his other extant works, however, it would be surprising if he accepted it in its entirety. Even al-Kindī, who is otherwise not too critical of Ptolemy in his paraphrase, highlights right at the beginning that Ptolemy's distinction should not be taken in such a way that one abandons natural philosophy because one needs both natural philosophy and theology to understand Ptolemy's *Almagest* and therefore astronomy in general. In this context, one of the most important features of al-Fārābī, though, is the explicit introduction of proofs of *that* and *why* (*innī* and *limmī*) for distinguishing between mathematics on the one hand, and physics and theology on the other hand. This distinction comes together with a more profound theory of the subordination and dependence of the various disciplines of philosophy. As Peter Adamson argued, the tradition around al-Kindī, in contrast, looked at each science rather differently. According to Adamson, one of the reasons for the shift from al-Kindī to al-Fārābī was the comparatively late translation of Aristotle's *Posterior Analytics* by Abū Bišr Mattā (d. AD 940).[202] In the present context, this late date of translation has particular importance, since the *Posterior Analytics* is the place where Aristotle introduced his *hoti/dihoti* distinction that now surfaces in al-Fārābī's distinction between mathematics and natural philosophy. Moreover, the development from al-Kindī to al-Fārābī can also help us understand that the relationship between mathematics and physics received more attention around one generation after the death of al-Fārābī, as I am going to show in what follows. In addition, this point by al-Fārābī will become important for the later *hay'a* tradition exemplified by Naṣīr al-Dīn al-Ṭūsī, who also makes use of that distinction to justify why one needs to include a discussion of the physical principles that underlie astronomy.[203]

In this list of the most prominent Muslim philosophers of the Middle Ages, Avicenna (d. 1037) should not be left out. He must be mentioned not only because of his enormous influence on subsequent traditions but also because he made some valuable contributions to astronomy more specifically. A very striking example of this is that he apparently was the first one to call astronomy *ʿilm al-hay'a* ('the science of configuration') instead of *ʿilm al-nuǧūm* ('the science of the stars'). As emphasized by F. Jamil Ragep, this is a major shift since *ʿilm al-hay'a* previously denoted the physical arrangement of the spheres, planets, and the Earth. Making this term the overarching name of astronomy puts the emphasis on the physical structure of the cosmos.[204]

Accordingly, Avicenna calls the astronomical part of his philosophical *summa*, *The Cure* (*Kitāb al-Šifā'*), by the same name: *ʿilm al-hay'a*. This part follows the *Almagest* in its general outlook quite closely and it is even called *Epitome of Ptolemy's Treatise on Mathematics, that is the Almagest* (*Talḫīṣ Kitāb Baṭlamyūs fī l-taʿlīm*

[202] Adamson, 'The Kindian Tradition', pp. 355–60, with reference to Peters, *Aristoteles Arabus*, pp. 17–20 for the Arabic tradition of the *Posterior Analytics*.

[203] See al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 38–46, and Janos, 'Al-Fārābī on the Method', pp. 262–63 and Janos, *Method, Structure*, pp. 82–84. See below (pp. 130–40).

[204] See Ragep's introduction in al-Ṭūsī, *Memoir on Astronomy*, pp. 34–35.

wa-huwa Kitāb al-Maǧisṭī). While al-Kindī's paraphrase has literal correspondences to the *Almagest* and Theon's commentary and was thus intended to introduce the reader into the main topics of Book I, and while al-Fārābī's commentary (at least concerning the extant parts) follows the text closely and expands on it, Avicenna's astronomical section is an abridged version (*talḫīṣ*) that omits, for example, some tables, proofs, or figures.[205] The first noteworthy omission, however, is that of the very first chapter. Thereby, Avicenna passes over Ptolemy's division of the sciences and his epistemological remarks. A possible explanation for this omission is that although this section on astronomy is basically an abbreviation of the *Almagest*, his entire *summa* deals with all of these different sciences and thus Avicenna does not need to elaborate on Ptolemy's division in the section devoted to astronomy. However, wherever Ptolemy made some remarks in the *Almagest* concerning the conjectural status of physical arguments or that one does not need them at all in the case where one has sufficient mathematical proof, Avicenna omits them entirely or does not say that such arguments are only persuasive or reasonable. For example, Avicenna does not mention Ptolemy's argument concerning the question of what is simple in the heavens from *Almagest* XIII.2. This fits with al-Fārābī's judgment that this question should rather be discussed in physics or metaphysics. When it comes to *Almagest* I.3, where Ptolemy made use of further 'reasonable' physical arguments for the perfect shape of a sphere, Avicenna simply states that there are other aspects that could 'convince' (*yaqnaʿ*) one of the spherical shapes of the heavens.[206] In his summary of this argument of the perfect status of the circular sphere, he does not explain that Ptolemy labels them as coming from natural philosophy. Next, Avicenna drops Ptolemy's remark that it is superfluous to investigate the causes why heavy objects move to the centre of the cosmos when observations already prove that the Earth has to be there. Surely, this is something that Avicenna would have judged as deeply un-Aristotelian. Instead, he gives an account of the natural motions of the four simple elements which is more detailed than Ptolemy's brief remarks. He closes this chapter as follows: 'This is a summary (*ǧawāmiʿ*) of what [Ptolemy] said, and we have indeed shown in [the section on] physics (*ṭabīʿiyyāt*) that this motion for the Earth is impossible.'[207] Contrary to Ptolemy, Avicenna apparently believes that his arguments from his section on natural philosophy (more specifically, from his reworking of Aristotle's *On the Heavens*) are, by themselves, sufficient proofs for the Earth's lack of locomotion.[208]

[205] cf. the differentiation between these kinds of treatises on the *Almagest* in Thomann, 'Terminological Fingerprints', pp. 302–03. For Avicenna's own description of his abbreviation, see Avicenna, ''Ilm al-hayʾa', pp. 15:8–16:6. For the following account, see also Janos, 'Moving the Orbs', pp. 170–71.

[206] Avicenna, ''Ilm al-hayʾa', p. 19:5.

[207] Avicenna, ''Ilm al-hayʾa', p. 26:8–9.

[208] See Avicenna, 'al-Samāʾ wa-l-ʿālam', especially the first chapters on pp. 1–36. On Avicenna's methodology of natural philosophy, see Lammer, *The Elements*, pp. 43–109. Avicenna's chapter on

Avicenna adds a final chapter to his abbreviation of the *Almagest* that is called 'Beginning of the book in addition to the abridgment of the *Almagest*, what is not demonstrated in the *Almagest*' (*Ibtidāʾ al-maqāla al-muḍāfa ilā mā ḫtaṣara min kitāb al-Mağisṭī mimmā laysa yadullu ʿalay-hi l-Mağisṭī*).[209] Right at the beginning of this chapter, Avicenna clearly states the need to combine astronomy and physics for a more complete cosmological understanding:

> It is necessary for us to draw a comparison between what has been mentioned in the *Almagest* and what is thought (*maʿqūl*) from physics and to know how these motions come about.[210]

Among other topics, Avicenna also addresses here the problem of the interaction of two nested spheres, and, more specifically, how an inner sphere is moved by an outer sphere when their axes are not collinear. We have seen that this issue had already attracted some interest in earlier times, as the example of Muḥammad ibn Mūsā illustrates. Curiously, in his Persian *summa*, the *Dānešnāme*, Avicenna writes about physics that it is the most accessible to humans, whereas it also offers the most uncertainties due to its subject matter, which involves change and motion.[211] This is the same argument that led Ptolemy to claim that mathematics is superior to physics and to highlight frequently that some of the arguments drawn from natural philosophy are merely persuasive. Nevertheless, as is clear from the previous overview, Avicenna does not follow Ptolemy in assuming that mathematics is more valuable for attaining true knowledge. Instead, when it comes to the physical arguments from the *Almagest*, he either omits them entirely or he drops Ptolemy's remarks about their epistemological inferiority. In an interesting passage on the relationship between astronomy and natural philosophy from the physical section of his *The Cure*, Avicenna seems to refer to *Almagest* I.3 in order to argue that astronomy and physics occasionally share not only premises, but also their subject matter. Concerning questions such as the sphericity of the heavenly body, Avicenna claims, astronomers adduce observational arguments that show the fact, whereas natural philosophers produce arguments from the cause. He certainly has here *Almagest* I.3 in mind, where the same argument concerning the homogeneous nature of aether is labelled as a 'physical consideration' after the enumeration of arguments from observation, which Avicenna ascribes to the mathematicians.[212]

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the lack of the Earth's motion from *The Cure* also circulated as an independent treatise, see Ragep and Ragep, 'The Astronomical and Cosmological Works', p. 6.

[209] For a brief overview, see Ragep and Ragep, 'The Astronomical and Cosmological Works', p. 6.

[210] Avicenna, ''Ilm al-hay'a', p. 651:3–4.

[211] Avicenna, *Le livre de science*, p. 134.

[212] See the Arabic text and English translation by Jon McGinnis in Avicenna, *The Physics of The Healing*, Vol. 1, p. 56:6–15 (Arabic part). My attention was drawn to this passage by a recently published article by Hossein Massoumi Hamedani, see Massoumi Hamedani, 'Physics and the Mathematical Sciences'. In this article (see especially pp. 27–30), Massoumi Hamedani argues that Avicenna opts against mixing the respective methods of each philosophical discipline, especially with

The fact that Avicenna starts his appended chapter 'on what is not demonstrated in the *Almagest*' with the claim that he wants to harmonize 'what has been mentioned in the *Almagest*' with natural philosophy shows that, in his opinion, the *Almagest* alone does not offer this harmonization. However, Avicenna does not provide an explanation of which Ptolemaic elements need to be discussed or reconsidered from a physical point of view. A suitable example of such an attempt is the infamous equant. As Avicenna's student al-Ǧūzǧānī (fl. first half of the 11th century AD) informs us, Avicenna claimed to have solved the problem of how to configure the equant's motion without violating physical principles. Since Avicenna did not share his solution with his students, al-Ǧūzǧānī offers his own solution in a work of his own.[213] Another interesting aspect is that Avicenna ascribes to Aristotle a planetary model that includes epicycles, an assertion that we have already found in Adrastus, who apparently tried to harmonize Peripatetic philosophy with recent astronomical theories.[214] Nevertheless, Avicenna did not compose an astronomical work that deals with the relationship between astronomical models and their physical reality as thoroughly as they are discussed in the *Planetary Hypotheses*, such as the ensoulment of spheres and planets, counteracting spheres, or other shapes of the spheres. Although the fact that his student al-Ǧūzǧānī refers to the *Planetary Hypotheses* in his astronomical work suggests that it circulated in Avicenna's direct environment, Avicenna does not show any knowledge of it in this abridged version of the *Almagest*. On the other hand, Avicenna does consider astronomical theories in the context of his metaphysical and physical works. Since there Avicenna has interesting things to say about celestial dynamics that are related to the issues discussed in the *Planetary Hypotheses*, I will return to this question in Chapter III.[215] Surely, these accounts had a great impact on later philosophical discussions, as did Avicenna's entire œuvre.[216] Nevertheless, there are more detailed investigations of Ptolemaic astronomy and its relationship with natural philosophy in other authors contemporary with Avicenna who are openly critical of Ptolemy, to whom I will turn in the following.

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respect to the examples of astronomy and physics. This would be the same position held by al-Bīrūnī. I am not certain whether such a need for a strict separation is what Avicenna intends in this passage or whether one should read it as a rather descriptive statement on astronomy and physics sharing the same subject matters and only diverging in the kind of proofs they offer. Even if Massoumi Hamedani's interpretation is true, Avicenna would not be as explicit about it as al-Bīrūnī, and he certainly does not follow such a separation of methods in the astronomical part of his *The Cure*, as I have just outlined, since he includes physical arguments there.

213 See Saliba, 'Ibn Sīnā and Abū 'Ubayd al-Jūzjānī', and Ragep, 'The *Khilāṣ kayfiyyat*'.

214 See Avicenna, *al-Mabda'*, p. 68:10–22. I will discuss this passage in more detail in Chapter III.

215 For example, he discusses the topic of the number of spheres within metaphysics, as it is a question about the number of unmoved movers (in the tradition of Aristotle's *Metaphysics*).

216 See, for example, Morrison, 'Falsafa and Astronomy'.

The Rise of a New Cosmological Tradition: al-Bīrūnī, Ibn al-Hayṯam, and Kūšyār ibn Labbān

In the context of ninth- and tenth-century astronomical treatises, one can observe that the authors of that time usually left out certain aspects of Ptolemaic cosmology. We have seen the examples of Ṯābit ibn Qurra and Muḥammad ibn Mūsā, who thought about the transmission of motion from one sphere to the other in physical terms. Nevertheless, topics such as the distinction between mathematics and natural philosophy or the shape of the spheres were not as popular as planetary distances and sizes, for example. In his investigation of astronomy in the Islamicate world before the astronomers from Marāġa, George Saliba stated that 'in the eleventh century, criticism of Ptolemy seems to have become more systematized.'[217] In fact, we see an increased interest in addressing the topics in which we are interested in this chapter exactly around AD 1000.

Let us start with one of the most important medieval astronomers, Abū l-Rayḥān al-Bīrūnī (d. around AD 1050). Like his younger contemporary Avicenna, he travelled a lot during his life in the Islamic East and eventually came to the court of Maḥmūd of Ġazna (d. AD 1030). This last period of his life turned out to be very productive, as he found the time to finish three major works in Ġazna, first, an introduction to astrology dedicated to Rayḥana bint al-Ḥasan, the *Instruction in the Principles of the Art of Astrology* (*Kitāb al-Tafhīm li-awāʾil ṣināʿat al-tanǧīm*); second, his famous work on Indian traditions, beliefs, and astronomical teachings, the *Verification of what among the Indians is Acceptable to Reason or Unacceptable* (*Kitāb fī Taḥqīq mā li-l-hind min maqūla maqbūla fī -l-ʿaql aw marḏūla*) (here briefly called *India*); and third, his main astronomical work *al-Qānūn al-masʿūdī* (briefly *Qānūn*), dedicated to Maḥmūd's son and successor Masʿūd. The basic structure of al-Bīrūnī's cosmos cannot surprise us by now, for it consists of the well-known nested spheres that are in direct contact with each other. In both the *Instruction in the Principles* and the *Qānūn*, this is part of the very beginning of his presentation of astronomy, and al-Bīrūnī introduces the term aether, which he ascribes to the philosophers (*falāsifa*) in his *Instruction in the Principles*. In this latter work, al-Bīrūnī is more explicit about the thickness of each sphere (he generally uses *kura* for these main spheres), as he connects it with the fact that the planets, which move inside these spheres, have a smallest and a greatest distance from the Earth. Al-Bīrūnī shows his allegiance to the Aristotelian and Ptolemaic worldview in distinguishing the circularly moving aether from the four sublunar elements that naturally move in a rectilinear fashion.[218] These principles from natural philosophy are explained in the beginning of the astronomical section in

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217 Saliba, 'The Astronomical Tradition', p. 88. See also Saliba, *Islamic Science*, pp. 93–94.

218 al-Bīrūnī, *Kitāb al-Tafhīm*, pp. 43:5–46:12 (Arabic text), and al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 21:19–23:2.

the *Instruction in the Principles* and in an introductory chapter in the *Qānūn* with the title 'on the information about the configuration of the entirety of existing things in the world in order to give a summarizing and concise introduction'.[219] Before we proceed with al-Bīrūnī to the celestial realm, it must be pointed out that despite following Aristotle in the general cosmological outlook, he also departs from him in the details. For example, he suggests, in both the *Instruction in the Principles* as well as in the earlier famous correspondence with Avicenna, that fire is generated by friction between the lunar sphere and air, and that the sphere of fire does not have a strictly spherical shape, since there is no friction at the resting poles.[220] In the same correspondence, he wonders whether air and fire, which are light according to Aristotle and thus move naturally upwards, also move downwards but because they are not as heavy as earth and water, they are thus pushed upwards.[221] Since the focus of the present study is on the celestial realm, this is just to show that al-Bīrūnī generally adopted Aristotle's teaching on the natural motion of the five elements but occasionally expressed certain doubts or alternatives. We see something similar concerning the spherical shape of the celestial spheres.

In Simplicius' commentary on Aristotle's *On the Heavens*, we have seen that Alexander of Aphrodisias was struck by Aristotle's argument against lentil- or egg-shaped spheres. Al-Bīrūnī expresses the same worry, stating that an ovoid sphere might rotate around its longer axis and the lenticular sphere around its minor axis without creating a void. This does not mean, however, that al-Bīrūnī really believed in such a shape of the spheres. He was surprised by Aristotle's poor argument, as he makes clear at the end of his question to Avicenna:

> I do not claim this in the conviction that the celestial sphere (*kurat al-falak*) is not spherical but ovoid or lenticular. [Instead,] I have worked on replying to that claim, whereas I was astonished by the follower of logic (*ṣāḥib al-manṭiq*, i.e. Aristotle).[222]

Ptolemy is not mentioned in the correspondence with Avicenna, although the first book of the *Almagest* is a well-known place to look for arguments for the sphericity of the heavens (*Almagest* I.3) and of the Earth (I.4). Al-Bīrūnī picks that up in his *Qānūn*, where he devotes a long chapter to the cosmological

219 al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, p. 21:7–8.

220 See al-Bīrūnī, *Kitāb al-Tafhīm*, p. 46:4–12 (Arabic text), and Avicenna and al-Bīrūnī, *al-As'ila*, pp. 30:13–33:5.

221 See Avicenna and al-Bīrūnī, *al-As'ila*, pp. 38:12–39:2.

222 See Avicenna and al-Bīrūnī, *al-As'ila*, pp. 27:9–28:10 for the entire question, especially p. 28:8–10 for the quoted passage. In his reply, Avicenna points to the long tradition of al-Bīrūnī's criticism in late antiquity (see pp. 28:11–29:14). Compare this with the translation and analysis by Tzvi Langermann in Langermann, 'Revamping Ptolemy's Proof', pp. 173–75, based on the edition by al-Yāfī, which does not deviate much from the edition I have used.

principles (he later calls them *uṣūl*) from *Almagest* I.3–8. He introduces this chapter as follows:

> The opinions on the issues are various and the accounts thereof manifold. This is not the place to lay out the contrast of the confusions (*šubah*) and to isolate the truth from the filth of doubts (*šukūk*). Even though the foundations (*mabādiʾ*) of this art are necessary, for they rely on geometrical proofs, in the well-known books, they are not arranged in a manner that the certainty is strengthened by them, so that one can point and refer to them, even (*wa-ḥattā*) in the *Almagest*, which is the foundation (*dustūr*) of this art and which is [written] by the leader (*imām*) of these specialised people [viz. mathematicians], for this in Greek is called *Syntaxis*, which means 'arrangement'. [...] It would not be good (*bi-ḥasan*) to turn away from the arrangement of the foundations (*mabādiʾ*) according to their truest order.[223]

The list of the principles that follow upon that introduction imitates the order in the *Almagest*. One might briefly point out that he explicitly decided to not write a work about the doubts (*šubah* and *šukūk*). The aim of his work is thus completely different from Ibn al-Hayṯam's *Doubts about Ptolemy*. Further, he apparently thought that other astronomical works, including the *Almagest*, did not establish these cosmological principles sufficiently. Al-Bīrūnī stresses the point that astronomy takes its starting point from geometrical proofs, and thus he attempts to give a better representation of the necessary proofs for the foundations of astronomy. This leads him to provide a much more detailed account of these cosmological principles and their geometrical proofs than in the previously discussed treatises from the ninth and tenth centuries AD.[224]

I want to draw special attention to the first principle that al-Bīrūnī discusses, namely the sphericity of the heavens.[225] First, al-Bīrūnī reiterates the argument by Ptolemy that we see the planets and stars rising and setting every day, always in the same diurnal direction from east to west, and that they do not diminish in size, as would be necessary if they moved in a rectilinear fashion. This argument from observation is directly taken from *Almagest* I.3, as al-Bīrūnī makes clear, and he explains that he omits the refutation of such — in his view — 'weak opinions' (*ārāʾ rakīka*) that include kindled and extinguishing stars.[226] Next, in the *Almagest*, Ptolemy adds 'physical considerations' (*physikōn tinōn*), using

[223] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 24:15–25:4.

[224] In the Hyderabad edition with approximately 19 lines per page, the discussion of the principles from the *Almagest* covers approximately 33 pages. In comparison, the discussion of these principles takes only 13 pages in Golius' edition of al-Farġānī's *Summary of Astronomy* (*Elementa Astronomica*, Chapters 2–5).

[225] For the following discussion, I rely on Langermann, 'Revamping Ptolemy's Proof', pp. 172–78.

[226] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 25:14–27:6. Compare Ptolemy, *Syntaxis*, Vol. 1, pp. 10:4–12:18, where Ptolemy disproves previous theories of stars that move in straight lines in the diurnal direction and, instead of setting under the horizon, extinguish and can thus not be seen anymore.

arguments based on the exalted nature of aether, as discussed in the beginning of this chapter concerning Ptolemy's epistemology.[227] This is what al-Bīrūnī has to say about that:

> Then Ptolemy infers the sphericity of the heavens from physical reasoning (*qiyāsāt ṭabīʿiyya*), derived from first methods. However, every science has a method and a canon (*manhāǧ wa-qānūn*) on which nothing that is outside of this [science] is firmly established. Thus, what [Ptolemy] presented from outside this science is persuasive (*iqnāʿī*), not necessary. As long as we find in the science something acceptable and resting on its methods (*manāhiǧ*), one [should] not depart from it towards something outside of its methods (*ṭuruq*) and paths (*madāriǧ*).[228]

Al-Bīrūnī embeds his critical engagement with Ptolemy's physical arguments within the general epistemological demand that arguments in a certain science are only demonstrative if they apply the 'method' of that science. The example at hand illustrates what al-Bīrūnī actually has in mind, for he does not deem the arguments on the natural motion of aether as demonstrative for astronomical principles that should be established by observing the celestial motions. His idea, therefore, seems to be that some physical arguments are based on physical presuppositions that are not proven by observation, the main method of astronomy. Therefore, they are not as certain when they are applied in astronomy as astronomical arguments themselves. Note that al-Bīrūnī is actually not too far away from Ptolemy himself, who labelled these arguments as 'probable'. Al-Bīrūnī, in his turn, uses the same phrase that occurs in the Arabic version of Book II of the *Planetary Hypotheses* to mark arguments drawn not from mathematics but from natural philosophy, namely 'physical reasoning' (*qiyās ṭabīʿī*). When al-Bīrūnī considers these arguments as merely 'persuasive', this is, in fact, not in contradiction to Ptolemy. Nevertheless, al-Bīrūnī's reason why he considers these arguments as persuasive is slightly different. Ptolemy held that all other sciences except mathematics offer only conjectural results, whereas al-Bīrūnī sees the problem to be the fact that one draws on physical arguments for reaching a conclusion in a mathematical science, namely astronomy. It seems that he is a bit more favourable than Ptolemy toward natural philosophy itself, but only criticises the intermingling of different sciences. In fact, he accepts the existence and natural circular motion of aether, as we have just seen. Nevertheless, he criticises Ptolemy's 'physical arguments'. In what follows the quoted passage, he attempts to replace them with geometrical proofs. At the end of this section on the sphericity of the heavens, al-Bīrūnī highlights that Ptolemy only establishes the circular motion of the stars and planets, but not that the spheres are necessarily perfectly spherical. At the end of the section on the sphericity of the heavens, al-Bīrūnī states that one first

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[227] Ptolemy, *Syntaxis*, I.3, Vol. 1, pp. 13:21–14:16. See above p. 34.

[228] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 27:7–12. This passage has already been translated and partly discussed by Abdulhamid Sabra in Sabra, 'Configuring the Universe', pp. 325–26.

needs to consider the arguments for the sphericity of the Earth and then one can better judge about the sphericity of the heavens.[229]

In his analysis of the reception of arguments for the sphericity of the heavens in Ibn al-Hayṯam, Ǧābir ibn Aflaḥ, and al-Bīrūnī, Tzvi Langermann observed that they adjusted the arrangement of the arguments from *Almagest* I.3 and apparently felt that the arguments for the sphericity of the Earth should be prior to the arguments for the sphericity of the heavens. With some hesitance, as a possible explanation, Langermann suggests that there is more empirical evidence from observation for the Earth's sphericity than for that of the heavens. In support of this analysis, I want to draw attention to al-Bīrūnī's critique of Ptolemy's 'physical' arguments as being merely persuasive in astronomy. He accepts Ptolemy's arguments from observation, only to conclude afterwards that Ptolemy's other arguments are not drawn from observations and geometrical calculations but from natural philosophy, which makes them not demonstrative. Only after he offers more observational proofs for the sphericity of the Earth than Ptolemy actually does in *Almagest* I.4, al-Bīrūnī settles for both the sphericity of the Earth and of the entire heavens and spheres.[230] Thus, al-Bīrūnī considers mathematical arguments drawn from observation as demonstrative for astronomical research, and since he lacked these from the investigation of the shape of the heavens, he first turned to the sphericity of the Earth to get further proof.

It is already evident that al-Bīrūnī is distinct from the authors at whom we looked previously because of his distinction of mathematical and physical proofs. On the one hand, he is in the tradition of Ptolemy himself, since this distinction is the major part of the epistemology underlying his cosmology. On the other hand, al-Bīrūnī uses this distinction to attempt to strengthen the cosmological principles, which he apparently shares with Ptolemy, by further mathematical proofs. A further example is the often repeated claim that al-Bīrūnī engaged in the question of whether the Earth rotates or not. He touches on this question in his *Complete Study of the Possible Ways to Construct the Astrolabe* (*Istīʿāb al-wuǧūh al-mumkina fī ṣanʿat al-aṣṭurlāb*), stating that there are 'some people' (*baʿḍ al-nās*) who ascribe the diurnal rotation to the Earth and not to the celestial sphere. He acknowledges that this is indeed a difficult question that cannot be answered by 'those who rely on measurable lines', namely 'geometers and astronomers' (*al-muhandisīn wa-ʿulamāʾ al-hayʾa*). Instead, only 'natural philosophers' (*al-ṭabīʿiyyīn min al-falāsifa*) should be entrusted with deciding that question.[231] The reason is the same as the one we

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[229] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 29:17–30:10. See Langermann, 'Revamping Ptolemy's Proof', pp. 175–76.

[230] For more details, see Langermann, 'Revamping Ptolemy's Proof', especially p. 177.

[231] al-Bīrūnī, *Istiʿāb*, p. 128:14–20. See also al-Bīrūnī, *Kitāb fī Taḥqīq mā li-l-hind*, p. 232:6–7, where he states that the rotation of the Earth is impossible 'from different aspects' (*min ǧihāt uḫar*), i.e. different from astronomy. See Pines, 'La théorie de la rotation', and Rezvani, *Two Treatises*, pp. 204–05.

already know from the *Almagest*: from the mathematical point of view, there is no difference between these two options, so one has to turn to arguments from natural philosophy. He again deals with that topic in his *Qānūn* in the chapter of Ptolemy's arguments for the central position and immobility of the Earth, where he again emphasizes that the question whether the Earth rotates or not cannot really be decided in astronomy. Nevertheless, he reiterates Ptolemy's argument that lighter objects seem to move faster than heavy objects. On this argument, al-Bīrūnī writes that it is 'more fitting to physical investigation than to mathematical, however [merely] persuasive.' Shortly afterwards, al-Bīrūnī adds that from the 'mathematical investigation' (*naẓr taʿlīmī*), one could argue that if the Earth indeed moved, the clouds would never move faster than the Earth and thus could never be seen to move eastwards.[232] Although both statements appear together in Ptolemy's refutation of the rotation of the Earth, al-Bīrūnī here splits this argument into two elements, one being 'physical' and 'persuasive', and the second being 'mathematical'.[233] Thus, in all the different places where he discusses the possibility of a rotating Earth, he signals that this should mostly be answered by natural philosophers. In the *Qānūn*, the latest of these works, he seems to have reconsidered the status of at least this one partial argument by Ptolemy and acknowledges this as a sufficient mathematical proof, in contrast to the other 'persuasive' arguments by Ptolemy. Again, al-Bīrūnī's criticism of a demonstrative argument resurfaces: in a mathematical investigation, only mathematical arguments are necessary, whereas physical arguments need to be considered as persuasive, since they belong to a different science.

Al-Bīrūnī elaborates further on the difference between the mathematical and the physical approach towards cosmology in Chapters 4 and 5 of the sixth book of his *Qānūn*. The main objective of these chapters is to explain the status of the eccentric model of the Sun. First, al-Bīrūnī uses the opportunity to state the main problem of ancient and also medieval cosmology. The celestial region, on account of its apparent lack of any change, consists of aether, a 'body' whose motion is 'specified by circularity and uniformity, for it is the most continuous and over the course of time the most persistent.' This has led philosophers (*al-maʿniyyūn bi-l-mabāḥiṯ al-ḥikmiyya*) to assume the exalted status of aether, as al-Bīrūnī goes on, whereas the mathematicians (*al-riyāḍiyyūn*) discovered the anomalies of planetary motions.[234] In the rest of Chapter 4, he presents the basics of Ptolemy's eccentric solar model, which is needed to account for both the philosophers' goal of regular motion and the anomalies observed by the astronomers. The next chapter, Chapter 5 of the sixth book, is called 'on the imagination (*taṣawwur*) of the motion of the spheres, in which they supposedly cut each other'. This chapter starts as follows:

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[232] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, pp. 49:15–18 and 50:9–12.

[233] This argument is from Ptolemy, *Syntaxis*, I.6, Vol. 1, pp. 24:18–25:14; see Pedersen, *A Survey*, p. 44.

[234] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 624:3–10.

> It is customary that if the astronomers (*ahl hāḏihi al-ṣināʿa*) turn to what they find of the anomalistic motion and of its lack of (*ṣarfi-hā*) regularity — as much as it is possible to conceive of its existence — that they treat [the motion] in the way of imaginary lines without any expression about them being bodily, [...]. We have just described what Ptolemy [had to] face for the anomaly found in the motion of the Sun. He preferred the eccentric sphere (*falak al-awǧ*) over the epicycle, giving preference to simplicity over composition. [...] It is known that the spheres are expressions about circular bodies carrying their planets. Thus, when the parecliptic [sphere] is a body separate from what it carries and when the centre of the epicycle is composed on it, then likewise, it is necessary that they cut each other and then the motion of the epicycle is impossible on its carrier, making impossible the motion of the body of the Sun on the circumference of the epicycle. The same is the case of the eccentric sphere. [...] Therefore it is necessary that one imagines [as] someone reflecting not on an image that employs them in his [geometrical] calculation (*taqdīr*).[235]

According to al-Bīrūnī, the astronomers mostly confine themselves to providing geometrical models. He alludes to Ptolemy's argument from *Almagest* III.4 that the eccentric solar model is simpler and should thus be preferred, although the epicycle would also give a proper geometrical explanation for the Sun's motion. Since the heaven is supposed to consist of circular bodies, he goes on, one has to imagine the spheres as being different from the abstract lines, for they constantly cut each other, which is impossible for actual bodies. Therefore, he describes how the spheres must have a certain thickness to accommodate the spheres and planets, and he tries to arrange them in such a way that they do not interfere with each other. It remains unclear whether he includes that passage because he thinks that Ptolemy's argument from simplicity is not satisfying. However, in his configuration, al-Bīrūnī does not go into the details of celestial mechanics. The Sun is always fixed in a carrying sphere, and al-Bīrūnī only once compares the motion of the solar apogee to a passenger on a ship, a very prominent example from Aristotle.[236] He closes this discussion by the following claim:

> Thus, this is what is imagined of the motions that are found in aether and what is imagined of their possibility. God knows best their realities, for they are entirely hidden.[237]

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[235] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 633:3–14. For my addition of 'geometrical', see a little bit below the fuller expression *taqdīr handasī*, p. 634:8.

[236] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, pp. 633:14–634:16. For al-Bīrūnī's criticism of Ptolemy concerning the motion of the solar apogee, see Hartner and Schramm, 'Al-Bīrunī and the Theory'. See also Aristotle's *On the Soul*: *An.*, 406a5–8.

[237] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 634:16–17. Abdulhamid Sabra has already referred to this passage (see Sabra, 'Configuring the Universe', p. 293 n. 7). There, Sabra also quotes *Qānūn*, Book VII, Chapter 9, on the model of the Moon: 'How difficult is it to imagine them and [their] anomaly, especially for someone who imagines these many spheres, only in order to make their motions in the aether uniform and to make their essence free from any irregularity.' See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 838:9–11.

This statement fits quite well with al-Bīrūnī's previous reservation towards natural philosophy. It suggests that al-Bīrūnī seems to consider the configuration and dynamics of the celestial realm to be uncertain. It is in this context of the arrangement of celestial spheres that we finally find the first direct critique of Ptolemy's sawn-off pieces in al-Bīrūnī's *Qānūn*:

> Now, in his *Planetary Hypotheses* (*Kitāb al-Manšūrāt*), Ptolemy departs from the way that he had pursued in the *Almagest*, in the direction of what belongs to the opinions, which lie outside of this art (*ṣināʿa*, i.e. astronomy), of the many's belief in celestial bodies [with] life, sensibility (*šuʿūr*), perception (*iḥsās*), and choice (*iḫtiyār*), so that it is preferable (*li-l-afḍal*) regarding the motions [to assume that] conducting powers (*quwā mudabbira*) are sent out from the stars to their spheres, just as they are sent out in the case of [ensouled things] to the limbs (*aʿḍāʾ*). He even says (*ḥattā qāla*) with regard to the paths of the stars [that] he cuts off the spheres that are similar to anklets and bracelets, that are called sawn-off pieces. He gives up preserving the spheres that the stars do not need for their motions and that they do not reach in their latitudes. He abandons his own physical and persuasive (*iqnāʿiyyat*) arguments in the *Almagest* about the sphericity of the heavens, on the basis of the simplicity of the motion and the resemblance of the distances and parts in the sphere and its extent and the circle and both their finitude with respect to the utmost perfection of the shape. He does not explain what [this part] from both sides of the sawn-off pieces [consists of]:
>
> [A] Is it [i.e. the part sawn off from the sphere] from the [same] element (*ǧins*) as aether, so that it comes back to what he had rejected? It would then complete the sphere and it would not remain for him except for the resting [of the sphere] and moving of the sawn-off piece and the attaching to the remainder that it moves naturally. This is absurd in his view.
>
> [B] Or is it from an element of what is below aether [i.e. from one of the four sublunar elements]? Then its place would be higher than it [i.e. it would be lifted upon its natural place], but this is even more impossible.
>
> [C] Or is it a sixth element, in which case the argument about the fifth nature would fail? [...]However, these are isolated investigations that have separate places [to discuss them].[238]

Al-Bīrūnī's criticism picks up his demand just discussed that astronomers should mostly use arguments from mathematics and not from physics. He labels these latter arguments as 'opinions' (*ārāʾ*). The first point of attack is Ptolemy's theory of the souls' capacities that direct the motions of the spheres and his comparison of spheres to animals' limbs. Apparently, the ascription of life and soul to the celestial bodies is exactly the kind of argument that al-Bīrūnī considers to be extraneous to astronomy. We should have his previous statement in mind that only God can know

[238] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, pp. 634:18–635:17. For a previous translation and brief comments about al-Bīrūnī's demarcation of physics and astronomy by F. Jamil Ragep, see his introduction in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 40–41.

the realities of celestial motions. However, Ptolemy did not use only physical proofs for the sphericity of the heavens in *Almagest* I.3. According to al-Bīrūnī, Ptolemy even contradicts these arguments with his theory of sawn-off pieces, since these are not perfectly spherical. Al-Bīrūnī also sees a further problem of the sawn-off pieces: how can we explain the nature of these parts that Ptolemy cut away and therefore distinguished from the complete sphere in order to achieve the sawn-off shape? Al-Bīrūnī discusses three options for the element of these parts (neglecting the possible explanation of a void, probably because this is negated by Ptolemy himself). In fact, Option A is Ptolemy's assumption, namely that these pieces consist of aether just like the now sawn-off pieces. According to Ptolemy, the 'rest of the aether' moves naturally in the diurnal direction and imparts this motion to all the sawn-off pieces. Al-Bīrūnī, however, finds it absurd that this cut-off piece then forms a separate part of aether. Instead, he thinks that if both the sawn-off piece as well as the part around the pole, which Ptolemy detached from the sawn-off piece, were made out of aether, this would again complement the sawn-off piece to make a complete sphere, with the impossible result that there would be two different motions for a single complete sphere. If this area consisted of one of the sublunar elements, al-Bīrūnī argues, this would make it stay outside of its natural place (Option B). The third option, C, is that there is yet another element beyond the well-known five. Interestingly, al-Bīrūnī's approach used to argue against Ptolemy's sawn-off pieces resembles Ptolemy's approach for arguing against celestial poles. Both wonder about the consequences of the theory in question in the context of the basic elemental theory, a classical topic from natural philosophy. Perhaps we should therefore consider al-Bīrūnī's riposte in this way, namely that Ptolemy's arguments against celestial poles as transmitting motions can also be turned against his own sawn-off pieces.

Before I round off the discussion on al-Bīrūnī, it must be added that he also engaged with planetary distances and sizes in the three works mentioned at the beginning of this chapter, namely the *Instruction in the Principles*, *India*, and *Qānūn*. Concerning the values al-Bīrūnī uses in his works, he revised some of them by providing different roundings.[239] More importantly for the present investigation, however, he directly refers to the *Planetary Hypotheses* in this context. In his *India*, for example, al-Bīrūnī gives the following account that I have already quoted above:

> This teaching [the one reported by Yaʿqūb ibn Ṭāriq, see above] is contrary to that on which Ptolemy built the discussion of the distances in his *Planetary Hypotheses* (*Kitāb al-Manšūrāt*) and which the ancients and the moderns followed. For their principle

239 See the overviews in Hartner, 'Medieval Views', pp. 272–73 and 275–78, and Swerdlow, *Ptolemy's Theory*, pp. 148–56 and 182–87. For his use of al-Ḫāzin, see Ragep's commentary in al-Ṭūsī, *Memoir on Astronomy*, Vol. 2, p. 527 nn. 9 and 10. Guillaume Loizelet prepared a new critical edition and French translation of the chapter on planetary distances, see Loizelet, *Mesurer et ordonner*, pp. 431–82.

> concerning [the distances] [builds] upon the fact that the farthest distance of each planet [corresponds to] the closest distance of [the planet] above it, while there is no space devoid of action (*muʿaṭṭal ʿan al-fiʿl*) between both their spheres.[240]

Al-Bīrūnī gives a similar but more detailed account of the method used to calculate the distances in his *Qānūn*, there, however, ascribing it to the 'Greeks', again in opposition to the teaching of the Indians. His main point is how the Greeks arrived at an order of the planets by using these two principles: that the spheres are nested (and have a thickness to accommodate for the planetary motions) and that there is no void. Again, al-Bīrūnī is not entirely satisfied, for he writes that 'the first hypothesis is more apt for the metaphysical philosophy and better in physical investigations.'[241] He then describes his own calculations in detail on the following pages and compares them with the ones from the *Planetary Hypotheses*.[242] In fact, Ptolemy has a similar understanding of these principles in the *Planetary Hypotheses*, for he concludes that the calculated distances are only true if it is correct that there is indeed no void. As a last point, one can better understand al-Bīrūnī's description of a void as a 'space devoid of action' if one looks back at his introductory chapter. There, he writes that every planet is moved 'for a reason' (*li-šaʾn*) and adds that 'nothing futile (*ʿabaṯ*) is created, but [creation is only] by apparent wisdom and shining fate, that is well-ordering for the world and caring for the creation for [its] benefit.'[243] The claim that there is no thing futile and therefore no void space in the world is supported by a theological argument about God's creation.

From al-Bīrūnī, we get an ambivalent picture. At first sight, he has this very strict understanding that only geometrical and observational arguments should be used in a mathematical science like astronomy. Otherwise, arguments that borrow their principles from other sciences such as natural philosophy are not decisive. In his version of the cosmological principles from the *Almagest* in the *Qānūn*, he is highly critical of such physical arguments by Ptolemy because they are only persuasive and thus do not help in proving these principles. Although he does not explain every time why the physical arguments are only persuasive, it is clear that it is due to their application in astronomy. This is why he continuously highlights such arguments as physical in his astronomical work and tries to offer mathematical alternatives. Despite that, he also relies on such physical principles without providing mathematical proofs, most importantly the existence of aether as a fifth element that naturally moves in a circular and regular fashion, which he ascribed to the natural philosophers. This example is especially intriguing because it is apparently

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[240] al-Bīrūnī, *Kitāb fī Taḥqīq mā li-l-hind*, p. 400:1–4.
[241] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 3, pp. 1303:13–1304:19.
[242] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 3, pp. 1304:20–1310:5.
[243] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, p. 24:7–9.

contradicted by the irregular planetary motions.[244] In his cosmological accounts in the *Instruction in the Principles* and the *Qānūn*, he does not offer any proof for the regular circular motion of aether. This means that although al-Bīrūnī claims that one should rely solely on mathematical proofs in astronomy, the example of the existence of aether shows that this ideal might have been hard to realize fully.[245]

Be that as it may, one needs to keep in mind that al-Bīrūnī's general idea of the superiority of astronomical proofs and the probable nature of physical proofs had its predecessor in Ptolemy himself. Usually, when al-Bīrūnī labels his arguments as physical, Ptolemy had already done the same himself. Thus, perhaps one should not say that al-Bīrūnī criticises Ptolemy's method, but that he reminds his reader — who is obviously supposed to know the *Almagest* — that physical arguments are only of an uncertain status in Ptolemy himself. This does not mean that al-Bīrūnī is dismissive of natural philosophy in general. He acknowledges that the natural philosophers study cosmology in physical terms, something mathematicians should also at least have in mind. The main critique against physical arguments can be found in the *Qānūn*, a work mostly on mathematical astronomy. In this context, he finds that observational arguments for the sphericity of the heavens and the Earth are stronger than arguments such as the noble nature of the spherical shape, an argument that actually goes back not only to Ptolemy's *Almagest* but even to Aristotle's *On the Heavens*.[246] Although the *Qānūn* is a work on mathematical astronomy and although al-Bīrūnī prefers observational proofs in this context, this does not mean that he is an instrumentalist in the strict sense that he thinks that the mathematical models have no correspondence in reality. He does acknowledge that natural philosophers should argue about the astronomical models in physical terms and that even mathematicians should keep that in mind. He also inherits the probabilistic status of natural philosophy from Ptolemy, but only in a mathematical context. For al-Bīrūnī, scientific arguments are strongest when they are applied in their specific science and when they are not mixed with each other.

A different perspective on the intermingling of the scientific disciplines has been put forward by Ibn al-Hayṯam (d. around AD 1040). Although he lived around the same time as al-Bīrūnī, he was active in Cairo and we have no evidence that either

[244] In one of his questions to Avicenna, al-Bīrūnī attacks Aristotle's argument for the eternity of the world on the basis of the apparently never-changing celestial realm. Al-Bīrūnī's question suggests that there could be some change in the heavens, albeit so marginal that humans are simply not able to perceive it. The existence of the unchanging fifth element, however, is not up for debate. See Avicenna and al-Bīrūnī, *al-As'ila*, pp. 12:7–31:1, and Hullmeine, 'Al-Bīrūnī's Use', pp. 184–95.

[245] On the question whether medieval astronomers could actually rely on astronomically proven principles solely, see Ragep, 'Freeing Astronomy', pp. 58–60, where Ragep refers to al-Bīrūnī as well as al-Ṭūsī. For a discussion of al-Ṭūsī, see below, pp. 130–40.

[246] *Cael.* II.4, 285b10–287a5.

of them knew about the astronomical works of the other.[247] In the following, I will discuss three cosmological and astronomical works, namely *On the Configuration of the World* (*al-Maqāla fī Hay'at al-ʿālam*), the *Commentary on the Almagest* (supposedly *Šarḥ al-Maǧisṭī*), and the *Doubts about Ptolemy* (*al-Šukūk ʿalā Baṭlamyūs*).[248]

As Tzvi Langermann has argued, Ibn al-Hayṯam's *On the Configuration of the World* is a cosmological work which differs in some aspects from Ptolemy's *Planetary Hypotheses*: there are no discussions on celestial dynamics, as in Book II of the *Planetary Hypotheses*, or on the physical configuration, as in the second part of Book I. Here, Ibn al-Hayṯam shows no knowledge of the *Planetary Hypotheses*. His project rather consists of a non-technical presentation of the geometrical models from the *Almagest* in terms of physical bodies.[249] For the present investigation, the introduction is the most interesting part. Ibn al-Hayṯam starts with a critique of his predecessors, whose assessment of previous authors is only 'persuasive' (*muqniʿ*).[250] What exactly does he mean by that? His main point of critique is that they arrived at 'true facts' (*ḥaqā'iq*) concerning the structure of the cosmos, including the planetary distances and sizes, and concerning the planetary positions and motions, but only at the level of imaginary points and circles.[251] They did not prove, however, how these motions come about through physical spheres:

> Their purpose was not to elucidate the manner by means of which those various motions may possibly be consummated, all the while that they are assumed [to take place] on the surfaces of solid spheres, nor [did they explain] the particular circumstances of their deferent spheres with their various centres. […] For their aim was none other than to make it easy for one who is interested in acquiring knowledge of the configurations of those motions by way of acceptance, not investigation; by following the practitioners of the art, not through probing the understanding of that which has been set down concerning this; nor [questioning] the imagining (*taḫayyul*) of that which has been defined and described. Their doctrines, moreover, are not perfectly clear in all places, nor also are they exhaustive in all

[247] The only small instance of al-Bīrūnī's knowledge of Ibn al-Hayṯam's scientific output is a remark in his work on the *Extraction of the Chords in the Circle* (*Istiḫrāǧ al-awtār fī l-dā'ira*), where he cites a proof by 'Abū ʿAlī al-Ḥasan ibn al-Husayn al-Baṣrī'. See al-Bīrūnī, 'Das Buch der Auffindung', p. 22. I thank Jan P. Hogendijk for this reference.

[248] Roshdi Rashed suggested on many occasions that one should distinguish between the philosopher Muḥammad Ibn al-Hayṯam and the astronomer al-Ḥasan Ibn al-Hayṯam. See Rashed, 'The Configuration' (especially p. 50 n. 4 for his earlier publications on this question). Against Rashed, see Sabra, 'One Ibn al-Haytham or Two?' and Sabra, 'One Ibn al-Haytham or Two? Conclusion'. Despite such doubts concerning their authorship, these three works are rather similar with respect to the topic at hand, namely the epistemological status of mathematics and natural philosophy, which is why I treat them here together.

[249] See Langermann's introduction in Ibn al-Hayṯam, *On the Configuration*, pp. 2–7 and 11–25. Sabra, 'Configuring the Universe', pp. 295–98 puts more emphasis on the similar project of the two works.

[250] Ibn al-Hayṯam, *On the Configuration*, p. 5:26 (Arabic part).

[251 see] Ibn al-Hayṯam, *On the Configuration*, p. 5:6–17 (Arabic part).

> that the issues demand. Rather, they are persuasive (*muqniʿ*) in some places, gratuitous in others.[252]

This characterization of previous astronomical works is, as far as we know, a fair rendering of at least some of the treatises discussed above, namely al-Farġānī's *Summary of Astronomy*, or the treatises on sizes and distances. Obviously, these authors did believe in the existence of corporeal spheres carrying the planets and Ibn al-Hayṯam acknowledges that. However, he thinks that they did not elaborate more on that and were satisfied with brief allusions. This lack of demonstration of how the corporeal spheres actually constitute the planetary motions is what he calls only 'persuasive'.[253] In this respect, he is similar to someone like Proclus. As shown above, Proclus criticised the astronomers, and with them also Ptolemy, for relying only on geometrical figures and not offering a causal account. In contrast to Ptolemy and al-Bīrūnī, who emphasized the persuasive status of physical arguments in their astronomical works, Ibn al-Hayṯam now claims that geometrical representations are not sufficiently demonstrative and that one needs to put more emphasis on how these circles, lines, and points can be transferred into a coherent physical picture:

> Since our doctrine is in accordance with what he [Ptolemy] explained and arranged, and he avoided the use of any bodies, we investigated each of the motions which he mentioned in such a manner that that motion may appear to be the result of a spherical body that is moving with a simple, continuous, and unceasing motion. With this, it is possible to join together all those bodies which have been assumed for each one of the motions without there resulting any hindrance, repelling, or impediment. Rather, their motions, including their combinations, are unceasing and continuous. For each motion which we shall call 'simple', we shall assume a spherical body moving about its centre with a continuous motion since this is most likely (*ašbah*) for the eternal thing which is not subject to change and is free from defects.[254]

Nevertheless, as already noted, he does not speak about celestial dynamics and does not provide a complete cosmological configuration himself. These principles of regular, unceasing motions that are never altered or hindered in any way, and their application to an eternal substance are the only cosmological principles. As described by Tzvi Langermann, there is a spurious 'appendix' (*taʿlīq*) in one of the manuscripts (now MS London, British Library, IO Islamic 1270, f. 116^{r}).[255] On

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[252] Ibn al-Hayṯam, *On the Configuration*, pp. 5:17–6:1 (Arabic part), tr. by Tzvi Langermann, pp. 53–54, slightly modified.

[253] I rely on the summary in Langermann's introduction to Ibn al-Hayṯam, *On the Configuration*, pp. 2–7, and also Ragep's comments in al-Ṭūsī, *Memoir on Astronomy*, pp. 30–33.

[254] Ibn al-Hayṯam, *On the Configuration*, p. 6:16–25 (Arabic part), tr. by Tzvi Langermann, p. 55, slightly modified.

[255] See Ibn al-Hayṯam, *On the Configuration*, p. 7. Cf. Schramm, *Ibn Al-Haythams Weg*, pp. 67–69 and 130–37.

half a folio, this part summarizes the basic cosmological principles, namely that each body moves only by one motion, that these motions are uniform and regular, that the heavens are never influenced or acted upon, and that there is no void in the cosmos.[256] The main argument of this section, however, is an addition to the main text, namely that the planets are fixed on a sphere that carries them and that all the spheres only rotate in their place so that they do not create any empty space in their motion. Since I will address the issue of the motion of the planets in Chapter III, it remains here to say that this appendix served the reader of that manuscript as a handy summary of the cosmological principles that are partially presupposed in the main work. It might also be interesting to point out that this appendix, added to *On the Configuration of the World* in this single manuscript, is similar to the *Doubts about Ptolemy* that I will discuss in a moment.

For now, let us consider Ibn al-Hayṯam's *Commentary on the Almagest*.[257] For Book I, this commentary basically follows the structure from the *Almagest*. It starts with a reiteration of Ptolemy's division of the sciences, and Ibn al-Hayṯam subscribes to the superiority of mathematics by saying that there cannot be any error or doubt in mathematics. On the other hand, he omits the analogous statement that physics and theology are conjectural, on which Ptolemy relies in his epistemology. Following Ptolemy's *Almagest*, Ibn al-Hayṯam then presents the cosmological principles. As Ptolemy before him, he does not solely rely on mathematical proofs but also uses physical arguments. In the chapter on the sphericity of the cosmos, he even alludes to Aristotle's *Metaphysics*.[258] He also relies heavily on physical arguments in the section on the motion of the Earth. Whereas he briefly points to one mathematical argument (MS Istanbul, Topkapı Sarayı Müzesi, Ahmet III 3329, f. 48^{r}:12–18), the material of the physical arguments covers the entire remainder of the section (ff. 48^{r}:18–49^{v}:22). Although he explicitly labels these different sets of arguments as 'mathematical' or 'physical', this does not entail any epistemological consequence. He presents both approaches to establish these cosmological principles without any sign of preferring one over the other. In this respect, Ibn al-Hayṯam departs in his commentary from Ptolemy. That Ibn al-Hayṯam does not hesitate to mix these two branches of philosophy is also apparent from his chapter on the solar model. Departing from the observed motions of the planets, he gives an account of previous discussions on whether the planets are made out of a fifth element or composed of the four sublunar elements, a discussion without a counterpart in the *Almagest*, and

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[256] Summarized at the end under the heading 'last section' (*faṣl āḫir*), Ibn al-Hayṯam, *On the Configuration*, p. 67:5–10 (Arabic part).

[257] Extant in MS Istanbul, Topkapı Sarayı Müzesi, Ahmet III 3329, ff. 38^{v}–158^{r}, covering only the first six books of the *Almagest*. For an overview, see Sabra, 'One Ibn al-Haytham or Two?', pp. 33–39.

[258] On this chapter (ff. 39^{v}–43^{v} in MS Istanbul, Topkapı Sarayı Müzesi, Ahmet III 3329), see Langermann, 'Revamping Ptolemy's Proof'.

he even adds Galen's medical perspective of this debate.[259] When he gives an account of the Sun's anomaly afterwards, he writes that Ptolemy decided on an eccentric sphere for the Sun 'because it is simpler and more appropriate for the slight anomaly of the Sun' (*lianna-hū absaṭ wa-alyaq bi-ḥarakat al-šams al-qalīla al-iḫtilāf*), again without judging whether this argument is demonstrative or only persuasive. He then adds that Ptolemy's successors observed the motion of the solar apogee and therefore added an epicycle to the solar model.[260] Although Sabra was right in pointing out that the main bulk of this commentary depends on the mathematical discussions of the *Almagest*, it is also clear that in this work, Ibn al-Hayṯam considers physical arguments as important for reading and understanding the *Almagest*.[261] From these two works, it is therefore rather obvious that Ibn al-Hayṯam is eager to give a coherent picture of astronomy and natural philosophy, and even metaphysics. Certainly, he follows Ptolemaic astronomy closely, but in contrast to Ptolemy and al-Bīrūnī, his account is more influenced by his aim to provide a complete cosmological system that combines the different sciences rather than looking at them separately. Given the fact that in the list of works attributed to Ibn al-Hayṯam, commentaries on Aristotelian works also appear, it seems reasonable to suspect that he must be placed in the epistemic tradition of Aristotle, though his astronomy is still Ptolemaic. What he tries to achieve is therefore a compromise between these two traditions, an important part of which is the rejection of Ptolemy's probabilistic account of natural philosophy.

In a discussion of the reception of Ptolemaic astronomy and especially of the *Planetary Hypotheses* in the Arabic tradition, Ibn al-Hayṯam's *Doubts about Ptolemy* must be mentioned. Ibn al-Hayṯam divides his work into three sections, the first dealing with the *Almagest*, the second with the *Planetary Hypotheses*, and the third with the *Optics*.[262] Concerning the cosmological principles from Book I of the *Almagest*, he only has remarks on two specific points and no general critique of Ptolemy's method or epistemology.[263] After Book I, however, Ibn al-Hayṯam immediately proceeds to Book V and Ptolemy's lunar theory. In this context, as well as in the context of the other planetary theories, he presents one of the most fundamental problems he sees in Ptolemy's astronomy, namely that geometric entities are considered to cause physical motions. These are the so-called prosneusis point in the case of the lunar theory, which accounts for a slight anomaly of the apogee,

[259] MS Istanbul, Topkapı Sarayı Müzesi, Ahmet III 3329, ff. 135^r:25–135^v:11. He refers to Galen's *On Natural Faculties* (*Kitāb fī [l-]Quwā l-ṭabīʿiyya*).

[260] MS Istanbul, Topkapı Sarayı Müzesi, Ahmet III 3329, f. 136^r:10–16.

[261] See Sabra, 'Configuring the Universe', pp. 35–37.

[262] This work was edited by Sabra and Shahaby, see Ibn al-Hayṯam, *al-Šukūk*, with the section on the *Planetary Hypotheses* being on pp. 42–64. It was translated into English by Don L. Voss, see Ibn al-Hayṯam, *Doubts*.

[263] These remarks concern two aspects of the sphericity of the cosmos and the central position of the Earth, see Ibn al-Hayṯam, *al-Šukūk*, pp. 5:8–9:9.

and the equant point in the case of the planets, around which the celestial motions are supposed to move uniformly.[264] Ibn al-Hayṯam divides his argument against the prosneusis point into three parts. First, 'imaginary' (*mutaḫayyil*) points, lines, or planes do not move in a sensible fashion so that something 'existing' (*mawǧūd*) comes about. Only physically existing bodies move in this way.[265] Therefore, there must be a physically existing moving body for this additional motion, and Ibn al-Hayṯam devotes a lengthy discussion to the nature of this mover. Nevertheless, he ends up claiming that this assumption leads to one of the two results: either one body would move naturally by two contradicting motions or if this moving body were a separate body, the phenomena would require the two motions to stop occasionally.[266] Both possibilities clearly contradict Ptolemy's cosmology, which implies that every motion is assigned to just one body and that each body only moves with a single uniform motion. Thus, he concludes that each of these three possibilities is 'impossible' or 'absurd' (*muḥāl*). The same point that one body would receive two contradictory motions when we transfer Ptolemy's model into physical bodies comes up in Ibn al-Hayṯam's discussion of the equant. Here, however, his most important point is that a sphere can only move uniformly with respect to its centre and not to a different point.[267] Ibn al-Hayṯam picks up on these issues in his conclusion of the *Almagest*, which actually is a wider critique of Ptolemy's method. Citing from *Almagest* IX.2, he wants to show that Ptolemy himself admitted that in using bare circles, he applied a method 'outside of reasoning' (*ḫāriǧ ʿan al-qiyās*).[268] Ibn al-Hayṯam repeats this critique more explicitly, mixing the terminology from the Arabic translation of the *Almagest* with his own when he claims that 'his assumption, which is an assumption on imagination (*taḫayyul*), not on existence (*wuǧūd*), is outside of reasoning (*ḫāriǧ ʿan al-qiyās*).'[269]

As should be clear by now, one major issue for Ibn al-Hayṯam is to emphasize the need to give an astronomical model that can be turned into a physical cosmos. To be fair, this is Ptolemy's goal in the *Planetary Hypotheses*, and Ibn al-Hayṯam was aware of that, of course. What is his strategy now in his section on the *Planetary Hypotheses*? Most of the points he raises are comparisons between the mathematical account from the *Almagest* and the physical models presented in the *Planetary Hypotheses*. A couple of examples should suffice to underline this point:

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[264] See Pedersen, *A Survey*, pp. 192–95 and 273–76. For previous discussions of the passages that are discussed in the following, see Sabra, 'Configuring the Universe', pp. 300–05, and Saliba, *Islamic Science*, pp. 97–104.

[265] Ibn al-Hayṯam, *al-Šukūk*, p. 16:1–5.

[266] Ibn al-Hayṯam, *al-Šukūk*, p. 19:8–15.

[267] Ibn al-Hayṯam, *al-Šukūk*, pp. 26:3–29:14. See Saliba, *Islamic Science*, pp. 98–99.

[268] Ibn al-Hayṯam, *al-Šukūk*, p. 37:14–17. The citation goes back to Ptolemy, *Syntaxis*, IX.2, Vol. 2, pp. 211:22–212:1, where the Greek expression is *para ton logon*.

[269] Ibn al-Hayṯam, *al-Šukūk*, p. 38:15.

- In the models of Book I of the *Planetary Hypotheses*, Ptolemy omits ten motions in comparison with the *Almagest*.[270]
- The planetary motions in latitude, as presented in *Almagest* XIII, do not conform to the bodies that Ptolemy describes in Book II of the *Planetary Hypotheses*.[271]
- More motions from the models of Venus, Mercury, and the Moon from the *Almagest* are dropped in Book II of the *Planetary Hypotheses*.[272]

How does Ibn al-Hayṯam react to these inconsistencies? Of course, they provide him with a nice illustration of the fact that the mathematical models from the *Almagest* are indeed hard to explain in physical terms. Nevertheless, after summarizing the planetary models from Book II of the *Planetary Hypotheses* he notes that:

> It is immediately clear that his assumptions of [complete] spheres and sawn-off pieces in the second book of the *Planetary Hypotheses* (*Kitāb al-Iqtiṣāṣ*) for the motions of the planets are contrary to what he established of the motions in the *Almagest*. The true [account] of the motions is what he established in the *Almagest*, for there he had established the motions by observations and instruments (*bi-arṣād wa-maqāyīs*).[273]

Despite Ibn al-Hayṯam's critical remarks, this passage illustrates that he was not dismissive of the entire *Almagest*. He already made his respect for Ptolemy clear in the beginning of the *Doubts about Ptolemy*, where he explicitly writes that Ptolemy was 'distinguished in the mathematical sciences'.[274] In turn, the assertion that the results from the *Almagest* should be favoured since they are based on observation means that this is, in Ibn al-Hayṯam's view, not the case for the *Planetary Hypotheses*. One reason why he disapproves of the cosmological account in the *Planetary Hypotheses* is certainly the sawn-off pieces. He already states in his presentation of the planetary models from Book II of the *Planetary Hypotheses* that they are not in accordance with the models from the *Almagest*, as apparent from the quotation above. In addition, he explains that the motion of the sawn-off pieces could not work when they are supposed as physical bodies:

> As for the sawn-off pieces which Ptolemy supposed for the five planets, monstrous absurdities follow from them that are of two kinds. One of the two is that a body vacates a place and occupies another. The other is that a body moves by opposite, non-uniform motions. In the body, there follows necessarily one type [of absurdity], namely the two opposite motions, each of which is non-uniform in itself. Nevertheless, it follows for each of the planets and the Moon that the motions which he established for them are fewer in

[270] Ibn al-Hayṯam, *al-Šukūk*, p. 43:6–9.

[271] Ibn al-Hayṯam, *al-Šukūk*, p. 54:16–20.

[272] Ibn al-Hayṯam, *al-Šukūk*, pp. 58:15–59:12. These points of divergence between the *Almagest* and the *Planetary Hypotheses* are summarized in Saliba, *Islamic Science*, pp. 104–07.

[273] Ibn al-Hayṯam, *al-Šukūk*, p. 50:12–15, tr. by Voss in Ibn al-Hayṯam, *Doubts*, p. 68, modified.

[274] Ibn al-Hayṯam, *al-Šukūk*, p. 4:7–8.

> number than the motions which he had established in the *Almagest*. If the motions are brought about by [the alternate] interpretations [that we discussed], then another error follows in addition to the absurdities [which result from] his incompetence concerning the motions. This is what we have discussed and made clear; all of what Ptolemy established for the motions of the planets is demolished if their movers are sections.[275]

Both of these absurd consequences have their origin in Ibn al-Hayṯam's critique of Ptolemy's new latitude theory. Mostly, he is worried that this new latitude theory does not fit the observed phenomena as described in the *Almagest*. As another part of this attack, he especially engages with the two sawn-off pieces of an epicycle and the question of how the smaller sawn-off piece in the epicycle, which is compared to a tambourine, can move within the larger hollow one. This leads him to also set out the two physical problems that he finally summarizes as quoted above.[276] This once more shows Ibn al-Hayṯam's strategy of indicating that Ptolemy did not sufficiently dealt with the physical consequences of his geometrical models. A bit redundantly, he emphasizes this a couple of times when he concludes the discussion of the *Planetary Hypotheses*, for example as follows:

> He was satisfied by what he had done only because he was not able to do better than that. The correct [fact] about which there is no doubt is that the configurations (*hay'āt*) of the planetary motions are correct, existing, and continuous (*ṣaḥīḥa mawǧūda muṭarrida*) configurations from which follow no absurdities and no contradictions. These are not the configurations that Ptolemy established. Ptolemy did not understand them, nor did his understanding attain the imagination of their true nature.[277]

As a side note, Ibn al-Hayṯam does not concern himself too much with the section on planetary distances and sizes (a fact that the *Doubts about Ptolemy* has in common with *On the Configuration of the World*). Only the last sentence before the discussion of Book II of the *Planetary Hypotheses* gives a small insight: 'Then, he [Ptolemy] mentions the ratios of the distances of the planets from the Earth and their sizes in a persuasive way (*bi-ṭarīq iqnāʿī*)'.[278] This remark might seem strange, given that Ibn al-Hayṯam strongly emphasizes the need to give a physical explanation of the cosmos and he himself subscribes to the non-existence of void, a principle that Ptolemy endorses for calculating the distances but labels as merely persuasive. Ibn al-Hayṯam simply copies Ptolemy's own disclaimer and, in doing so, he agrees that Ptolemy left the more certain method of the *Almagest*. However, a more generous reading could point out that Ibn al-Hayṯam is not criticizing persuasive arguments as, for example, al-Bīrūnī did. In the *Doubts about Ptolemy*, 'persuasive' might also

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[275] Ibn al-Hayṯam, *al-Šukūk*, pp. 59:13–60:2, tr. by Voss in Ibn al-Hayṯam, *Doubts*, p. 79, modified.

[276] See Ibn al-Hayṯam, *al-Šukūk*, pp. 45:5–58:14. For Ptolemy's latitude theory, see Swerdlow, 'Ptolemy's Theories', and for a summary of Ibn al-Hayṯam's criticism, see Voss' commentary in Ibn al-Hayṯam, *Doubts*, pp. 147–69, and also Saliba, *Islamic Science*, pp. 105–07.

[277] Ibn al-Hayṯam, *al-Šukūk*, p. 64:2–5, tr. by Voss in Ibn al-Hayṯam, *Doubts*, p. 85, modified.

[278] Ibn al-Hayṯam, *al-Šukūk*, p. 45:4.

be understood as opposing the 'absurdities' or 'impossibilities' (*muḥālāt*), especially those arising from Book II of the *Planetary Hypotheses*. In either case, he apparently did not have something substantially to criticise about that section.

In this context, one must also refer to another work by Ibn al-Hayṯam, called *The Resolution of Doubts Against the Winding Motion* (*Fī Ḥall šukūk ḥarakat al-iltifāf*).[279] This work relies on two earlier lost treatises, first a treatise named *On the Winding Motion* by Ibn al-Hayṯam himself, and second a critical remark against this work by an anonymous author, a treatise apparently called *Doubts Against the Winding Motion*. What Ibn al-Hayṯam has in mind by 'winding motions' are additional motions by the planets on their epicycles that Ptolemy described in the *Almagest*. Ibn al-Hayṯam's initial critique of Ptolemy is that he did not provide a system of physical bodies to account for these motions in the *Planetary Hypotheses*, and this is what he apparently attempted in his work *On the Winding Motion*. Regardless of the underlying mathematical arguments and model for this motion, what is of importance here is the fact that the anonymous author apparently thought that Ptolemy attempted to create this motion through his sawn-off pieces. Thus, in his reply, Ibn al-Hayṯam refutes this and argues that such a motion would be impossible to generate by these sawn-off pieces. In contrast to the arguments against sawn-off pieces in his *Doubts about Ptolemy*, here, his argument is based on the mathematical impossibility.[280] Apparently, Naṣīr al-Dīn al-Ṭūsī had access to the initial work by Ibn al-Hayṯam and writes about his model of the winding motion: 'Ibn al-Hayṯam states that one could reach the same result by assuming sawn-off pieces (*manāšīr*) instead of [complete] spheres, but to set forth something other than a sphere would not be appropriate for the models of this science.'[281] This again sounds rather in line with the criticism expressed in the *Doubts about Ptolemy*. In light of our loss of Ibn al-Hayṯam's *On the Winding Motion* that was available to al-Ṭūsī, one can only cautiously suggest that Ibn al-Hayṯam might have developed this line of argument against the sawn-off pieces in combination with his critique of Ptolemy's new latitude theory from the *Planetary Hypotheses* at a later stage. Anyway, this treatise informs us not only about another aspect of Ibn al-Hayṯam's critique, but also about an unknown scholar from the same time as Ibn al-Hayṯam who attempted to defend Ptolemy's sawn-off pieces. These fragments reported by

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[279] This work was edited twice, first in Sabra, 'Ibn al-Haytham's Treatise', and recently in Rashed and Penchèvre, 'Ibn al-Haytham'. Note that the motion that is called 'winding motion' here (Arabic: *ḥarakat al-iltifāf*) is not the same as the *iltifāf* motion that comes up in the *Planetary Hypotheses*, as already pointed out by Sabra (see Sabra, 'Ibn al-Haytham's Treatise', p. 389).

[280] See the introduction in Rashed and Penchèvre, 'Ibn al-Haytham', pp. 61–65. The sawn-off pieces are frequently mentioned throughout this text. As an example of Ibn al-Hayṯam's rejection, see Sabra, 'Ibn al-Haytham's Treatise', p. 410:6–7, or Rashed and Penchèvre, 'Ibn al-Haytham', p. 95:8–9.

[281] al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 217:2–4, tr. by Ragep on p. 216, slightly modified. Regarding this fragment, see Ragep's comments in Vol. 2, pp. 450–52.

Ibn al-Hayṯam in his reply are therefore the only witness of that time for such a positive engagement with the sawn-off pieces.

This material sufficiently shows Ibn al-Hayṯam's main worry with Ptolemaic cosmology. As seen from his critique of the *Planetary Hypotheses*, he is generally more favourable toward the mathematical project of the *Almagest*. However, he complains about the fact that they do not really conform to the cosmological principles on which nearly every author agreed, most importantly uniform motion and that each body moves only by a single motion, but also the non-existence of a void. Astronomy should not be discussed merely on the basis of points and lines, but on physically existing bodies. This is actually similar to the first two works ascribed to Ibn al-Hayṯam. In these three works (*On the Configuration of the World*, *Commentary on the Almagest*, and *Doubts about Ptolemy*), we do not find the same reservation about natural philosophy that Ptolemy and al-Bīrūnī show. *On the Configuration of the World* and *Doubts about Ptolemy* equally show the conviction that astronomy should not only be concerned with geometrical entities. With respect to the *Planetary Hypotheses*, Ibn al-Hayṯam is concerned with physical principles such as the motion of spheres within other spheres and the existence of a void. Although the three works discussed here show differences in other details, such an intermingling of natural philosophy and mathematics can also be observed in the *Commentary on the Almagest*, whereas *On the Configuration of the World* provided us with a similar issue of finding the physical counterparts of the geometrical components of the models. This approach is rather different from the one chosen by al-Bīrūnī, who is always eager to distinguish between mathematical and physical arguments. While al-Bīrūnī denoted physical arguments as 'outside of that science', in the *Doubts about Ptolemy*, Ibn al-Hayṯam marks the restriction on circles as 'outside of reasoning'. In turn, this means that it is reasonable to provide the observed phenomena and their mathematical calculations with the foundations of natural philosophy inherited from the ancient tradition and most famously presented in Aristotle's *On the Heavens*. However, in neither of these three works do we actually get a detailed account of a cosmological picture emerging from this interaction between astronomy and physics by Ibn al-Hayṯam.[282]

There is yet a third approach to the relationship between astronomy and physics from the same time, as illustrated by Kūšyār ibn Labbān (fl. around AD 1000). Interestingly, we know that he met al-Bīrūnī in Rayy.[283] His astronomical handbook *al-Zīǧ al-Ǧāmiʿ* is divided into four main parts. Of special interest for the present investigation is the third book 'On Cosmology' (*Fī l-Hay'a*),[284] which starts with an introduction into cosmological terminology. Kūšyār defines the sphere (*kura*)

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[282] For this, see Rashed, 'The Celestial Kinematics'.

[283] See Bagheri's introduction in Kūšyār ibn Labbān, *Az-Zīj al-jāmiʿ*, p. xiv.

[284] Books I and IV have been edited and translated by Mohammad Bagheri, see Kūšyār ibn Labbān, *Az-Zīj al-jāmiʿ*; for the astronomical tables of Book II, see the recent edition and translation in van Dalen, *Ptolemaic Tradition*. Since Book III has not been edited yet (with the exception of the

as a 'bodily shape' (*šakl muǧassam*) and thereby establishes his aim to provide a cosmology with physical bodies.[285] One should devote some attention to Chapter 14 of Book III, which is entitled 'on the order of the spheres that encompass the entirety of the motions of every planet and their number' (*fī tartīb al-kurāt al-muḥtawiyya ʿalā ǧumlat ḥarakāt kull kawākib wa-ʿadadi-hā*). The first half of this chapter reads as follows:

> The mathematicians, as they are the followers of this science (*aṣḥāb hāḏihi l-ṣināʿa*), found the motions of the planets on account of (*ʿalā*) their anomaly in speed and slowness, and turning back and being stationary, and rising and setting, and locomotion from north to south and from south to north by means of observational instruments and geometrical methods. By their refined thoughts and precise minds, they found spheres (*aflāk*) for these motions, I mean spheres (*kurāt*) that preserve the motions of the planets although their anomaly has been discovered through the senses [and although] there is no speed and slowness, and turning back and being stationary, and rising and setting, and no locomotion in any direction according to the physical structure (*niẓām ṭabīʿī*). By these spheres (*aflāk*) and their hypotheses (*awḍāʿ*), they demonstrated the calculation of the formation of the planets and the rest of their states in a regular (*muṭarrid*) proof and calculation. They expressed the motions of these spheres by motions of circles, lines, and points in a metaphorical and concise way of expression (*bi-l-istiʿāra wa-īǧāz al-lafẓ*). The investigation of these motions [concerned the question] whether they are essential (*ḏātiyya*) for moved things or accidental (*ʿaraḍiyya*) to them and whether there occurs an alteration in the sphere (*falak*) or not, I mean that they [i.e. the planets] move by themselves so that they penetrate the sphere (*falak*), or that they move by spheres moving them so that there does not occur penetration in the sphere.[286] Because they did not need it in their science, they omitted a discussion of [this investigation] and left this investigation for (*bi-*) its followers, may their discussion on that point be true or convincing (*ḥaqīqiyyan aw iqnāʿiyyan*).[287]

Kūšyār presents the way in which mathematicians dealt with the configuration of the heavens. They provided geometrical models based on circles, lines, and points to present the celestial motions. This does not mean that Kūšyār rejects their approach as isolated from their physical realities. Instead, he acknowledges that they applied geometrical methods but nevertheless tried to account for the apparently irregular

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part on planetary distances and sizes, for which see Bagheri et al., 'Kūshyār ibn Labbān'), I rely on MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, ff. 91r–131r. This manuscript has been chosen as the main witness in Bagheri et al., 'Kūshyār ibn Labbān'.

285 MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, f. 92v:7–8.

286 Partially omitted in MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, f. 104r:4–5, additions in MS Leiden, Universiteitsbibliotheek, Or. 8, f. 89v:14 and margin, complete in MS Alexandria, Baladiyya, 4285 C, ff. 12v:19–13r:1. The last witness is said to have been copied from an autograph (see Bagheri et al., 'Kūshyār ibn Labbān', p. 79).

287 MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, ff. 103v:10–104r:6.

motions in terms of the 'physical structure'. For Kūšyār, natural philosophy demands celestial motions to be regular, and this was rightly considered by previous astronomers. What they did not discuss, though, is the causal relationship between the spheres and planets, and the origin of celestial motions. Are celestial motions accidental or essential, and are the planets fixed on the spheres moving them or do they move on their own account within a sphere? In Kūšyār's view, this marks the line between what astronomers dealt with and what philosophers, and perhaps metaphysicians, should debate. Since he himself does not discuss these issues, we can assume that he considered this distinction as fair. In addition, he writes that accounts of these issues may either be 'true or convincing'. As he does not elaborate on that point any further, it is not entirely certain whether he sees a major epistemic difference between 'true' and 'convinving'. I take him to mean here that the decision regarding whether some of the arguments on these non-mathematical questions are *true* or only *dialectically persuasive* does not belong to the task of the astronomer. If this is true, it signals a certain reservation about at least some of these debates on Kūšyār's behalf. In turn, this also underlines that he does not consider the 'physical structure', namely the principle of regular planetary motions despite their observed irregular appearances, as merely convincing but, to the contrary, as important principles that need to be considered by the astronomer.

In what follows after this quoted passage, he presents the configuration of the cosmos as consisting of nine nested spheres (*kura*, pl. *ukar*), one for each of the five wandering planets, the Sun, the Moon, the fixed stars, and one starless sphere to account for precession.[288] In this configuration, he generally follows Ptolemy, as is apparent from his presentation of planetary sizes and distances. After a simple presentation of the values in Chapter 22 of this third book, there is an appendix that explains the method in more detail, which also circulated independently from the rest of Kūšyār's *al-Zīǧ*. In this respect, he clearly stands in the tradition of similar accounts from the ninth and tenth centuries AD. It remains to say that although Kūšyār himself writes that he provides the distances and sizes 'according to Ptolemy's reasoning' (*ʿalā qiyāsāt Baṭlamyūs*), the values themselves slightly depart from the ones in Ptolemy's *Planetary Hypotheses*.[289]

Despite the brevity of Kūšyār's account, we detect an awareness that astronomers deal with physical spheres and only describe them by circles in a metaphorical way, but do not go into the details of celestial dynamics. Although Book III of Kūšyār's *al-Zīǧ* is rather different from al-Bīrūnī's *Qānūn* (which is a most technical and voluminous work on mathematical astronomy) as well as from the works ascribed to Ibn al-Hayṯam, these three authors from the first half of the 11th century AD share an interest in which questions can or should certainly be answered by astronomers or

[288] MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, f. 104r:7–13.

[289] See Swerdlow, *Ptolemy's Theory*, pp. 146–47 and 181–82, and Bagheri et al., 'Kūshyār ibn Labbān'.

by natural philosophers. Certainly, none of these authors is a mere instrumentalist, although they all have different views on the degree to which the astronomer should rely on natural philosophy. A first option is the demand to keep the sciences and their methods separate from each other, a position that has much in common with Ptolemy's own claim of the conjectural epistemic value of physics. Al-Bīrūnī transforms this view in such a way that he ends up with the claim that, at least in a work on mathematical astronomy, physical arguments are not demonstrative.

Kūšyār allows some physical principles such as the perfect and regular nature of celestial motions. These principles are necessary in order to avoid astronomers ending up as mere instrumentalists. Nevertheless, he strictly demarcated what astronomers do not need to investigate, namely mostly physical and metaphysical questions on celestial dynamics. These investigations might be merely persuasive and probable, or hit the truth, but Kūšyār obviously does not want to elaborate on this distinction any further. Lastly, the three works attributed to Ibn al-Hayṯam highlight the need for a cosmological picture that brings together Ptolemaic astronomy and natural philosophy as laid out in Aristotle's *On the Heavens*, although the emphasis on natural philosophy is certainly even stronger and more explicit in *On the Configuration of the World* and the commentary on the *Almagest* than in the *Doubts about Ptolemy*. In these works ascribed to Ibn al-Hayṯam, we find no trace of Ptolemy's probabilistic account of physics, which is more prominent in al-Bīrūnī and, slightly less so, in Kūšyār.

In this respect, one can detect a general shift around AD 1000, since similar topics were not part of earlier cosmological works. This shift can also be detected in the introduction of new topics to astronomical works. In fact, Ptolemy's sawn-off pieces as well as the question about whether the planets penetrate the spheres were not discussed at all before al-Bīrūnī and Ibn al-Hayṯam.[290] One can compare this with the observation by F. Jamil Ragep already mentioned above, namely that Avicenna was the first to use the term *ʿilm al-hay'a* for astronomy in general, whereas this term previously only denoted the part of astronomy that dealt with the physical configuration of the celestial bodies (as discussions on distances and sizes, for example). Ragep related this terminological finding to Ibn al-Hayṯam's physical rather than mathematical cosmology in *On the Configuration of the World*.[291] In this context of emphasizing the physical aspects of celestial bodies, these authors from the first half of the 11th century AD tried to determine to what extent mathematical astronomy should depend on natural philosophy or even metaphysics, and by which criteria arguments should be considered as 'true' or 'convincing', thereby picking up a distinction already made by Ptolemy in the *Almagest* and the *Planetary Hypotheses*. As shown by Peter Adamson and explained in the previous chapter, we can consider

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[290] Since the latter issue of planets penetrating the spheres relies on Ptolemy's ascription of psychological self-motion to the planets, I discuss this in more detail in Chapter III.

[291] See the introduction by Ragep in al-Ṭūsī, *Memoir on Astronomy*, pp. 33–35.

the translation of Aristotle's *Posterior Analytics* and further discussions about the intermingling and dependence of the various sciences in the philosophical school around al-Fārābī to have triggered this shift around AD 1000. This picture becomes more convincing in light of the fact that there was obviously no clear separation between 'philosophers' and 'astronomers'. Al-Fārābī, as the author of logical works as well as the commentary on the *Almagest*, is himself a good example of that, as is the 12th-century mathematician Ibn al-Ṣalāḥ, who not only criticised al-Fārābī's commentary, but also wrote a short comment on an argument in Aristotle's *Posterior Analytics*.[292] Thus, according to the development of the philosophical discussions about the division and ranking of the philosophical branches from the eighth to the ninth century AD, and from al-Kindī to al-Fārābī, Ptolemy's commentators from around AD 1000 noticed the need to distinguish properly between physical and mathematical arguments, and to discuss their epistemological status.

The *Planetary Hypotheses* plays a major role in the context of these discussions, expecially in the works by al-Bīrūnī and Ibn al-Hayṯam. Al-Bīrūnī adopts Ptolemy's epistemology, which then, however, leads him to take a critical stance against Ptolemy's sawn-off pieces from the *Planetary Hypotheses* and some of the physical arguments from the first chapters of the *Almagest*. Thus, his critique is directed towards aspects that Ptolemy himself had labelled as conjectural. Although Ibn al-Hayṯam also suggests some improvements for the *Almagest*, his most fundamental critique concerning the epistemic status of Ptolemy's theories is directed towards the *Planetary Hypotheses*, as well. This becomes clear when he claims that, in general, Ptolemy followed sure methods, namely observations, in his *Almagest*, but abandoned this sure path in the *Planetary Hypotheses*. On this ground, a picture emerges of rising criticism against some of the cosmological doctrines of the *Planetary Hypotheses* around AD 1000 in the Islamic East, which had its roots in Ptolemy's own conviction that there are some elements of cosmology that cannot be determined with the same certainty as mathematical calculations of planetary motions. In the following chapter, we will see that criticism of Ptolemaic astronomy even started at a more fundamental level in the Islamic West, namely the planetary models from the *Almagest*.

Philosophers in al-Andalus on Ptolemaic and Aristotelian Astronomy

Before we take a look at the usual suspects when it comes to a discussion of astronomy and philosophy in medieval al-Andalus, there is a comparatively early witness of astronomical theories. In a manuscript held in Istanbul (MS Istanbul, Süleymaniye Kütüphanesi, Carullah 1279, ff. 315r–333r), one finds a treatise called *On the Configuration* (*Kitāb al-Hay'a*) ascribed to Qāsim ibn Muṭarrif al-Qaṭṭān

[292] See Thomann, 'Al-Fārābīs Kommentar' and Thomann, 'The Oldest Translation'.

al-Andalusī al-Qurṭubī.[293] He can roughly be dated to the first half of the tenth century, AD which makes him predate the other Andalusian philosophers whom I will discuss in this chapter by at least 150 years. His *On the Configuration* is basically a non-technical summary of astronomy very similar to works from the Islamic East from the ninth and tenth centuries, most notably al-Farġānī's *Summary of Astronomy*. Of particular interest is Chapter 30 on planetary distances and sizes in which he gives an account of nested spheres, as it was widely spread in the east. As argued by Josep Casulleras, this chapter shows a strong resemblance to the work of Ibn Rustah, who was born in Iṣfahān and lived until the early tenth century AD.[294] The planetary distances given by Qāsim ibn Muṭarrif al-Qaṭṭān are the same as the ones by Ibn Rustah, and both correspond closely to the ones in the *Planetary Hypotheses*.[295] Thus, if the attribution to Qāsim ibn Muṭarrif al-Qaṭṭān is correct, we have an evidence for a very early indirect transmission of Ptolemy's nested cosmos to al-Andalus via an author from the Islamic East. In the text itself, there does not seem to be any explicit reference to the *Planetary Hypotheses*, at least not in the chapter on planetary distances. The value of our knowledge of this work lies in it being a very early example of a cosmological text in al-Andalus that gives a description of a clearly physical cosmos, regardless of whether the author had direct access to the *Planetary Hypotheses* or not. In fact, this is very similar to the situation of the ninth- and tenth-century astronomers in the Islamic East, in whose works we can see the same kind of account of the cosmos without explicit reference to Ptolemy.

There is also the evidence of the group of astronomers active in Toledo in the 11th century around Ibn al-Zarqālluh (d. AD 1100). George Saliba described one treatise simply entitled *Treatise on Configuration* (*Risālat al-Hay'a*) and — although it is anonymous — ascribed it to a contemporary of Ibn al-Zarqālluh.[296] In his article, Saliba provides the following excerpt in translation:

> You should know that the practitioner of this art (*ṣināʿa*), after having extracted from the observations the motions that are like the foundations and principles (*al-mabādi' wa-l-*

[293] On this manuscript, see Rosenthal, 'From Arabic Books'. On the author and his astronomical work, see Sezgin, *Geschichte des arabischen Schrifttums VI*, pp. 197–98. I learned about the existence of this work from the English translation of an article originally in Spanish by Josep Casulleras, see Casulleras, 'The Contents'. For a more recent overview, see Samsó, *On Both Sides*, pp. 502–06. For a comparison between these early astronomical activities and the so-called 'revolt' of the 12th century, see Samsó, 'On al-Biṭrūǧī'.

[294] See Casulleras, 'The Contents', p. 341.

[295] For the values in Ibn Rustah, see Swerdlow, *Ptolemy's Theory*, pp. 142–43. For the chapter by Qāsim ibn Muṭarrif al-Qaṭṭān, see MS Istanbul, Süleymaniye Kütüphanesi, Carullah 1279, ff. 320v:9–321r:34.

[296] See Saliba, 'Critiques of Ptolemaic Astronomy', where one also finds an overview of the group of astronomers in Toledo. This work is preserved in a unique manuscript in Hyderabad (MS Hyderabad, Osmania University Library, 520 RH), which I have not seen. On the reception of Ibn al-Zarqālluh in later Andalusian authors, see Forcada, '*Saphaeae* and *Hay'āt*'.

> *uṣūl*), he should then seek from the art of geometry the manner in which these motions could be achieved, and which configuration (*hay'a*) would be the one necessitating them. While searching for that, he should not deviate from that which he has accepted from the physical sciences (*ʿilm ṭabīʿī*) of the foundations (*mabādiʾ*) of this art.[297] He should not abandon the spheres, the circles, and the circular uniform motions, and pass on to other than that like a non-spherical body (*ǧism ġayr kurī*) or a non-circular shape. If by virtue of his power he was able to discover many configurations (*hay'āt*) for each of the planets, all of them leading to the same result and all of them in perfect accord with the observable particular motions, then he should opt for the simplest and most straightforward and that which resembles the celestial bodies as was done by Ptolemy when he opted for the eccentric in the case of the Sun and not the epicycle.[298]

This passage shows that in 11th century-Toledo, there was already concern regarding the relationship between astronomy and other disciplines. On the one hand, astronomers need to rely on geometry to find abstract mathematical models for the observed phenomena. In order to finally arrive at a proper configuration (*hay'a*), one must, however, also accept certain principles from natural philosophy as the 'foundations' of astronomy. The anonymous author touches in the end on Ptolemy's argument of simplicity from *Almagest* III.4. More importantly, the author claims that one should not replace perfectly spherical spheres with non-spherical bodies. This shows, firstly, that this passage is not only concerned with an abstract mathematical model that must conform to the idea of uniformly moving circles and striving for the simplest version of such an abstract model, but rather that this needs to be applied to bodies (*ǧism*) as well. Further, it shows that the author is not worried about eccentric spheres or epicycles, as both are perfectly spherical bodies. Instead, other shapes must be excluded, such as ovoid or lenticular spheres or even Ptolemy's sawn-off pieces. Against an earlier assessment of this passage that read it as 'purely instrumental in that he [i.e. the anonymous author] only attempts to make an abstract representation of the phenomena',[299] I take it that the author argues that a proper configuration of celestial motions must adhere to the principles of natural philosophy. He clearly talks about celestial bodies and not just their geometrical representation. One must not forget that Ptolemy's criterion of simplicity does not concern the simpler geometrical representation when the astronomer draws the figure of a planetary model, but Aristotle's claim that *nature* does nothing in vain, and thus the simpler configuration more probably accounts for the natural reality than the more complicated one.

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[297] The Arabic reads (see Figure 1 in Saliba, 'Critiques of Ptolemaic Astronomy', p. 11): *wa-lā yufāriq fī baḥṯi-hī ʿan ḏālika mā yusallimu-hū min al-ʿilm al-ṭabīʿī min mabādiʾ hāḏihi l-ṣināʿa*.

[298] Saliba, 'Critiques of Ptolemaic Astronomy', p. 14, slightly modified. Although I do not have direct access to the manuscript, luckily, Saliba included an image of the folio of that passage in his article (p. 11). In this way, I was able to check the Arabic terminology. Another version that is not as literal as this previous one can be found in Saliba, *Islamic Science*, pp. 177–78.

[299] Forcada, '*Saphaeae* and *Hay'āt*', p. 268.

These few remarks are in line with the critique that we have already detected in Ibn al-Hayṯam. The anonymous author refers in this work to yet another work of his own that is lost (briefly referred to as *Kitāb al-Istidrāk*). In fact, Saliba supposes that this second work might have looked like Ibn al-Hayṯam's *Doubts about Ptolemy*.[300] We will encounter similar statements on the principles of astronomy which need to be taken from other sciences in the Eastern tradition in Marāġa.

That being said, it is certainly true that the cosmological tradition in al-Andalus differed in some respects from the one in the Islamic East. Abdulhamid I. Sabra spoke of the 'Andalusian revolt' against Ptolemaic astronomy in the twelfth century.[301] In a nutshell, this 'revolt' is ascribed to a small group of philosophers, namely Ibn Bāǧǧa (fl. first half of the 12th century AD), Ibn Ṭufayl (d. AD 1185), Averroës (d. AD 1198), Maimonides (d. AD 1204), and al-Biṭrūǧī (d. around AD 1200) and their way of addressing the question whether two of the most fundamental devices of Ptolemaic astronomy, namely the epicycle and the eccentric sphere, violate Aristotelian natural philosophy. Their focus, therefore, lay on providing astronomical models that not only followed the observed phenomena in an abstract mathematical form but also, most importantly, adhered to Peripatetic physics.[302] Of these authors who are usually considered as the drivers of the 'Andalusian revolt', al-Biṭrūǧī is the only one of whom we have a complete astronomical model, through which he intended to replace the Ptolemaic models with a kind of homocentric system. However, to start with the earliest of these authors, we do have an astronomical work by Ibn Bāǧǧa that is completely different from the astronomical works I have discussed above. This is a small treatise entitled *Discourse on Configuration* (*Kalām fī l-Hay'a*).[303] Although one might expect from the title a treatise on astronomy, its most important concern is the proper scientific method in the tradition of Aristotle's *Posterior Analytics* and al-Fārābī.[304] While this is not the place to discuss Ibn Bāǧǧa's theory of scientific

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300 See Saliba, 'Critiques of Ptolemaic Astronomy', pp. 12–15, and Saliba, *Islamic Science*, pp. 94–95.

301 See Sabra, 'The Andalusian Revolt'. This article offers a valuable overview of the relevant texts for the cosmological views in al-Andalus in the 12th century, and thus a significant part of this chapter follows its main insights. For a much earlier assessment of the astronomical views of Ibn Bāǧǧa, Ibn Ṭufayl, and Averroës, see Gauthier, 'Une réforme'; for a recent investigation with special emphasis on these authors' competence in astronomy, see Samsó, *On Both Sides*, pp. 516–44.

302 There were certainly other astronomers in al-Andalus with a more mathematical focus, most notably Ǧābir ibn Aflaḥ, who was a contemporary of Ibn Bāǧǧa and wrote the *Correction of the Almagest* (*Iṣlāḥ al-Maǧisṭī*). For the difference between Ǧābir's mathematical approach and the one by philosophers such as Ibn Bāǧǧa and Averroës, see Bellver, 'El lugar del *Iṣlāḥ*'. For a case study of his argument concerning the sphericity of the cosmos, see Langermann, 'Revamping Ptolemy's Proof', pp. 167–72.

303 See the edition in Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 151–56, which follows upon an English translation and commentary. This work is extant in a single incomplete copy that is now held in Cracow (MS Cracow, Biblioteka Jagiellońska, formerly Berlin, Staatsbibliothek Preußischer Kulturbesitz, Wetzstein 87 [Ahlwardt 5060]).

304 As argued by Forcada: see the commentary on the text in Forcada, 'Ibn Bājja's *Discourse on Cosmology*'. On Ibn Bāǧǧa's classification of the sciences, see Forcada, 'Ibn Bājja and the Classification', and Wirmer, *Vom Denken der Natur*, pp. 626–34.

method in detail, a couple of remarks on this short work can help us understand the impact of Ibn Bāǧǧa's reading of the *Posterior Analytics* for his attitude towards astronomy. We know that Ibn Bāǧǧa considered astronomy a science worthy of pursuit: he himself said that he moved to Seville to learn more about astronomy and that he observed a conjunction of Mars and Jupiter, and we know that he disagreed with Ǧābir ibn Aflaḥ on the positions of Mercury and Venus with respect to the Sun.[305] The first major part of his *Discourse on Configuration*, however, is the investigation of how a proper syllogism should be applied. To summarize it very briefly, Ibn Bāǧǧa claims that astronomers are unable to demonstrate the fact that a specific planetary model is the *only* model that meets the observations. Thus, this cannot be used as an absolute premise in a demonstration that proves the cause of the observations. Ibn Bāǧǧa even suggests that the reason for the astronomers' failure is that they did not have proper 'training' (*riyāḍa*) in logic.[306]

In the end, we do not learn much about Ibn Bāǧǧa's astronomical convictions from this treatise.[307] An important takeaway is the way in which the search for the proper scientific methodology influenced astronomical activities. I have argued above that the Baġdād Peripatetics of the tenth century AD around al-Fārābī might have been an important factor for the inclusion of methodological questions in the reception of Ptolemaic astronomy. As evidenced through the cosmological and philosophical works of Ibn al-Hayṯam, al-Bīrūnī, and Avicenna, issues such as the subordinations of the sciences and the distinction between *that* and *why* proofs led scientists to reconsider some of Ptolemy's arguments themselves and their relationship with principles from other disciplines, most notably natural philosophy. Although one must have in mind the different political and historical situation in the Islamic East and West,[308] Ibn Bāǧǧa provides us with evidence of a comparable trend in al-Andalus.

Another important issue for the study of Ibn Bāǧǧa's astronomy is the question whether he allowed for non-homocentric spheres. On this question, we have conflicting evidence from Ibn Bāǧǧa's commentaries on Aristotle's *Physics* and *Meteorology*, and from reports by other authors, most importantly Maimonides.[309] Although Maimonides' report in his *Guide of the Perplexed* (*Dalālat al-ḥā'irīn*) has already

[305] See Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 75–76, and Wirmer, *Vom Denken der Natur*, pp. 10–11.

[306] See, very briefly, Endress, 'Mathematics and Philosophy', p. 151, and, in more detail, Forcada, 'Ibn Bājja's *Discourse on Cosmology*', especially pp. 132–38 for the critique of astronomy.

[307] One reason might be that the only extant copy is incomplete. On this ground, Forcada argues that it is possible that the statement by Maimonides that I discuss in what follows relies on this missing part. See Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 142–43.

[308] On the special historical situation of 11th- and 12th-century al-Andalus and its relationship with the 'revolt', see Sabra, 'The Andalusian Revolt', pp. 143–44.

[309] For a full discussion and the references to the commentaries, see Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 78–79 (especially n. 40) and 142–46, and Wirmer, *Vom Denken der Natur*, pp. 10–14.

been cited frequently in modern literature, it must be given here in full, since it provides us with a narrative of cosmological discussions in 12th-century al-Andalus.

> You know of astronomical matters what you have read under my guidance and understood from the contents of the *Almagest*. But there was not enough time to begin another speculative study with you. What you know already is that as far as the action of ordering the motions and making the course of the stars conform to what is seen is concerned, everything depends on two principles: either that of the epicycles or that of the eccentric spheres or on both of them. Now I shall draw your attention to the fact that both those principles are entirely outside the bounds of reasoning (*ḫāriǧ ʿan al-qiyās*) and opposed to all that has been made clear in natural science. In the first place, if one affirms as true the existence of an epicycle revolving round a certain sphere, positing at the same time that that revolution is not around the centre of the sphere carrying the epicycles — and this has been supposed with regard to the Moon and to the five planets — it follows necessarily that there is rolling (*daḥraǧa*), that is, that the epicycle rolls and changes its place completely. Now this is the impossibility that was to be avoided, namely, the assumption that there should be something in the heavens that changes its place. For this reason Abū Bakr Ibn al-Ṣā'iġ [Ibn Bāǧǧa] states in his extant discourse on astronomy that the existence of epicycles is impossible. He points out the necessary inference already mentioned. In addition to this impossibility necessarily following from the assumption of the existence of epicycles, he sets forth there other impossibilities that also follow from that assumption. I shall explain them to you now. The revolution of the epicycles is not around the centre of the world. Now it is a fundamental principle (*qā'ida*) of this world that there are three motions: a motion from the midmost point of the world, a motion toward that point, and a motion around that point. But if an epicycle existed, its motion would be neither from that point nor toward it nor around it. Furthermore, it is one of the preliminary assumptions of Aristotle in natural science that there must necessarily be some immobile thing around which circular motion takes place. Hence, it is necessary that the Earth should be immobile. Now if epicycles exist, theirs would be a circular motion that would not revolve round an immobile thing.
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> I have heard that Abū Bakr has stated that he had invented an astronomical system in which no epicycles figured, but only eccentric circles. However, I have not heard this from his pupils. And even if this were truly accomplished by him, he would not gain much thereby. For eccentricity also necessitates going outside the limits posed by the principles established by Aristotle (*ʿam-mā aṣṣala-hū Arisṭū*), those principles to which nothing can be added. It was by me that attention was drawn to this point. In the case of eccentricity, we likewise find that the circular motion of the spheres does not take place around the midmost point of the world, but around an imaginary point (*nuqṭa mutawahhima*) that is other than the centre of the world.[310]

[310] Maimonides, *Le guide*, Vol. 2, pp. 51b:1–52a:13, tr. by Shlomo Pines in Maimonides, *The Guide*, Vol. 2, pp. 322–23.

In this famous passage, Maimonides ascribes to Ibn Bāǧǧa a couple of reasons why he rejected the theory of epicycles. The first of these is that there should be no rolling motion in the heavens, which is what epicycles do since they have a motion around their centres, while these centres themselves also move around the centre of the deferent. This rejection of rolling motions in the heavens goes back to *On the Heavens* II.8, although Aristotle denies it only for the planets and stars themselves and not explicitly for the spheres.[311] The next argument that Maimonides ascribes to Ibn Bāǧǧa also originates from Aristotle's *On the Heavens*: there are only three motions in the cosmos, namely to the centre, away from the centre, and around the centre. While Ptolemy and his followers also subscribed to this distinction in general, the point made by Ibn Bāǧǧa and Maimonides is that Aristotle implied that circular motion in the heavens can only be around *the one* centre of the world, which is the foundation of Aristotle's homocentric cosmology. This argument needs to be read together with the one that Maimonides lists afterwards, namely that there can only be one immobile centre in the cosmos. In the background of this notion of a 'unique centre' and 'immobility' is Aristotle's theory of the natural motions of the elements. This single centre is immobile because the heavy elements (earth and water) have a natural downward motion towards the centre of the cosmos. Another immobile point in the cosmos around which other spheres could circulate would mean that we would have two centres in the cosmos to which the heavy elements are drawn, which would result in a conflict of natural motions. Therefore, there can only be one immobile centre of circular motion in the cosmos.[312] To make things even worse, the theory of epicycles would also mean that there are centres for circular motion that are moved themselves and thus not immobile, which violates Aristotle's notion that every circular motion must be around one *immobile* centre of the cosmos. So far, Maimonides presents Ibn Bāǧǧa's arguments against epicycles. He then goes on to claim that he heard that Ibn Bāǧǧa developed an astronomical system with eccentric spheres. Against this, however, Maimonides argues that one can make the same arguments against eccentric spheres, and he wonders why no one before him discovered that.

There are some interesting points to make about this passage. First, we learn that Ibn Bāǧǧa gathered some arguments against epicycles in an astronomical treatise. Given that the extant version of *Discourse on Configuration* is not complete, one might assume that Maimonides' account goes back to the missing part.[313] If this is a true rendering of Ibn Bāǧǧa's astronomical theory, one can compare him to Ibn Ṭufayl, who lived one generation after Ibn Bāǧǧa. As al-Biṭrūǧī informs us, Ibn

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[311] See *Cael.* II.8, 290a7–29.

[312] See, for example, *Cael.* I.8, 276a18–b21.

[313] As suggested in Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 142–43. Cf. Ibn Ṭufayl's complaint that most of Ibn Bāǧǧa's writings are 'not complete' or 'break off at their ends' (Ibn Ṭufayl, *Hayy ben Yaqdhān*, p. 12:13–14 (Arabic section)).

Ṭufayl similarly dismissed epicycles (and also eccentric spheres, like Maimonides).[314] We will see shortly that Averroës argued against epicycles and eccentric spheres, and that this sort of reasoning triggered al-Biṭrūǧī's attempt to devise an astronomical model without these Ptolemaic non-homocentric spheres. Therefore, Maimonides' testimony allows us to consider Ibn Bāǧǧa as an early figure of the 'Andalusian revolt' against Ptolemy.

It is also interesting to take a look at Maimonides' wording, as he says in the beginning of the passage quoted that epicycles and eccentric spheres are 'outside of reasoning'. The Arabic rendition, *ḫāriǧ ʿan al-qiyās*, appears in the same way as a translation of the Greek *para ton logon* in *Almagest* IX.2 and it is picked up again by Ibn al-Hayṯam in his critique of Ptolemy's methodology.[315] As described before in this chapter, Ibn al-Hayṯam also rejected some of Ptolemy's theories because they did not adhere to the physical principles, most importantly his sawn-off pieces and imaginary devices such as the equant. This makes a statement by Ibn Bāǧǧa from an extant letter in which he severely criticises Ibn al-Hayṯam even more intriguing. He writes that although Ibn al-Hayṯam was right in pointing out some of Ptolemy's errors in his *Doubts about Ptolemy*, nevertheless, Ibn al-Hayṯam was only superficially familiar with astronomy and not a reliable expert in this science.[316] Because of a lack of an astronomical theory by Ibn Bāǧǧa himself, it remains speculative why Ibn Bāǧǧa thinks so little of Ibn al-Hayṯam's astronomical expertise. Perhaps the outline of his *Discourse on Configuration* is important. I have noted before that most of this treatise is an investigation of the proper scientific method along the lines of the *Posterior Analytics*, which then leads into brief remarks on Ptolemaic astronomy. This might indicate that Ibn Bāǧǧa deems the arrangement of the celestial bodies in the cosmos a philosopher's and not a mathematician's task. Given the evidence from his *Discourse on Astronomy*, we might think that, in Ibn Bāǧǧa's view, one can only achieve a true 'configuration' (*hayʾa*) of the cosmos when one understands the methods of the different sciences, their claims on truth, and how they are connected with each other — topics that Ibn al-Hayṯam does not address in the *Doubts about Ptolemy* to which Ibn Bāǧǧa refers.

In fact, Maimonides lays down arguments from Aristotle's *On the Heavens* as the principles to which astronomers must adhere if they want to get to a configuration of the cosmos that is not 'outside of reasoning'. Given that Maimonides refers to Ibn Bāǧǧa in this context, this was certainly also Ibn Bāǧǧa's idea. This means that Ibn Bāǧǧa bases his *Discourse on Configuration* on Aristotle's *Posterior Analytics*. Maimonides, following Ibn Bāǧǧa, also starts his astronomical discussion with Aristotle's *On the Heavens*. This, taken together with the criticism that Ptolemy's works had to face in 12th-century al-Andalus, illustrates that for Ibn Bāǧǧa Ptolemy

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314 See al-Biṭrūǧī, *On the Principles*, Vol. 2, p. 49:1–5 (and Vol. 1, p. 61 for the English translation of that passage).

315 See above, p. 101.

316 Ibn Bāǧǧa, 'Min kalāmi-hī mā baʿaṯa', p. 78:7–13. This passage is translated in Samsó, 'Ibn al-Haytham and Jābir b. Aflaḥ', pp. 201–02, and Endress, 'Mathematics and Philosophy', p. 148.

is not the main authority in astronomy but Aristotle is instead. We will see another example of this in the astronomical work of al-Biṭrūǧī.

Before we turn to Averroës and then al-Biṭrūǧī, let us stay very briefly with Maimonides' *Guide of the Perplexed* because his own stance in these discussions seems to be a bit different from them. Although some passages from the *Guide of the Perplexed* seem to suggest that Maimonides held the position that humans can never attain demonstrative knowledge about the celestial realm, he also emphasized that astronomy, in fact, provides us with some demonstrative proofs that need to be considered in natural philosophy. As an example, Maimonides refers to the *fact* that the Sun moves along an inclined path, although he quickly adds that the astronomers did not prove whether this is *because* the Sun is carried by an eccentric sphere or by an epicycle.[317] In addition, he acknowledges that the science of astronomy has made progress from the time of Aristotle until his own time. Perhaps one can understand the final remarks of Chapter II.24 of his *Guide of the Perplexed* in this sense, namely that someone else will come up with a proper astronomical system that fits Aristotelian physics after him. These instances, together with the possibility that Maimonides himself did not reject epicycles but only eccentric spheres, led Tzvi Langermann to conclude that Maimonides' attitude towards astronomy is different from the views of his Andalusian fellows.[318] Another way to highlight such a difference is to point to Maimonides' 'descriptive' statement that the astronomers' task is not simply to account for the physical reality of their models.[319] In contrast, Ibn Bāǧǧa emphasizes that astronomers must also provide demonstrative proofs that adhere to the rules of logic. With the kinds of syllogisms by previous astronomers alone, Ibn Bāǧǧa complains, we do not have a proper scientific understanding of astronomy.

Averroës' engagement with Ptolemaic astronomy is known through his abbreviation of the *Almagest* that survived only in its Hebrew translation and through many scattered remarks in his various commentaries on Aristotle.[320] Let us start with a passage from one of the earliest of these commentaries, namely the *Epitome of On the Heavens* (*Ǧawāmiʿ Kitāb al-Samāʾ wa-l-ʿālam*). This treatise can be dated to the time before AD 1159 when he had finished the epitomes of *On the Heavens*, *Physics*,

[317] See Maimonides, *The Guide*, Vol. 2, p. 273.

[318] See Langermann, 'The True Perplexity', especially pp. 169–70. For this brief summary on Maimonides, I relied mostly on this cited article by Tzvi Langermann and in addition on Langermann, 'My Truest Perplexities', and Freudenthal, 'Instrumentalism and Realism', especially pp. 233–41.

[319] See Maimonides, *The Guide*, Vol. 2, p. 326. The interpretation I describe here stems from Freudenthal, 'Instrumentalism and Realism', pp. 235–36.

[320] There already has been a good amount of modern research on Averroës' astronomy and cosmology between the Aristotelian and the Ptolemaic tradition. As an early example, see Gauthier, 'Une réforme', especially pp. 501–06, and later also Carmody, 'The Planetary Theory', Sabra, 'The Andalusian Revolt', especially pp. 138–42, Endress, 'Averroes' *De Caelo*', Endress, 'Mathematics and Philosophy', especially pp. 151–57, and Hasse, 'Averroes' Critique'.

On Generation and Corruption, and the *Meteorology*.[321] Right at the beginning of this short summary, Averroës finds the opportunity to oppose Ptolemaic cosmology and Aristotelian natural philosophy. Following the thought of *On the Heavens* I.2–4, he argues that there is — in addition to the upward and downward motions of the light and heavy elements — a fifth substance that has a natural circular motion:

> In the case of this motion [viz. the uniform circular motion], it is clear that it is natural and that in the body moving by it, there is no principle opposing the moving (*muḍadd li-l-muḥarrik*), as is the case for the animals. When this is the case, it is obvious that the circular motion — through the fact that it is circular — has necessarily a centre and poles. What is endowed with this property is necessarily the sphere (*kura*, i.e. complete sphere). As for the spheres with ground poles (*al-ukar al-maḥrūqat al-aqṭāb*)[322] that Ptolemy supposes in his *Planetary Hypotheses* (*Kitāb al-Iqtiṣāṣ*), it is something that is not true for those things that rotate naturally (*dawaran ḥaraka ṭabīʿiyya*). In addition, if the stars moved by themselves in rotation (*dawaran*), as these people (*ḏālika qawm*) think, their motion would not be natural at all. Otherwise, why would it be that they [the planets] are in a place and moving (*tataḥarriku*) to this very same place [again]? Then their motion would be pointless. Therefore, the rotating motion belongs to the spherical body insofar as it is spherical, since it is not moved [from one place to another] in its entirety, but is moved rather with its parts. These are the considerations (*umūr*) employed by Aristotle to show that there is a spherical body, distinct from the nature of the bodies that are moved rectilinearly, and in possession of a fifth nature.[323]

This passage, although not yet discussed in modern research, is of crucial importance because it illustrates Averroës' engagement with Ptolemy's *Planetary Hypotheses*. As is well-known, Aristotle characterizes the circular motion as not having any natural, contradicting motion. For him, it is clear that uniform circular motion in the heavens must be conducted by spheres that have a centre and poles around which they always move. The centre and the poles must be fixed because there is no change to be seen in circular motion of the cosmos, as in the case of animals. This is the reason why he considers celestial slices of spheres as impossible: they lack these fixed poles because the areas around the poles are 'ground' off, as Averroës describes Ptolemy's sawn-off pieces. This transition to Ptolemaic cosmology happens quite suddenly. It is very surprising to see him make this point at this early stage of his epitome because one would expect that the sawn-off pieces are discussed in the context of astronomical models and not the context of the first chapters of Aristotle's *On the Heavens*. In fact, the line of criticism is the same as in al-Bīrūnī, who had claimed that the theory of sawn-off pieces contradicts *Almagest* I.3 on the

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[321] See Lay, 'L' Abrégé', pp. 25–26. For a study of the three commentaries by Averroës on *On the Heavens*, see Endress, 'Averroes' *De Caelo*'.

[322] MS Madrid, Biblioteca Nacional, 5000, f. 27^r:1 reads *al-kuwar al-maḥrūmat al-aqṭāb*, which still would be a clear reference to the sawn-off pieces.

[323] Averroës, '[Ǧawāmiʿ] Kitāb al-Samāʾ wa-l-ʿālam', pp. 5:19–6:11.

sphericity of the heavens.[324] Similarly, Averroës argues that since Aristotle settled the existence of a naturally circularly moving cosmos and since, therefore, the cosmos must be shaped like a complete sphere, Ptolemy's theory is impossible. However, Averroës does not leave it at that. He ascribes yet another impossible theory to 'these people' (*ḏālika qawm*), namely that the planets move on their own account. This is an anticipation of *On the Heavens* II.8, where Aristotle argues that planets have no motion of their own but are only fixed on the spheres, and he concludes that the spheres as well as the stars must be spherical because only this shape ensures that they rotate in place.[325] Averroës now uses this notion and argues that the complete sphere is the shape that moves uniformly by nature with all its parts in one place (for every point on the circumference is of equal distance to the centre). When he states that the stars' motion back to their starting place is 'superfluous', he has in mind the difference between rotation in place, which is a sign of the perfection of celestial motions, and locomotion from one place to another, which can be compared with a rolling motion. The point of Averroës' argument is to emphasize the *natural* circular motion of the cosmos, which is a rotation in place.[326] This fundamental theory of Aristotelian natural philosophy could be questioned if we claimed that the stars do not move through the natural motion of their spheres but instead on their own accord. The never-ceasing circular motion of the celestial bodies is the main sign of Aristotle's theory of a spherical body, namely the cosmos, and its completely different nature in comparison with the sublunar bodies. If the planets moved on their own, there would be no need for this spherical body and its natural circular motion. But whom is he addressing by 'these people'? One idea is that he simply follows Aristotle's argument in *On the Heavens* II.8. However, given that Averroës refers to 'these people' directly after the reference to Ptolemy's *Planetary Hypotheses*, where Ptolemy indeed makes the same suggestion that the planets move on their own, it is more reasonable to assume that Averroës has Ptolemy and his potential followers in mind, and uses the opportunity to reject two important cosmological theories by Ptolemy in one passage.

Thus, this passage first shows Averroës' knowledge of the *Planetary Hypotheses* and, second, the fact that he attempts to follow strictly Aristotelian cosmology. As a result, he rejects any Ptolemaic theory that violates one of these principles, namely the theory of sawn-off pieces, as well as the theory of planetary self-motion. Shortly after his *Epitome of On the Heavens*, he wrote his *Summary of the Almagest* (*Muḫtaṣar al-Maǧisṭī*, extant in Hebrew under *Qiṣṣur al-Magisṭi*). Within the prologue, Averroës states that for this summary, he decided to follow the generally accepted astronomy and that he hopes to have the opportunity later in his life to investigate this science in more detail. Although he thereby admits that he will give

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[324] See above, pp. 93–94.

[325] See *Cael.* II.8, especially 290a29–b11.

[326] On celestial and natural motion in Averroës, see Donati, 'Is Celestial Motion a Natural Motion', which is mostly based on *De substantia orbis*.

the reader an insight into Ptolemaic astronomy, he already hints at some reasons why one should not rely too much on it. According to Averroës, astronomy is not a demonstrative science. Astronomers gather information on the planetary motions by their senses, but since these observations exceed the lifetime of one generation, astronomers also rely on earlier observations by others. This means that the final result is not demonstrated knowledge but only something that is generally accepted.[327] In addition, most of the astronomers' theories are impossible. He gives the epicycle as an example because 'it has been shown in natural philosophy' that circular motion must be around one centre.[328] The general critical attitude is also mirrored by the sources he explicitly uses, most importantly Ibn al-Hayṯam and Ǧābir ibn Aflaḥ.[329] The most programmatic account stems, however, from a much later work, namely the *Long Commentary on Metaphysics* (*Tafsīr Ma baʿd al-ṭabīʿa*). This passage has already been translated in full in previous studies, but because of its importance, it must be quoted here in full again:

> The theory of the eccentric sphere or the epicycle is an affair outside of nature. As for the epicycle, it is altogether impossible because the body moving in a circle moves rather about the centre of the universe, not outside of it, since that which moves in a circle produces the centre. Thus, if there were circular motion outside of this centre, there would be another centre outside of this centre and thus another Earth outside of this Earth. The impossibility of all this has been shown in natural philosophy (*ʿilm ṭabīʿī*). This is what the situation seems to be with regard to the eccentric sphere postulated by Ptolemy. For if there were several centres, there would be heavy bodies outside of the [natural] place of earth, and the centre would not be one but would have breadth and could be divided; all this is not correct. Also, if there were eccentric spheres, there would be [something] superfluous among the celestial bodies, with no purpose but filling [an empty space], as is thought to be the case in animal bodies.[330] But there is nothing in the apparent motions of the planets that compels [us] to postulate the existence of the epicycle or eccentric sphere.

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[327] For Galen, the continuous observations of the sizes of celestial bodies, with the result that they do not change, are a sufficient indication of the incorruptible status of the world. This point made in the lost *On Demonstration* was criticized in the Arabic tradition by Abū Bakr al-Rāzī and also al-Ġazālī, who argue that astronomical observations made by humans do not cover a sufficient span of time to judge decisively about this issue, and al-Rāzī adds that destruction could happen all at once. See Abū Bakr al-Rāzī, *Doutes sur Galien*, p. 13, and al-Ġazālī, *The Incoherence*, pp. 48–49.

[328] I rely on the French translation of some parts of the prologue by Juliane Lay in Lay, 'L' Abrégé', pp. 53–55.

[329] Lay, 'L' Abrégé', pp. 40–48.

[330] I take it that Averroës considers the example of a superfluous part in animals as counterfactual, comparable with the non-existence of something superfluous in the celestial realm. As an example of someone who did admit that there are superfluous things in animals, see Theophrastus, *On First Principles*, p. 151. Averroës might address other philosophers or medical authors who held that there is something filling up otherwise empty space inside animals.

> Perhaps the spiral motions posited by Aristotle in this astronomy on the authority of his predecessors would allow us to do without these two things. It seems that the astronomers before Hipparchus and Ptolemy had postulated neither epicycles nor eccentric spheres. Ptolemy explained this in his book known as *Planetary Hypotheses* (*al-Iqtiṣāṣ*). He claimed that Aristotle and his predecessors had posited, instead of these, spiral motions, and he claimed that according to them, there is an increase in these motions.[331] But their successors, he claimed, found a simpler method than this, namely that they were able to account for the phenomena by reference to fewer [celestial] bodies, by which he referred to the epicycle and the eccentric sphere. He claimed that this method is preferable (*afḍal*) with regard to the acknowledged principle that nature does not act in vain and that if it can move something with few instruments, it will not move it with many. Ptolemy was not aware of what had compelled the Ancients to accept spiral motions, namely the impossibility of the epicycle and the eccentric sphere. When people came to think that this astronomy made it simpler and easier for [explaining] the recurrence of the motions, namely that established in Ptolemy's book, they abandoned the old astronomy until the knowledge of it passed away, and today, one cannot understand what Aristotle says in this passage on the authority of these people. Alexander and Themistius acknowledged this but they did not understand the reason that we have mentioned.
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> We must examine this old astronomy from the beginning, for it is the true astronomy (*hay'a ṣaḥīḥa*) which is in accordance with the natural principles (*uṣūl ṭabīʿiyya*). It is based, I think, on the motion of one single sphere about one single centre and different poles, which may be two or more, according to the phenomena, because motions like these can make a planet go faster and slower, forwards and backwards, and have the other motions for which Ptolemy was unable to find a configuration (*hay'a*). On account of that, a planet can appear to approach and recede as the Moon appears to do. In my youth, I hoped to make a complete study of this, but now that I have grown old, I have given up this idea because of the obstacles I found in my way before. But this explanation will perhaps induce somebody to study these things later. For the astronomy (*ʿilm al-hay'a*) in our time is no longer something real; the configuration (*hay'a*) that can be found in our time is a configuration conforming to calculation (*ḥusbān*), not to what exists (*wujūd*).[332]

This section starts with a couple of reasons for the physical impossibility of epicycles and eccentric spheres. By saying that they are 'outside of nature', Averroës labels these proofs indirectly as coming from natural philosophy and the arguments indeed stem

[331] As explained before, Averroës knew and used Ibn al-Hayṯam's *Doubts about Ptolemy* (see again Lay, 'L' Abrégé', pp. 47–48). This could mean that Averroës might not have known the *Planetary Hypotheses* directly, but only through Ibn al-Hayṯam. This passage, however, contradicts this possibility, as Ibn al-Hayṯam does not mention Ptolemy's critique of Aristotle's homocentric cosmology.

[332] Averroës, *Tafsīr Ma baʿd al-Ṭabīʿa*, Vol. 3, pp. 1661:8–1664:7, tr. by Charles Genequand in Averroës, *Ibn Rushd's Metaphysics*, pp. 178–79. I have modified the translation, occasionally following the alternative by Abdulhamid Sabra, see Sabra, 'The Andalusian Revolt', pp. 141–42. Parts of this passage have already been translated from the Latin version and analysed in Carmody, 'The Planetary Theory', pp. 566–68 and 571–72.

from Aristotle's *On the Heavens*. The first argument against epicycles is the same as what we have seen in Maimonides' report on Ibn Bāǧǧa, namely that there can only be one Earth as the immobile centre of celestial circular motion, which, according to Averroës, can also be used against eccentric spheres. In addition, there is the further impossibility concerning eccentric spheres, namely that parecliptic spheres imply by their existence that they are not responsible for the motion of the planet carried by the eccentric sphere but only 'fill the space'. Such a sphere without any use within the planetary motions is against the principle that nature does nothing in vain. Thus, Averroës attempts to establish that these non-homocentric spheres violate Aristotelian natural philosophy and he adds that we are not forced to adopt this theory because there is an alternative astronomy.[333] Before I discuss this alternative, it should be noted that this latter statement is not as un-Ptolemaic as it looks at first sight. As argued in the beginning of this chapter, we see Ptolemy weighing up different models against each other, for example, in the case of the Sun in *Almagest* III.4 and in the case of his theory of sawn-off pieces in Book II of the *Planetary Hypotheses*. He does not claim that the Sun's eccentric sphere is necessarily the true model or that we necessarily have to think that some celestial spheres are only slices. He mostly relies on the argument of economy as a reason why his choice is more probable. However, Averroës and Ptolemy are very different with respect to the astronomical models that they think are impossible. Again, Ptolemy found the Aristotelian homocentric system with celestial poles as transmitters of motion and the counteracting spheres to be impossible on the grounds of physical arguments, just as the Andalusian authors rejected epicycles and eccentric spheres from physical arguments.

What does Averroës have to say about the alternative model he has in mind? The first important point is a terminological one. Averroës uses the word 'spiral' (*lawlabī*) to refer to the astronomy of Aristotle and his predecessors. This word was used for a variety of translations: in the Arabic version of *Physics* V.4 (where it is not applied to celestial motions), it is used to translate *helix*, 'spiral', and in the Arabic version of *On the Heavens* II.8, *idāra lawlabiyya* is used for *dinēsis*, 'rotating'.[334] Averroës relies on the Arabic version of *Metaphysics* XII.8, where *lawlabī* is used to translate Aristotle's counteracting spheres (*anelittousai*). As has been pointed out in previous scholarship, this translation was perhaps rather confusing, and it is doubtful whether Averroës correctly understood Aristotle's idea of counteracting spheres. After all, the counteracting spheres are not responsible for the apparent motion of the planet to which they belong, but instead cancel its motions so that

[333] For Averroës' rejection of eccentric spheres and epicycles, see also his *Long Commentary on On the Heavens* (*Šarḥ al-Samāʾ wa-l-ʿālam*), extant in its Latin translation in Averroës, *Commentum magnum super libro De celo et mundo*, Vol. 2, p. 394:7–11. Note that this passage is in contradiction to some passages from the *Epitome of Metaphysics*. Since these refer to Ptolemy's theory of celestial animation, I discuss them in the next chapter. On the contradiction between these two works, see Sabra, 'The Andalusian Revolt', pp. 140–42.

[334] See Hasse, 'Averroes' Critique', p. 74, and Sabra, 'The Andalusian Revolt', pp. 146–47 n. 7.

they are not imparted to the following planet.[335] Al-Bīṭrūǧī uses this term to denote the motion of poles around other poles and one can compare the resulting motion to the basic device of Eudoxus, the hippopede.[336] Nevertheless, one must not neglect the fact that in this passage, Averroës explicitly refers to a discussion in Ptolemy's *Planetary Hypotheses*, namely to Chapters II.5–6.[337] There, Ptolemy first describes that Aristotle added certain spheres to ensure that the inner spheres all partake in the diurnal motion but are still different from each other, which is a fair rendering of the counteracting spheres. Later, he laments that the adoption of these spheres leads to an excessive amount of spheres that are, in fact, not needed for the apparent motions of a planet. Ptolemy uses the word *iltifāf/iltaffa* to refer to the motions of these additional spheres posited by Aristotle. Averroës now correctly understands Ptolemy's rationale behind his rejection of the Aristotelian spheres, namely his principle of economy: 'nature does nothing in vain'. The question is why Averroës uses the term *lawlabī* instead of *iltifāf* in his presentation of Ptolemy's argument. The best explanation is that Averroës correctly identifies *Metaphysics* XII.8 as the target of Ptolemy's attack and then uses the terminology with which he is acquainted from *Metaphysics* and not from the *Planetary Hypotheses*. This tells us that Averroës had a thorough understanding of the *Planetary Hypotheses*, although it remains unclear — especially given his statement in the end that he was not able to find a physically working astronomical model — whether he completely understood Aristotle's counteracting spheres.

Despite this open question, Averroës leaves no doubt that this 'old' astronomy by Aristotle (in relation to the astronomical model presented by Ptolemy roughly 500 years after Aristotle) and his predecessors is the 'true' astronomy. What made astronomers in the time between Aristotle and himself follow Ptolemy was their pursuit of the most economical model, the one that needed the fewest spheres. For Averroës, a more important criterion for an astronomical model than its simplicity is its adherence to natural philosophy. He considers the 'old' homocentric theory as the 'true' one because it better fits the 'physical principles' (*uṣūl ṭabīʿiyya*). Given his points of criticism, as shown previously, these principles are similar to that of Maimonides, namely that all circular motions need to rely on one single centre. Against this, the Ptolemaic mainstream astronomy of his time serves only for calculational purposes but does not have any claim regarding true existence, because it does not follow the principles from natural philosophy and is therefore impossible from a

[335] See, for example, Charles Genequand's introduction in Averroës, *Ibn Rushd's Metaphysics*, pp. 55, and also Endress, 'Mathematics and Philosophy', p. 156, and Hasse, 'Averroes' Critique', pp. 74–75.

[336] See especially Forcada, '*Saphaeae* and *Hay'āt*', pp. 278–81. Cf. Goldstein's statement in his introduction to the translation of al-Biṭrūǧī's astronomical work: 'On the evidence of the original text of al-Biṭrūǧī, it is, however, clear to me that the model of Eudoxus was completely unknown to al-Biṭrūǧī and had no influence on the construction of his models.' See al-Biṭrūǧī, *On the Principles*, Vol. 1, p. 45. See, in addition, Mancha, 'Al-Bitruji's Theory'.

[337] As briefly noticed by Sabra, see Sabra, 'Ibn al-Haytham's Treatise', p. 389.

physical point of view. These are, basically, similar reservations about Ptolemaic astronomy to what we find in the East in Marāġa (take, for example, the astronomical work of al-ʿUrḍī). The abovementioned shift in astronomical discussions around AD 1000 from a purely mathematical to a wider approach towards the different philosophical disciplines and their relationship with each other bears similar fruit in the Islamic East and West: what are the elements of Ptolemaic astronomy that do or do not violate physical principles? However, while these doubts revolved in the East around things like the equant or the prosneusis, i.e. mathematical devices that are responsible for the fact that a circular motion is not uniform with respect to its own centre, the Andalusian authors thought that the problems already started at a more basic level, namely eccentric spheres and/or epicycles.

I have briefly hinted at the possibility that one reason for this discrepancy might be the different status of the authority of Aristotle and Ptolemy in the East and the West. Although Eastern astronomical works are mostly based on Aristotelian natural philosophy (including the existence of aether and the impossibility of a void), they take their starting point from Ptolemaic astronomy. In the astronomical work of al-Biṭrūǧī, who is the only author of that time in al-Andalus for whom we have a complete extant astronomical system, one can see a different approach. This unique position within the Andalusian astronomical tradition has already received much scholarly attention in the last decades, which, however, has involved severe modern criticism of al-Biṭrūǧī's astronomical models.[338] Instead of evaluating the quality of these models, it is far more important for the present investigation to take a look at al-Biṭrūǧī's long introduction to his *On the Configuration* (*Kitāb fī l-Hay'a*).

The first pages of this introduction contain several points of criticism regarding Ptolemaic astronomy, the most important of which are Ptolemy's description of the two primary motions in the heavens and the inclusion of non-homocentric spheres. Concerning the former, he contrasts some passages from Book I of the *Almagest* with Aristotle's discussion of motion and movers in *Physics*, on the basis of which al-Biṭrūǧī argues that there is only one Prime Mover and thus also only one primary motion in the heavens, which is the diurnal one.[339] Already at this early point in the work, one clearly sees the main objective of his work, namely the correction of every part of Ptolemy's astronomy that is in conflict with Aristotelian physics. Certainly, al-Biṭrūǧī concedes that some parts of the *Almagest* are still valuable. He adopts the planetary sizes and distances, the knowledge of the times of conjunctions and

[338] See the introduction by Goldstein in al-Biṭrūǧī, *On the Principles*, Vol. 1, especially pp. 7–18, Kennedy, 'Essay Review: Alpetragius', and Sabra, 'The Andalusian Revolt', p. 137. While this work became very popular in the Medieval Latin tradition, critical engagement with its astronomical models had already started in the thirteenth century AD, for which, see Avi-Yonah, 'Ptolemy vs. al-Bitruji'. For a more recent reconstruction of al-Biṭrūǧī's models, see Mancha, 'Al-Bitruji's Theory'.

[339] See the English translation by Bernard R. Goldstein in al-Biṭrūǧī, *On the Principles*, Vol. 1, pp. 53–57.

eclipses, and the computation of the positions of the stars and planets.[340] These positive aspects mirror the sort of critique that we have just seen in Averroës, who wrote that this 'new' (i.e. Ptolemaic) astronomy serves the purpose of calculation but not of providing a physical explanation of the celestial phenomena. This is exactly the same point that we see in al-Biṭrūǧī's argument against the two Ptolemaic 'principles' (*aṣlān*), namely the epicycle and the eccentric sphere. His main worry is how one can imagine that a non-concentric sphere moves within the sphere that encompasses it without the creation of a void whenever it moves within it from one place to another.[341] The same argument has already been put forward by Ibn al-Hayṯam in his *Doubts about Ptolemy*. However, Ibn al-Hayṯam applied this argument only to sawn-off pieces that move inside a complete sphere, and not to epicycles and eccentric spheres, which he accepts in general.[342] This shows again that scholars of different times and environments had different views not only on how to overcome the tensions between Aristotelian physics and Ptolemaic astronomy, but also on the choice of the devices of Ptolemaic astronomy that are responsible for this tension in the first place.

Al-Biṭrūǧī then steps back and explains that he was 'perplexed' by the problems posed by Ptolemaic astronomy, thereby invoking the same vocabulary that Maimonides also used to express his concerns.[343] The remaining parts of his introduction mostly deal with the way in which he finally arrived at his alternative astronomy. This part starts with a quotation from *On the Heavens* II.8, where Aristotle explains the two possible motions for the spherical bodies, namely rotating (*dinēsis*) and rolling (*kylisis*). While al-Biṭrūǧī's citation differs from the extant Arabic translation of *On the Heavens* by al-Biṭrīq in its choice of rendering 'rolling', both versions have *idāra lawlabiyya* for *dinēsis*, 'rotation'.[344] Al-Biṭrūǧī correctly explains that Aristotle is engaging in this passage with his predecessors who thought that the stars might make one of these motions by themselves, but he argues against the idea that stars are carried by their spheres. After he gives this explanation, al-Biṭrūǧī leaves the Aristotelian ground and writes:

> Since this is so, the planets cannot have this spiral motion (*idāra lawlabiyya*) while adhering to their places of their spheres, except for a motion that occurs due to the poles of their spheres on which they are fixed, while there is a rotation (*dawarān*) about the poles around certain circles.[345]

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[340] al-Biṭrūǧī, *On the Principles*, Vol. 1, pp. 59–60.
[341] al-Biṭrūǧī, *On the Principles*, Vol. 1, p. 60.
[342] See above, pp. 102–03.
[343] Al-Biṭrūǧī uses the term *mutaḥayyir* in al-Biṭrūǧī, *On the Principles*, Vol. 2, p. 45:3; we find an expression derived from the same root *ḥ-y-r* for Maimonides' famous 'true perplexity', *al-ḥayra bi-l-ḥaqīqa* (see Maimonides, *Le guide*, Vol. 2, p. 53ᵛ:15–16).
[344] See Sabra, 'The Andalusian Revolt', pp. 146–47 n. 7.
[345] al-Biṭrūǧī, *On the Principles*, Vol. 2, p. 53:2–6 (following the alternative reading in the note to Line 4), tr. by Bernard R. Goldstein in Vol. 1, p. 62, heavily modified.

Thus, although he has acknowledged that Aristotle talked about the individual motions of the stars and planets, he apparently did not quite understand the correct meaning of what al-Biṭrīq translated as 'spiral motion' (*idāra lawlabiyya*). While Aristotle used *dinēsis* to mean a rotation in place about its own axis, al-Biṭrūǧī interprets *lawlabiyya* in a way that the Aristotelian passage refers to the complex motions of the planets. Given that he himself had just explained that Aristotle is talking about the question whether the planets and stars are fixed on their spheres or not, al-Biṭrūǧī is supposedly aware that he is pushing his interpretation very far and that he understands that there is, in fact, no connection to the planetary complex motions themselves. It also seems very likely that the confusing translation of *dinēsis* as *lawlabiyya* played its role here. Nevertheless, al-Biṭrūǧī achieves something very important with this interpretation: he manages to provide his own cosmological theory of celestial poles that rotate about other poles with an Aristotelian basis. Notably, he does not rely on the notorious passage from *Metaphysics* XII.8 on the Eudoxean models, which might support the theory that he was not aware of Eudoxus' cosmological system.[346] On the other hand, he might have the Arabic version of *Metaphysics* XII.8 in mind, where this term also came up as a translation of Aristotle's counteracting spheres and on which Averroës relied for his usage of *lawlabiyya*. However, even without an explicit reference to the *Metaphysics*, he makes it clear that his own astronomical model indeed takes its starting point from Aristotle and not from Ptolemy.

This impression is further strengthened by the following account in the introduction, where he briefly touches on Aristotle's theories of the Prime Mover who imparts motion to the cosmos, and of the sublunar elements and their natural motions. Previous astronomers only relied on sense perception, which is not an infallible source of truth (which was similarly put forward by Averroës), whereas they neglected what 'the natures [of the celestial bodies] imply'.[347] Thus, instead of starting with a reconstruction of the apparently irregular motions, al-Biṭrūǧī demands that one should start with an investigation of the 'natures' of the celestial bodies, and thus with a physical theory on which one builds the astronomical models. This was the mistake committed by Ptolemy.

> The amounts for all these motions were fixed from observations, and some of the [motions] are contrary to others. Ptolemy was obliged to set down these principles (*uṣūl*) conforming to these conditions, and the configuration (*hay'a*) for these motions is arranged according to them. [...] [Al-Zarqālluh] gave conditions and principles (*uṣūl*) for this motion just as the principles by Ptolemy that he had set down for the wandering planets, but they are far

[346] See p. 123 n. 336.
[347] See al-Biṭrūǧī, *On the Principles*, Vol. 1, pp. 63–67.

> from the truth. All these principles are rather fanciful, given the fact that they have moving and moved circles as well as moving and moved lines. They are not principles in reality.[348]

These points of critique are not entirely new in themselves. The accusation that Ptolemy's astronomy only deals with abstract mathematical entities and not real existing bodies was put forward by scholars from Ibn al-Hayṯam around AD 1000 in the East to Averroës in the time of al-Biṭrūǧī in the West. For al-Biṭrūǧī, this leads to the demand that astronomers should first of all investigate the physical nature of the celestial bodies before they start transferring the observed planetary motions to an astronomical model. Fittingly, when he introduces the basic notions of his cosmological account in what follows, he again takes explicit recourse to Aristotle and, quite interestingly, claims that Aristotle relied on 'trustworthy observations'.[349]

The Aristotelian character of al-Biṭrūǧī's approach to astronomy should be clear from all these passages from the introduction. This does not necessarily mean that he was indeed successful in his attempt to provide a physically working astronomical theory that was mostly based on Aristotle's natural philosophy.[350] Nevertheless, we see from works such as Ibn Bāǧǧa's *Discourse on Configuration* and al-Biṭrūǧī's *On the Configuration* that astronomy starts with a discussion of the Aristotelian corpus in al-Andalus, namely the *Posterior Analytics* in the case of Ibn Bāǧǧa and the *Physics* and *On the Heavens* in the case of al-Biṭrūǧī and Averroës. As stated frequently in modern research, this is the most distinguishing feature of the Andalusian cosmological tradition of the 12th century AD, namely that it was brought forward by Aristotelian philosophers. However, the two works by Ibn Bāǧǧa and al-Biṭrūǧī in particular illustrate that these philosophers covered astronomical topics in their commentaries of Aristotle's *Metaphysics* and *On the Heavens*, and thus they were forced to engage with astronomy by the texts on which they commented. Moreover, they obviously thought that every astronomical engagement should take its starting point not from pure mathematics but instead from natural philosophy, and that observation was a feeble basis for a fully demonstrative discipline.

There is certainly a variety of historical, political, and social reasons for this distinct development in al-Andalus, an assessment of which goes beyond this current investigation.[351] Here, my focus is on the reception of Ptolemaic astronomy against

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[348] al-Biṭrūǧī, *On the Principles*, Vol. 2, pp. 91:9–92:1 and 95:3–7, tr. by Goldstein in Vol. 1, pp. 68–69, modified. See also al-Biṭrūǧī's conclusion, Vol. 1, p. 154.

[349] This is a rather free translation by Bernard R. Goldstein of al-Biṭrūǧī, *On the Principles*, Vol. 2, p. 97:11, which, however, nicely expresses the core of al-Biṭrūǧī's account (for the translation, see Vol. 1, p. 69).

[350] In addition to modern doubts of the mathematical exactness of his models, consider, for example, the brief note by José Luis Mancha that there are indeed some aspects of his models that seem to be in contradiction to Aristotle. For example, in al-Biṭrūǧī, a single celestial sphere has a complex motion (see Mancha, 'Demonstrative Astronomy', p. 325 n. 6).

[351] For some brief introductory statements, see Sabra, 'The Andalusian Revolt', pp. 143–44, and Forcada, 'Ibn Bājja's *Discourse on Cosmology*', pp. 74–76.

the background of this Aristotelianism. Despite the fact that some parts of their astronomical works have been lost (as in the case of Ibn Bāǧǧa and Ibn Ṭufayl) or that others declared that they failed to write a complete astronomical work during their lifetime (such as Averroës), we now know through the testimony of Averroës that not only the *Almagest* but also the *Planetary Hypotheses* played a certain role in this story. As the clearest evidence for this, we have Averroës' rejection of Ptolemy's sawn-off pieces, his theory of independently moving planets, and his demand for simplicity. One must keep in mind that Averroës referred to the sawn-off pieces as 'spheres with ground poles' because this lack of poles in Ptolemy's sawn-off pieces seems to have been a major worry for the Andalusian tradition. Although al-Biṭrūǧī himself does not refer to the *Planetary Hypotheses*, his familiarity with this theory and thus with the *Planetary Hypotheses* might explain why he emphasizes the need for poles for celestial motions over and over again. After all, he asserts, against Ptolemy, that the complex motions do not arise from a variety of centres but from a variety of poles.[352] Especially given the fact that we do not have any definite traces of an ongoing tradition of these sawn-off pieces either in the Islamic East or West, it is curious that he explicitly refers to the celestial poles as required by Aristotle's *On the Heavens*. To consider this as a reply to Ptolemy's sawn-off pieces is a good way to explain al-Biṭrūǧī's emphasis on this point.

Although one must definitely acknowledge the distinctive character of the Andalusian cosmological tradition, there are at least some interesting connections to developments in the East. While the mathematical–astronomical value of these works should probably not be overestimated, the important aspect with respect to the history of philosophy and science is their strong emphasis on the physical reality of the celestial bodies and their motions in an Aristotelian framework. As became apparent especially in the work of Ibn Bāǧǧa, this reliance on Peripatetic philosophy brought with it the question of the role of logic in cosmology, which can be traced back to al-Fārābī's introduction of the superior status of demonstrations of the cause into the Arabic tradition. Although Aristotle refers to mathematical and astronomical examples for perfect demonstrations on many occasions in the *Posterior Analytics*, Ibn Bāǧǧa stresses the point of the superior status of causal explanations that are not given in mathematics. In contrast, Ptolemy and later al-Bīrūnī call for mathematical demonstrations and deny the need for causal explanations once mathematics has provided us with an explanation of the fact. In between these two positions, one can place someone like Maimonides, who ascribes different kinds of demonstration to different scientific fields, without specifying that one of these approaches is inferior to the other.

Usually, the tradition in the East associated with the observatory in Marāġa is considered to have brought about far superior astronomical theories that supposedly even influenced the Copernican revolution. We nevertheless know that Copernicus

[352] al-Biṭrūǧī, *On the Principles*, Vol. 1, p. 70.

was aware of the astronomical tradition in al-Andalus, as well, because he refers to al-Zarqālluh, Averroës, and al-Biṭrūǧī in his *On the Revolutions of the Celestial Orbs* (*De revolutionibus orbium caelestium*).[353] In the works of the scholars connected with Marāġa, we also see the same attempt to formulate astronomical theories in accordance with Aristotelian natural philosophy, though focusing on different aspects of Ptolemaic astronomy. These will be discussed in the next section.

The Marāġan Astronomers: between Ptolemaic Astronomy and Aristotelian Natural Philosophy

While there are several astronomical works at least partly on the configuration (*hay'a*) of the cosmos such as al-Farġānī's *Summary*, Ṯābit ibn Qurra's *Simplification*, and the works on planetary sizes and distances from the ninth and tenth centuries AD, it is remarkable that they avoided any discussion of the epistemic values of the different sciences and how astronomy relates to other (philosophical) disciplines. This does not mean that these astronomers thought of celestial spheres as mere mathematical entities, but simply that they did not address the question of how this celestial configuration can be brought in harmony with natural philosophy. As shown in the previous sections, a remarkable change that might go back to philosophical discussions on the division and epistemological status of mathematics, natural philosophy, and metaphysics can be seen in the works of Ibn al-Hayṯam, al-Bīrūnī, and Kūšyār ibn Labbān. In these authors from around AD 1000, who lived in the Eastern part of the Islamicate world as well as in Cairo, we find debates on the interplay between natural philosophy and a coherent cosmological picture that have their starting point in Ptolemy's *Almagest* and *Planetary Hypotheses*. After that, I looked at what has been called the 'Andalusian revolt', namely how Andalusian scholars emphasized the superior importance of Aristotle's scientific method and natural philosophy. Now, it is time to see how this relationship was debated in one of the most creative and interesting times in the history of Arabic astronomy, namely the astronomical tradition of the so-called Marāġa school from the middle of the 13th century to the middle of the fourteenth century AD.[354]

The name of this school goes back to the observatory in Marāġa, the construction of which started in AD 1259 under the patronage of the Mongol emperor Hülegü.[355] Previous characterizations of the scholars working in this tradition emphasized their

353 The influence of Arabic or Islamic astronomy on the Latin tradition is the subject of more and more modern research. For an overview, see Ragep, 'Copernicus and His Islamic Predecessors' (especially p. 77 n. 1 for the Arabic names cited by Copernicus).

354 There are some major astronomical contributions that can be attributed to scholars from this environment. In the following, I do not deal with the details of the planetary theories in particular (although I touch on some of them). Instead, I keep to the topics that I have discussed so far in the present chapter.

355 The standard source for the history of this observatory is Sayılı, *The Observatory*, pp. 187–223.

aim of harmonizing mathematical astronomy with philosophical principles.[356] In fact, this is also the case for the best known scholar at the observatory in Marāġa, namely its first director, Naṣīr al-Dīn al-Ṭūsī (d. AD 1274). He provides a straightforward description of the position of astronomy among the other philosophical disciplines in his *Memoir on Astronomy* (*al-Taḏkira fī ʿilm al-hayʾa*). This treatise is one of the best-known examples of the astronomical tradition called *ʿilm al-hayʾa*, and it was widely received in the following centuries.[357] Right at the beginning of this work, al-Ṭūsī explains the subject, principles, and problems of astronomy as follows:

> Every science has a subject (*mawḍūʿ*), which is investigated in that discipline; principles (*mabādiʾ*), which are either self-evident or else obscure, in which case they are proven in another science and are employed in this science, given that they are accepted; and problems (*masāʾil*), which are proved in this science. The subject of astronomy (*al-hayʾa*) is the simple bodies, both superior and inferior, with respect to their quantities, qualities, positions, and intrinsic motions. Those of its principles that need proof are demonstrated in three sciences: metaphysics, geometry, and natural philosophy. Its problems aim at gaining knowledge of these bodies in and of themselves, of their shapes, of the manner of their arrangement and motions, of the amounts of their motions and distances, and of the reasons for changes in position.[358]

Al-Ṭūsī's description of the subject of astronomy is close to Ptolemy's enumeration in *Almagest* I.1.[359] Concerning its principles, astronomy needs to take some principles for granted that are proven in other sciences, and al-Ṭūsī explicitly mentions metaphysics, geometry, and natural philosophy. In the following section of the introduction to his *Memoir*, al-Ṭūsī first provides the reader with the geometrical and then the physical principles that one needs to know in order to understand astronomy, while he is silent about metaphysical principles. The physical principles are: the distinction between compound and simple bodies; the distinction between supralunar and sublunar bodies; the impossibility of a void; the principles of self-motion, namely soul and nature; the distinction between natural motions, namely rectilinear and circular; and the lack of any change in the celestial realm.[360] Al-Ṭūsī thus believes that the astronomer needs to rely on these principles from natural philosophy. In fact, Ptolemy presents similar principles in *Almagest* I.1, most prominently the superior nature of aether. One should also not forget that Ptolemy devotes Chapter II.3 of

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[356] Such brief assertions are part of the introductory characterizations of that tradition, such as Saliba, 'The Role of Maragha', p. 256, and Langermann, 'Arabic Cosmology', pp. 198–99.

[357] This work is perfectly accessible through Ragep's edition, translation, and commentary. See al-Ṭūsī, *Memoir on Astronomy*, especially Vol. 1, pp. 55–58 regarding its later influence.

[358] al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 91:10–18, tr. by F. Jamil Ragep, p. 90, slightly modified. This list of three elements that define a science is very common in that time. For an example, see al-Īǧī's (d. AD 1355) definition of the subject, principles, and problems of *kalām* in van Ess, *Die Erkenntnislehre*, pp. 37–59 (and for the primary text, especially pp. 40–41 and 54–55).

[359] See Ptolemy, *Syntaxis*, I.1, Vol. 1, pp. 5:25–6:4.

[360] al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 99–101.

the *Planetary Hypotheses* to the 'physical reasoning' and discusses the distinction between regular aethereal motion and rectilinear sublunar motion — similar to the physical principles laid out by al-Ṭūsī.

In the following part of the *Memoir*, al-Ṭūsī turns to the 'configuration of the celestial bodies' (*hay'at al-aǧrām al-'ulwiyya*). He starts this section with a chapter on the cosmological foundations from *Almagest* I.3–I.7. Unsurprisingly, he accepts the sphericity of the cosmos and Earth, the central position of the Earth, that the size of the Earth is negligible in comparison with that of the entire cosmos, and that the Earth does not have any locomotion.[361] Concerning the last point, al-Ṭūsī significantly departs from Ptolemy's rationale. Against Ptolemy, he argues that it would be indeed conceivable that the area between the Moon and the Earth would move along with the motion of the Earth, if one assumes that it has any, whereas this possibility is explicitly rejected by Ptolemy. Following this line of criticism, al-Ṭūsī has to find another rationale for arguing against the Earth's motion, which is the natural inclination of the heavy elements to move rectilinearly downwards, i.e. to the centre of the cosmos. This excludes the possibility that the heavy elements move circularly, and therefore the mass of the element earth, namely the Earth, does not move away from this centre or rotate in its place.[362] Al-Ṭūsī closes the presentation of these principles from the *Almagest* with the following distinction:

> The above proofs (*adilla*) are 'proofs of the *that*' (*inniyya*), which convey existence; those which convey the necessity of that existence are 'proofs of the *why*' (*limmiyyāt*) and are given in *On the Heavens* of natural philosophy.[363]

Most of the proofs used by al-Ṭūsī are clearly mathematical or astronomical, in the sense that they are taken from observation. Al-Ṭūsī himself highlights that when he writes about the first couple of principles, they are firmly established by 'proofs'. This means that he adopts the idea that mathematics, or astronomy specifically, provides us with proofs of the fact, whereas the proofs of the cause belong to another branch of philosophy, namely natural philosophy or physics, which he explicitly connects to Aristotle's *On the Heavens*. Evidently, this is the distinction between philosophical disciplines with respect to the different sorts of proofs they offer, which can be found in the Arabic tradition as early as in al-Fārābī. As I have argued above, this is also in line with Ptolemy's own assertion in *Almagest* I.7. However, one could wonder, in the case of the last discussed principle of the Earth's motion, whether al-Ṭūsī's argument about the rectilinear upward motion of the heavy elements is a proof of the fact or of the cause. Apparently, later commentators such as al-Nīsābūrī (d. around AD 1330) considered it as a *limmī* argument taken

[361] al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 103–07.

[362] Compare Ptolemy, *Syntaxis*, I.7, Vol. 1, pp. 25:15–26:3 with al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 107:5–22. See Ragep's commentary in al-Ṭūsī, *Memoir on Astronomy*, Vol. 2, pp. 383–85.

[363] al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 107:23–24, tr. by Ragep, p. 106, slightly modified.

from natural philosophy.[364] This position is, in fact, reasonable when we consider that the main source of the motions of the elements is surely Aristotle's *On the Heavens*, and one can say that arguing on the basis of the natural motion of the simple elements provides us with the reason why they move as observed. On the other hand, one could take a look again at *Almagest* I.7: 'Hence I think it is idle to seek for causes for the motion of objects towards the centre, once it has been so clearly established from the actual phenomena that the Earth occupies the middle place in the universe, and that all heavy objects are carried towards the Earth.' Here, Ptolemy refers back to previous observational proofs of the central position of the Earth, arguing that this shows that the Earth does not move away from its central position. Then he goes on to describe the observed downward motion of the heavy objects.[365] For Ptolemy, therefore, both the Earth's stability in the central position of the cosmos as well as the downward motion of earth and water are, first of all, observed facts rather than an argument of the cause.

Although al-Ṭūsī thus distinguishes between astronomical and physical proofs, and mostly relies on the former in the context of the cosmological foundations of the *Almagest*, he also believes that the astronomer needs to take some principles — such as the non-existence of void and the distinction between simple and compound, and between sublunar and supralunar bodies — from natural philosophy, as we have seen before. However, he does not explicitly emphasize in the *Memoir* that this makes astronomy subordinate to physics with regard to its epistemic value.[366] One could juxtapose this position with that of al-Fārābī, who, as we have seen, thinks that the science that provides us with the proofs of the *why* is superior to another science which only offers proofs of the *that*. In addition, al-Ṭūsī does not follow Ptolemy's assertion that the investigation into the causes is superfluous when we have definite observational proofs.

In this context, one finds additional material in al-Ṭūsī's redaction of the *Almagest*: the *Taḥrīr al-Maǧisṭī*. This work became enormously influential in the following centuries, as is apparent from the extant manuscripts and the supercommentaries by al-Nīsābūrī and al-Bīrǧandī (d. AD 1525–1526), among others. Al-Ṭūsī composed it in AD 1247, and thus it is earlier than the *Memoir*.[367] When one takes a look at al-Ṭūsī's redaction of Book I, it becomes clear that he does not depart very much from Ptolemy's own text and arguments. In most cases, he offers a concise summary of Ptolemy's reasoning. Concerning *Almagest* I.1, for example, he summarizes Ptolemy's

[364] As pointed out by Ragep in al-Ṭūsī, *Memoir on Astronomy*, Vol. 2, p. 383.

[365] Ptolemy, *Syntaxis*, I.7, Vol. 1, pp. 21:14–22:11. See above, pp. 34–35.

[366] cf. Sabra, 'Configuring the Universe', pp. 305–16, especially pp. 307–08, who interprets the introduction of the *Memoir* in exactly this way, namely that al-Ṭūsī subordinates astronomy to physics.

[367] On the *Taḥrīr*, see Sezgin, *Geschichte des arabischen Schrifttums VI*, pp. 93–94, Rosenfeld and İhsanoğlu, *Mathematicians, Astronomers*, p. 215 s.v. 'A1', and Saliba, 'The Role of the *Almagest* Commentaries'. For the chronology of al-Ṭūsī's works, see Ragep's introduction in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 70–75.

account without any indication of his personal opinion on the separation of the sciences. The same is true for *Almagest* I.3 on the sphericity of the heavens where Ptolemy introduces some 'physical considerations' in addition to many arguments from observations of the stars and planets. In al-Ṭūsī's Arabic rendering, these become 'physical affairs' (*umūr ṭabīʿiyya*), and he again summarizes Ptolemy's account of aether and its never-changing, perfect nature. Here, al-Ṭūsī intervenes very briefly: 'I say some of these arguments (*ḥuǧaǧ*) are persuasive (*iqnāʿiyya*).'[368] Although he does not specify which of the above arguments he has in mind, a comparison with the corresponding passage in the *Memoir* can help, because in the latter, al-Ṭūsī omits Ptolemy's physical arguments and only relies on his observational proofs. This indicates that, once again, the term 'persuasive' comes up in the context of arguments drawn from natural philosophy, as we have already observed, for example, in al-Bīrūnī's *Qānūn*.[369]

This is a good occasion to refer to a collection of comments on the *Almagest* that can be traced back to the Marāġa school. This collection circulated under the name *Collections from the Almagest on Account of the Correction by Some of the Later [Scholars]* (*Mulṭaqaṭāt min Kitāb al-Maǧisṭī ʿalā ḥasab iṣlāḥ baʿḍ al-mutaʾaḫḫirīn*) and is extant in a small number of manuscripts. Sometimes, they are attributed to Naṣīr al-Dīn al-Ṭūsi alone, and sometimes also to his colleague Quṭb al-Dīn al-Šīrāzī.[370] The comments are given in the order of the respective passages of the *Almagest* on which they comment. The first of these passages concerns Chapter I.3 and is a paraphrase of al-Bīrūnī's notes on this chapter from his *Qānūn*.[371] In fact, this paraphrase starts with al-Bīrūnī's assertion that Ptolemy used further 'physical arguments' (*qiyāsāt ṭabīʿiyya*). This nicely establishes al-Bīrūnī as an important source for al-Ṭūsī and his colleagues in their attempt to arrive at a better understanding of Ptolemy's *Almagest* and its possible shortcomings. Given the high esteem in which al-Bīrūnī was held in general, and given the mythical size of the library at the observatory in Marāġa,[372] the simple fact that the scholars working there read al-Bīrūnī's *Qānūn* is not surprising at all. What is fascinating, though, is the inclusion of exactly this chapter of the *Qānūn* in this collection. It shows that al-Ṭūsī or al-Šīrāzī considered al-Bīrūnī's remarks important enough to include. In fact, when one reads al-Ṭūsī's *Memoir* and *Taḥrīr* together, it becomes clear that he has the same opinion about the

[368] MS Istanbul, Nuruosmaniye Kütüphanesi, 2941, f. 3r:4–11. A transcription of Book I in this manuscript can be found on the website of *Ptolemaeus Arabus et Latinus* (https://ptolemaeus.badw.de/text/M1068).

[369] See above, p. 89.

[370] See, for example, MS Istanbul, Topkapi Saray, Hazine 455, ff. 86r–115r, especially f. 115r:15–16 for the attribution to al-Ṭūsī alone, and MS Oxford, Bodleian Library, Thurston 3, ff. 59v–69v, especially f. 69v:11–14 for the engagement of both al-Ṭūsī and al-Šīrāzī in the editing of this collection. The relationship of these (possibly distinct) versions is yet to be investigated.

[371] See MS Istanbul, Topkapi Saray, Hazine 455, ff. 86r:3–86v:10.

[372] On the number of more than 400,000 volumes in the library, see Sayılı, *The Observatory*, p. 194, and Ragep's comment in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 14 n. 5.

persuasive status of Ptolemy's 'physical considerations' in *Almagest* I.3 as al-Bīrūnī (although one must admit that the sentence in which al-Bīrūnī explicitly calls them 'persuasive' is not included in the collection; nevertheless, there is no doubt that al-Ṭūsī knew about that.) This leaves us with a nice narrative of how al-Ṭūsī read Chapter I.3 of the *Almagest* and his reliance on al-Bīrūnī in that specific aspect.

Let us come back to al-Ṭūsī's *Taḥrīr al-Maǧisṭī*, for he closes his redaction of Chapter I.7 with the exact same phrase as I.3, namely: 'again, I say some of these arguments are persuasive.'[373] As for Chapter I.3, al-Ṭūsī follows Ptolemy's text closely here. He reiterates Ptolemy's statement that an investigation into the causes is superfluous (*faḍl*), and his arguments concerning the resting of the Earth given the observations of birds and clouds in the air, arguments that he later disapproves in his *Memoir*. Although al-Ṭūsī again does not name the 'persuasive' arguments explicitly, it is reasonable to assume that he has these arguments in mind, which he later dismisses.

This issue comes up again in his comments on *Almagest* XIII.2. In order to justify his rather complicated planetary models that even include devices such as the equant, Ptolemy makes the famous claim concerning the simple nature of the celestial realm and that the notion of simplicity in terrestrial affairs should not be compared with what can be considered as simple in the celestial realm.[374] To this, al-Ṭūsī comments: 'I say that this claim is outside of the science (*ḫāriǧ min al-ṣināʿa*) and not persuasive (*muqniʿ*) in this place.'[375] Al-Ṭūsī goes on to describe a version of what is known as the Ṭūsī-couple as an alternative to express certain Ptolemaic motions in regular terms.[376] Although his main worry in the following excursus is not general methodology, this brief sentence brings together two claims that we have now seen several times. Al-Fārābī used a similar expression, namely 'outside of the kind of mathematics' in the same context of *Almagest* XIII.2, whereas al-Bīrūnī labelled Ptolemy's physical remarks from I.3 as 'outside of this science'. Further, in al-Bīrūnī's *Qānūn* as well as in the previous chapters of al-Ṭūsī's *Taḥrīr*, arguments are said to be only persuasive if they are taken not from mathematics but from physics. Here, however, al-Ṭūsī says that Ptolemy's statement on simplicity in the heavens is not even persuasive in the present context. Thus, although some physical arguments are not necessarily proofs but can at least point us to a probable account, this argument does not even convey conjectural certainty. In general, this dichotomy of necessary and conjectural arguments arises from the tension between Ptolemy

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373 For the entire chapter, see MS Istanbul, Nuruosmaniye Kütüphanesi, 2941, f. 4r:1–31. The quoted sentence is from f. 4r:31.

374 See above, pp. 102–03, and Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:12–534:6.

375 MS Istanbul, Nuruosmaniye Kütüphanesi, 2941, ff. 102r:35–102v:1. The reading of 'persuasive' (*muqniʿ*) is not entirely certain, but this word is clearly written as such in other witnesses, for example MS Paris, Bibliothèque nationale de France, ar. 2485, f. 95:5.

376 For translations and discussions of this passage, see Saliba, 'The Role of the *Almagest* Commentaries', pp. 152–55, and Ragep, 'From Tūn to Toruń', pp. 168–71.

and Aristotle. As discussed above, Ptolemy's position is rather radical insofar as he describes natural philosophy in its entirety as a conjectural part of philosophy, since it deals with ever-changing objects. In contrast, Aristotle argued for the demonstrable character of each science. For someone like al-Ṭūsī, who, on the one hand, is a distinguished astronomer acknowledging Ptolemy's authority (despite the well-known points of critique raised in this chapter) but is also considered as a defender of Avicennian philosophy on the other hand, this raises the question of which authority he should follow. In this light, the position we already know from al-Bīrūnī may, in fact, be a possible solution for al-Ṭūsī. According to this view, an argument works in a specific science when it makes use of the methods of this science. In the case of astronomy, the most important is observation. An argument in physics might therefore be proven by some physical presuppositions that can, however, not be proven by observation alone, which makes this physical argument merely dialectically persuasive in the context of astronomy. In this way, one can still save the demonstrable character of each science in itself but still follow Ptolemy's distinction of necessary and conjectural arguments in astronomy. However, as we have just seen in the discussion on the reception of Ptolemy in al-Andalus, such a view is certainly not uncontested.

One can now easily see the different sources of influence on al-Ṭūsī's cosmological arguments and their status. In addition to the aforementioned influence of al-Fārābī and al-Bīrūnī (which is easily detectable concerning *Almagest* XIII.2, for example), it remains to say that the invention of the different versions of the famous Ṭūsī-couple clearly has its roots in the agenda formulated by Ibn al-Hayṯam around 200 years before al-Ṭūsī. These devices illustrate his attempts to find physical solutions for the Ptolemaic planetary models which were thought to violate basic principles from natural philosophy. This is exactly what Ibn al-Hayṯam demanded in his *Doubts about Ptolemy*. In this way, al-Ṭūsī established the genre *ʿilm al-hayʾa* in the form of cosmological summaries. In his *Memoir on Astronomy*, one finds two main trends which are fundamental for the treatment of cosmology and whose roots go back to Ptolemy in some way. First, astronomy must take some principles from other sciences, namely geometry and natural philosophy. Although al-Ṭūsī touches on essential and natural motions in the context of these physical principles, he omits any metaphysical reasoning in his *Memoir*.[377] Second, al-Ṭūsī distinguishes physics and astronomy by the kind of proof they convey, namely proofs of the *that* and of the *why*. In considering some physical arguments from the first cosmological chapters of the *Almagest* as 'persuasive' in the *Taḥrīr*, he comes close to Ptolemy's characterization of physical arguments that only have conjectural certainty. As in Ptolemy's *Almagest* and *Planetary Hypotheses*, al-Ṭūsī's *Memoir* raises a tension.

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[377] I will deal with his combination of metaphysics and the transmission of motion on which he elaborates in his commentary on Avicenna's *Pointers and Reminders*, for example, in Chapter III. See below, pp. 201–204.

Al-Ṭūsī introduces certain physical principles that are not unlike the ones we find in *Almagest* I.1 and *Planetary Hypotheses* II.3 as the necessary foundation of the following astronomical discussions. These physical principles include the nature of aether, its difference from the sublunar world, and elemental motions. Thus, in some sense, astronomers need to rely on them in order to arrive at a complete cosmological picture. On the other hand, they must previously be proven in another science, namely physics, and they do not prove anything in mathematics but are only persuasive.

One can better understand this complicated relationship between physics and astronomy if one acknowledges that al-Ṭūsī's works represent the culmination of the contributions made by his predecessors. Adoption of the distinction of proofs of the fact and the cause (as already done by al-Fārābī) allows him to disapprove of their intermingling in cases where we already have necessary observational proofs (as al-Bīrūnī did more strictly). This distinction allows him to stick with the observed facts and thus with the method of mathematics whenever possible. Such a primary focus on the astronomical method prevents the astronomer from conceiving of physical models that are incorrect in mathematical terms. On the other hand, there are still some principles from natural philosophy which one needs in order to choose those mathematical models that are viable in a physical cosmos (as emphasized by Ibn al-Hayṯam). This is the main reason behind the invention of planetary models that include new devices such as the Ṭūsī-couple. It is certainly not an original claim that Ptolemy himself attempted this in his *Planetary Hypotheses*. I do not intend to argue that these three authors, namely al-Fārābī, al-Bīrūnī, and Ibn al-Hayṯam, are the only previous authors on whom al-Ṭūsī relied. In fact, he does not even allude to them directly. Most importantly, Avicenna was certainly an important source for him for questions on the philosophy of science. What I have tried to show until now, however, is that we find all these elements of al-Ṭūsī's scientific methodology already present in Ptolemy's own account, and that they made their way through many centuries of cosmological discussions.

This is the essence of what one can gather from al-Ṭūsī's astronomical works regarding his attitude on the relationship between the different sciences and the status of their arguments. As already argued in modern research, his agenda in the *Memoir on Astronomy* is not unlike Ptolemy's in the *Planetary Hypotheses*.[378] The question remains whether he directly engages with this work. As pointed out by F. Jamil Ragep, although he does not refer to the *Planetary Hypotheses* by name, he nevertheless relies on information that can ultimately be traced back to it in his section on planetary sizes and distances.[379] As a last point of this investigation of al-Ṭūsī, however, I want to focus on two brief statements concerning sawn-off pieces which clearly show that he dealt with this important topic from the *Planetary*

[378] See the introduction by Ragep in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 27–29.
[379] See Ragep's commentary in al-Ṭūsī, *Memoir on Astronomy*, Vol. 2, pp. 517–28.

Hypotheses. The first of these statements occurs in the *Memoir on Astronomy*, though it in fact goes back to the aforementioned *Solution of the Doubts about the Winding Motion* by Ibn al-Hayṯam. Since this passage has already been discussed above and since al-Ṭūsī here simply reiterates Ibn al-Hayṯam's argument that the sawn-off pieces do not conform to physical principles,[380] we can proceed to al-Ṭūsī's own engagement with the sawn-off pieces in his commentary on Avicenna's *Pointers and Reminders* (*al-Išārāt wa-l-tanbīhāt*). Al-Ṭūsī provides extensive comments on a rather brief assertion by Avicenna: 'You can know that the sublime celestial bodies, their spheres and stars are many in number.'[381] He divides his comments into four objects of inquiry, the first of which concerns the number of celestial bodies. This investigation, al-Ṭūsī explains, belongs to the mathematical sciences (*ʿulūm riyāḍiyya*).[382] After a brief list of the celestial bodies including spheres, fixed stars, and wandering planets, al-Ṭūsī talks about the correct methodology:

> In order to know the existence of the stars, the method is vision (*iʿyān*), nothing else, and in order to know whether they wander or are fixed, it is observation (*raṣd*). The spheres, then, are many and the method to determine them is the deduction of the motions of the planets that are found by observation after introducing the philosophical principles [reading *al-uṣūl al-ḥikmiyya* instead of *al-uṣūl al-ḥakīma*]. These are: every motion depends on a body that moves by itself with this motion and it moves what it contains accidentally; the necessity of the continuity in the simple, circular celestial motions and the necessity of the uniformity in them; the impossibility of penetrating and mending their bodies.[383]

The basic methods of astronomy are vision and observation, the former providing the existence of the stars, and the latter being vision over a longer period of time, thus distinguishing between the fixed stars and the wandering planets. The astronomer can follow the planets' motions by observation because they are visible. In contrast, the celestial spheres are not seen, and therefore their number and kinds need to be determined through observing the planetary motions as well as through the application of certain philosophical (namely physical) principles. In this passage, al-Ṭūsī provides a specific argument why we need to rely on these non-mathematical foundations, namely because the spheres themselves are not visible. The philosophical principles that al-Ṭūsī presents here as necessary for investigations into the invisible spheres are part of the physical principles from his *Memoir* (though some are missing from the commentary on Avicenna's *Pointers and Reminders*, such as the non-existence of voids) and are, of course, in line with the basic Aristotelian cosmology from *On the Heavens*.[384] Next, he gives a

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380 See above, pp. 102–03.
381 Avicenna, 'al-Išārāt', Vol. 3, p. 185:3–4.
382 al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 185:8.
383 al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 186:1–9.
384 cf. al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, pp. 99:17–101:26.

summarizing account of the cosmos, claiming that mathematicians disagree about the exact number. First, he presents the eight main spheres (seven for the planets and one for the fixed stars), to which later authors, as he says, added a starless sphere. In the *Memoir*, al-Ṭūsī explicitly calls this extra sphere the 'ninth' and thus follows the main trend in Arabic cosmological works.[385]

Al-Ṭūsī then addresses the question of the overall number of spheres, since every main sphere must consist of a number of minor spheres so that we can end up with the complex planetary motions. For this purpose, al-Ṭūsī again divides the previous scholars into two groups. First, there are those who apparently do not follow the physical principles:

> Among those who are not accomplished (*min ġayr al-muḥaṣṣilīn*) are those who posit for these bodies non-spherical shapes, likes those claiming [the existence of] sawn-off pieces, rings, tambourines, and something similar. They make them stacked into each other in the space that contains them, which is the interior of its general sphere.[386]

Clearly, al-Ṭūsī here refers to Ptolemy's theory of sawn-off pieces. He does not add any further discussion of whether such spheres could actually exist in reality, but only adds that the followers of that theory do not agree about the number of spheres. In addition, he unfortunately does not tell us who followed this idea. As in the case of Ibn al-Hayṯam's treatise on the winding motions, we have here again only slight evidence that some scholars might have used these shapes for their planetary models, although it is also possible that he has only Ptolemy in mind. In this passage, al-Ṭūsī also does not establish a connection to the physical principles set out earlier, but he does so in what follows when he describes the second group:

> As for those who are accomplished, who stick to the philosophical principles (*qawānīn ḥikmiyya*), they also disagree about their numbers after they agree about the necessity of their circular shape and motion. The first teacher said that the number of all [of them] is close to 50 and beyond. Later [thinkers] followed the observations by the eminent Ptolemy.[387]

In the first sentence, al-Ṭūsī clearly defines the difference between the 'accomplished' and the 'non-accomplished'. The latter follow the philosophical principles, which, in turn, means that the former did not do so. Since al-Ṭūsī did not spend much time discussing this first theory, the question is which physical principle the theory of sawn-off pieces violates. Surely, he has the last one in mind, namely that celestial

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[385] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, pp. 186:10–187:3. For the ninth sphere in the *Memoir*, see al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 125:21, and also before p. 111:1–2, where it is not called the 'ninth'; in addition, see Ragep's commentary in Vol. 2, pp. 400–09.

[386] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 187:3–5. In the last sentence, al-Ṭūsī tries to explain that the empty space of these rings is filled by the smaller rings so that the general sphere becomes solid and thus there is no void.

[387] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 187:10–13. For the famous Aristotelian background, see *Metaph.* XII.8, 1073b38–1074a14.

bodies do not penetrate each other. We have already seen a similar argument in Ibn al-Hayṯam's *Doubts about Ptolemy*, namely that any other shape except complete spheres raises the difficulty that they cannot move circularly without vacating one space and filling another space.[388] When such shapes are nested within each other, this may mean that they indeed penetrate each other. This reminds us of the controversy about the argument in *On the Heavens* II.4, where Aristotle used this rationale to argue against ovoid or lenticular spheres. As described above, Alexander of Aphrodisias had already argued against Aristotle that even such spheres do not create void spaces when they rotate around the correct pair of poles. As a reply to Alexander, Simplicius then defended the perfect spherical shape of the celestial spheres by citing two passages from Ptolemy's *Almagest* I.3.[389] This argument concerns the perfect nature of aether whose parts are similar to each other, and is the foundation for the physical assumption of the uniformity of celestial bodies and motions. Al-Ṭūsī now refers to this argument by his own philosophical principle of 'the necessity of the continuity in the simple, circular celestial motions and the necessity of the uniformity in them'. This means that sawn-off pieces violate the philosophers' attempt (a) to avoid empty space and avoid celestial bodies that interfere with each other, and (b) to explain the apparent everlasting motion of the stars and planets by the exalted nature of its constituents. Therefore, al-Ṭūsī rejects Ptolemy's cosmology because it violates these principles of natural philosophy. It is obviously the same argument that was raised by al-Ṭūsī's predecessors and contemporaries against some of Ptolemy's geometrical devices, which required the motion of a physical sphere around a point other than its own centre. We therefore see that al-Ṭūsī strictly follows the methodology of his introduction to the *Memoir*. On the one hand, he has separated natural philosophy from works on astronomy because the former is a science that provides proofs of the *why*. On the other hand, he introduced a number of principles from natural philosophy as necessary starting points for a reliable astronomical account. By his rejection of not only Ptolemaic astronomy but also Ptolemy's cosmological claims from the *Planetary Hypotheses*, he remains true to his introduction of physical principles in the *Memoir*.

In the remaining part of the investigation into the number of spheres, al-Ṭūsī describes the Ptolemaic spheres that are needed to account for the complex planetary motions and emphasizes again that not all philosophers and mathematicians agree on the exact number, especially given the problematic motions that Ptolemy described in *Almagest* XIII. As a side note, al-Ṭūsī briefly speaks about the question whether the Sun is carried by an eccentric sphere or by an epicycle. He repeats Ptolemy's argument that the eccentric hypothesis is the simpler one, and he seems to accept

[388] See above, pp. 102–03.

[389] See above, p. 62, and especially n. 125 for the references.

this argument, since he adopts the eccentric sphere in his own model of the Sun in his *Memoir*, again by taking recourse to Ptolemy's argument of simplicity.[390]

With this non-technical summary of planetary models, al-Ṭūsī's first topic comes to an end, namely the number of spheres. The next topic is the number of celestial movers, which al-Ṭūsī labels as 'philosophical' (*ḥikmī*). Thus, he leaves the mathematical investigation. I follow his division and will come back to this question in the next chapter on celestial dynamics. However, this statement from his commentary on Avicenna's *Pointers and Reminders*, taken together with the introduction to the *Memoir*, gives us a nice example of his opinion concerning the astronomers' tasks. Most of the principles from the *Memoir* go back to the distinction between the unchanging supralunar and the ever-changing sublunar realms. Since these imply that celestial motions must be reconstructed in a regular, uniform way despite their apparent anomalies, they are necessary for an investigation into the number of spheres. This is an astronomical endeavour, as al-Ṭūsī engages with it in his astronomical works such as the *Memoir* and also in the first topic discussed above, which he labelled as mathematical. The number of celestial souls and intellects does not have any impact on the configuration of the planetary models themselves and thus this philosophical topic is not discussed in the *Memoir*.[391]

Al-Ṭūsī was not the only important figure of his time working in Marāġa. Another interesting astronomer to whom I want to draw attention here is Mu'ayyad al-Dīn al-ʿUrḍī (d. around AD 1266), whose major work is *On the Configuration* (*Kitāb al-Hay'a*).[392] Since al-ʿUrḍī refers frequently both to Ptolemy's *Almagest* as well as the *Planetary Hypotheses*, this work is a very important witness for the present investigation. Al-ʿUrḍī often compares the accounts he finds in both works or critically hints at weak points, covering nearly all aspects of these works. While those parts can be compared to Ibn al-Hayṯam's *Doubts about Ptolemy*, al-ʿUrḍī's *On the Configuration* is much more detailed and he emphasizes the need to not only raise doubts but also offer solutions. In these respects, this work is rather different from Ibn al-Hayṯam's *Doubts about Ptolemy*.[393] As a matter of fact, Ibn al-Hayṯam

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[390] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 187:22–24. Cf. al-Ṭūsī, *Memoir on Astronomy*, pp. 145:22–23 and 147:5–6.

[391] Thus, the separation of his discussion into a 'mathematical' (*riyāḍī*) and a 'philosophical' (*ḥikmī*) part does not necessarily mean that mathematics is, in al-Ṭūsī's view, not a philosophical discipline. Instead, the question is how to transfer abstract mathematical planetary models into the context of natural philosophy and metaphysics. Nevertheless, this distinction between mathematics and philosophy (*ḥikma*) in post-Avicennean philosophy might be an intriguing topic that deserves more detailed research.

[392] For the edition made by George Saliba, see al-ʿUrḍī, *Kitāb al-Hay'a*.

[393] For his critique of Ibn al-Hayṯam, who restricted himself to raising doubts, see al-ʿUrḍī, *Kitāb al-Hay'a*, p. 214:15–17. For al-ʿUrḍī's agenda, see the introductory remarks by Saliba in al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 36–39. Many of the passages that I discuss in the following have already been briefly discussed and even translated there. For al-ʿUrḍī's geometrical solutions, see Saliba, *Islamic Science*, pp. 151–55.

and al-ʿUrḍī show the best in-depth knowledge of the *Planetary Hypotheses* in the Arabic tradition.

After an introduction, al-ʿUrḍī starts with some fundamental chapters on the heavens in their entirety, on the four sublunar elements, on aether, and on the cosmological premises that made up Book I of Ptolemy's *Almagest*.[394] In these chapters, he does not depart significantly from his predecessors. More interesting is the way in which he begins his account of the arrangement of spheres for the wandering planets:

> Since it belongs to the things [already] established in philosophy (*ḥikma*) that the opinion which one has to believe concerning the motions of the celestial spheres is that they travel along by regular circular motions without any variation in them at all and that there is also nothing superfluous which is not needed, it is thus necessary for those of the mathematicians who start to clarify any aspect of these motions that they search — for the sake of verifying the motion that can be seen as irregular from the point of view of the centre of the world — for a way (*amran*) by which it can become clear and from which it can be constructed (*yatahayy'a*) that their movers (reading: *muḥarrikāti-hā*) move them in a uniform circular fashion in the same way from the point of view of the centres of the moved things.

After introducing the eccentric sphere, al-ʿUrḍī goes on:

> Ptolemy said at the end of Chapter III.1 of the *Almagest* that he aims at verifying the motions according to the principle that is appropriate for the nature of the celestial things and for the teaching which the wise [Aristotle] upheld.[395]

Before al-ʿUrḍī goes into the details of astronomical theories, he makes it perfectly clear that these have to be in conformity with certain philosophical requirements. He uses 'philosophy' (*ḥikma*) in the same sense as al-Ṭūsī, as both use this label to refer to philosophical arguments on the real, physical existence of celestial bodies in contrast to purely mathematical abstractions. As pointed out a couple of times throughout this investigation, Ptolemy received severe criticism for some of his mathematical devices in which spheres were supposed not to rotate around their own centres, such as the equant and the prosneusis points. Clearly, al-ʿUrḍī already foreshadows his critique of these devices when he insists that the rule of uniform circular motion must apply to a celestial body from the perspective of its own centre. He claims that also Ptolemy initially subscribed to these principles in the *Almagest* and adds that they are the same as that of Aristotle.[396] These are basically the same points of criticism already made by Ibn al-Hayṯam, and this is the background of al-ʿUrḍī's use of the term 'philosophy' in contrast to abstract mathematics.

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[394] al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 27–50.

[395] al-ʿUrḍī, *Kitāb al-Hay'a*, p. 64:7–18.

[396] cf. Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 208:18–27, where Ptolemy, however, does not refer to Aristotle.

In the rest of his work, al-ʿUrḍī discusses Ptolemy's models of the Sun, the Moon, and the remaining planets in much detail. He is especially careful to highlight the exact points of Ptolemy's models that he finds problematic. In many cases, these go back to his claim that astronomy must not violate the physical foundations. It is not feasible to highlight every point of critique in the current investigation. Instead, I want to draw attention to some passages that illustrate al-ʿUrḍī's agenda. The first large part after the introduction concerns Ptolemy's solar and lunar model. George Saliba has already summarized his criticism of Ptolemy's lunar models.[397] After that, al-ʿUrḍī begins the following chapter by saying that he now wants to go on in a similar fashion concerning the remaining wandering planets, namely discussing their states and motions, adding, however, that 'we must follow in our project the simplest [account] of which we are capable, by which their motions can take place according to regularity and circularity and according to what is uniform and fits with the nature of the heavens.'[398] He uses two passages from *Almagest* IX.2 and XIII.2 to argue that even Ptolemy himself noticed the departure from these principles. In these passages, Ptolemy indeed admits that he sometimes used an inexact procedure (*Almagest* IX.2) and that it might be impossible for a human to judge the simple nature of the heavens (XIII.2). In al-ʿUrḍī's eyes, these are merely rhetorical attempts to excuse the shortcomings of his models.[399] It is easy to see why astronomers who were eager to find planetary models that fitted better with Aristotelian natural philosophy liked these apologetic remarks by Ptolemy and happily referred to them. In addition to al-ʿUrḍī, I have already pointed at Ibn al-Hayṯam's usage of the same passages in his *Doubts about Ptolemy* and I hinted at the possible allusion to this statement by Proclus.[400]

Before al-ʿUrḍī proceeds to the remaining planets, he tries to situate his own work within the broader history of astronomy. He does not only complain about most of his predecessors who blindly followed Ptolemy, but also about those who raised some doubts but nevertheless 'did not reply to the doubt and did not put forward something' as an alternative. In contrast, he emphasizes that he himself has found 'the true state, by which I [viz. al-ʿUrḍī] corrected the motions of the Moon according to the requirements of philosophy (*ʿalā muqtaḍā l-ḥikma*).'[401] Once again, he underlines the need for astronomical models to conform to natural philosophy, though now highlighting not only that Ptolemy failed to provide such a model, but also that he himself is the first to do so.

In the following, al-ʿUrḍī goes into detail about the elements of Ptolemy's astronomy that need to be rejected, most importantly the infamous equant. He

[397] See Saliba's introduction in al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 50–55.
[398] al-ʿUrḍī, *Kitāb al-Hay'a*, p. 185:4–5.
[399] al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 188:8–190:8. Cf. Ptolemy, *Syntaxis*, IX.2, Vol. 2, pp. 211:21–212:23, and XIII.2, Vol. 2, pp. 532:12–534:6.
[400] See above, pp. 55–58 (for Proclus) and p. 101 (for Ibn al-Hayṯam).
[401] al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 190:9–191:11.

concludes that one renders the entire project of astronomy superfluous once one accepts that there are irregular celestial motions, namely circular motions that are not uniform with respect to their own centre.[402] This leads him directly to the topic of sawn-off pieces, about which he says:

> In the *Planetary Hypotheses* (*Kitāb al-Iqtiṣāṣ*), Ptolemy says that the bodies moving the planets are either spheres, their number being 41 […] or [the bodies] moving the planets are sawn-off pieces instead of [complete] spheres, because the motions are, in his opinion, generated in this way by bodily entities, their number being 29, which is less than the number of [complete] spheres. This is why he chooses the sawn-off pieces. The impossibility (*al-muḥāl*) that necessarily follows from the [sawn-off pieces] is even more repulsive and repugnant than [the case of complete] spheres, because in the case of the [sawn-off pieces], the same impossibilities necessarily follow that we have mentioned of the lack the uniformity of their motions from the point of view of their centres, and in addition, on account of the sawn-off pieces, it follows necessarily that one construes non-spherical spheres but [only] sections that cannot be separated into uniform planes. This is impossible with respect to natural philosophy (*ʿilm ṭabīʿī*).[403]

First, al-ʿUrḍī correctly explains the reason why Ptolemy introduces and later prefers the sawn-off pieces, namely for reducing of the number of celestial spheres. He even thinks that Ptolemy 'chooses' (*iḫtāra*) the sawn-off pieces, although Ptolemy is, in fact, not explicit about that point. However, al-ʿUrḍī does not consider them a better solution because (a) the sawn-off pieces do not remove the problem of irregular motions with respect to the centres of the spheres, as in the example of the equant, and (b) they add the problem that their shape is not uniform either. Therefore, they worsen Ptolemy's models that are already defective with respect to the assumption of complete spheres. Thus, we see here again the conflict between mathematical simplicity and compatibility with the physical picture of the cosmos. Al-ʿUrḍī picks up the sawn-off pieces again in a later section that explicitly is devoted to the number of spheres.[404] He closes this section by adding another argument against the sawn-off pieces:

> Concerning the sawn-off pieces — which are those for which Ptolemy opts in his *Planetary Hypotheses* (*Kitāb al-Iqtiṣāṣ*) — their number, together with the [complete] spheres of which one needs such that they encompass the sawn-off pieces, is, according to him, 29: of these, three are [complete] spheres and 26 sawn-off pieces. These sawn-off pieces are round bodily entities like rings, without poles or axes. Thus, on which thing do they

[402] al-ʿUrḍī, *Kitāb al-Hayʾa*, p. 212:7–9, and similarly later p. 218:9–11.

[403] al-ʿUrḍī, *Kitāb al-Hayʾa*, p. 212:10–16.

[404] In Saliba's edition, this section consists of two chapters, the first entitled 'on the number of spheres (*aflāk*) of the planets' and the second is 'exposition of the number of spheres of the planets and their arrangement according to al-ʿUrḍī'. See al-ʿUrḍī, *Kitāb al-Hayʾa*, pp. 239–44. Al-ʿUrḍi provides a table comparing the different accounts in Ptolemy's *Almagest* and in the *Planetary Hypotheses* with his own account. The numbers given in this table are corrupt. See the footnotes by Saliba in his edition, al-ʿUrḍī, *Kitāb al-Hayʾa*, p. 240.

> depend in their motions? In general, no one adopts them because they are outside of the account that is most likely and most appropriate (*al-amr al-aš̆bah wa-l-awlā*) for what one believes concerning celestial bodies.[405]

In this passage, al-ʿUrḍī once again tells the reader that Ptolemy calculated the number of sawn-off pieces as 29. Since he has already stated that briefly before, one might wonder why he mentions this exact number again. Between these two statements concerning the sawn-off pieces, al-ʿUrḍī presents his own account and gives an explanation of the number one needs in his cosmological scheme, a number much higher than that thought of by Ptolemy. As is apparent from the first quote on the sawn-off pieces, al-ʿUrḍī was aware of Ptolemy's argument for the sawn-off pieces, namely that one needs fewer of them in comparison with a model of the cosmos with complete spheres exclusively. This means that al-ʿUrḍī apparently considered this economical argument as seriously promoting Ptolemy's view. Therefore, he adds yet another criticism against these sawn-off pieces, namely that they lack poles and thus also a complete axis and a proper support (*iʿtimād*) for their motion. This is a direct reply to *Planetary Hypotheses* II.5, where Ptolemy argued at length why one actually does not need celestial poles as sources of celestial motions or as a point of support.[406] Although al-ʿUrḍī does not go into any detail and does not attempt to refute Ptolemy's arguments, for example, that concerning the question whether we have to imagine these poles as motionless or moved or as geometrical or physical entities, it is clear that he rejects Ptolemy's idea that the sawn-off pieces move inside the complete sphere of the fixed stars as fish swim in water. Also quite noteworthy is the way in which he expresses his final rejection: 'no one adopts them because they are outside of the account that is most likely and most appropriate (*al-amr al-aš̆bah wa-l-awlā*) for what one believes concerning celestial bodies.' First, we learn that al-ʿUrḍī did not know of any predecessor or contemporary who followed Ptolemy in supposing the existence of sawn-off pieces. We do not need to consider the possibility that he deliberately passes over otherwise unknown authors, for he happily told us more than once that most astronomers blindly followed Ptolemy in other respects. We can therefore be certain that indeed al-ʿUrḍī did not know any text embracing a cosmos of sawn-off pieces. Second, al-ʿUrḍī's statement that such a cosmological configuration is 'outside' of what is 'most likely and most appropriate' is a direct rejoinder to the *Almagest* and the *Planetary Hypotheses*. We find nearly the same expression both in the Arabic translation of *Almagest* I.1 by Isḥāq ibn Ḥunayn and Ṯābit ibn Qurra ('most likely and appropriate', *aš̆bah wa-aḥrā*) translating the statement that physics and theology are 'guesswork' (*eikasia*), as well as in *Planetary Hypotheses* I.18 ('most likely', *āš̆bah al-umūr*) in the context of planetary distances. In the latter, Ptolemy similarly refers to the

[405] al-ʿUrḍī, *Kitāb al-Hayʾa*, p. 244:3–8.

[406] See *Plan. Hyp.* II.5, and the commentary on Chapters II.5–6.

principle that nature does nothing in vain as 'appropriate' (*ḫalīq*).[407] While taking over Ptolemy's way of referring to arguments taken from natural philosophy and not from mathematics, al-ʿUrḍī judges that Ptolemy's own account of omitting the poles and axis of the spheres cannot be called likely or appropriate, and hence cannot convince in physical terms.

Let us conclude the discussion of al-ʿUrḍī's *On the Configuration* by highlighting yet some more passages. The many explicit references to the *Planetary Hypotheses* and the chapter that is devoted to the configuration and number of spheres 'in the *Planetary Hypotheses*, not in the *Almagest*' demonstrate his in-depth knowledge of this work. In fact, his *On the Configuration* must be considered (together with Ibn al-Hayṯam's *Doubts about Ptolemy*) as the most detailed engagement with the *Planetary Hypotheses*. Further evidence for this can be found in the section on planetary distances. First, al-ʿUrḍī acknowledges that Ptolemy determined the distances of the Sun and the Moon 'by a reliable demonstration' (*burhān mawṯūq bi-hī*) in the *Almagest*. He then makes a comparison between the *Almagest* and the *Planetary Hypotheses*, with the result that 'the *Almagest* depends on clear proofs (*adilla wāḍiḥa*), whereas there is no proof (*dalīl*) at all in the *Planetary Hypotheses* (*al-Iqtiṣāṣ*).'[408] Although this certainly is a severe attack against Ptolemy — and although Ptolemy would probably not admit that he did not provide any demonstration in his discussion of the distances of the remaining five wandering planets — it is certainly true that Ptolemy himself at least admits that this calculation relies on the assumption of the non-existence of aether, for example, which is a principle taken from natural philosophy and therefore conjectural.

Although I have already referred to a couple of passages in which al-ʿUrḍī stresses the importance of astronomical theories being adjusted along the lines of natural philosophy, there are more statements later in the work that go in a similar direction (for example, in his chapter on the model of Mercury) that even pick up this idea of the conjectural status of some parts of cosmology:

> This entire account (*maǧmuʿ*) necessarily follows from a number of points (*umūr*). Among these are observation, demonstration (*burhān*) that relies on observation, circular motions, the configuration that one conjectures (*ḥadasa-hā*), and the directions of the motions. As for observation, demonstration, and circular motions, one cannot reject any aspect of them, since nothing contradicting them becomes clear.

[407] See *Plan. Hyp.* I.18, p. 276:11–12, and II.6, p. 298:14; cf. Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 6:12 in comparison to its Arabic translation in MS Tunis, Dār al-kutub al-waṭaniyya, 7116, f. 2^{r}:9. See below, p. 365.

[408] al-ʿUrḍī, *Kitāb al-Hayʾa*, pp. 291:7 and 295:12–13. Al-ʿUrḍī's discussion of planetary distances and sizes was already discussed by Bernard R. Goldstein and Noel Swerdlow, who, at that point, treated this work as anonymous before George Saliba identified it. See Goldstein and Swerdlow, 'Planetary Distances'.

> As for the method of conjecture (*ḥads*), he is not more entitled to it than anyone else once his mistake had been made clear. If someone else finds an account (*amr*) in agreement with the principles (*uṣūl*) and in conformity with what is found by observations concerning the particular motions of the planets, he is more entitled to getting to the truth.[409]

The mere fact that al-ʿUrḍī highlights the necessary connection among astronomical observations, mathematical demonstrations, and physical principles several times illustrates nicely that this is not just a mere justification to write another astronomical work. Instead, it shows that he is very serious about this agenda and that he really considers this harmonization as one of the most important tasks of the astronomer. This quote, though, is highly relevant for a different reason. Al-ʿUrḍī describes observation, demonstration, and circular motions as infallible. While the first two are clearly methods used by mathematicians and philosophers, the last one refers to the philosophical principle that all celestial motions must be circular (with respect to their own centre, one might add). He opposes these certain methods and principles to what he calls briefly 'configuration', *hay'a*, the method of which is conjecture. What he intends by *hay'a* here is certainly the process of connecting the results from observation and demonstration with the physical principle that every motion must be circular around its own centre in order to arrive at a coherent cosmological configuration. In this case, he does not claim that it is infallible, but he speaks instead about the question whose account should be preferred. According to al-ʿUrḍī, one should definitely not follow Ptolemy's model, since it can easily be refuted because of its incoherence with the physical principles. Thus, if someone else comes up with a configuration that improves on such shortcomings, one should instead follow this second model and not Ptolemy. Obviously, al-ʿUrḍī hopes to be this second scholar himself. In previous passage, he describes his understanding of the 'true configuration' (*hay'a ṣaḥīḥa*) and he adopts the idea of striving for the simplest possible model that emerges from observations and follows the principles.[410] The question therefore is what al-ʿUrḍī means by 'true' (*ṣaḥiḥ*). One should not understand it as certainly proven, as is apparent from the quotation above. Nevertheless, there are still some definitely incorrect configurations, namely if they do not adhere to the physical principles. By 'true', he means a configuration that does not violate either the observations or the philosophical principles, and one that is as simple as possible, though it cannot be certainly proven by observation or demonstration.[411]

Obviously, this notion of conjecture goes back to Ptolemy, as does al-ʿUrḍī's striving for the simplest possible model. I have argued above how Ptolemy's

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[409] al-ʿUrḍī, *Kitāb al-Hay'a*, pp. 250:13–251:2.

[410] See al-ʿUrḍī, *Kitāb al-Hay'a*, p. 218:12–16. On this point of simplicity in al-ʿUrḍī, see Sabra, 'Configuring the Universe', pp. 309–10.

[411] This means that the method of the major task of his work, given that it is simply called *On the Configuration* (*Kitāb al-Hay'a*), is conjecture and that, in al-ʿUrḍī's view, the 'science of configuration' is not demonstrative.

epistemological doctrine of physics as conjectural in *Almagest* I.1 permeates not only the *Almagest* but also the *Planetary Hypotheses*. In fact, Ptolemy has the same notion of conjecture, which does not mean that anyone can make any guess and that each guess is equally acceptable. Instead, he uses this merely as a *caveat* that he is leaving the certain demonstrable ground of mathematics. Nevertheless, he makes use of his criterion of simplicity and of the fact that nature does nothing in vain in order to argue that the simplest possible model should be preferred since it is 'more likely'. Al-ʿUrḍī follows this application of conjectural accounts when he says that an astronomer 'is more entitled' to coming close to the truth (*awlā bi-iṣābat al-ḥaqq*) when his configuration also adheres to physical principles.[412]

Despite all these similarities, there is also a difference between the application of conjecture in Ptolemy and in al-ʿUrḍī. Ptolemy argued that natural philosophy (together with metaphysics) is only conjectural, whereas al-ʿUrḍī seems to consider the physical principles to be proven by demonstration. Al-ʿUrḍī claims that only 'configuration', which means the merging of astronomical observations with physical principles, is conjectural. The physical principles themselves are not subject to conjecture in al-ʿUrḍī's view. This is why al-ʿUrḍī is so strict in rejecting any Ptolemaic device that includes circles which do not move uniformly circular around their own centres. As for Ptolemy, the fact that he considers natural philosophy as conjectural means that he is more willing to introduce circular motions that are not uniform around their own centres or celestial spheres that can carry the planets in a circular

[412] The term used by al-ʿUrḍī to refer to such a 'conjectural' account, as I have translated, is *ḥads*, which is a term with a complex history. The well-known example of an earlier application of the term in an epistemological context is Avicenna, in whose works it is usually translated as 'intuition'. See, for example, Gutas, 'Intuition and Thinking', and Black, 'Certitude, Justification', especially pp. 130–32. Al-ʿUrḍī applies this term in an explicitly Ptolemaic context, namely to the parts of the Ptolemaic planetary models that are not based on mathematical demonstrations. My translation of *ḥads* as 'conjecture' owes to the fact that Ptolemy himself had labelled those parts as conjectural. Otherwise, *ḥads* does not seem to be a common term in medieval Arabic astronomical literature. One can find another application of *ḥads* in a treatise entitled *Epitome and Revision of the Almagest* (*Kitāb Talḫīṣ al-Maǧisṭī wa-tahḏībi-hī*). This treatise was written on behalf of al-Kātibī al-Qazwīnī (d. 1276), who was teaching at the observatory in Marāġa. This dedication strengthens Sezgin's attribution of this work to Aṯīr al-Dīn al-Abharī (d. AD 1265), because we know that he worked closely together with al-Kātibī al-Qazwīnī (for the attribution to al-Abharī, see Sezgin, *Geschichte des arabischen Schrifttums VI*, p. 94). The second chapter deals with the sphericity of the heavens and the Earth, and is a very dense abridgment of some of the points made by Ptolemy in *Almagest* I.3–5. Al-Abharī calls each one of three doctrines — namely the spherical motion of the heavens, that the Earth is spherical as the heavens, and that the Earth is in the centre of the heavens — a *ḥads* and explains at the end of the chapter: 'These propositions (*muqaddimāt*) are laid down as conjectures (*wuḍiʿat ḥadsiyya*) without verification through geometrical demonstrations.' See MS Tehran, Kitābḫāna-yi Maǧlis-i šurā-yi Islāmi, 6195, ff. 7^{r-v} for the entire chapter and ff. 7^{r}:19–7^{v}:1 for the quoted sentence. Like al-ʿUrḍī, also al-Abharī uses *ḥads* to describe knowledge that does not rely on certain mathematical arguments. However, these two authors seem to have a different understanding of the particular teachings that are merely 'conjectural'. Despite this divergence, it is noteworthy that this term comes up in two astronomical works written within the Marāġa school, which leads to the question whether it became a more common term in that period.

way but are themselves not perfectly spherical. In this respect, al-ʿUrḍī's position is similar to al-Bīrūnī's and al-Ṭūsī's *caveat* that arguments are only necessary when they are applied in their own science and not transferred into another. Despite this difference, we see the influence of Ptolemy's labelling of some aspects of cosmology as 'conjectural' also appearing more than 1000 years later in al-ʿUrḍī in the Islamic East.

In al-ʿUrḍī's assessment of Ptolemy's sawn-off pieces, we thus find traces of arguments that were made by authors discussed previously. Around the same time and in the same place, namely Marāġa, al-Ṭūsī dismissed these slices because their shape does not fit the requirements of natural philosophy. Both al-Ṭūṣī and al-ʿUrḍī argue that if we take these philosophical principles for granted, we cannot think of any shape for the celestial spheres other than complete ones. In this respect, they follow the lines of critique previously laid out by Ibn al-Hayṯam, who claimed that the motion of slices of spheres inside complete spheres cannot be explained by the laws of natural philosophy, as well as those by al-Bīrūnī, who argued that the sawn-off pieces are in contradiction to Ptolemy's own arguments of the sphericity of the heavens in *Almagest* I.3.[413] In addition, I have argued that al-Bīrūnī's further reservations against sawn-off pieces relate in some way to Ptolemy's arguments against celestial poles, which means that one can turn Ptolemy's own arguments against himself. We have seen a similar connection in al-ʿUrḍī's concern that if we cut off the area around the poles from the spheres, we lack a point of support for these spheres, without which it is hard to explain their motions. The most obvious point of attack was, therefore, the contradiction between physical principles and imperfectly circular spheres. From the examples of al-Bīrūnī and al-ʿUrḍī, it can be argued that medieval astronomers also replied to and rejected *Planetary Hypotheses* II.5–6 where Ptolemy tried to argue that celestial poles are not necessary for spherical motions in the heavens as opposed to the sublunar realm.

In the foregoing investigation of the relationship between Ptolemy's *Planetary Hypotheses* and the astronomers in Marāġa and their own methodology of *ʿilm al-hay'a*, I restricted myself to two very interesting figures. Al-Ṭūsī is the obvious first choice, since he was the head of the observatory. In addition, he is famous not only for his astronomical works but also because he had a great impact on post-Avicennian philosophy due to, for example, his commentary on Avicenna's *Pointers and Reminders*. We have seen that he tackled cosmological topics in both genres and presented astronomy and philosophy as two disciplines, which are, on the one hand, clearly distinguishable on account of the kind of proof they offer (think of his distinction between proofs of the fact and of the cause) but which, on the other hand, are very much dependent on each other. While al-ʿUrḍī's focus lies arguably on astronomy and not so much on philosophy, he nevertheless was also convinced that a proper astronomical model should adhere not only to the observed facts but also

[413] George Saliba already compared Ibn al-Hayṯam with al-ʿUrḍī, see Saliba, *Islamic Science*, p. 106.

to basic principles taken from natural philosophy.[414] Both authors found their way of dealing with the famous problems caused by Ptolemaic astronomy. The so-called Ṭūsī-couple and the ʿUrḍī-lemma illustrate their astronomical achievements. In addition to the methodological arguments, what made them especially important for the present investigation is the fact that they directly replied to the *Planetary Hypotheses* in their cosmological accounts.

This does not mean, of course, that they are the only important figures of their time connected to Marāġa. The observatory attracted many more scholars from different parts of the Islamicate world, and it is still a task for future research to understand all these various actors and their connections.[415]

[414] Sabra, 'Configuring the Universe', pp. 324–25, concludes that 'there is no evidence [...] that any of those who promoted the *hay'a* program [...] ever thought of questioning the physical requirements they were trying to satisfy.'

[415] The most important descriptions of the Marāġa-school and its network are Sayılı, *The Observatory*, pp. 187–223, Saliba, 'The Astronomical Tradition', and most recently Yang, 'Like Stars', pp. 391–99. Another important figure is Quṭb al-Dīn al-Šīrāzī (d. AD 1311), of whose works we still lack modern editions and translations. Given that we have just seen that the *Planetary Hypotheses* were studied at Marāġa, it is no surprise that also al-Šīrāzī, in his Persian work *Iḫtiyārāt-i Muẓaffarī*, cites Ptolemy's argument that there is no difference between sawn-off pieces and complete spheres from the mathematical point of view (*Planetary Hypotheses*, Chapter II.4). What is interesting about this citation is that he refers to the *Planetary Hypotheses* by both titles that were used in Arabic, namely *Iqtiṣāṣ* and *Manšūrāt* (see MS Tehran, Kitābḫāna-yi Maǧlis-i šurā-yi Islāmi, 6492, p. 120:23). Despite the lack of complete editions, there is an edition and translation of a chapter of al-Šīrāzī's *Tuḥfa* by Robert G. Morrison (see Morrison, 'Quṭb al-Dīn al-Shīrāzī's Hypotheses'). For further relevant literature, see Ragep, 'Freeing Astronomy', pp. 60–61, who reports that al-Šīrāzī emphasized his preference for mathematical proofs; Morrison, 'Falsafa and Astronomy', especially p. 313; and Niazi, *Quṭb al-Dīn Shīrāzī* for the most detailed study of al-Šīrāzī's cosmology. Another author who was connected to the observatory in Marāġa and who also referred to the *Planetary Hypotheses* is Bar Hebraeus (d. AD 1286). This reference can be found in the chapter on planetary distances in his *On Ascension* (see Bar Hebraeus, *Le livre de l'ascension*, Vol. 2, p. 195). Note that François Nau misinterpreted this reference as ps.-Ptolemy's *Centiloquium*. Also see the discussion in Swerdlow, *Ptolemy's Theory*, pp. 158–60. One important illustration of his interaction with the astronomers of the observatory is the fact that Muḥyī l-Dīn al-Maġribī wrote his commentary on the *Almagest* (*Ḫulāṣat al-Maǧisṭī*) upon the request of Bar Hebraeus; see al-Maġribī's foreword of his work in MS Doha, Matḥaf al-Fann al-Islāmī 791, f. 1^{r}:13–14.

III: The Dynamics of Celestial Motions

Ptolemy's Psychological Approach in *Planetary Hypotheses* II.5 and 6

When Ptolemy addresses the question in *Planetary Hypotheses* II.4 whether the celestial spheres are complete or only slices, he opens up another major point of discussion, namely the origin of celestial motion and the interaction of the spheres and planets. According to Ptolemy, previous astronomers ascribed an important role to the celestial poles: every sphere has two poles that are connected to the sphere encompassing it, so that there is always a physical connection between two spheres. In this way, the motion from the upper sphere is transmitted through these poles to the encompassed sphere, and complex motions are generated by a set of regularly moving spheres. In Chapter II.5, Ptolemy attributes such a system explicitly to Aristotle. This mechanical account of celestial motion poses serious challenges to Ptolemy's favourite model of sawn-off pieces, since these lack the area around the poles. Thus, Ptolemy first has to give some arguments against the transmitting role of the celestial poles before he can turn to arguments for his sawn-off pieces. His arguments focus on two main points: first, the distinction between the celestial realm that consists of the never-changing and always naturally rotating aether on the one hand and sublunar physics on the other hand, and second, the difficulty of describing whether this celestial pole would be a point or a body.[1]

While it is certainly true that Aristotle considered the celestial spheres to be perfect and complete (as famously evident from *On the Heavens* II.4), he does not explicitly state that the poles transmit motion.[2] What Aristotle says in *Metaphysics* XII.8 is simply that in Eudoxus' planetary models, the third sphere has its poles in the sphere above.[3] This is just a small hint that poles can be used to account for complex motions in a homocentric cosmos. Aristotle then asserts that one needs to add more spheres in order to save the mechanical interaction of the various sets of spheres.[4]

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[1] See the commentary on Chapters II.5–6.

[2] This has been put forward by Taub, *Ptolemy's Universe*, p. 116. However, there is one short note in the spurious *On Breath* (namely *Spir*. 484b11), where (pseudo-)Aristotle wonders whether bones can be considered as the origin (*archai*) of motion as the axis or pole (*polos*).

[3] *Metaph.* XII.8, 1073b17–33.

[4] cf. Schiaparelli, *Le sfere omocentriche*, especially pp. 7–10, where Schiaparelli gives a short introduction to the Eudoxean models. More recent studies on Eudoxus' astronomy are Maula, *Studies in Eudoxus*, Riddell, 'Eudoxan Mathematics', Yavetz, 'On the Homocentric Spheres' and Mendell, 'The Trouble'. A late ancient description of Eudoxus' theory, on which these studies are also based, has been provided by Simplicius. For example, with regard to the model of the Sun, one needs to assume three homocentric spheres, where the poles of the third are attached to the second sphere and the poles of the second to the first sphere, so that the third sphere takes part in the motion of the second and first sphere and thus the complex motion of the Sun comes about. See Simplicius, *In Cael.*, 493:11–494:22. Aristotle's adoption and addition of further spheres is described by himself in *Metaph.* XII.8, 1073b38–1074a14. In Simplicius, *In Cael.*, pp. 492:31–493:11, Simplicius explicitly

In contrast to this vague allusion to poles as transmitters of celestial motion in *Metaphysics* XII.8, there is a curious passage in *On the Movement of Animals*, where Aristotle engages critically with a similar theory of poles.[5] In Chapter 2, Aristotle posits the existence of an external unmoved support for the motion of an animal. In Chapters 3 and 4, Aristotle expands this principle to the motion of the universe, stating that the cosmos also needs an external principle of motion. In this context, he mentions the theory that the poles of the spheres, while they themselves have no spatial expansion, must be considered as the movers of the cosmos. Aristotle accepts the premise that the mover cannot lie within the sphere and cannot be part of the sphere at all. Otherwise, the mover would itself be moved or the contiguity of the sphere would be destroyed.[6] Although Aristotle builds upon the very same premises for his theory of an external unmoved mover, he nevertheless objects to the assumption of the poles as movers for two reasons. First, a geometrical point does not have the power to physically induce motion (Ptolemy uses the same argument in *Planetary Hypotheses* II.5), and second, one motion cannot be induced by two movers, i.e. poles.[7]

This refutation in *On the Movement of Animals* seems to contradict Ptolemy's report that Aristotle upheld a theory of poles that transmit motion from the Prime Mover down to the lowest celestial spheres. However, Aristotle does not argue against poles that lie on the sphere above. In this way, they can be imagined as being external to the sphere they move. Stephen Menn has argued that Aristotle's account from *On the Movement of Animals* can be compatible with *Physics* VIII and, since Aristotle is not very explicit about the nature of unmoved movers, also with *Metaphysics* XII. One could imagine that the movers of the lower spheres are moved *per accidens* by the sphere in which they are embedded, whereas the Prime Mover is unmoved also *per accidens*. Therefore, one can interpret the unmoved movers as exerting their influence directly on the celestial poles.[8] Perhaps more importantly from the astronomical point of view, Aristotle's introduction of counteracting spheres would be superfluous if there was no mechanical influence from the upper

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informs us that Aristotle and Callippus improved on this model because Aristotle liked the fact that it needed only strictly homocentric spheres. Certainly, Ptolemy did not suppose that Aristotle departed from Eudoxus in that respect, either. For overviews of Aristotle's astronomy, see (in addition to the sources to which I refer on the following pages) Hanson, 'On Counting Aristotle's Spheres', Lloyd, 'Metaphysics Lambda 8', Beere, 'Counting the Unmoved Movers', and Bodnár, 'Aristotle's Rewinding Spheres'.

[5] I rely on the analysis by Primavesi and Corcilius in their recent edition and German translation. See their commentary in Aristotle, *De motu animalium*, pp. 79–83. For an analysis of the chapters in question, see also Coope, 'Animal and Celestial Motion'.

[6] *Mot. An.* 699a17–20.

[7] *Mot. An.* 699a22–24.

[8] See Menn, 'Aristotle's Theology', pp. 440–42.

to the lower spheres.[9] Clearly, Ptolemy supposed that Eudoxus and Aristotle shared the same homocentric system, including celestial poles that transmit the motions to the lower spheres. Through a paraphrase in Simplicius' commentary on *On the Heavens*, we know that Sosigenes also explained Aristotle's counteracting spheres with celestial poles.[10] This indicates that Ptolemy's interpretation was, in some way, the state of the art at that time.

From Ptolemy's rejection of this doctrine, however, arises the need for an alternative explanation. As seems to be suggested in *Planetary Hypotheses* II.5, Ptolemy also rejects the existence of unmoved movers.[11] His alternative approach is evident from Chapters II.7 and 8. All the spheres that belong to a planet move on behalf of a certain 'capacity from soul' ascribed to the planets. The ensouled planets send out an emission to the surrounding spheres, which then act accordingly and thus can be compared to animals' organs and limbs.[12] Ptolemy even wonders whether the planets are carried by the last sphere within such a system or whether they move freely on their own account within the penultimate sphere, which can be compared to an animal swimming against the stream of a river.[13]

Ptolemy's account is perhaps best understood against the background of his criticism of Aristotle's cosmology.[14] As just highlighted, one major problem that Ptolemy points out with respect to the transmission of motion through celestial poles is that it supposedly contradicts the never-changing, never-influenced natural motion of aether. For Ptolemy's own system, this basically means two things. First, the spheres receive this impulse only from the planet to which they belong and they do not receive any motion whatsoever from spheres of the other planets, and thus Ptolemy does not need to introduce a device similar to Aristotle's counteracting spheres. The comparison to a flock of birds or a group of dancers strongly makes

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[9] See, for example, Alan C. Bowen's remarks on Simplicius' commentary: Bowen, *Simplicius on the Planets*, pp. 274–75. More hesitant is Lindsay Judson in his commentary on *Metaphysics* XII (see Aristotle, *Metaphysics. Book Λ*, p. 246), correctly pointing out that Aristotle is silent about the way in which motion is transmitted.

[10] See Simplicius, *In Cael.*, pp. 498:10–499:1.

[11] See below on pp. 160–62.

[12] The importance of Chapters II.7–8 on which I am focussing in this section is mirrored by the attention it has received in modern scholarship. For partial translations and interpretations, see Sabra, 'The Andalusian Revolt', pp. 150–51 n. 29, Langermann's introduction in Ibn al-Hayṯam, *On the Configuration*, pp. 18–20, Murschel, 'Structure and Function', pp. 38–39, Taub, *Ptolemy's Universe*, pp. 113–25, Hamm, *Ptolemy's Planetary Theory*, pp. 221–22, Pedersen, *A Survey*, pp. 396–97, and Feke, *Ptolemy's Philosophy*, pp. 195–200.

[13] For a short discussion on this last point, see my commentary on Chapter II.17. See also Ptolemy's description of the celestial spheres moving freely through aether in Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:22–533:10.

[14] See the comparison of Aristotle's and Ptolemy's celestial physics in Judson, 'Aristotle's Astrophysics'. I also address some of the problems that Judson identifies in Aristotle and Ptolemy in this chapter, for example, those concerning the interaction of the different spheres and aether in Ptolemy.

this point.[15] Second, Ptolemy has to harmonize this strict notion of the aethereal nature with the various different motions that are needed for the complex motion of a planet. Indeed, as we have seen, each 'celestial animal', which means a set of spheres with their planet, has some motions proper to it, which are different from the 'general circular motion' of aether.[16] How is this psychological explanation compatible with Ptolemy's own argument that aethereal motion is never influenced? The key to this question lies in the fact that the planetary motion, and also the motions of the spheres that come about by means of this impulse sent out from the planet, are voluntary. These voluntary motions differ from each other and from the pure aethereal motion, which Ptolemy seems to identify with the diurnal westward motion of the heavens, in their speed and direction. However, they are similar to each other in another sense, namely that they are free from any external force. In the end, every celestial motion itself is not only regular and circular, but also voluntary.[17] In addition, there is one sentence that seems to ascribe a voluntary power to aether:

> In it [i.e. aether], the regular circular motion remains pure itself through a will, which is absolute [in the sense] that there is no obstacle with respect to what is similar. [The circular motion] is proper for the wonderful intellect (*ʿaql ʿağīb*) and the will, which has no obstacle and in which no alteration or change of opinion is evident.[18]

This passage seems to suggest that Ptolemy thinks that also the circular motion of aether itself comes about by volition. He also briefly refers to some kind of intellect, but does not further elaborate on this notion. We therefore should probably assume that Ptolemy sees no differences among the various celestial motions, in the sense that they are all regular, circular, and voluntary, either from the planets or from the will that is ascribed to aether itself.

Apart from his brief reference to an impulse according to which the various spheres act, Ptolemy does not explain how we can understand this impulse. Sometimes one finds in modern literature the notion that it is the stars' rays that fulfil this task.[19] This, however, goes back to a misinterpretation based on Nix's German translation of *ḍiyāʾ* as 'rays', whereas it means 'brightness'. In fact, the connection between this brightness and the powers of the stars is not spelled out. On the basis of the Arabic version, it cannot be entirely ruled out that the rays from the *Tetrabiblos* play a role here, but Ptolemy certainly does not make this connection explicit.[20]

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[15] *Plan. Hyp.* II.8, p. 304:1–4.

[16] See *Plan. Hyp.* II.7 and 8.

[17] One might think of Aristotle's argument in *On the Heavens* I.4 as to why there is no opposite motion to circular motion: one could say that circular motion can happen in two different directions, for example, clockwise–anti-clockwise or westwards–eastwards. Nevertheless, every circular motion comes back to the same starting point.

[18] *Plan. Hyp.* II.3, p. 290:15–17.

[19] For instance, in Feke, *Ptolemy's Philosophy*, pp. 197–98.

[20] See *Plan. Hyp.* II.3, p. 288:16–17. For a discussion of rays in the *Tetrabiblos*, see Feke, *Ptolemy's Philosophy*, pp. 176–87.

In the *Planetary Hypotheses*, Ptolemy does not provide an explanation of his terminology or of his psychological theories. In this respect, his *On the Kriterion and the Hegemonikon* turns out to be useful, as in the previous chapter.[21] In the first of the two parts of this treatise, Ptolemy analyses the criterion of truth. He distinguishes soul and body by claiming that the former is the cause of motion and can only be perceived by the action of the latter, namely motion.[22] This lack of a direct perception of the soul can also be seen as the reason for studying astronomy, since it is by the motions of the planets and stars that one can attain knowledge about the divine celestial realm that otherwise cannot be perceived. Furthermore, Ptolemy wonders why the actions of soul are not always the same. One solution would be that if soul's nature is one, the differences in the organs connected to the soul are the cause for the multiplicity of the actions caused by the soul.[23] These two points fit with what he writes in the *Planetary Hypotheses*, namely that celestial motions are caused by souls and that the different motions of the various spheres (eccentric spheres, epicycles, and so on) can be compared to the different motions of muscles, nerves, legs, and wings within an animal's body.[24]

Of course, this still is not an explanation of why or how the eccentric sphere, for instance, is different from the epicycle. For example, in *On the Kriterion* Ptolemy also makes the assertion that bones, tendons, flesh, and blood differ in their mixture of elements, which can explain why they react differently to the soul's impulse. Because the heavens only consist of aether, one lacks a similar explanation there. Ptolemy also briefly remarks on this in *On the Kriterion*, which is otherwise devoid of any explicit relationship to astronomy. The second part of this work is devoted to the ruling part of the soul, the *hegemonikon*. He first categorizes the elements into passive elements (water and earth), active elements (aether), and both active and passive elements (air and fire). Since aether is only active, it always stays the same (*aei hōsautōs echonta*), a statement repeated in *Planetary Hypotheses* I.1.[25] Ptolemy transfers this distinction to his tripartition of the soul: the part of sense perception (*aisthētikon*) is only passive, the intermediate part of impulse (*hormētikon*) is both active and passive, whereas the faculty of thought (*dianoētikon*) is only active. This intermediate impulsive part, however, can be further divided into an appetitive part (*horektikon*), in which air is dominant and which is passive, and an emotive part (*thumikon*), which mostly consists of fire and is more active. Ptolemy even assigns specific places within the human body to these faculties. Most importantly, he identifies the heart as the seat of the emotive part, which is the higher part of

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[21] For bibliographical references to this work, see above, p. 46 n. 61.

[22] Ptolemy, 'Peri Kritēriou', p. 11:9–13.

[23] Ptolemy, 'Peri Kritēriou', pp. 12:18–13:2.

[24] In this respect, Ptolemy surely was influenced by the discovery of the nervous system by Herophilus in Alexandria in the first half of the third century BC. See Solmsen, 'Greek Philosophy', and von Staden, *Herophilus*, pp. 159–60.

[25] See Ptolemy, 'Peri Kritēriou', p. 19:15–19. Compare this with *Plan. Hyp.* II.1, p. 288:7.

impulse, and the brain as the seat of thought.[26] As for the seat of the *hegemonikon*, Ptolemy offers two options, depending on what we in fact mean when we speak of the 'ruling part'. Either it can be located in all parts of the body if we consider that each power of the soul is in control 'of its proper function'; or we can identify it with thought, in which case the seat is in the brain, because it is the most exalted of part of the soul: 'Its place is the highest position, heaven in the universe, the head in man.'[27]

This scheme of the human faculties and the parts of the soul corresponds nicely to the description of a bird's motion in *Planetary Hypotheses* II.7. From the soul of the bird arises a drive or impulse (*inbiʿāṯ*) to move. The nerves receive the impulse, are set in motion and thus forward this impulse to the completely passive parts, namely the wings and legs. Can we transfer this scheme to the celestial realm? After all, Ptolemy compares the capacity of the bird's soul to the capacity of the planet, which similarly emits an impulse that reaches the epicycle, the eccentric sphere, and the homocentric sphere within the cosmos. Thus, it seems, Ptolemy assumes that there is a part in the cosmos that is analogous to the impulsive part (*hormētikon*), the planet fulfilling the function of the active emotive part and the spheres that of the passive appetitive part. But what about thought? In fact, this might a good way to understand Ptolemy's remarks about the unhampered aether. In contrast to the case of the planetary spheres, which react to the impulse from the planet, the entire substance of aether is animate and there is a 'wonderful intellect' and never-changing will at work. The result is the general circular motion of aether, which corresponds to the notion in *On the Kriterion* that the *dianoētikon* is solely active and consists of pure aether.[28] Although Ptolemy is silent about these psychological theories in the *Planetary Hypotheses*, these few remarks help us to get a better insight into how Ptolemy thinks his dynamical system works in more detail, because some concepts from *On the Kriterion* seem to resurface here. Nevertheless, there still remain major problems if we transfer the psychological scheme from *On the Kriterion* to the celestial realm. Most importantly, Ptolemy states frequently that the heavens consist entirely of aether and of no other element. So how can there be a purely active part and an intermediate part that is both active and passive in the heavens if we connect this distinction of activity and passivity to the different elements? In addition, it remains unclear how the planetary motions that are generated by the planets' impulses relate to the pure motion of aether and to the wonderful intellect. I am going to show later that such questions become very important in cosmological treatises by other authors. We see, for example,

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[26] Ptolemy, 'Peri Kritēriou', pp. 20:13–21:10.

[27] Ptolemy, 'Peri Kritēriou', p. 22:1–12. The translated parts follow the translation in Ptolemy, 'On the Kriterion', p. 211.

[28] This can be compared with Plato's description of rotating reason in the *Laws*, see *Leg.* X, 898a3–c5, and with Aristotle's assertion that aether is in animals' souls in *On the Generation of Animals*, see *Gen. Anim.* II.3, 736b29–a1.

that a discussion arose about which capacities or senses the celestial bodies have. In Alexander of Aphrodisias, one can see that the gap between the first heavenly motion and the individual planetary motions is filled with concepts such as 'desire', which is completely lacking in Ptolemy. Although Ptolemy does not provide us with a full-fledged theory of celestial dynamics, we can at least differentiate between the completely active aether that is connected to a 'wonderful intellect' and is responsible for the diurnal rotation of the cosmos, on the one hand, and between the complex planetary motions, on the other. These planetary motions still adhere to their nature as they are made out of aether as well and thus move in a circular fashion, whereas the various spheres react to the planetary impulses in different ways (i.e. in different directions and speeds). This distinguishes them from the absolute will and the wonderful intellect of aether. Ptolemy seems to already have such a distinction between the regular motion of aether and the complex motions of the celestial spheres in mind in *Almagest* XIII.2:

> For provided that each of the phenomena is duly saved by the hypotheses, why should anyone think it strange that such complications can characterise the motions of the heavens when their nature is such as to afford no hindrance, but of a kind to yield and give way to the natural motions of each part, even if [the motions] are opposed to one another? Thus, quite simply, all the elements can easily pass through and be seen through all other elements, and this ease of transit applies not only to the individual circles, but to the spheres themselves and the axes of revolution.[29]

Ptolemy suggests here that aether's nature not only consists of moving circularly in a single uniform way, but also giving way to all kinds of circular motions, even if they go in opposite directions. Although the general motion of the cosmos, namely what he ascribes to the wonderful intellect in the *Planetary Hypotheses*, goes in one direction, it is still conceivable for him that other parts of the cosmos have a different natural motion, though still adhering to circularity.

One should keep in mind that Ptolemy emphasizes at the end of Chapter II.8 of the *Planetary Hypotheses* that he mentions all these different arguments in order to check which of these accounts are compatible with 'sound physical investigation'. This refers back to the principles from natural philosophy that he introduced in Chapter II.3, which consist of two main features: the elementary motion of the sublunar elements and the voluntary motion of the celestial bodies. Ptolemy ascribes an 'inclination' (*mayl*) to the four sublunar elements, by which they tend to move in a straight line to their natural place once they are drawn out of it. The aethereal bodies, however, cannot be changed or altered, and their motions are circular and voluntary. In this way, Ptolemy connects his theory of celestial dynamics with his

[29] Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:22–533:10, tr. by Toomer in Ptolemy, *Almagest*, pp. 600–01.

elemental theory, which is why a brief digression into his account of elemental motions is needed here.

The distinction between sublunar and celestial motion in the *Planetary Hypotheses* is certainly reminiscent of Aristotle. In addition to the *Planetary Hypotheses*, there are two other works by Ptolemy on elemental motion, namely *On the Elements* and *On the Inclinations*. Although these works are not extant, we have a certain idea of their content through several testimonies, which were gathered and discussed by Marwan Rashed.[30] In general, Rashed's analysis is in line with the previously cited passage from the *Planetary Hypotheses*. Rashed points out that one could consider Ptolemy's account as a refinement of Aristotle's, insofar as Ptolemy maintains the natural circular motion of the heavens. Although Ptolemy first refers to the 'weight' of the sublunar elements and seems to ascribe a 'natural motion' to them, he immediately afterwards explains that sublunar elements rest in their natural place and only show their inclination once they are forced into an unnatural place. One of the testimonies discussed by Rashed stems from Simplicius, who reports Ptolemy's doctrine that the elements either rest *or* move in a circular fashion in their natural place.[31] The account from the *Planetary Hypotheses* suggests that Ptolemy most probably refers to the sublunar elements as resting and to aether as moving in a circle. However, Simplicius explicitly writes that rest applies to earth, water, and a certain portion of air, whereas circular motion belongs to air and fire. This seems to be at variance with the theory in Ptolemy's *Planetary Hypotheses*.[32] However, there is also the possibility that Ptolemy admitted a circular motion for air and fire at some point.

In another report from his commentary on *On the Heavens*, Simplicius writes that Ptolemy, Plotinus, Proclus, and Aristotle share the teaching that the *hypekkauma*, the highest region of fire, receives some circular motion from the celestial spheres. There are briefs remarks in the *Planetary Hypotheses* as well as in the *Tetrabiblos* that might support Simplicius' report.[33] Nevertheless, Simplicius probably refers again to either *On the Elements* or *On the Inclinations*,

[30] See Rashed, 'Contre le mouvement', especially pp. 19–33. In this paper, Marwan Rashed also argues against a thesis put forward by Michael Wolff that Ptolemy's theory of elemental motion is Stoic rather than Aristotelian. See Wolff, 'Hipparchus and the Stoic Theory', pp. 499–501 n. 31.

[31] See Simplicius, *In Cael.*, p. 20:10–25, quoted in Rashed, 'Contre le mouvement', pp. 25–26.

[32] This is the conclusion by Jacqueline Feke. See Feke, *Ptolemy's Philosophy*, pp. 181–82.

[33] See Simplicius, *In Cael.*, pp. 37:33–38:2; cf. *Plan. Hyp.* II.7, p. II: 'If someone imagines that earth is the centre and that air and fire revolve along with what ecnompasses them and what compels them to move'. Another passage in Book I seems to suggest some influence between air and aether, although in the other direction, namely from air to the overlying aether, see *Plan. Hyp.* I.17, p. 272:11–12: 'Thus, the spheres closer to the air move by various kinds of motions and thereby resemble the nature of the element that is contiguous with them.' See also Ptolemy, *Tetrabiblos*, I.2, pp. 4–7, to which already Rashed, 'Contre le mouvement', p. 32 n. 26 pointed. The aetheral influence on fire and air is also mentioned in Aristotle's *Meteorology*, see *Meteor.* I.2–3, especially 340b32–341a12. Cf. Taub, *Ptolemy's Universe*, pp. 123–24.

works that are primarily devoted to such questions. Ptolemy's intention in the *Planetary Hypotheses*, on the other hand, is clear. He simply wants to highlight the supreme nature of aethereal and thus celestial motion, which is regular and circular, as opposed to what we see with regard to the sublunar elements. It is not possible for aethereal bodies to be influenced or hindered in such a way as earth and water, for example. This is, in the end, quite similar to Aristotle and also to the physical principles as Ptolemy presented them in the introductory chapters of the *Almagest*.

This allegiance to Aristotelian natural philosophy brings with it the adoption of the fifth element. Ptolemy does not provide any reason why he follows Aristotle on this point. He does not prove the existence of aether in general or that the heavenly bodies are made out of this fifth substance. The only thing he states is that the heavenly bodies are not changed or acted upon, which makes them different from the sublunar four elements. In contrast, Aristotle provided arguments for the existence and the superiority of aether in *On the Heavens* I.2. He argued that every simple motion needs to have a simple body that moves by it, and since the four sublunar elements are characterized by different rectilinear motions, there must be a fifth element for the superior circular motion. To this first proof, Aristotle adds in *On the Heavens* I.3 that aether indeed is neither heavy nor light, and that there is no generation, corruption or any kind of alteration in it.[34] Modern scholars have pointed to some inconsistencies by comparing it with passages from other works and some doubts concerning this rationale itself. Christian Wildberg even wrote that the defence of Aristotle's aether for a period of about 2000 years 'may perhaps be regarded as a scandal in the history of philosophy'.[35] Today, we know of at least two major opponents of the theory of aether in antiquity. Xenarchus had already severely criticized the theory of a fifth substance in the first century BC.[36] His criticism concerned, most importantly, Aristotle's ascription of one simple body to every simple motion. In the time after Alexander and Ptolemy, the denial of a fifth substance was most prominently upheld by Philoponus.[37] Ptolemy, however, does not address such concerns. He seems to be quite happy with adopting the fifth substance to allow the celestial bodies to move in a regular fashion.[38] The fact that

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[34] *Cael.* I.3, 269b18–270b4.

[35] General accounts of *On the Heavens* I.2–4 and its problematical implications are offered in Moraux, 'Quinta essentia', cols 1198–04; Wildberg, *John Philoponus' Criticism*, pp. 9–100. In the latter, see especially p. 99 for the quoted statement.

[36] See Sambursky, *The Physical World of Late Antiquity*, pp. 122–32, and Moraux, *Der Aristotelismus. Erster Band*, pp. 197–214.

[37] The most important analysis of Philoponus' critique is Wildberg, *John Philoponus' Criticism*, especially pp. 103–233. Simplicius' restatement and refutation of Xenarchus and Philoponus can be found spread throughout the commentary on *On the Heavens* I.2. See Simplicius, *In Cael.*, pp. 10–59.

[38] However, not even his somewhat superficially introduced theory is free from inconsistencies. For example, he writes in *Planetary Hypotheses* I.17 that the Moon and Mercury move more irregularly than the upper planets because they are closer to the sublunar influence of air. Ibn al-Hayṯam pointed

Ptolemy does not address such problematic issues himself is an indication of the dominant role of the theory of a fifth substance in the cosmological thought of his time. Surely, there were Platonists who assumed that the celestial bodies were made of fire, not aether. But even Xenarchus, who pointed out some inconsistencies in Aristotle's teaching, probably never offered a viable alternative. One must not forget that Aristotelian physics provided a coherent view of natural motion.[39] That the theory of aether, in its strict separation between sublunar and supralunar nature, was very attractive for astronomers in particular, is apparent through the wider reception of this theory in the Middle Ages.

This brief investigation of Ptolemy's elementary theory illustrates that Ptolemy not only engages critically with Aristotle (for instance, in the case of the celestial poles), but also adopts essential parts of his cosmology.[40] Most importantly, Ptolemy clearly follows an Aristotelian framework when he defends the strict separation between sublunar and aethereal physics and in making use of the principle that nature does nothing in vain. In a way, Ptolemy thus argues that his cosmological setup with sawn-off pieces and with celestial motions that are induced by souls is a better realization of Aristotle's own physical foundations than a mechanical system of complete spheres.

There is a very important question that sheds more light on Ptolemy's engagement with Aristotle: is there any need — or at least room — for Aristotle's unmoved movers in the cosmology of the *Planetary Hypotheses*? The first thing to note is that Ptolemy himself does not explicitly include any external movers in his cosmological setup. The only mention of a deity in a Ptolemaic astronomical work can be found in the very first chapter of the *Almagest*, where he writes that 'the first cause of the first motion of the universe [...] can be thought of as an invisible and motionless deity.' In addition,

to the fact that this contradicts what Ptolemy writes about the unchanging nature of aether. See Ibn al-Hayṯam, *al-Šukūk*, pp. 46:15–47:5.

[39] This is how Wildberg tried to explain the success of this theory. See Wildberg, *John Philoponus' Criticism*, pp. 99–100.

[40] Another indication of their similar approach is that Ptolemy focuses on the concept of elementary motion in his presentation of the physical approach to astronomical questions. This is, as Solmsen pointed out as a contrast to Aristotle's predecessors, also the most fundamental concept in *On the Heavens*. See Solmsen, *Aristotle's System*, pp. 253–60, especially p. 259: 'In founding his cosmology to such an extent on the specific movements of the four elements and on (what fundamentally comes to the same) their weight and lightness, Aristotle has achieved something that by all indications must have been a matter of great concern to him. He has constructed an essential part of his system from purely physical premises. [...] In this point of principle his procedure contrasts sharply with that adopted by Plato. Plato's description of elements as constructed from solid regular bodies is criticised by Aristotle in *On the Heavens* III.7, 306a1–b2 and is completely lacking in Ptolemy. However, there are a few passages, especially in Plato's *Phaedo* and *Timaeus*, which were used by Neoplatonic authors to ascribe a fifth element to Plato as well. See *Tim.* 55c4–6 and *Phd.* 109b7–9. See also Wilberding, *Plotinus' Cosmology*, pp. 13–14 n. 83 for references to passages in Simplicius and Proclus. This might also be the case for Ptolemy, namely that he himself did not consider the differences between Aristotle and Plato on the nature of the heavens as being that significant.

Ptolemy sometimes calls the aethereal region 'divine' in the *Almagest*.[41] Despite his silence on immaterial substances as celestial movers, it is clear that he does not need a number of external celestial movers corresponding to the number of spheres, as Aristotle suggests in his *Metaphysics*.[42] Ptolemy's use of self-moving planets makes such an account superfluous because the planetary capacities are responsible for the impulse to move. The question, however, remains about what to do with the 'absolute will' and the 'wonderful intellect'. We can possibly identify them as important Platonic features, if we compare them to Plato's World Soul, which conducts the celestial motions of the 'Same' and the 'Different' in the *Timaeus*. Quite famously, Plato called the cosmos a living being (*zōon*), embracing all other living beings. This can be brought into harmony with Ptolemy's theory of the origin of motion in animals and in the cosmos that can be gathered from *On the Kriterion* and the *Planetary Hypotheses*.[43] Plato also ascribes individual souls to the stars and planets, and, as Gregory Vlastos concluded, 'all celestial motion is to be explained as psychokinesis'.[44] In this picture, Ptolemy's 'wonderful intellect' could be interpreted as being analogous to the World Soul, which also contains the motions of the self-moving planets and their spheres.

On the other hand, Ptolemy's remark from *Almagest* I.1 sounds like it refers to the Aristotelian Prime Mover, and there are also passages in *On the Heavens* suggesting that the heavens and/or the stars are alive and thus ensouled.[45] According to this interpretation, the 'wonderful intellect' has the same role as Aristotle's Prime Mover

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[41] This citation stems from Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 5:13–16, tr. by Toomer in Ptolemy, *Almagest*, p. 35. For the references to the 'divine' heavens, see Ptolemy, *Syntaxis*, I.3, Vol. 1, p. 14:9; IX.2, Vol. 2, p. 208:8; XIII.2, Vol. 2, p. 532:15.

[42] See *Metaph.* XII.8, 1073b3–1074a18.

[43] See *Tim.* 32c5–33b4 and 36b6–37c5. See Feke, *Ptolemy's Philosophy*, pp. 195–97 for the same comparison. Of course, the depiction of the cosmos as a living being is also an important feature of Stoic cosmology. See for example Hahm, *The Origins of Stoic Cosmology*, especially Chapter V, which is fittinlgy entitled 'Cosmobiology'.

[44] Vlastos, *Plato's Universe*, p. 31. Cornford has drawn attention to Proclus' commentary on the *Republic*, where he writes that in the *Timaeus*, Plato states that some planets 'have a forward and backward movement according to their own will (*kata tēn autōn boulēsin*)'. Proclus, *In Rep.*, Vol. 2, p. 233:3–5, cited in Cornford, *Plato's Cosmology*, p. 107 n. 3. At first sight, this seems to be very similar to the account of the *Planetary Hypotheses*. Vlastos, however, strongly opposed Cornford's view that the planets choose to decide to deviate from the motion of the Other. For Cornford's interpretation, see Cornford, *Plato's Cosmology*, pp. 86–87 and 106–12. For Vlastos' critique, see Vlastos, *Plato's Universe*, pp. 58–59. See Wilberding, *Plotinus' Cosmology*, pp. 16–19 for a very short summary.

[45] See, for example, *Cael.* II.2, 285a27–31 and II.12, 292a20–21. I rely on the concise overview offered in Wilberding, *Plotinus' Cosmology*, pp. 29–32. Even if one follows the interpretation by some modern scholars (see a list in Moraux, 'Quinta essentia', col. 1199) that the souls move the celestial bodies in accordance to their natural motion, this is not compatible with Ptolemy's view in the *Planetary Hypotheses*, since Aristotle explicitly writes that the stars are not self-moved but fixed on their respective sphere (*On the Heavens* II.8), and there is no Aristotelian passage that would ascribe the impulse toward celestial motion to the planets and stars themselves. On the different accounts of celestial motion in the *On the Heavens*, *Physics* VIII, and *Metaphysics* XII, see also Judson, 'Heavenly Motion'.

in the sense that it causes the 'general motion of aether', as the Prime Mover causes the motion of the sphere of the fixed stars, and the planetary souls just fill in for at least some of the other unmoved movers from *Metaphysics* XII.[46] Against this interpretation, we have Ptolemy's rejection of an external or an unmoved principle of motion in *Planetary Hypotheses* II.5. Given that he also does not have a theory of different kinds of causation so that the unmoved movers can function as the final causes, one cannot conclude from the *Planetary Hypotheses* that unmoved movers are an essential part of Ptolemy's cosmology. Moreover, one can consider his psychological explanation, which implies that the impulse for movement comes from the planet and thus from inside the spheres, as an alternative approach not only to the mechanical transmission of motion via celestial poles, but also to Aristotle's unmoved movers. Perhaps the best way to harmonize these arguments from the *Planetary Hypotheses*, on the one hand, and the deity from the *Almagest* as well as the 'wonderful intellect' from the *Planetary Hypotheses*, on the other, is to conclude that Ptolemy does not want to offer a full-fledged metaphysical or theological picture. Unlike Aristotle, Ptolemy does not have an interest in immaterial substances in particular. What is important for Ptolemy is his theory of celestial mechanics on a psychological level. The planetary motions arise through a combination of the general motion of the cosmos, since the planetary spheres are embedded in aether and thus are carried away by it, and an impulse from the planets themselves. Since the motions of the spheres are voluntary, and also the aethereal motion comes about through a certain will — whatever its exact nature might be — it is at least safe to conclude that the heavenly motions in Ptolemy's cosmology are caused by souls.[47]

Although one can close some gaps in Ptolemy's dynamical account by referring to *On the Kriterion*, one cannot but conclude that Ptolemy left us with some uncertainties and open questions concerning the details of his theory of celestial dynamics. This is why I will devote the next section to an analysis of how other philosophers dealt with these topics in order to see whether we can apply similar solutions to Ptolemy. I focus especially on Alexander of Aphrodisas, because he lived around the same time as Ptolemy, because he addressed the same issues, and because he is a key figure in the subsequent medieval Arabic tradition. There is, however, a decisive difference between Ptolemy and other Hellenistic philosophers. As shown in Chapter II, his aim in the *Planetary Hypotheses* is to present the most economic and thus most probable cosmological account. Questions such as the involvement of unmoved movers do not have an influence on the resulting number of spheres. When Ptolemy denies Aristotle's mechanistic account and replaces it with his theory of celestial dynamics that involves souls, he achieves a reduction in

[46] This interpretation has recently been put forward by Jacqueline Feke. See Feke, *Ptolemy's Philosophy*, pp. 198–200. The crucial point in her argument is that the planets are 'not only ensouled but also desiring'. In the *Planetary Hypotheses*, Ptolemy does not ascribe any desire to celestial bodies.

[47] In short, Ptolemy expresses this by opposing celestial motion to sublunar motion, which is called 'the motion that is not from soul' (*al-ḥaraka ġayr nafsāniyya*). See *Plan. Hyp.* II.3, p. 290:9.

the celestial bodies that are needed to bring about the complex planetary motions. Therefore, as brief as his description of voluntary celestial motions might appear, this is, in fact, enough for Ptolemy to arrive at the — in his view — most economical cosmology. When one considers the uncertain epistemological status of theology and physics, one could also add that Ptolemy does not need further arguments from another uncertain branch of theoretical philosophy, namely theology, after having already used some principles from natural philosophy.

Comparable Trends in Ancient Peripatetic Philosophy

We have seen Ptolemy's critical engagement with Aristotle throughout the general presentation of heavenly physics. On the one hand, he builds his own account close to some of the most important Aristotelian doctrines; on the other hand, he dismisses some important features of Aristotle's cosmos. To make it short: the criticized elements stem from *Metaphysics* XII and not from *On the Heavens*. In fact, Aristotle speaks about the arrangement of the spheres only in the former with respect to the question of the number of movers. With only this question in mind, Aristotle starts to present and further develop the astronomical systems he inherits from Eudoxus and Callippus. This means that the issue of the arrangement of heavenly spheres is, for Aristotle, also a metaphysical one, because the number of celestial movers depends upon the number of celestial spheres. While Aristotle brings astronomy into play because he aims to determine the number of unmoved movers, in his assessment of Aristotle, Ptolemy focuses on his astronomical theory from *Metaphysics* XII and does not elaborate on the theory of divine entities acting as movers. Ptolemy alludes to a divine mover only in the first chapter of the *Almagest*. However, he discusses and criticizes other elements from *Metaphysics* XII in the *Planetary Hypotheses* and depicts them as falling under the 'physical approach'.

This characterization nicely highlights again that Ptolemy considers Book II of the *Planetary Hypotheses* as a work on the physical representation of the heavenly motion. Even more so, Ptolemy apparently thinks that the discussion of counteracting spheres, celestial poles, and the transmission of motion does not belong to metaphysics but to physics. We find a similar reorganization of the Aristotelian material long before Ptolemy, namely in the works of Aristotle's pupil Theophrastus (fl. fourth to third centuries BC). Today, there is an extant work called *On First Principles*, which also goes under the title *Metaphysics*. Indeed, this short treatise offers a critical engagement with Aristotle's *Metaphysics*, especially Book XII.[48] Because of the aporetic character of this work, Theophrastus' own positions are not always discernible. However, especially in comparison with the *Planetary Hypotheses*, it is

[48] See Devereux, 'The Relationship'. The Greek and Arabic versions of this text have been edited by Dimitri Gutas in Theophrastus, *On First Principles*.

important to note that Theophrastus does not discuss counteracting spheres in his work. Like Ptolemy, Theophrastus also treats this topic as physical, not metaphysical, and although his works on physics are lost, we have some traces of them in later commentaries on Aristotle's *Physics*. We learn through three remarks in Simplicius' commentary on *On the Heavens* that Theophrastus dealt with the Aristotelian theory of the spheres (specifically starless spheres and counteracting spheres).[49] Although this is not to say that Theophrastus had a direct influence on Ptolemy, a superficial look at the topics covered in *On First Principles* is useful in order to understand the history of the interaction between philosophy and astronomy. There is the already mentioned shift in Theophrastus to addressing the question of the numbers of movers independently from the discussion of the homocentric model of the spheres.[50] Then what are the topics discussed by Theophrastus in his work on metaphysics? A substantial amount of Theophrastus' *On First Principles* deals with the question of the number of unmoved movers.[51] In connection with the overall question of the ensoulment of the heavenly spheres, Theophrastus addresses the issue of the relationship between desire and celestial motion. Apparently, he was the first to do so and he was followed by later peripatetics, especially by Alexander of Aphrodisias.[52] Lastly, Theophrastus also touches on the interaction between the supralunar and the sublunar realms, and especially whether the celestial spheres have an impact on the world of generation and corruption.[53] Regarding this last topic, it is not entirely clear whether Theophrastus actually adopted Aristotle's teaching of a fifth element or not.[54]

This comparison provides us with a parallel between Ptolemy and Theophrastus, insofar as they separate the metaphysical discussion of unmoved movers and their number from Aristotle's astronomy. In this chapter, I locate Ptolemy's theory of celestial dynamics within the context of other cosmological accounts from the time between Aristotle and Ptolemy. This will help us to understand that the *Planetary Hypotheses* is not the first work devoted to topics on the intersection of physics, astronomy, and metaphysics, and to pinpoint Ptolemy's original contributions to this debate.

The first example from this period that had an enormous influence on later traditions is the spurious *On the World*, which, in the manuscripts, is ascribed to

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[49] Simplicius, *In Cael.*, 491:19–20, 493:17–20 and 504:4–6. This point was already made by Steinmetz, *Die Physik*, p. 159 n. 1.

[50] Another example of a similar new arrangement of Aristotelian topics is Simplicius, who includes the discussion of Aristotle's *Metaphysics* XII in his commentary on *On the Heavens* II.10–12.

[51] See Theophrastus, *On First Principles*, Chapters 6–12.

[52] See Endress, 'Alexander Arabus', p. 41. The passage in question is Theophrastus, *On First Principles*, Chapter 8.1. See also Gutas's analysis at Theophrastus, *On First Principles*, pp. 285–86.

[53] See Theophrastus, *On First Principles*, Chapter 10.

[54] See the summary in Moraux, 'Quinta essentia', cols 1231–32. For some arguments for a rejection of aether by Theophrastus, see Steinmetz, *Die Physik*, especially on pp. 163–67. These arguments have been criticized by Robert Sharples (see Sharples, 'Theophrastus on the Heavens', pp. 577–90).

Aristotle but is most often considered as a later product, not later than the second century AD.[55] As such, *On the World* is also an important work from the time between Aristotle and Alexander and thus is a valuable witness of the way in which cosmological questions were treated. It has further significance for our investigation because it was translated into Syriac and Arabic, and is today extant in at least three different versions.[56] In contrast to Theophrastus' *On First Principles*, *On the World* has a wider scope.[57] It can be divided into two main parts, the first being a description of the composition of the entire cosmos, starting from the heavens down to the sublunar elements. The second part discusses the relationship between God and the cosmos and, in that context, divine providence. The basic notions of the theory of aether as outlined in the second chapter are not new: it is 'pure and divine' (*akēraton te kai theion*), 'well-ordered' (*tetagmenē*), 'inflexible, unchangeable and impassive' (*atrepton kai aneteroiōton kai apathē*), and it is the substance of the heavens and of the stars.[58] Its motion is eternal (*aïdion*) and the motion of the entire heavens is compared to a dance (*synanaxoreuō/xoreuō*). Although this is controversial, there may be a brief allusion to a more complex system of the various celestial spheres of the planets. Explicitly mentioned is a sphere for each of the planets and one for the fixed stars, which are arranged concentrically.[59]

In contrast to the heavens, the sublunar realm is depicted in *On the World* as the realm of generation and corruption, as is evident from the various meteorological and geological phenomena. However, it has also been pointed out that this picture of a clear distinction between these two realms is blurred in the fifth chapter of the same work.[60] This is not necessarily a fundamental break with the Aristotelian concept of aether, since in Aristotle one can also find allusions to air or fire as being dispersed throughout the supralunar regions.[61] The fifth and sixth chapters of *On the World* concern the harmony of all elements in the cosmos and God's providence. God's power emanates throughout the entire cosmos and thus preserves and directs

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[55] I use the edition by Lorimer, see [ps.-]Aristotle, *Aristotelis qui fertur libellus de mundo*. The English translation by Johan Thom can be found in [ps.-]Aristotle, 'On the Cosmos'. For an overview of the debate of the dating and authenticity, see the introduction to the latest translation into English in Thom, *Cosmic Order*, pp. 3–8. The authentic authorship of Aristotle has been defended by Giovanni Reale and Abraham P. Bos, see Reale and Bos, *Il trattato Sul cosmo*.

[56] See Stern, 'The Arabic Translations', Stern, 'A Third Arabic Translation', Takahashi, 'Syriac and Arabic Transmission', and McCollum, 'Sergius of Reshaina' for overviews of the different versions.

[57] A concise summary of this work's content can be found in Moraux, *Der Aristotelismus. Zweiter Band*, pp. 5–82.

[58] *De mundo*, 391b16–19, 392a5–9 and 31–33, and 399a12. The English terminology goes back to Thom's translation, see [ps.-]Aristotle, 'On the Cosmos', pp. 22–25.

[59] See *De mundo*, 392a13–23. This is the interpretation by Abraham P. Bos, for which see Bos, 'Supplementary Notes', pp. 316–317.

[60] See the analysis by Onnasch, 'Die Aitherlehre'.

[61] For example *Cael.* I.2, II.7, and III.1, see again Onnasch, 'Die Aitherlehre', pp. 180–83. Also Moraux, 'Quinta essentia', col. 1209 concluded, though with respect to another set of problems, that Aristotle probably never upheld a consistent theory of aether.

everything in it, although the highest regions of the cosmos have a greater share in his power than the sublunar elements, for example.[62] By this power, God also induces celestial motions. This begs the question of the origin of the different observed planetary motions. The author of *On the World* explains:

> So also the divine being, by a simple movement of the first region, gives his power to the next things and from these again to those further away, until it permeates the whole. For one thing, being moved by another, itself again also moves something else in regular order, while all things act in a way appropriate to their own constitutions; but there is not the same way for all, but a different and diverse one, in some cases even the opposite, although there is just one initial striking of the key-note, as it were, that leads to movement. [...] So too in the cosmos: by means of a simple revolution of the whole heaven completed in a day and a night the different orbits of all [the heavenly bodies] are produced, although they are encompassed by a single sphere, some moving faster, some more leisurely according to the length of the distances and their own constitutions.[63]

And a little bit later:

> By a single impulse (*rhopē*) the proper functions of all things are performed when these are stirred into action, although this impulse is unseen and invisible.[64]

In sum, the author of *On the World* states that:
(1) Upon the impulse of God's power, the first celestial motion (the diurnal rotation of the sphere of the fixed stars) is brought forward;
(2) by their own revolution, the upper spheres transmit this impulse to the lower spheres;
(3) the way in which the spheres move are nevertheless different because they are different in themselves and thus naturally produce different kinds of motion.

Within this scheme, two major problems are manifest. The first is the gap between the natural circular motion of aether on the one hand and the variety of celestial motions on the other hand. This problem occurs in *On the World*, since in Chapter 2, it is said that the entire heavens, together with the stars and planets are made out of aether, but Chapter 5 states that the spheres nevertheless have different capacities or constitutions. A similar problem can be found in the Aristotelian corpus if one compares the account of aethereal natural motion from *On the Heavens* with the account of a separate unmoved mover for every celestial sphere in *Metaphysics* XII. This leads to the second major problem, since the model of an impulse that is transmitted

[62] *De mundo*, 397b20–398a6.

[63] *De mundo*, 398b19–399a6 tr. by Thom in [ps.-]Aristotle, 'On the Cosmos', pp. 45–47.

[64] *De mundo*, 399b11–12 tr. by Thom in [ps.-]Aristotle, 'On the Cosmos', p. 49. These two quotes stem from different analogies that are supposed to illustrate the relationship between God and the cosmos. For an overview of these analogies, see Betegh and Gregorić, 'Multiple Analogy', especially pp. 578–82, and more recently Betegh and Gregorić, 'God's Relation', pp. 187–94.

from the first to the lowest sphere renders all other unmoved movers except the Prime Mover superfluous. Moreover, the author of *On the World* explicitly states that God 'has no need of the contrivance and service from others'.[65] While *On the World* does not elaborate any further on this set of questions, we will immediately see that Alexander of Aphrodisias offers a solution to the tension between natural aethereal motion and celestial motions induced by movers. Nevertheless, before we move on to Alexander, it must be noted that there are certain parallels between Ptolemy and the quotes from *On the World*. In *Planetary Hypotheses* II.7, Ptolemy described the way in which the motion of a planet comes about: the planet sends out an impulse and every sphere belonging to that planet replies by starting to move with the motion appropriate to it. He compared this to the motion of the entire bird (which corresponds to the entire set of spheres belonging to one planet) and the motion of the nerves and limbs (which correspond to epicycles, eccentrics, and concentric spheres). All of these motions are different from each other, although they all depend on the same impulse.[66] One clearly sees that *On the World* offers a similar explanation for the occurrence of a variety of celestial motions. Even the gaps in both accounts are comparable, most importantly, the underexplained relationships among the Prime Mover or wonderful intellect, the natural motions of aether, and the complex planetary motions.

The importance of the works of Alexander of Aphrodisias' (fl. second century AD) in the medieval Arabic tradition can be seen through the large number of treatises translated into Arabic.[67] However, if we want to access Alexander's cosmological thought, the corpus in its extant state poses some difficulties. The commentary on Aristotle's *On the Heavens* is lost, as is his commentary on *Metaphysics* XII in Greek (the extant version is of a pseudepigraphic nature). In addition, the two most important cosmological treatises, *On the Cosmos* and *On Providence*, survived only in their Arabic translations. Because of the difficult history of *On the Cosmos*, its authenticity and attribution to Alexander is not without doubts.[68] Despite these caveats, there are at least two good reasons why these works offer some valuable insight to the present study. The first and most obvious one is that these latter works

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[65] *De mundo*, 398b10–11, tr. by Thom in [ps.-]Aristotle, 'On the Cosmos', p. 45.

[66] *Plan. Hyp.* II.7, p. 302:1–14.

[67] See the extensive list of works in Ibn Abī Uṣaybiʿa, *ʿUyūn al-anbāʾ*, Vol. 1, pp. 69–71, and for commented lists by modern authors, see Dietrich, 'Die arabische Version', pp. 92–100, Goulet and Aouad, 'Alexandros d'Aphrodisias', and Fazzo, 'Alexandros d'Aphrodisias'.

[68] In his introduction to the edition of *On the Cosmos*, Charles Genequand argues for its authenticity, see Alexander of Aphrodisias, *On the Cosmos*, pp. 1–3. Doubts have been raised by Dimitri Gutas, see Gutas, *Avicenna and the Aristotelian Tradition*, p. 247 n. 46. An overview of the three versions of *On the Cosmos* can be found in Endress, 'Alexander Arabus', pp. 42–47, and Fazzo and Zonta, 'Towards a Textual History'.

were known to the Arabs under Alexander's name and influenced the way in which medieval authors thought about Aristotelian cosmology.[69]

The second reason, on the other hand, is that although the authenticity of the Arabic treatises can be doubted, they include certain teachings that can be attributed to Alexander. This becomes evident by a comparison with the fragments of the lost commentaries on *Metaphysics* XII and *On the Heavens* that are preserved in Simplicius and Averroës. The former, in particular, preserves many Alexandrian passages in his own commentary on *On the Heavens*, whereas Averroës uses some material from Alexander's commentary on *Metaphysics*.[70] The most important of these Alexandrian elements is definitely his account of planetary motion. How do they come about? What is their relationship to the Prime Mover? Alexander, as it seems, found a straightforward solution to a certain ambiguity arising from the Aristotelian corpus, because it is not entirely clear whether Aristotle held the position that the heavenly bodies are ensouled and, if so, what role the souls play in celestial motions. This difficulty arose from the contrast between the description of circular motion as being natural for the heavens and of ensouled celestial bodies, making soul and not nature the cause of their motions.[71] *On the Cosmos* addresses these issues and takes a comparison of different principles of motions as the starting point. Inanimate (soulless) beings move by inclination (*mayl*, the same term that we find in the Arabic version of Ptolemy's *Planetary Hypotheses*) towards their proper

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[69] Consider, for instance, the citations in Averroës and Avicenna. See Endress, 'Alexander Arabus', pp. 55–60, and Genequand's introduction in Alexander of Aphrodisias, *On the Cosmos*, pp. 20–26.

[70] cf. Freudenthal, 'Die durch Averroes erhaltenen Fragmente' for a translation and discussion of the fragments in Averroës. The authenticity of these fragments has lately been analysed and questioned by Matteo Di Giovanni and Oliver Primavesi. See Di Giovanni and Primavesi, 'Who wrote Alexander's Commentary'. See also Moraux, *Der Aristotelismus. Dritter Band*, pp. 181–241 for a reconstruction of Alexander's commentary on *On the Heavens*, which was at least partially known to the Arabs, as well as Coda, 'Alexander of Aphrodisias in Themistius'.

[71] For a brief but concise summary, see Merlan, 'Plotinus Enneads 2.2', pp. 179–82, and Wilberding, *Plotinus' Cosmology*, pp. 29–32. Friedrich Solmsen, for example, emphasizes the importance of the circular motion that is natural for the celestial element, aether, and concludes that Aristotle expanded the physical explanation of motion to the heavens and that thereby, the Platonic World Soul loses its essential role in the heavenly motions. See Solmsen, *Aristotle's System*, pp. 288–91. In his commentary on *On the Heavens*, Leo Elders points to the apparent inconsistency within Aristotle's works. There are allusions to the ensoulment of the heavens in *On the Heavens* II.2, 9 and 12, which are, however, contradicted by II.1, 284a27–29. Thus, Elders detects two different lines of argument in Aristotle, the first including a Prime Mover and ensouled heavens and the second involving heavenly bodies that move because of their inborn nature without the influence of a Prime Mover. Nevertheless, Elders also concludes that this does not necessarily mean that these two lines disagree with each other. See Elders, *Aristotle's Cosmology*, pp. 27–33. A solution to this problem has been offered by William D. Ross, who argued that Aristotle needed the heavenly souls to be the 'powers of initiating movement', see Ross's introduction in Aristotle, *Physics*, pp. 97–98. Moraux, 'Quinta essentia', cols 1198–00 suggests that although Aristotle upheld both the ensoulment of celestial bodies as well as the natural aethereal motion, he did not complete the task of harmonizing them with each other, but this was left for his successors.

place, where they reach perfection.[72] Animate beings that are equipped with a soul, however, are moved by their souls and have a desire, which is directed towards the best of all existing things. This is ultimately the Aristotelian Prime Mover. The souls of the heavenly bodies are equated with their nature. Thus Alexander is able to conclude that celestial motion that arises from the desire within their souls is, at the same time, natural.[73] The inclination within inanimate beings is analogous to the desire that arises from the souls of animate beings. Both inclination and desire are called 'impulse' (*iš̌tiyāq*). This means that in both Alexander and Ptolemy, 'impulse' (*iš̌tiyāq* in the former, *inbiʿāṯ* in the latter) fulfils the same task, namely inducing motion in ensouled beings, with the slight terminological difference that Ptolemy distinguishes between impulse and inclination for the animate and inanimate beings, respectively, and Alexander considers impulse as the general term for what is to be called 'desire' in animate beings and 'inclination' in inanimate beings.[74] For Alexander, however, this concept of impulse does not mean that non-animate bodies have the same impulse as animate beings, which would be problematic, given certain passages in Alexander's other works.[75] Before the author of *On the Cosmos* turns to a discussion of the Prime Mover, he gives the following summary of celestial motion:

> We must consider that all the spheres possess souls and that each one of them has a soul proper to itself and moves only with its natural motion through the impulse proper to it in its nature. For the nature of these things is the soul, since the form of the divine body is the most perfect of forms and the souls of the divine bodies do not at all need different organic bodies in order to [perform] the acts that proceed from them.[76]

The most important aspect of the cosmology of *On the Cosmos* is exactly the author's answer to the abovementioned problem in Aristotle, whether soul or nature is the efficient cause of the spheres' motions. In *On the Cosmos*, soul is simply equated with nature. The spheres are ensouled and their souls have an impulse, namely desire, causing their motion. However, this motion is natural, in the sense that 'the nature is the soul'. Whereas natural and voluntary motions are contrasted in the sublunar realm, this solution suggests that they coincide in the celestial realm only. This picture also includes the Prime Mover and solves the discrepancy in Aristotle

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[72] Alexander of Aphrodisias, *On the Cosmos*, Section 4. Simplicius had already likened this theory of sublunar motion to Ptolemy's (and to the one by Xenarchus and Plotinus) with respect to the fact that motion ceases once sublunar bodies reach their proper place. See Simplicius, *In Cael.*, pp. 20:10–25:21, where Simplicius discusses not only Ptolemy's account, but also Alexander's refutations of Xenarchus.

[73] Alexander of Aphrodisias, *On the Cosmos*, Sections 4–8, 17–19, and 97.

[74] The two different Arabic terms for 'impulse' might go back to the same Greek term, namely *hormē*. For Ptolemy's use of *hormē* in *On the Kriterion*, see above pp. 155–57, and for Alexander, see Wolfson, 'The Problem of the Souls', p. 74.

[75] For the references, see the extensive remarks in Bodnár, 'Alexander's Unmoved Mover', p. 392 n. 11.

[76] Alexander of Aphrodisias, *On the Cosmos*, Section 96, tr. by Genequand, modified.

between the natural motion of aether in *On the Heavens* and the causal role of the unmoved movers in *Metaphysics* XII.[77] Thus, heavenly motion is both efficiently caused by soul and nature. Whatever one thinks about the authenticity of *On the Cosmos*, this solution is also ascribed to Alexander by Simplicius in his commentary on *On the Heavens*.[78] Of particular interest is a similar quotation from Alexander in Simplicius' commentary on *Physics*:

> For he [viz. Alexander] thinks that soul and nature are the same in the heavens. He indeed writes in the commentary on the second book of *On the Heavens* the following: 'We intend to prove that the nature and the soul of the divine body are not different, but like the weight of earth and the lightness of fire' and shortly afterwards 'For what other nature would it have besides this [the soul]? For soul is a more complete nature, and it is reasonable that the nature belonging to the more complete body is itself more complete.'[79]

This paragraph contains the same themes we encountered already in *On the Cosmos*: (1) nature and soul are the same with regard to the celestial realm, (2) the spheres' natural motion that is induced by an impulse of the soul is compared to the inclination of the sublunar elements, and (3) the souls of the spheres have a desire towards that which is even more complete than themselves, namely the Prime Mover.[80] There are more passages in Simplicius' commentary that are consistent with the overall argument in *On the Cosmos*.[81] One further important example is Alexander's theory of providence, which occurs in *On the Cosmos* and *On Providence*, as well as in Simplicius' commentary. According to all of these three sources, Alexander claimed that the eternal motion of the heavens is the reason why the sublunar bodies are changed into each other, generated, and corrupted in an

[77] See again Moraux, 'Quinta essentia', col. 1207.

[78] See the citations of Alexander's lost commentary in Simplicius, *In Cael.*, pp. 379:18–381:2 and 387:5–25, where Simplicius explicitly criticizes Alexander for mixing nature and soul. Simplicius himself wants to maintain that only soul activates motion and nature provides the heavens with an inclination for being moved.

[79] Simplicius, *In Phys. V–VIII*, p. 1219:1–7, tr. by Bodnár et al. in Simplicius, *On Aristotle Physics 8.1–5*, p. 128.

[80] That motion comes about through a desire towards the Prime Mover is also ascribed to Alexander in Simplicius, *In Phys. I–IV*, p. 258:23. Similar summaries of Alexander's cosmology can be found in Sharples, 'Alexander of Aphrodisias', pp. 1214–15, and Endress, 'Alexander Arabus', pp. 49–55. Apparently, John Philoponus was also aware of this interpretation by Alexander, but claimed that one could not ascribe such a theory to Aristotle. According to Philoponus, Aristotle himself had denied the causal role of souls in celestial motion, probably also alluding to *On the Heavens* II.1, 284a27–29, see Simplicius, *In Cael.*, pp. 78:12–79:14, and Philoponus, *Against Aristotle*, fragment 49.

[81] See, for example, Simplicius, *In Cael.*, pp. 16:22–30 and 676:19–20, where Alexander is said to have argued that the beginning of natural motion lies within the natural bodies themselves, explicitly with regard to the sublunar elements, which can be compared to the inclination theory from *On the Cosmos*.

orderly fashion.[82] The well-ordered nature of the cosmos plays a crucial role when Alexander tries to tackle the question why the celestial motions are natural, even though the daily westward rotation is countered by the eastward rotation of the planets. According to Alexander's lost commentary, the planets choose to move in their specific directions to preserve the cosmic order.[83]

Another major problem for Alexander is the number of celestial movers. *On the Cosmos* devotes an entire section to a discussion of the question whether there is really one separate mover for every sphere (as Aristotle seems to have upheld in *Metaphysics* XII.8) or whether there is only the Prime Mover. The complicated history of the texts in question makes it hard to come to a conclusion regarding Alexander's final answer to this problem. More recent studies, however, tend to ascribe only a single unmoved mover to his cosmological system. In this scheme, the unmoved movers from *Metaphysics* XII could be interpreted as the spheres' souls and not as separate movers. All ensouled spheres desire the one separate mover, which is the Prime Mover, and diverse celestial motions come about through the variety of spheres' souls.[84] In this context, it is important to note that Alexander conceived of souls for the spheres, not for the planets themselves. This is explicitly stated in *On the Cosmos* and confirmed by Simplicius: Alexander apparently upheld the theory of ensouled spheres instead of ensouled planets in order to make sure that it was the spheres that moved and carried the planets along.[85] The background of the discussion is formed by Aristotle's argument in *On the Heavens* II.8 against the motion of the stars. Aristotle supplements his argument there by stating that the stars do not have organs for locomotion as animals do.[86] By assigning the soul

[82] In *On the Cosmos*, the relationship between this well-ordered change in sublunar bodies and the divine heavenly motion is compared to the governance of a city, see Alexander of Aphrodisias, *On the Cosmos*, Sections 127–51. For the corresponding passages in *On Providence*, see various passages in the edition and translation in Ruland, *Die Arabischen Fassungen*, especially pp. 51–70. See also Sharples, 'Alexander of Aphrodisias on Divine Providence', Sharples, 'Alexander of Aphrodisias', pp. 1216–18, and Freudenthal, 'Cosmology', pp. 314–17. The report by Simplicius can be found in Simplicius, *In Cael.*, pp. 404:4–405:27.

[83] See Simplicius, *In Cael.*, pp. 472:8–20.

[84] This interpretation can be found in Endress, 'Alexander Arabus', p. 46, in Genequand's introduction to his edition of *On the Cosmos.* See Alexander of Aphrodisias, *On the Cosmos*, pp. 10–14 and, most recently, Bodnár, 'Alexander's Unmoved Mover' regarding Alexander of Aphrodisias, *On the Cosmos*, especially Sections 79, 86, 91, 95, and 96. Support can also be gained from Simplicius, *In Cael.*, pp. 270:5–12, as well as Simplicius, *In Phys. V–VIII*, p. 1261:30–33. These testimonies have also been discussed by Bodnár, see Bodnár, 'Alexander's Unmoved Mover', pp. 400–15. Making use of the testimony in Simplicius' commentary on *Physics*, Robert W. Sharples, on the other hand, also argued that Alexander followed Aristotle's *Metaphysics* in assuming a separate mover for every sphere. See Sharples, 'Alexander of Aphrodisias on Divine Providence', pp. 208–10, who had access to *On the Cosmos* only through Badawī's earlier edition and translation.

[85] Compare Alexander of Aphrodisias, *On the Cosmos*, Section 96, and Simplicius, *In Cael.*, pp. 447:4–449:2.

[86] *Cael.* II.8, 290a29–b11.

and thus the seat of the moving force to the sphere, Alexander makes sure not to disagree with Aristotle. One can find an echo of Aristotle's argument on the lack of any celestial organs in the above-quoted section (96) of *On the Cosmos*: 'souls of the divine bodies do not at all need different organic bodies in order to [perform] the acts that proceed from them'.

At this point, some differences between Alexander's and Ptolemy's cosmologies arise. In making the planets the origin of the emission of an impulse to move, Ptolemy argues that the planets themselves are the seats of the souls, whereas the various spheres (eccentrics, epicycles, homocentrics) fulfil the function of organs, as he explicitly states. While Ptolemy openly opposes other Aristotelian doctrines, he does not bother to mention that he is in opposition to *On the Heavens* II.8 in this respect.[87] The contrast between Alexander and Ptolemy lies in the causal role the planets play in their own motion, which then leads to a discussion of whether the planets have a motion of their own, a possibility that Ptolemy leaves open, but not Alexander. Simplicius has already observed the difference between Alexander and Ptolemy on this point. He felt the need to refer to the *Planetary Hypotheses* as an alternative to Aristotle's and Alexander's accounts in the context of *On the Heavens* II.8. On their arguments that the stars themselves rest, he remarks that it still might be possible that the stars rotate in their place in a way not visible to us. He then adds a citation from the *Planetary Hypotheses* II.12, where Ptolemy states that the beginning of the motion arises from the planet itself, but in the context of rolling motion.[88] Thus, Simplicius sides with Ptolemy's theory of motions that are induced by souls and at the same time originate from the stars. He ultimately argues that the celestial bodies choose their proper motion according to their 'proper impulse'.[89] Another difference between Ptolemy and Alexander is the setup of the cosmos. Although it is again hard to get to Alexander's actual position, he apparently adopted at least a version of Aristotle's homocentric system. In *Quaestio* I.25, for example, he speaks of only eight spheres, but perhaps this is only to avoid the problem of the exact number of spheres, given the obvious problem with Aristotle's counting in *Metaphysics* XII.8. István Bodnár thus argued that Alexander still allowed the existence of further spheres within one 'bundle' of spheres, which should remind us of how Ptolemy uses the term 'sphere', as well.[90] In all, it is reasonable

[87] It might be that Ptolemy does not believe that this difference has a similar impact on the question at hand, namely the number of spheres, to Aristotle's theory of counteracting spheres. Whether we call the spheres 'organs' in an analogy to birds or not, this does not alter the number needed for planetary motion. Perhaps of relevance in this context is Ptolemy's criticism of philosophers who only fight over words, see Ptolemy, 'Peri Kritēriou', pp. 8:1–9:20.

[88] See Simplicius, *In Cael.*, p. 456:7–27, and above Chapter II, p. 59.

[89] See Simplicius, *In Cael.*, pp. 448:6–8 and 473:2–7. For a summary and further references, see Bowen, *Simplicius on the Planets*, pp. 34–36.

[90] See Bodnár, 'Alexander of Aphrodisias', and Moraux, *Der Aristotelismus. Dritter Band*, p. 500, who points to the fragments in Averroës (see above, p. 168 n. 70). Alexander's confusion about the number of spheres in Aristotle is preserved by Simplicius, see Simplicius, *In Cael.*, p. 503:10–26

to compare Alexander's cosmology to previous attempts to harmonize Aristotelian natural philosophy and recent astronomical models, as already seen in the case of Alexander's teacher Sosigenes. At the present state of research, we might ascribe a similar approach to Alexander.[91]

Apart from these two major differences, the investigation of Alexander's cosmological treatises has revealed important parallels between Alexander and Ptolemy. Although they disagree about the seat of the celestial souls, both of them maintain the importance of the souls' faculties for heavenly motions. Ptolemy comes close to Alexander's equation of soul with nature when he connects the circularly revolving nature of aether with the capacity of heavenly bodies to move according to this nature. That they have a similar, if not the same, theory of sublunar motions that must be understood as innate inclination was already pointed out by Simplicius. As a further point of similarity, in the *Planetary Hypotheses*, we find a statement on providence that should remind us of the abovementioned theory outlined by Alexander:

> For locomotion is prior to the other motions. In the things with an eternal nature there is only this single motion. This is the reason for the contrary changes in quality and quantity that occur in the non-eternal things. These changes are not only in what is apparent to us of them, as is the case for what is eternal, but [also] in themselves and their substances.[92]

One must admit that one can find Alexander's notion that celestial motions govern the regular change of sublunar bodies only in the one word 'reason' (*sabab*). However, this picture is consistent with what we find in Ptolemy's astrological work, the *Tetrabiblos*. In the introduction, Ptolemy writes:

> A very few considerations would make it apparent to all that a certain power emanating from the eternal ethereal substance is dispersed through and permeates the whole region about the Earth, which throughout is subject to change, since, of the primary sublunar elements, fire and air are encompassed and changed by the motions in the ether, and in turn encompass and change all else, earth and water and the plants and animals therein.[93]

Ptolemy goes on to explain why astrology, despite the reservations one might have against it as a science, is worth pursuing. Farmers and sailors, for example, are able to tell from the constellations in the heavens the quality of their harvest and the

(cf. pseudo-Alexander's commentary on *Metaphysics*, see [ps.-]Alexander of Aphrodisias, *In Aristotelis metaphysica*, pp. 705:39–706:13). See also Moraux, *Der Aristotelismus. Dritter Band*, pp. 224–25.

[91] On the fragments of Sosigenes' work, see again Moraux, *Der Aristotelismus. Dritter Band*, p. 224. For Sosigenes' astronomy and its relationship to the Aristotelian cosmos, see Schramm, *Ibn Al-Haythams Weg*, pp. 55–63, and Aiton, 'Celestial Spheres', pp. 81–83. For a recent overview, see Kupreeva, 'Sosigenes'. The comment by Alan C. Bowen in Bowen, *Simplicius on the Planets*, pp. 278–83, is also helpful, as he also draws a comparison with Ptolemy's *Planetary Hypotheses*. See also above Chapter II, pp. 43–44.

[92] *Plan. Hyp.* I.15, p. 262:8–11.

[93] Ptolemy, *Tetrabiblos*, I.2, pp. 4:19–6:7, tr. by Robbins, slighly modified.

imminence of a storm.[94] This means that the aethereal celestial motion has a regular impact on changes in the sublunar world.

How do these obvious similarities help us understand Ptolemy's *Planetary Hypotheses*? To answer this question, one should again look at what exactly Ptolemy is doing in Book II of his work. Chapter II.3 opens up the discussion of how we should conceive of the organisation of the cosmos and the causing of planetary motions as mathematics reveals them to us. Ptolemy begins this chapter with the phrase 'the physical reasoning (*al-qiyās al-ṭabīʿī*) leads us to saying', which suggests that he offers a more general account and not necessarily his own. The list of physical principles that follows should be quite familiar to us by now: the never-changing, eternal aether and celestial bodies, which are never influenced or forced to unnatural motion; their circular shape; that their motions are voluntary but also always in accordance with the aethereal nature; an impulse and the variety of celestial motions that occur though the different constitutions of the spheres; the theory of the inclination of the sublunar elements. In addition, Ptolemy uses terms such as 'will' and 'intellect', which he does not explain any further in his *Planetary Hypotheses*. Thus, when he introduces these terms in his description of the 'physical reasoning', he lays out not simply his own representation of the physical foundations of his cosmos, but the cosmological theory of his time, or at least, to be clear, those parts of the cosmological theory of his time to which he also subscribes. An investigation of the treatment of these issues in Theophrastus, *On the World*, and in Alexander of Aphrodisias has shown how these issues were treated in the time between Aristotle and Ptolemy. In this way, one can think of Theophrastus as paving the way for a critical engagement with the Aristotelian texts by identifying certain cosmological questions left open or not sufficiently presented by Aristotle. This tradition of Aristotelian cosmology, often mixed with Platonic elements and, later, more recent astronomical findings, can easily be followed up to the time of Ptolemy. One needs to read Ptolemy's *Planetary Hypotheses* as a contribution to these debates. First, he presents the 'physical reasoning'. In the next step, Ptolemy sets out the few Aristotelian theories that he dismisses, namely celestial poles as transmitters of celestial motion and counteracting spheres. Although the counteracting spheres have been treated in Aristotle's *Metaphysics* XII, he obviously considered them as physical and not metaphysical elements. In doing so, he had Theophrastus as an example. In the third step, Ptolemy presents his own solution to the problems at hand and thus we find a theory of celestial motion in *Planetary Hypotheses* II.7 that is distinctly Ptolemaic, in the sense that it is a development peculiar to Ptolemy's *Planetary Hypotheses*. This is his theory that the planets themselves direct their own complex motions by sending out impulses to their respective spheres. Thus, it is not only the case that celestial bodies in general are ensouled and strive to imitate unmoved movers or deities (as in Alexander), but each planetary system is primarily

[94] See Ptolemy, *Tetrabiblos*, I.2, pp. 8–11.

considered as a single animal endowed with spheres as the limbs and organs, and the planet as the seat of the soul. Furthermore, this makes it possible for the planets to be not only carried but also to have a motion independent from the carrying sphere. Since there is, at least to my knowledge, no other cosmological account that includes planets (a) as a source of the impulse to move, and (b) that move independently from a sphere, this theory serves as a suitable criterion for following the impact of the *Planetary Hypotheses* on subsequent traditions.

Celestial Dynamics in the Arabic Tradition

Merging Natural Philosophy with Astrology and Astronomy: al-Kindī

In order to follow the traces of Ptolemaic cosmology in the Arabic tradition, one must acknowledge that Aristotle's natural philosophy was the main point of reference for the question of the nature of the heavens and the different causes of their motions, issues with which Aristotle deals in his *On the Heavens*, *Physics*, and *Metaphysics*. This chapter will deal with the way in which medieval Islamic authors discussed Ptolemy's cosmological theories in light of the outstanding influence that these works had on the Arabic tradition. However, as already noted at the beginning of the previous chapter, Aristotle or Ptolemy were not the only key figures in this context, but also the commentaries by Alexander, Simplicius, and Philoponus, as well as further pseudepigraphic material such as *On the World* also had a great impact on medieval cosmology.

A good example of how the various sources entered the medieval Arabic cosmological discussions is the wide corpus of treatises by al-Kindī. I have already described how al-Kindī was well acquainted with Ptolemy's *Almagest* and borrowed the divisions of philosophy and their epistemological status from him, whereas it is unclear whether he also knew the *Planetary Hypotheses*.[95] What is clear, however, is that in his cosmological treatises, he draws extensively on Alexander and thus exemplifies Alexander's major subsequent influence.[96] For a coherent picture of al-Kindī's cosmology, it is necessary to rely on a number of smaller treatises. He bases his cosmological ideas on the same assumption about the nature of the elements as outlined in Aristotle's *On the Heavens*. In *On the Explanation that the Nature of the Celestial Sphere is Different from the Natures of the Four Elements* (*Risāla fī Ibāna ʿan ṭabīʿat al-falak muḫālifa li-ṭabāʾiʿ al-ʿanāṣir al-arbaʿa*), al-Kindī compares the rectilinear movement of sublunar elements and the circular movement of aether. After characterizing earth, water, air, and fire as active or passive, al-Kindī makes the

[95] See above Chapter II, pp. 79–80, and Gannagé, 'Al-Kindī, Ptolemy'.

[96] This has been established by Fazzo and Wiesner, 'Alexander of Aphrodisias'. For summaries of al-Kindī's cosmological treatises, see, most importantly, Wiesner, *The Cosmology*, and Adamson, *Al-Kindī*, pp. 181–206, on which the following account relies heavily.

assertion that once they reach their natural place, their motion ceases.[97] This is entirely different from the celestial realm, where the circular motion of the spheres never stops, at least as long as God wants the cosmos to exist. For al-Kindī, this completely different nature of the celestial element indicates its distinctiveness from the four sublunar ones. Thus this treatise aims to prove the existence of aether.[98] In another treatise, al-Kindī adds geometrical proofs that the spheres of the sublunar elements and of the heavens are circular.[99] Thus, the general outlook of al-Kindī's cosmos is not revolutionary in any way. However, his reception of Alexander's work *On Providence* in his own *On the Proximate Efficient Cause of Generation and Corruption* (*Kitāb al-Ibāna ʿan al-ʿilla al-fāʿila al-qarība li–l-kawn wa-l-fasād*) has drawn some attention in modern studies.[100] As a brief summary, al-Kindī distinguishes between God as the remote cause and celestial motion as the proximate cause.[101] The celestial bodies influence the sublunar elements by their motion and the resulting heat, which is how God ultimately determines every terrestrial event through the mediation of the celestial spheres. In this way, these treatises bring together certain elements from Aristotle's *On Generation and Corruption*, from Alexander of Aphrodisias, and also Ptolemy.[102] In this context of divine providence, al-Kindī offers an argument for the real existence of eccentric and epicyclic spheres. Without the Sun's eccentricity, for example, there would be only two instead of four seasons. This means that the Sun must be carried on a physical sphere that has a centre different from the centre of the cosmos.[103] The real existence of the eccentric sphere of the Sun not only

[97] al-Kindī, *Rasāʾil*, Vol. 2, p. 44:10–11, and the English translation by Peter Adamson and Peter Pormann in Adamson and Pormann, *The Philosophical Works*, p. 191. This treatise has already been translated in Khatchadourian and Rescher, 'Al-Kindī's Treatise on the Distinctiveness'. The active and passive role of the different elements can be compared to Ptolemy's account in *On the Kriterion*, see above pp. 155–57.

[98] al-Kindī, *Rasāʾil*, Vol. 2, p. 46:1–14, and Adamson and Pormann, *The Philosophical Works*, p. 193.

[99] See al-Kindī's 'That the Elements and the Outermost Body are of Spherical Shape' in al-Kindī, *Rasāʾil*, Vol. 2, 48–53. Although this is in line with *Almagest* I.3–4, it is nevertheless noteworthy that al-Kindī's geometrical method goes beyond what Ptolemy (and also Aristotle) did before. See the introductory remarks by the translators in Khatchadourian and Rescher, 'Al-Kindī's Epistle on the Concentric Structure', especially p. 191.

[100] See Wiesner, *The Cosmology*, pp. 41–73, Fazzo and Wiesner, 'Alexander of Aphrodisias', pp. 141–47, and Adamson, *Al-Kindī*, pp. 185–88. The Arabic text can be found in al-Kindī, *Rasāʾil*, Vol. 1, pp. 214–37.

[101] In addition, al-Kindī seems to equate God with Aristotle's Prime Mover in his paraphrase of the *Almagest*, which leads to a set of further problems. See Twetten, 'Aristotelian Cosmology', p. 349.

[102] Although the details of his account of providence stem from Alexander, he could find support in *On Generation and Corruption*, see *Gen. et Corr.* II.10, 336b26–337a1. For Ptolemy's rather implicit statements, see above p. 158 n. 33.

[103] See al-Kindī, *Rasāʾil*, Vol. 1, p. 230:6–12. For the example of the Moon, see al-Kindī, *Rasāʾil*, Vol. 1, p. 232:12–16. He might have derived this idea from Alexander's *On Providence*, where a similar thought is presented, though without specific reference to an eccentric circle. See Ruland, *Die Arabischen Fassungen*, pp. 35–36. The influence of the Sun on the seasons was also addressed by Aristotle, although he does not refer to the Sun's eccentricity, which would contradict his homocentric cosmos. See *Gen.*

needs to be considered to account for its apparent motion, but is connected to the way in which God acts on the sublunar world. In this way, al-Kindī connects the geometrical devices of Ptolemaic astronomy with his theory of divine providence.

Al-Kindī also has something to say about celestial dynamics and the ensoulment of the heavenly bodies, namely in another cosmological work that is called *On the Explanation of the Prostration of the Outermost Body and its Obedience to God* (*Risāla fī l-Ibāna ʿan suǧūd al-ǧirm al-aqṣā wa-ṭāʿati-hī li-llāh ʿazza wa-ǧalla*).[104] Starting from *Qurʾān* 55:6, where it is said that the stars prostrate themselves to God, al-Kindī investigates the nature of the celestial bodies. He interprets this verse as saying that the heavens act on God's command, which serves as a bridge to his account of providence.[105] In the next step, al-Kindī connects the statements about the regular circular motion of aether[106] and its influence on sublunar generation and corruption to the question of what the heavens need to fulfil that task. In general, he believes that what has the capacity to choose to follow someone's command must have reason and thus also be alive. There is a puzzle, however, about which celestial bodies exactly al-Kindī has in mind for which kind of task. Is it the planets that have reason and choose their motions (which would be similar to Ptolemy's account in the *Planetary Hypotheses*), or are the spheres doing that job? First, it must be noted that the *Qurʾān* speaks in the respective *sūra* of the 'stars' (in the generic plural, *al-naǧm*). Supposedly referring to these stars, al-Kindī speaks in the introduction, which, in a way, summarizes and lays the ground for the following arguments, of the 'individuals on high' (*ašḫāṣ ʿāliyya*). These follow God's order and thus must have, according to al-Kindī, choice and rational souls.[107] In the next paragraph, al-Kindī turns his attention to the 'outermost body' (*ǧirm aʿlā*) or simply the 'celestial sphere' (*falak*). What has been briefly ascribed in the introduction to the 'individuals on high' (i.e. the stars) is now also ascribed in more detail to the 'outermost body with all of its individuals': it is alive, it is not moved by another body, it is equipped with the senses of hearing and vision, and it is rational. In this account, al-Kindī now offers some arguments why all of this is necessarily the case, arguing from the noble nature of the regular celestial motion and its influence on the living things of the world of generation and corruption.[108] However, there is a

et Corr. II.10, 336b17–19. The connection of the Sun's eccentricity to divine providence in order to bring about the seasons on Earth was widely spread in the Middle Ages. One of the most famous examples is certainly Dante's *Paradiso*, see Dante Alighieri, *Commedia*, Vol. 3, *Paradiso* X:10–21.

[104] I rely on the edition and French translation in Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, pp. 176–99, as well as the English translation in Adamson and Pormann, *The Philosophical Works*, pp. 174–86, from which I drew the English terminology of this paragraph.

[105] Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, p. 181:12–13.

[106] Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, pp. 195:21–23.

[107] Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, p. 179:18–21.

[108] See Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, pp. 181:9–193:9. For these arguments in more detail, see Adamson, *Al-Kindī*, pp. 183–85, and Adamson and Pormann, *The Philosophical Works*, pp. 173–74.

terminological shift within these arguments. Al-Kindī first seems to talk about the sphere of the fixed stars (and the fixed stars themselves). Suddenly, he starts talking about the rational faculty of the 'celestial bodies' (*aǧrām falakiyya*). This raises the question whether he talks here about spheres, planets, or both. Most probably, he is alluding to the heavens in their entirety, which are enclosed by the outermost sphere, namely the sphere of the fixed stars. Fittingly, he writes that the 'individuals on high' cause the alternation of the seasons (*azmān*).[109] Although these individuals are then ascribed to the outermost sphere, which would indicate that they are the fixed stars, it is strictly speaking the Sun that brings about the seasons through its inclined motion, whereas the fixed stars indicate the diurnal change of day and night.

Al-Kindī closes this treatise with a comparison of the entire cosmos to one living animal. He draws an analogy to a human as a microcosm because in both, one can find the various elements and the soul. This animalistic cosmos is permeated, somehow, by capacities from souls (*quwā nafsaniyya*), which is the same term that can be found in the *Planetary Hypotheses*. These powers extend up to the sublunar region, where they can be found in ensouled beings.[110]

To sum up, how do the celestial motions come about according to al-Kindī? On the one hand, al-Kindī agrees with Aristotle and also Ptolemy about the natural motion of the aethereal bodies. On the other hand, they are equipped with not only rationality but even choice, which raises the question why they never choose to move in a different way. For al-Kindī, the answer lies in their obedience to God. He is not clear about (and perhaps it is not important for him) whether it is the stars and planets that desire and choose to follow God's orders or the celestial spheres. Given that it was the standard picture that the planets are simply carried by their spheres, it seems more likely that al-Kindī also follows, in this respect, Alexander's example in assuming that the spheres are in charge of taking the planets with them.[111] But as already indicated, since al-Kindī conceives of the cosmos as one animal, his focus lies on the transmitting role of the entire cosmos in his scheme of how God takes care of the sublunar world. God is the final cause for celestial motions in general, whereas the souls of the celestial bodies are the proximate causes of their motions and decide to follow God's orders. This clear focus on God's providence also means that al-Kindī does not provide a dynamic model of celestial motions and the interactions among the celestial spheres themselves.[112]

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[109] See Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, p. 181:2–3. For the use of *zamān* (pl. *azmān*) for 'season', see, for example, Abū Maʿšar, *The Great Introduction*, Vol. 1, p. 209:3–15.

[110] Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, p. 197:18–199:7; cf. *Plan. Hyp.* II.7.

[111] That the planets themselves are motionless and fixed on the spheres according to Alexander is reported by Simplicius, see Simplicius, *In Cael.*, p. 452:21–22. That the spheres are ensouled and desire the Prime Mover is preserved in *On the Cosmos*, see Alexander of Aphrodisias, *On the Cosmos*, Sections 96–97. Cf. *Cael.* II.8.

[112] See Adamson, *Al-Kindī*, p. 184. The same holds true for the problematic *On Rays* (*De radiis*), where the rays that are transmitted from the planets do not serve as an explanatory factor for celestial

His cosmology emerges from a combination of different sources, most importantly Aristotle and Alexander of Aphrodisias, but also Ptolemy. In addition to al-Kindī's paraphrase of the *Almagest*, the Ptolemaic influence is demonstrated by the calculation of the distance of the sphere of the fixed stars that goes back — although the path of transmission remains unclear — to Ptolemy's *Planetary Hypotheses*. In *On the Prostration*, al-Kindī uses this calculation to highlight the noble nature of the heavens in comparison with the tiny sublunar realm.[113] Another example is that the Sun's eccentric circle must necessarily exist in reality to ensure its influence on the seasons. Mathematical–astronomical knowledge therefore has theological implications insofar as the solar path reflects divine providence for regular sublunar changes. In this way, al-Kindī exemplifies how Greek philosophical and scientific texts were received from the ninth century onwards and how they could be used for philosophical and even theological discussions about the meaning of the *Qur'ān*. In this process, it is only natural that al-Kindī had interests different from Ptolemy in writing about cosmology. For example, the question of which senses the celestial bodies have was of no interest to Ptolemy, but this became rather important for the later Arabic tradition (as it had been in late antiquity).[114] In later Islamic philosophers, such as al-Farābī and Avicenna, we find much more detailed accounts of the ensouled celestial bodies, with the introduction of God as the Prime Mover and the addition of a more complex theory of intellect. On the other hand, the astronomical tradition also has something to say about the interactions of the ensouled celestial bodies.

Ibn al-Hayṯam and al-Bīrūnī: Criticism of Ptolemy's Dynamic Theory

Through Ibn al-Hayṯam's *Doubts about Ptolemy*, we get an impression of how an astronomer reacted to the philosophical account presented in the *Planetary Hypotheses*. His way of referring to the doctrines of celestial motions is unique, since he is not interested in embedding it in a coherent philosophical system. He devotes a considerably long section to some 'doubts' concerning Book II of the *Planetary Hypotheses*. He starts with a number of literal quotes concerning the physical principles from the first chapters of this second book. These are basically accepted, whereas the main bulk of the doubt is directed against the divergences between the planetary models from the *Almagest* and the *Planetary Hypotheses*. In the previous chapter, I have mentioned that Ibn al-Hayṯam comes to the conclusion that the sawn-off pieces do not account for the planetary motions as laid out in the *Almagest* and that Ptolemy contradicts his own principles of the impossibility of a void in the cosmos and of the economy of the number of spheres. Nevertheless, his arguments that these sawn-off pieces contradict some of Ptolemy's own physical

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motions, but only for the planetary influence on the sublunar world. I rely on the translation in Adamson and Pormann, *The Philosophical Works*, pp. 219–34. See Adamson, *Al-Kindī*, pp. 188–91.

113 See again Rashed and Jolivet, *Œuvres philosophiques*, Vol. 2, p. 193:10–18.

114 See Walzer, 'New Studies', pp. 230–32, and Wolfson, 'The Problem of the Souls'.

principles indicate that Ibn al-Hayṯam has not only the mathematical consequences of the *Planetary Hypotheses* in mind. To give another example, Ibn al-Hayṯam points out in passing that Ptolemy writes, in *Planetary Hypotheses* I.15, that 'each of [the planets] has a volitional motion and a motion to which it is compelled'. He contrasts this citation with Chapter II.3, where Ptolemy also writes: 'this [occurs] regarding [the aethereal bodies] not by force or necessity, forcing them from outside. For there is nothing stronger than what does not receive alteration so that it could force it.'[115] Ibn al-Hayṯam is satisfied by simply hinting at that problem and does not provide a possible explanation.

Ibn al-Hayṯam devotes some time to the question whether the planets move themselves and thus do not need a sphere carrying them. Remarkably, he asserts at the beginning of this section that Ptolemy mentions this principle not only once but twice in the *Planetary Hypotheses*. According to Ibn al-Hayṯam, this indicates that Ptolemy was taking self-moving planets as a serious possibility for his cosmos.[116] Ptolemy did not explain in more detail how this would work in physical terms and avoided the problem of the planet penetrating the sphere in which it is supposed to be self-moved. Ibn al-Hayṯam sees two possible outcomes, both of them highly problematical:

> If the planet moved by itself instead of the tambourine or the small sphere, without something moving it, so that it would vacate space and fill space [at the same time], then whatever fills the space of the tambourine of the heavens would either receive alteration or its space would be void.[117]

These are the same two impossible consequences that Ibn al-Hayṯam already ascribed to Ptolemy's sawn-off pieces. The assumption is that the planet is not motionless and fixed on the smallest sphere, but somehow moves independently with an own motion within the next sphere, the larger epicycle in the case of Saturn. In the next step, Ibn al-Hayṯam wonders how a self-moving planet can also inherit the motion from the larger epicycle, because we still need to generate a complex motion that consists of a certain number of motions added to each other. This would — according to Ibn al-Hayṯam — only be possible if the planet is in direct contact with the larger epicycle at some point. In this case, it would be fixed within the larger epicycle, which would result in (a) a rolling motion from the self-caused motion within that sphere, and (b) the motion of that sphere. However, as Ptolemy had already claimed, rolling motions are not a viable option either. As Ibn al-Hayṯam notes, in Ptolemy's picture, the planets move the surrounding spheres by 'choice' (*ḥaraka iḫtiyāriyya*, a term that is not used in the *Planetary Hypotheses* but is ascribed to Ptolemy by Ibn al-Hayṯam). It is clear that 'motion by choice' refers to Ptolemy's

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115 Ibn al-Hayṯam, *al-Šukūk*, p. 47:3–5, cf. *Plan. Hyp.* I.15, p. 15, and II.3, p. 290:7–9. For a possible solution, see the commentary on Chapter I.15.

116 Ibn al-Hayṯam, *al-Šukūk*, p. 61:1.

117 Ibn al-Hayṯam, *al-Šukūk*, p. 61:1–4, translation by Don L. Voss in Ibn al-Hayṯam, *Doubts*, p. 81, modified. For Ptolemy's account, see the commentary on Chapter II.17.

voluntary motions, because Ibn al-Hayṯam explicitly quotes the passage where Ptolemy describes how Saturn sends out an emission to the surrounding spheres. Since rolling motions are not voluntary and Ptolemy claims that celestial motions should be voluntary, the larger epicycle also needs to be abandoned. Ibn al-Hayṯam takes this argument to the end, claiming that there is no way in which we could connect both theories with each other, namely voluntarily self-moving planets and the assumption that they are still embedded in a system of planetary spheres. He concludes that this would mean that Ptolemy should get rid of all spheres.[118] Although this picture might be appealing to the modern reader as a first step in the direction of Tycho Brahe and Johannes Kepler,[119] this radical consequence was a *reductio ad absurdum* for Ibn al-Hayṯam. Neither was it the model that Ptolemy intended: he makes it perfectly clear that the assumption of volitional planetary motion enables us to reduce the number of spheres only by one per planet. As Ibn al-Hayṯam points out in the beginning of his discussion of the doubts concerning the *Planetary Hypotheses*, Ptolemy claimed that there should be one celestial body for every motion in the heavens.[120]

Since Ptolemy did not engage with that question in more detail, we do not know how he conceived of the interaction of a self-moving planet with its carrying sphere. To avoid the following problematic consequences laid out by Ibn al-Hayṯam, he needs to argue how a planet can move itself within a carrying sphere (a) without the existence of a void but (b) still enabling the planet to partake in the motion of the carrying sphere. In *Planetary Hypotheses* II.6, Ptolemy explains how a sawn-off piece can be taken away by the enclosing piece of aether in the diurnal direction. He gives the example of 'things swimming in running rivers'.[121] Generally speaking, this would be a way for Ptolemy to at least answer to Objection (b). For Objection (a), however, he would need a theory of motion, in general, which he is lacking. Ibn al-Hayṯam transfers the problem of how motion can be explained from the sublunar region to the supralunar region. Such a general discussion of motion — which prominently also included arguments from and against voids and atomism — was not dealt with in an astronomical context because a planet was usually considered as being fixed on its carrying sphere. Consequently, Ibn al-Hayṯam is right when he claims that Ptolemy's assertion of self-moving planets that could, in some way, penetrate the carrying sphere raises the question of how motion can be explained without the existence of a void.

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[118] The entire argument can be found in Ibn al-Hayṯam, *al-Šukūk*, pp. 61:6–62:20. On p. 63:1–9, Ibn al-Hayṯam gives the motion of the Sun as further example. A brief discussion can be found in Saliba, *Islamic Science*, p. 107.

[119] See Krafft, 'orbis (sphaera)'.

[120] Ibn al-Hayṯam, *al-Šukūk*, p. 46:8.

[121] See *Plan. Hyp.* II.6, p. 298:13. See the commentary on Chapter II.17 (pp. 387–88) and also p. 153.

This passage nicely fits the general aim of Ibn al-Hayṯam's *Doubts about Ptolemy*. He most heavily criticizes how Ptolemy's models from the *Almagest* cannot be represented by physical bodies.[122] The discussion of self-moving planets and of the existence of sawn-off pieces are further intriguing instances of Ibn al-Hayṯam's concerns with the physical consequences of Ptolemy's cosmology. We learn from Ibn al-Hayṯam's *Doubts about Ptolemy* that he rejected both these claims from Ptolemy's *Planetary Hypotheses*. One can see this rejection in the light of Ibn al-Hayṯam's criticism of Ptolemy's methodology in the *Planetary Hypotheses*.[123] In the context of this methodological criticism, I have already quoted the following passage on the different number of motions in the *Almagest* and the *Planetary Hypotheses* above:

> It is immediately clear that his assumptions of [complete] spheres and sawn-off pieces in the second book of the *Planetary Hypotheses* (*Kitāb al-Iqtiṣāṣ*) for the motions of the planets are contrary to what he established of the motions in the *Almagest*. The true [account] of the motions is what he established in the *Almagest*, for there he had established the motions by observations and instruments (*bi-arṣād wa-maqāyīs*).[124]

In turn, this means that for Ibn al-Hayṯam, the theory of sawn-off pieces in the *Planetary Hypotheses* is not based on observations but is highly doubtful. Is the same true for other theories such as the assertion of ensouled celestial bodies? Although Ibn al-Hayṯam does not explain that explicitly, one could argue that an investigation into the ultimate cause of celestial motions and into the celestial souls is not important for the project Ibn al-Hayṯam has in mind, namely finding the 'true configuration' of planetary motions.

I have already addressed al-Bīrūnī's position on Ptolemy's methodology in Chapter II.[125] He connects this claim of the different agenda of physics and astronomy explicitly with Ptolemy's account of planetary motions that is based on soul:

> Now, in his *Planetary Hypotheses* (*Kitāb al-Manšūrāt*), Ptolemy departs from the way that he had pursued in the *Almagest*, in the direction of what belongs to the opinions, which lie outside of this art (*ṣināʿat*, i.e. astronomy), of the many's belief in celestial bodies [with] life, sensibility (*šuʿūr*), perception (*iḥsās*), and choice (*iḫtiyār*), so that it is preferable (*li-l-afḍal*) regarding the motions [to assume that] conducting powers (*quwā mudabbira*) are sent out from the stars to their spheres, just as they are sent out in the case of [ensouled things] to the limbs (*aʿḍāʾ*).[126]

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[122] See Sabra, 'Configuring the Universe', especially pp. 298–305, and Saliba, *Islamic Science*, pp. 97–104.

[123] See above, pp. 96–105.

[124] Ibn al-Hayṯam, *al-Šukūk*, p. 50:12–15, translation by Voss in Ibn al-Hayṯam, *Doubts*, p. 68, modified.

[125] See above, pp. 86–96.

[126] al-Bīrūnī, *Kitāb al-Qānūn*, pp. 634:18–635:3, compared with Ragep's translation in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 40.

This testimony is important for a number of reasons. First, it shows that al-Bīrūnī properly understood Ptolemy's description of ensouled celestial bodies and that the planets conduct the motions of the surrounding spheres by these 'governing powers'.[127] This in itself is not very surprising. What is striking, however, is that even this brief testimony also contains elements that cannot directly be found in the *Planetary Hypotheses*. Ptolemy indeed ascribed capacities from souls to the planets. It is not far-fetched to assume that he thus thought of the planets as being alive. On the other hand, there is no discussion about the other senses in the *Planetary Hypotheses* or about the planets' choice. Ibn al-Hayṯam also used the term 'choice' to describe the capacity by which the planets conduct the motions of their spheres. This terminology goes back to philosophical works such as those by Alexander of Aphrodisias and not to Ptolemy himself. As an example of the way in which these questions ('Which senses do the celestial bodies have?' and 'Do they choose their motion?') were introduced into the Arabic tradition, we have seen the telling example of al-Kindī, who drew extensively on material borrowed from Alexander's account of providence. Al-Bīrūnī now either has the Hellenistic and late ancient testimonies in mind, a contemporary debate in the Arabic philosophical tradition, or both when he says that these issues are believed by 'many'. Ibn al-Hayṯam and al-Bīrūnī thereby show how the *Planetary Hypotheses* had been read against this background of philosophical psychology. Again, Ptolemy did not explicitly engage in a discussion about the capacities of the celestial souls or about the question if or why the planets choose the apparent motion instead of other possible motions. In introducing terms like 'choice' and sense-perception in a Ptolemaic context, al-Bīrūnī notes that Ptolemy's ensoulment of the planets includes or, at least leads to, this further set of philosophical questions.

For al-Bīrūnī, the introduction of such issues leads to the question whether an astronomer should deal with them or not. He groups the 'opinions' concerning the life and senses of the celestial bodies together with the sawn-off pieces, and thereby implies that the latter belong to the same epistemological category, namely to 'opinions'. In this context, we encounter al-Bīrūnī's brief critical remark against Ptolemy's self-moving planets. Al-Bīrūnī thinks that the planets would move by non-circular motions if they 'swam like birds' and thus move on their own account.[128] His understanding is that the resultant planetary motion is not circular and that if we want to replace the epicycle by an independently moving planet, we need to ascribe a non-circular motion to the planet. That was certainly not Ptolemy's intention: he believed that if we ascribe only the single circular motion of that sphere which carries the planet – which in most cases means the smallest epicycle – the planet also has a regular circular motion on its own account and that its resulting motion

[127] The term used by al-Bīrūnī, *quwā mudabbira*, is not the same term used in the extant text of the *Planetary Hypotheses*, namely *quwā raʾīsiyya*.

[128] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 635:13–16.

is complex as the planet is embedded within all the other spheres as is a bird in the sky or a fish in a river.

In the end, he concludes that this is not the right place to discuss these questions.[129] Whether the planets are ensouled or not, whether they have hearing and vision or not, and whether governing powers are actually emitted from the planets to the surrounding spheres: such questions are not part of mathematical astronomy and are only subject to opinions. In a way, al-Bīrūnī follows Ptolemy's own epistemology from *Almagest* I.1 and his various cautious remarks about the status of the physical arguments that he uses himself in the *Planetary Hypotheses*. Therefore, this highlights once more al-Bīrūnī's wish to strictly avoid the intermingling of different sciences.

Nevertheless, there is at least one passage in al-Bīrūnī's *Qānūn* which shows his approach towards divine providence:

> Each one of [the planets] is moved for a cause (*li-ša'n*) and strives for a resting place (*ǧādd li-mustaqirr*), devoting itself to what is natural for it. Nothing futile is created, but [creation is only] by apparent wisdom and shining fate, that is well-ordering for the world and caring for the creation for [its] benefit.[130]

The planets thus fulfil their task to care for the well-being of the cosmos. This is just another sign of the wide permeation of a theory of divine providence that is visible also in the order of the celestial bodies. Nevertheless, one must certainly conclude that al-Bīrūnī does not spend too much time on Ptolemy's dynamic theory or an alternative scheme. Despite the fact that Ptolemy starts discussing souls' capacities to solve an astronomical problem in order to replace the overly complicated mechanical system of Aristotle with a more economic one, al-Bīrūnī obviously thought that such discussions take the astronomer too far away from the *Almagest* and thus from *the* astronomical work *par excellence*. On the other hand, Ibn al-Hayṯam notes that, for example, Ptolemy's theory of self-moving planets is in apparent contradiction to the *Almagest*. While this conclusion fits Ibn al-Hayṯam's general attitude towards Ptolemy's physical theories, it is nevertheless also the case that we do not get an alternative account by Ibn al-Hayṯam himself.[131]

When we take stock of these accounts, it becomes evident that the question of the celestial dynamics and the origin of the heavenly motions was approached from different directions. First, there is the discussion whether astronomers should deal with questions that seem to dive into the realm of natural philosophy, and we have seen in detail that people gave different answers to that. However, there is the further problem on the level of natural philosophy alone whether we consider merely

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[129] See al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 2, p. 635:16–17.

[130] al-Bīrūnī, *Kitāb al-Qānūn*, Vol. 1, p. 24:7–9.

[131] For a possible reconstruction of Ibn al-Hayṯam's works concerning their cosmological and kinematic accounts, see Rashed, 'The Celestial Kinematics', especially pp. 51–55, where Rashed argues that Ibn al-Hayṯam later in his life turned away from an attempt to reconstruct an astronomical model in the tradition of material spheres and attempted to provide a purely geometric, kinematic model.

the natural motion of the heavens as consisting of aether or whether we consider the heavenly bodies as being equipped with volition, senses, and life in general. In the next section, I will show that Ptolemy's account receives more attention in the context of yet another discipline, namely in the context of metaphysical discussions on the number of separate intellects and celestial movers, since this number was usually connected to the number of celestial motions and spheres.

The Inclusion of Ptolemaic Cosmology in Metaphysical Discussions: al-Fārābī and Avicenna

The authors discussed so far did not engage with the question of how celestial motions are actually brought about. We may also have in mind that there are serious gaps in Ptolemy's own explanation of the causes for celestial motions. His most important goal was to give an alternative account to a mechanical transmission of celestial motion, which he achieved by emissions from the planets, thus establishing an immanent cause for the spheres' motions. However, he did not go into the details of these emissions and how it was possible that the spheres reacted to these impulses. As for the Arabic tradition, decisive steps in the direction of a more coherent picture of the interaction of the celestial bodies, souls, intellects, and movers were taken in the *falsafa* tradition, probably starting with al-Fārābī. Astronomy and metaphysics are strongly linked to each other in al-Fārābī's philosophy.

Al-Fārābī is famous for his scheme of emanation, which is described in a number of his works, including *On the Perfect State* (*Mabādi' ārā' ahl al-madīna al-fāḍila*, *The Principles of the Opinions of the Inhabitants of the Perfect City*) and *On Ruling the Community* (*al-Siyāsa al-madaniyya*).[132] Both treatises start with the first cause of every being. From the first cause emanates the first separate intellect. In al-Fārābī's cosmology, the starless outermost sphere emanates from the self-thinking of the first intellect. Since the first intellect also thinks of the Prime Mover, it gives rise to the second intellect. In this way, every separate intellect causes the existence of a celestial sphere and the next separate intellect.[133] The number of separate intellects is tied to the number of spheres. In the context of the later philosophical tradition, the consequences of this assertion should not be underestimated, despite the fact that the main idea goes already back to *Metaphysics* XII.8, where Aristotle addressed

[132] See Walzer's summary in al-Fārābī, *On the Perfect State*, pp. 362–63. For the following discussion of al-Fārābī's general account of emanation and how it relates to cosmological questions, I rely here on *On the Perfect State* as the primary source. There are certainly additional important passages that are relevant to the present discussions to be found in other treatises, such as his *On the Intellect*. However, these have already been dealt with in detail, most importantly in Janos's reconstruction of al-Fārābī's cosmology, see Janos, *Method, Structure*. To keep this study within a feasible frame, I refer to this work for further textual evidence. See also Davidson, *Alfarabi, Avicenna, and Averroes*, pp. 44–48, and Maróth, 'The Ten Intellects'.

[133] al-Fārābī, *On the Perfect State*, Chapter II.3 (following Walzer's division), pp. 100–05.

the question of the number of unmoved movers and claimed that it should be the astronomers' task to answer that question. For example, we have seen that the extant treatises of Alexander of Aphrodisias lack such a straightforward statement, so it is hard to decide whether Alexander believed that the efficient causes for the spheres' motions are their souls or separate unmoved movers.[134] For al-Fārābī, however, it is clear that the first nine separate intellects correspond to the nine main spheres (the starless sphere, one for the fixed stars, and seven for the five planets, the Sun, and the Moon), belief in which was widespread in medieval Arabic thought.[135] This does not mean that he necessarily maintains the existence of nine spheres. Instead, he follows authors such as Alexander of Aphrodisias in speaking only of the nine main spheres, which contain the different minor spheres (such as eccentrics and epicycles) that are responsible for the various planetary motions. These main spheres are called 'groups' (*ǧumal*) by al-Fārābī.[136] Later in *On the Perfect State*, al-Fārābī gives a short account of his planetary model. His main interest is in showing that the various motions never change in themselves, although they appear to change in relation to each other and to the observer on the Earth. Even though al-Fārābī does not mention epicycles and eccentrics by name, the differing ratios can be explained if we assume that al-Fārābī alludes to eccentrics and epicycles when he writes about the independent motions of 'every sphere and the corporeal circles within them' (*kull wāḥid min al-ukar wa-l-dawāʾir al-muǧassama allatī fī-hā*).[137] All of these celestial bodies, in their turn, take part in the diurnal rotation of the first sphere, but not by compulsion, since there is no compulsion in the supralunar world.[138] The tenth separate intellect, the Active Intellect, marks the transition to the sublunar world and is important for a role that we already know from al-Kindī's cosmology, namely the celestial influence on the sublunar world. For al-Fārābī, the celestial motions, together with the Active Intellect, are responsible for the sublunar changes.[139]

Until now, we have seen that al-Fārābī's cosmology is a blend of a theory of the emanations of the spheres and intellects on the one hand, and of Ptolemaic astronomy on the other hand. The question remains whether he has an account of celestial dynamics. Previous research has already shown that his theory of intellects is primarily an ontological theory. Al-Fārābī focuses on the causation of the celestial spheres and their relation to the sublunar world.[140] But what about the

[134] See above pp. 167–73.

[135] al-Fārābī, *On the Perfect State*, Chapter II.3, pp. 100–05 and Chapter III.6, pp. 112–15. See Hullmeine, 'Was there a Ninth Sphere'.

[136] al-Fārābī, *On the Perfect State*, Chapter III.7, p. 118:12–119:3. See Walzer's commentary at al-Fārābī, *On the Perfect State*, p. 365.

[137] al-Fārābī, *On the Perfect State*, Chapter III.7, p. 128:12.

[138] al-Fārābī, *On the Perfect State*, Chapter III.7.

[139] See Druart, 'Al-Fārābī's Causation'. The most important passage is al-Fārābī, *On the Perfect State*, Chapter III.8. Twetten, 'Aristotelian Cosmology', p. 364, also emphasizes al-Kindī's influence on al-Fārābī.

[140] See Janos, *Method, Structure*, pp. 163–64, and Twetten, 'Aristotelian Cosmology', p. 368.

causes for the motions of the spheres and planets? First, one needs to emphasize again that many of al-Fārābī's works are not extant, including his commentaries on Aristotle's *Physics* and *On the Heavens*, as well as two works called *On the Stars* (*Kitāb al-Nuǧūm*) and *On the Eternal Motion of the Sphere* (*Kitāb fī anna ḥarakat al-falak sarmadiyya*).[141] As Damien Janos has argued, the lack of a detailed account of celestial motions could be grounded on the lack of available sources, but also on a certain hesitance on the side of al-Fārābī about trying to resolve some of the discrepancies found in his Greek predecessors.[142] It is a remarkable feature of al-Fārābī's cosmology that he does not mention Aristotle's aether in *On the Perfect State*. He briefly states that the supralunar bodies move 'circularly by their nature', which is usually ascribed to the fifth element, aether, in the Peripatetic tradition. But there is no further explanation of what he means by the term 'by nature'.[143] Instead, it seems that the separate intellects, and thus also the souls of the celestial bodies, play a role in moving the celestial bodies.[144] This is suggested by a passage in *On Ruling the Community*, which seems to state that the celestial bodies move circularly by virtue of their souls. In his treatise *On the Intellect* (*Fī l-ʿAql*), al-Fārābī calls the separate intellects 'movers'.[145] In making capacities from souls the main cause for celestial motions instead of their essence or their nature, al-Fārābī generally follows Alexander of Aphrodisias. Al-Fārābī's First Cause, which is described as the 'object of love' (*maḥbūb* and *maʿšūq*), is parallel to Alexander's Prime Mover, which is the ultimate object of the spheres' desire, although al-Fārābī adds the intermediate separate intellects. After all, this psychological explanation for celestial motions is found not only in Alexander, but also in Ptolemy and in the Neoplatonic tradition, where aether was under severe attack.[146]

Although the loss of probably important treatises on these issues must be emphasized again, the brief statements available indicate that al-Fārābī stays within this tradition that considers celestial souls as proximate movers of the celestial

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[141] See Rudolph, 'Abū Naṣr al-Fārābī', p. 403, and Janos, *Method, Structure*, pp. 16–17 and 335. As already described in Chapter II, from his commentary of the *Almagest*, only Books IX–XIII have recently been identified. See Thomann, 'Ein al-Fārābī zugeschriebener Kommentar', Thomann, 'Al-Fārābīs Kommentar', and Thomann, 'Terminological Fingerprints'.

[142] See Janos, *Method, Structure*, pp. 335–36, especially n. 6.

[143] al-Fārābī, *On the Perfect State*, p. 104:11.

[144] See Walzer's commentary in al-Fārābī, *On the Perfect State*, p. 366, Twetten, 'Aristotelian Cosmology', pp. 367–68, and Janos, *Method, Structure*, pp. 342–43. As Janos points out, al-Fārābī only alludes to a theory of a fifth element, the natural motion of which is circular, in works that are supposed to defend Aristotle's doctrines. Janos explains this by an evolution in al-Fārābī's thought and works, see again Janos, *Method, Structure*, pp. 203–35.

[145] al-Fārābī, *al-Siyāsa al-madaniyya*, p. 34:1. Compare the different translations in McGinnis and Reisman, *Classical Arabic Philosophy*, p. 83 and Janos, *Method, Structure*, p. 349. For the reference to *On the Intellect*, see Janos, *Method, Structure*, p. 350.

[146] See also Janos, *Method, Structure*, pp. 153–55 for a comparison of Alexander's and al-Fārābī's cosmological setup. For aether in al-Fārābī, see Walzer's commentary in al-Fārābī, *On the Perfect State*, pp. 375–76.

bodies. In addition, al-Fārābī explicitly ascribes a certain power (*quwwa*) to the celestial bodies. The most important passage is from *On Ruling the Community*. All celestial bodies are connected to the 'power' of the outermost sphere, and thus everything in the supralunar world takes part in the diurnal rotation of the entire cosmos. In addition, the various planetary motions are explained by 'other powers' (*quwā uḫar*) that differ from each other and are ascribed to the various spheres. However, one must bear in mind that al-Fārābī's main interest is not to provide a causal explanation for celestial motions. Instead, he highlights how sublunar generation and corruption take place, namely through an interplay of the diurnal rotation of the cosmos (constantly generating prime matter) and the manifold planetary motions (change of forms in prime matter), thus following in the footsteps of al-Kindī.[147]

There is a striking gap in the cosmological descriptions of al-Kindī and al-Fārābī as presented so far, namely a theory of how the celestial motions come about. One can refer at this point again to Ptolemy's *Planetary Hypotheses*. Ptolemy used powers induced by souls in order to give an alternative explanation for the cause of the various celestial motions in the heavens that could work without the assumption of the physical principles of motion we know from the sublunar realm. His main aim was to free the heavens from any irregularity and from any influence by a physical entity. In Ptolemy's view, all the minor spheres that make up the bundle of spheres and thus generate the complex motion of the planets are directed by the capacity of the respective planet. This is important to stress again, since such a description of celestial dynamics is exactly what is missing in al-Fārābī (as presented up to now) and also earlier in al-Kindī. So far, we only have seen that al-Fārābī divided the heavens into nine main spheres, which each possess a celestial soul that, in turn, thinks of its respective separate intellect.

However, this does not necessarily mean that al-Fārābī never developed a theory of the origin and transmission of celestial motions. As Damien Janos has argued, there is a testimony of al-Fārābī's theory of celestial motions in Book IX of Avicenna's metaphysical section of *The Cure*. We therefore need to turn to Avicenna at this point in order to get a complete picture of al-Fārābī's cosmology. The relevant Avicennean passage on the number of separate intellects is very famous and often quoted in modern literature.[148] Because of the importance of this passage, I quote it here, as well:

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[147] al-Fārābī, *al-Siyāsa al-madaniyya*, pp. 55:13–56:12, see the translation in McGinnis and Reisman, *Classical Arabic Philosophy*, p. 96. As Janos *Method, Structure*, pp. 347–48 stresses, these powers within the supralunar world and their obvious connection to motion are also part of Ptolemy's *Planetary Hypotheses*.

[148] Janos uses this passage in Janos, *Method, Structure*, pp. 356–69 for reconstructing al-Fārābī's cosmology as well as in Janos, 'Moving the Orbs', pp. 184–92 for reconstructing Avicenna's cosmology. For Janos's identification of al-Fārābī as the possible source of Avicenna's description, see Janos, *Method, Structure*, especially pp. 362–69. For a further discussion about the possible Ptolemaic influence

> Thus, the number of the separate intellects after the First Principle would be the same as the number of the movements. If in the spheres (*aflāk*) of the wandering [planets] the principles of the movement of the spheres (*kurāt*) of each planet is a power (*quwwa*) emanating from the planets, then it would not be unlikely that the [separate] intellects would have the same number as the number of the planets, not the spheres (*kurāt*), and their number would be ten, after the First. Of these, the first would be the unmoved mover that moves the sphere (*kura*) of the outermost body, then the one similar to it [that moves] the sphere (*kura*) of the fixed stars, then the one similar to it [that moves] the sphere of Saturn, and so on, terminating in the intellect that emanates on us, namely, the intellect of the terrestrial world, which we call the Active Intellect. If, however, this is not the case, but if each moving sphere (*kura*) and each planet has a rule governing its own motion, then these separate [intellects] would be of greater number. It would follow, according to the doctrine of the first teacher, that there would be something close to fifty or over, the last of them being the Active Intellect. But you have known, from what we have said in the *Mathematics*, what we have attained in ascertaining their number.[149]

First, it is important to highlight Avicenna's terminology here. He uses here the term *kura* for what we called a minor orb before. These are the eccentric and epicyclic spheres, which can be subsumed as a single bundle of spheres belonging to each planet, to which Avicenna refers as *falak*.

In this paragraph, then, Avicenna discusses the number of separate intellects as celestial movers. There are basically two possible ways to count them. The second is the one we know from Aristotle's *Metaphysics* XII, namely that there is one mover for every motion in the heavens. We will take a closer look at this possibility when discussing Avicenna's theory of celestial dynamics. What is of interest now is the first option, which reminds us of Ptolemy's *Planetary Hypotheses*, although Ptolemy's worry is not the number of unmoved movers. Nevertheless, there are certain elements that are close to the *Planetary Hypotheses*. The heaven is divided into bundles of spheres or main spheres, which include a varying number of minor orbs or spheres. When we forget about the fixed stars for a moment, there is exactly one planet for each of these bundles. From the planet itself, a power is emitted throughout the entire corresponding bundle and thus to all the minor spheres. In this sense, the dynamic theory described by Avicenna is very similar to the one we get in the *Planetary Hypotheses*.

How does this report by Avicenna relate to the topic at hand, namely al-Fārābī's cosmology? When we take the features of this dynamic theory together, we get a picture that is compatible with what al-Fārābī has to say about celestial motions within

on al-Fārābī and Avicenna, see Janos, 'The Reception of Ptolemy's Theory'. I thank Damien Janos again for sharing an earlier version of his article. Since our studies were produced simultaneously, I do not refer to his article in detail here. However, my following analysis of the relevant passages from al-Fārābī and Avicenna agrees with Janos's account.

149 Arabic text and tr. by Marmura, see Avicenna, *The Metaphysics of The Healing*, IX.3, pp. 325:14–326:4, translation slightly revised.

his emanation scheme. First, Avicenna follows al-Fārābī's initial simple equation of the number of separate intellects or movers with the number of celestial spheres. This exact connection of astronomy and metaphysics that stems from Aristotle's *Metaphysics* XII.8 apparently was brought to attention by al-Fārābī and then taken to the next level by Avicenna. Next, Avicenna's theory of ten separate intellects and their emanation, the division of the heaven into nine main spheres, and the emission of powers in the celestial world echo al-Fārābī's account.

These comparisons between the model described by Avicenna on the one hand and between Ptolemy's *Planetary Hypotheses* as well as al-Fārābī's cosmology on the other enable us to conclude that similar elements appear in all three sources. Admittedly, there are some differences between Avicenna's description and the extant Arabic text of the *Planetary Hypotheses*. For instance, the terminology of emanation (*fayḍ*) that is used by Avicenna is lacking from Ptolemy's text. This terminological shift can be explained insofar as Ptolemy does not provide us with a theory of separate intellects as unmoved movers, nor with the Active Intellect as the intermediary between the celestial and the sublunar world. In addition, in similar passages from other works which will be discussed below, Avicenna adds that the planet can be compared to an animal's heart, which is something that cannot be found in the *Planetary Hypotheses*. With respect to these instances of slight shifts and additions, Avicenna's description apparently borrows from elements present in al-Fārābī, who, for example, makes the heart the seat of the soul and the ruling organ.[150] Furthermore, we have seen that al-Fārābī depends heavily on the Neoplatonic tradition. This influence is evident in al-Fārābī's theories of emanation, of the First Cause and how it relates to the separate intellects, of using terms such as 'desire' and 'love' to label the relationship between the celestial souls and the intellects or the intellects and the First Cause, and in his discussion of which capacities the celestial souls have.

All in all, it seems reasonable to follow Janos's suggestion that Avicenna relies on and refers to al-Fārābī's cosmology here, although we are lacking the primary source by al-Fārābī himself. Avicenna provides us with the following picture: Ptolemaic cosmology was received through the Arabic translation of the *Planetary Hypotheses*. Some of the predecessors of Avicenna — and Avicena has probably al-Fārābī in mind — took the idea of bundles of spheres (which was admittedly present not only in Ptolemy's *Planetary Hypotheses* but also in Alexander's *On the Cosmos*) and of souls' powers that permeate each of these bundles from the *Planetary Hypotheses* and transferred it to the emanation cosmology as inherited from the Greek Neoplatonic tradition.[151] We thus learn from Avicenna's report that the system from Book II of Ptolemy's *Planetary Hypotheses* combined with certain elements from (al-Fārābī's)

[150] See Avicenna, *al-Mabda'*, p. 71:15–18, as well as Avicenna, 'al-Samāʾ wa-l-ʿālam', pp. 45:12–14, as well as Janos, *Method, Structure*, p. 367. For Ptolemy's location of the *hegemonikon* in Ptolemy's *On the Kriterion*, see above, p. 156.

[151] See also Walzer's brief comments on the possible influence of the *Planetary Hypotheses* in al-Fārābī, *On the Perfect State*, pp. 365–66.

works on emanation was present and the subject of ongoing discussions in his time. Apparently, some philosophers found this account useful in their attempt to combine the unmoved movers from *Metaphysics* XII, Aristotle's theory of aether from *On the Heavens*, the conviction that the celestial bodies must be ensouled, and Neoplatonic emanation. This attempt to combine these doctrines is also mirrored heavily in Avicenna's own works.

I will now turn to Avicenna's own stance within this discussion and to the question whether he directly knew the *Planetary Hypotheses*. The passage quoted above, where Avicenna lays down the two concepts of celestial motions, stems from Book IX of the metaphysical part of *The Cure*. This book (together with the preceding Book VIII) deals with emanation of all things from the First Cause and thus the cosmological passage stands in a context similar to al-Fārābī's cosmological section in *On the Perfect State*. The process of emanation in itself is also similar to al-Fārābī's, namely that the first separate intellect emanates from the First Cause, after which the outermost sphere and the next intellect emanate from the first separate intellect. As in al-Fārābī, this scheme goes on until the last of the separate intellects, the Active Intellect, which then is responsible for the sublunar world. Certainly, some modifications were made by Avicenna to al-Fārābī's system, one of the most important being the threefold emanation from every intellect. According to Avicenna, every intellect creates not only the next intellect and the corresponding sphere, but he explicitly describes that both the body and the soul of the sphere emanate from a separate intellect, in addition to the next intellect.[152] More important for the present discussion than such modifications concerning the scheme of emanation are Chapters IX.2 and 3 of the metaphysical part of *The Cure*, where Avicenna tries to establish the causes for the motions of the celestial spheres.

His main argument in Chapter IX.2 is to show that the soul is the proximate cause for celestial motions. He asserts that one can call the continuous creation of the first sphere's inclination to move in a circular fashion 'natural' only if we allow that this use of 'nature' involves an act of the soul. This passage should be read against Alexander's equation of nature and soul as the cause for celestial motions.[153] Instead, Avicenna prefers to stress that celestial motion arises from the spheres' souls as proximate causes and he is more explicit than al-Fārābī in making them the causes of motion and not only of existence. Like al-Kindī and al-Fārābī before him, Avicenna addresses the question of which faculties the celestial souls possess. According to

[152] For Avicenna's theory of emanation, see Avicenna, *The Metaphysics of The Healing*, IX.4. For these three step, see especially p. 331:2–13. See Davidson, *Alfarabi, Avicenna, and Averroes*, pp. 74–83, Janssens, 'Creation and Emanation', and the summary in Twetten, 'Aristotelian Cosmology', pp. 375–79. D'Ancona, 'Ex uno' provides an important investigation of the principle that from one only one can come into existence, its relation to Avicenna's scheme of emanation and the Neoplatonic sources.

[153] Avicenna, *The Metaphysics of The Healing*, IX.2, p. 308:12–21. On p. 316:17–19, Avicenna argues that Aristotle does not contradict himself when he sometimes asserts that the celestial motion is natural but on other occasions that it is psychological.

Avicenna, the celestial souls desire their corresponding separate intellects by will and choice, and also imagination and estimation.[154] This means that the number of celestial souls has to correlate with the number of separate intellects, and this is the context of the passage that we have already discussed above in the context of al-Fārābī's cosmology. As explained there, the first of the two models presented results in dividing the heaven into nine main spheres or bundles of spheres. The planets of each of these bundles send out an impulse to all the corresponding minor spheres within their respective bundle, and only nine separate intellects (plus the Active Intellect) are needed as the objects of the desire of the soul of each main sphere. Avicenna introduces an alternative model that basically goes back to Aristotle's *Metaphysics* XII, as this model requires every celestial motion and thus every minor sphere to have a proper soul desiring the proper separate intellect. Here is Avicenna's description of this second model again:

> If, however, this is not the case, but if each moving sphere (*kura*) and each planet has a rule governing its own motion, then these separate [intellects] would be of greater number. It would follow, according to the doctrine of the first teacher, that there would be something close to fifty or over, the last of them being the Active Intellect. But you have known, from what we have said in the *Mathematics*, what we have attained in ascertaining their number.[155]

When he writes about the fifty motions or more, Avicenna directly refers to the number motions in Aristotle's astronomical system from *Metaphysics* XII.8, where Aristotle also writes that there should be an unmoved mover for every motion.[156] Concerning the exact number, Avicenna writes that one can infer it from the mathematical part of *The Cure*, thereby probably referring to his discussion of Ptolemy's *Almagest*. This part of *The Cure* is usually considered as a paraphrase of the *Almagest* and indeed it closely follows the structure of the entire *Almagest*. Avicenna lays out the different planetary models as they are presented in the *Almagest* and thus Avicenna probably means that by adding the number of the spheres for every planet, one can get the overall number of celestial motions.[157]

Both of these two models are generally in agreement with Avicenna's theory of emanation. In order to determine the number of the separate intellects that emanate from the First Cause, one has to choose one of them. In the direct context of the passage from the metaphysical part of *The Cure*, Avicenna does not show any preference for either the first model, which seems to be based on the *Planetary Hypotheses* and

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[154] Avicenna, *The Metaphysics of The Healing*, IX.2, pp. 311:15–16 and 313:5–6; the details are presented in Janos, 'Moving the Orbs', pp. 201–11.

[155] Avicenna, *The Metaphysics of The Healing*, IX.3, p. 326:1–4, tr. by Marmura, slightly revised.

[156] See *Metaph.* XII.8, 1073a23–b3.

[157] This part of Avicenna's *The Cure* is edited as part of the mathematical section in Avicenna, ''Ilm al-hay'a', but still awaits detailed research. For an overview, see Ragep and Ragep, 'The Astronomical and Cosmological Works'. Cf. Janos, 'Moving the Orbs', p. 193, especially n. 77 for a slightly different reading of the last sentence of this passage.

al-Fārābī, or the second one based on Aristotle's *Metaphysics*. Nevertheless, a first indication of Avicenna's choice already appears a little before the passage in question. Avicenna touches on the problem of the number of intellects when he discusses the plurality of movers, asserting that the 'first mover of the whole of heaven' can only be one, 'even though there is for each of the celestial spheres (*li-kull kura min kurāt al-samāʾ*) a proximate mover proper to it, and an object of desire and love proper to it, as the First Teacher and those Peripatetic scholars of attainment after him see it.'[158] Here, Avicenna uses the term *kura*, which he will later use to refer to the minor spheres. He thereby sets himself in the tradition of the Aristotelian commentators Alexander of Aphrodisias and Themistius, who upheld the theory that although there is only one Prime Mover, there are movers for every sphere.[159] The assignment of one mover to every minor sphere, in turn, corresponds to the second model described by Avicenna, which is not the one by Ptolemy and al-Fārābī.

In order to answer the question which cosmological model was chosen by Avicenna, Damien Janos turned to other works, where Avicenna addresses the number of intellects in a quite similar fashion.[160] First, the presentation of Alexander's and Themistius' opinions concerning the plurality of celestial movers that one finds in *The Cure* basically follows the account of the earlier *The Provenance and Destination* (*al-Mabdaʾ wa-l-maʿād*), with the difference that in the latter, the chapter in question is called 'on the fact that every particular sphere (*falak ǧuzʾī*) has a primary, separate mover'.[161] Despite the fact that much material from *The Provenance and Destination* is repeated in the metaphysical part of *The Cure*,[162] there is an important passage that deserves special attention because it introduces a further difficulty for the discussion of the number of movers. The beginning of this section is similar to the account from *The Cure*, with the difference that Avicenna ascribes the first of the two models (the one depending on the *Planetary Hypotheses*) to some recent authors (*al-mutaʾaḫḫirūn*).[163] Avicenna then adds the following section that is not present in *The Cure*:

> If there is a separate intellect for each motion, then the number of motions must be counted. According to the opinion of Ptolemy, which is based on the fact that the epicycle penetrates

[158] Avicenna, *The Metaphysics of The Healing*, IX.2, p. 317:1–4, tr. by Marmura, and similarly p. 318:1–3. Directly afterwards, Avicenna discusses the existence of the starless sphere, the invention of which he ascribes to Ptolemy.

[159] Avicenna, *The Metaphysics of The Healing*, IX.2, p. 317:11–16. See Janos, 'Moving the Orbs', pp. 182 and 194. Although Avicenna uses the term *kura* in his paraphrase of Alexander's *On the Cosmos*, in the citation from Themistius, the term *falak* is used. Avicenna himself also uses *falak* in the same context in which he used *kura* before (Avicenna, *The Metaphysics of The Healing*, IX.3, p. 325:6), so the terminology is probably not decisive on this point.

[160] See Janos, 'Moving the Orbs', pp. 192–201, from where most of the following references stem.

[161] Avicenna, *al-Mabdaʾ*, p. 61:14. See Janos, 'Moving the Orbs', p. 195.

[162] See Gutas, *Avicenna and the Aristotelian Tradition*, p. 101. See also the summary of the important cosmological sections of this work in Endress, 'Alexander Arabus', pp. 57–60.

[163] Avicenna, *al-Mabdaʾ*, p. 68:1.

> (*taḫriq*) the deferent, the planet either penetrates the epicycle insofar as an epicycle is posited, or the planet itself penetrates the orb if no epicycle is posited, as [in the case of] the Sun according to the more likely account of Ptolemy (*ʿalā ġālib ẓann Baṭlamyūs*).[164]
>
> As for the opinion of the philosopher [Aristotle], which is that for each planet there is a sphere (*falak*) that endows it with its own motion, without the planet penetrating the sphere, but rather with the planet being fixed in it, the sphere carries [the planet] along, because the epicycle revolves on its own account and rotates the planet that is fixed in it. The epicycle does not move from place to place (*yantaqil*) at all, but the deferent moves [the epicycle] from place to place. And this teaching (*maḏhab*) is not weak, and the configuration (*al-hay'a*) is not contradicted by it, even though this increases the number of motions.
>
> If the motions are counted according to the two teachings, the number of separate intellects [may be said to equate] the number of [motions]. According to the first teaching, the separate intellects are of a lesser number by far than the number [of the second]. But the most likely [interpretation] according to reasoning (*aqrab ilā l-qiyās*) is the teaching of the philosopher [Aristotle], although there remains the obscure point concerning the fixed stars, and this is no small question. It is not unlikely that it can be solved, but we shall not delve into this matter lest our discussion digress too much.[165]

This passage illustrates two different accounts of the number of celestial motions. As the introductory sentence makes clear, the following discussion is necessary once one accepts not the first, but the second of the dynamic models presented before, namely which supposes one separate mover for every motion and not simply for every bundle of spheres. Whereas Avicenna, in *The Cure*, is satisfied with simply referring to his reworking of the *Almagest* for the exact number of motions, here, in *The Provenance and Destination*, he feels the need to explain that there is a disagreement about the number of motions between Aristotle and Ptolemy. This passage suggests that Avicenna was hesitant about the question at hand, but ultimately thought that it was most likely that there were as many separate intellects as there were celestial motions, and that no planet or sphere passes through another one, just as in Aristotle's cosmology.

However, this passage also gives rise to two interesting points for the history of cosmology in general, and for the question of how Avicenna received Aristotle's and Ptolemy's cosmology more specifically.[166] First, Avicenna ascribes a cosmological system to Aristotle that includes epicycles. In doing so, he supposedly stands within a larger tradition of philosophers trying to combine Aristotelian metaphysics with more recent astronomical trends. This ahistorical ascription can be compared to the

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164 This is, in fact, a nice rendering of Ptolemy's decision to posit an eccentric sphere for the Sun and it fits my analysis in Chapter II, see above p. 35.

165 Avicenna, *al-Mabda'*, p. 68:10–22, tr. by Janos in Janos, 'Moving the Orbs', p. 196, modified.

166 These two points are already discussed in Janos, 'Moving the Orbs', pp. 197–98.

tradition of the Peripatetic philosophers such as Adrastus, as shown before.[167] Second, Avicenna does not clearly state where he got the information that Ptolemy supposed that the planets or epicycles cut through the epicycle or deferent. Nevertheless, one can safely identify the *Planetary Hypotheses* as the ultimate source for these assertions and thus explain (a) what Avicenna actually means by 'penetrating' (*ḫaraqa*), and (b) why he ascribes this 'penetrating' to Ptolemy. As Avicenna writes towards the end of the quoted passage, the system presented here as Ptolemaic has fewer motions than the supposedly Aristotelian one. Although Ptolemy did not elaborate on the separate intellects and their number in his astronomical works, he tried to reduce the number of spheres needed for every planetary model in Book II of the *Planetary Hypotheses*, and his system of sawn-off pieces enabled him to achieve that. Along the way, Ptolemy also suggested getting rid of the last sphere of each bundle of spheres, namely the one that carries the planet, once one accepts that every planet moves voluntarily on its own account. These references to the *Planetary Hypotheses* explain Avicenna's assertion that the planet penetrates the surrounding orb, since in that case, the planet has an independent motion by itself and is no longer carried by a sphere on which it is fixed. Instead, it changes its position within the next sphere, which one still needs to account for the complex planetary motion. Since the last carrying sphere can be nullified in that picture, the total number of spheres is decreased.[168] It is more difficult to explain Avicenna's other assertion that the epicycle also cuts through its deferent sphere, but I would suggest that he misunderstands Ptolemy in that respect. Instead, Ptolemy is able to reduce the number of spheres through his adoption of sawn-off pieces because in the case of the planetary models, the sawn-off deferent piece is embedded in one contiguous sphere that is homocentric with the centre of the cosmos.[169] Thus, the *Planetary Hypotheses* can explain Avicenna's assertion that, in Ptolemy's picture, the planets penetrate the spheres and how this is connected to the question of the number of spheres. The fact that, as far as we know, Avicenna is the first one to articulate such a criticism (for he finds it rather implausible that the planets actually pass through their orbs) in a philosophical context is a strong indication for his acquaintance with the *Planetary Hypotheses*. Around the same time, Ibn al-Hayṯam also raises similar criticisms against Ptolemy's sawn-off pieces. He formulates the same worry, though in a different way. He did not call this independent motion by the planets 'penetrating', but rather spoke of 'vacating one place and occupying another', which necessitates the existence of a void, and he repeats the same doubt concerning the sawn-off pieces.[170]

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[167] See above p. 43.

[168] In this interpretation, it appears that Avicenna equates the number of separate movers with the number of celestial spheres and not motions and he does not address the question whether an independently moving planet would need a separate mover, as well.

[169] See *Plan. Hyp.* II.17 and the commentary on Chapter II.17.

[170] See above, p. 180.

Before we turn to other cosmological passages from Avicenna's corpus, it might be helpful to recapitulate Avicenna's reception of Ptolemy's *Planetary Hypotheses*. First, he mentions a dynamic model in which the planet emits an impulse to its proper spheres, on account of which they then move. As far as we know, this theory was only put forward in *Planetary Hypotheses* II.7. Second, I have just shown that Avicenna was well-acquainted with Ptolemy's planetary models based on sawn-off pieces, as they are presented in *Planetary Hypotheses* II.11–17. He even understood that Ptolemy's suggestion of independently moving spheres leads to a reduction of the number of spheres. In addition, Avicenna's texts are also helpful as witnesses of the reception of this dynamic model in the time before him. As pointed out before, he ascribes this model not to Ptolemy or some ancient authors in general, but to more recent authors (*muta'aḫḫirūn*) in his *The Provenance and Destination*. In the same work, he writes that this model can be compared to the motion of an animal, namely that in that case, the planet would correspond to the heart. However, the same people upholding this theory also say that this is not the case with respect to the sphere of the fixed stars, for there is not only one planet but a huge number of stars in only one sphere. In that case, it is the other way round, namely that 'as if the sphere were a heart and the stars in it were limbs'.[171] In this passage, Avicenna also explicitly distinguishes between the main spheres (*kura kulliyya*) and minor or particular spheres (*kura ǧuz'iyya*), a distinction already mentioned before. More important, however, is that although Ptolemy compares these minor spheres to the birds' limbs, he never compares the planet to the heart. Though this assumption might not be far-fetched once one considers the heart to be the seat of an animal's soul, it nevertheless shows that philosophers before Avicenna, probably including al-Fārābī, directly elaborated on the received Ptolemaic theory. To this reception of earlier accounts, one can add that Avicenna himself only compares the entire heaven to an animal (which is not what Ptolemy does in the *Planetary Hypotheses*) when he compares an animal's soul to the celestial soul in the metaphysical part of *The Cure*. Here, one must have in mind that Avicenna also deals with the comparison of celestial and terrestrial souls in the psychological part of *The Cure*, concluding that terms such as 'soul' and 'life' can be used both for celestial and animal souls only in an equivocal way.[172]

Ptolemy's dynamic model misses a similar explanation of how this model should work for the fixed stars. Do they all send the same impulse to the sphere carrying them? It seems that in the Arabic tradition before Avicenna, people addressed this

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[171] Avicenna, *al-Mabda'*, p. 71:15–18.

[172] See Avicenna, *The Metaphysics of The Healing*, IX.2, p. 312:3–4, where he compares the celestial soul to an animal's soul and, before that (IX.1, p. 307:4–6), the entire heaven to an animal. For the passage from Avicenna's psychology, see Avicenna, *De anima*, pp. 12:9–14:11, and the English translation by Alpina in Alpina, *Subject, Definition, Activity*, pp. 202–04. For a more detailed discussion of Avicenna's accounts of celestial souls in both his metaphysical as well as psychological works, see Alpina, 'Is the Heaven an Animal'.

question and argued that it is the sphere that emits an impulse and not each of the fixed stars. Avicenna describes this solution in his reworking of Aristotle's *On the Heavens* in *The Cure* (in the following: *On the Heavens and the World*). In Chapter 6 of this part, which is called *On the Motions of the Planets*, Avicenna deals with the same set of questions that he also addressed in the metaphysical part of *The Cure* and *The Provenance and Destination*, although in a much more dialectical way. He divides the opinions of people who think that the planets are fixed on the spheres and do not pass through them into three groups:

> 1) [There are] those who claim that despite this [i.e. despite the fact that the planets are fixed and themselves motionless] the planet is the first principle for emanating the power to move [something else] from it, like for example the heart or the brain despite their motionless state. 2) There are those who think that the principle of motion is within the body of the heavens, since it moves itself, namely from the essence. 3) And there are those who think that [a] in the case of some celestial bodies, the powers of their motions are emitted (*tanbaʿiṯ*)[173] from their planets, namely in the case of the motion that is composed (*multaʿima*) for them [in a way] that it consists (*taltaʾim*) rather of a number of spheres and one planet, like the spheres of the planets which they call 'wandering'; and that [b] in the case of the other celestial bodies, it is contrary to that, namely in the case of the motion that is composed (*multaʾima*) [in a way] that it consists (*taltaʾim*) of one sphere and a number of stars, like the sphere of the stars which they call 'fixed'. However, to me, it is not clear and obvious whether the fixed stars are in one sphere or in [a number of] spheres enclosing each other, except by persuasions (*iqnāʿāt*). But it is possible that this is clear for someone else.[174]

With the second option, Avicenna presents Aristotle's own doctrine from *On the Heavens*, which simply reflects that this section is from Avicenna's discussion of *On the Heavens* and not *Metaphysics*.[175] In the first and the third group, on the other hand, we once again come across the model that is influenced by the *Planetary Hypotheses*. Here, Avicenna describes the comparison between the planet and either the heart or the brain of an animal, probably depending on where the adherents of this doctrine located the soul in animals. The third group, finally, is similar to the first one, except that some people apparently draw the distinction between the planets and the fixed stars, which Avicenna also addresses briefly in *The Provenance and Destination*. In what follows, Avicenna tackles again the question whether the planets penetrate the spheres, but this time without reference to Ptolemy. Instead, he

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[173] The same term is used in the Arabic version of the *Planetary Hypotheses*, see *Plan. Hyp.* II.7, p. 302:3. For the term *inbaʿaṯa* in the context of Avicenna's emanation, see Janssens, 'Creation and Emanation', pp. 465–67.

[174] Avicenna, 'al-Samāʾ wa-l-ʿālam', pp. 45:12–46:7.

[175] Note the passage in the metaphysical part where Avicenna argues that Aristotle does not contradict himself when he sometimes asserts that the celestial motion is natural but, on other occasions, that it is psychological. See Avicenna, *The Metaphysics of The Healing*, IX.2, p. 316:17–19.

compares it to someone swimming in a running river, an example that also appears in the *Planetary Hypotheses*:

> If [someone] swims in the opposite direction of the stream of the water, then he could be motionless. It would appear that the stream surpasses him and he would remain in his place. And he could do the opposite of that, for if this standstill by him is complete resting, it would be the opposite [case], namely that he flows off with the stream by a motion, while he does not penetrate (*yaḫriq*) the water and what meets him does not depart from him. The same is the case for the planets.[176]

Of course, it is possible that Avicenna alludes here to the famous Aristotelian examples of the sailor who moves through the motion of the ship on which he stands or of the boat on the river in his discussion on place.[177] However, in this context of a comparison to a planet's motion inside a sphere, the *Planetary Hypotheses* is a more likely point of reference. The rest of this chapter deals with the question of whether the planets move by themselves or not, but here, Avicenna stays in the frame that Aristotle had given in *On the Heavens* II.8 regarding planetary rolling and rotational motions.

Although all these passages from the various works by Avicenna are somehow repetitive, each of them adds an interesting feature to the current discussion.[178] When one takes a step back and tries to look at the celestial dynamics in early *falsafa*, the following picture emerges. As early as al-Kindī, one can identify many different sources of his cosmological teachings. However, although he reveals knowledge and usage of Aristotelian elements, late ancient sources, and even Ptolemaic elements, he does not tackle the problem of how celestial motions come about. The few things al-Kindī has to say about them, namely their origin from souls and their influence on the sublunar world of generation and corruption, make their way to al-Fārābī, who connects these with his metaphysical theory of emanation. If Janos's reconstruction of al-Fārābī's cosmology is correct, al-Fārābī heavily depends on Ptolemy's *Planetary Hypotheses* and Alexander's *On the Cosmos* to combine this emanation with a working theory of a psychological connection between the planets and their spheres, though neglecting Aristotle's and Ptolemy's theory of aether. Even if someone is hesitant about al-Fārābī's cosmology because of the loss of possibly important physical and cosmological works, Avicenna completes the picture: he reports about a certain group of scholars, in which we can include al-Fārābī, who indeed upheld a theory that is dependent on Book II of the *Planetary Hypotheses*. As already highlighted before, al-Bīrūnī reported of 'the many's belief' in such a

[176] Avicenna, 'al-Samāʾ wa-l-ʿālam', p. 46:12–15. Compare *Plan. Hyp*. II.6, p. 298:12–13.

[177] See *An.*, 406a5–8, and *Phys.* IV.4, 212a17.

[178] Avicenna presents the two cosmological models in yet another work that I do not discuss in particular, namely the psychological part of *The Cure*. See Avicenna, *De anima*, p. 13:3–10. For the relationship between Avicenna's statements on celestial souls and sublunar souls, I again refer to Alpina, 'Is the Heaven an Animal'.

model as well. Despite Avicenna's dismissal of this model, he nevertheless shows deep insight into Ptolemy's *Planetary Hypotheses*.

All of these three authors knew Ptolemy's astronomical teachings well, as is evident from their engagement with the *Almagest*. There is, however, one major difference between Avicenna and his forerunners (at least as far as the extant material is concerned). There is no evidence for a discussion of the causes of the particular celestial motions and how they interact with each other from a philosophical point of view in al-Fārābī's *summae*. In the context of the question of the number of separate intellects, Avicenna considers these discussions, which seem to have been taken place before him, in different philosophical disciplines, such as in the metaphysical sections as well as those on natural philosophy within *The Cure*.

I have already briefly mentioned al-Ǧūzǧānī, who lived and worked together with Avicenna. He composed an astronomical treatise called *Epitome of How the Spheres are Arranged* (*Ḫilāṣ kayfiyyat tarkīb al-aflāk*), which takes al-Farġānī's *Summary of Astronomy* as starting point for a number of different discussions.[179] As already indicated, al-Ǧūzǧānī explicitly refers to the *Planetary Hypotheses* in the introduction of this treatise, which makes it rather unlikely that Avicenna did not have access to this work.[180] Since we lack an edition of this text, it suffices here to say that al-Ǧūzǧānī apparently returns to a theory of mechanically interconnected spheres. Although, in the *Planetary Hypotheses*, Ptolemy tries to refute a theory in which motion is transmitted from the enclosing to the enclosed sphere through poles, al-Ǧūzǧānī argues for such a means of transmission and thus dismisses Ptolemy's solution that includes powers from souls.[181]

In the Footsteps of Ibn al-Hayṯam and Avicenna: al-Ḫaraqī and Naṣīr al-Dīn al-Ṭūsī

Before I proceed with one of the most important followers of Avicenna, namely Naṣīr al-Dīn al-Ṭūsī, I want to add a couple of notes on the analogy of a fish or a swimmer in water in the context of a planet penetrating a sphere. In Chapter II, I pointed to similar statements in two other authors, namely Kūšyār ibn Labbān and the anonymous appendix to Ibn al-Hayṯam's *On the Configuration of the World*. Above, I quoted the subsequent part from *al-Zīǧ al-Ǧāmiʿ*, where Kūšyār ibn Labbān opposes the two positions that the planets either are accidentally moved by the spheres or move by themselves and penetrate (*taḫriq*) the sphere. Similarly, the appendix in Ibn al-Hayṯam's *On the Configuration of the World* explains that if the planets move on their own account and if there can be no void in the heavens, then the spheres would be penetrated (*tanḫariq*) by the planets.

[179] See the overview in Ragep, 'The *Khilāṣ kayfiyyat*'. There is also an extract of this work edited by George Saliba, see Saliba, 'Ibn Sīnā and Abū 'Ubayd al-Jūzjānī'. See also the brief discussion above, p. 85.
[180] MS Mashhad, Āstān-i Quds, 392, f. 92:20.
[181] See Ragep, 'The *Khilāṣ kayfiyyat*', p. 304.

Although the anonymous author of this appendix rejects this way of planetary motion by this reasoning, Kūšyār only states that the astronomers do not deal with these issues, 'may their discussion on that point be true or convincing.'[182] Thus, in two works that stem from approximately the same time as Avicenna, we have similar statements on the theory of independently moving planets that apply the same terminology. One should consider this finding in the context of the rise of a debate on the relationship between the different sciences, their principles, and their methods around AD 1000 that I have highlighted in Chapter II. Nevertheless, the analogy to something swimming in water that was introduced by Avicenna is not used by Kūšyār or in the spurious appendix. This changes with the work of Abū Bakr al-Ḫaraqī, who lived in the first half of the twelfth century AD in the Islamic East and thus in the time between Avicenna and al-Ṭūsī. In the introduction to his astronomical work *The Utmost Degree of Understanding the Divisions of the Spheres* (*Muntahā l-idrāk fī taqāsīm al-aflāk*), al-Ḫaraqī first complains — in a fashion similar to Ibn al-Hayṯam, to whom he, in fact, refers a little later as a better example — about the fact that previous astronomers merely dealt with circles and lines and not with physical bodies. He goes on:

> Then, the judgment (*ḥukm*) concerning the calculation is the same, regardless of [whether] the planet moves from one point to another by itself or to [the other point] by the motion of sphere, just as one journey for us from one place to another either walking or riding is the same concerning the calculation. This light-minded [attitude] led some people to a major mistake as they thought that it is the planets in the spheres that move by themselves (*bi-ḏawāti-hā*) and not that they are moved in an accidental way (*ʿalā sabīl al-ʿaraḍ*) by the motions of the spheres. They are forced to an impossible position, namely in what they believed of the penetration (*inḫirāq*) of the spheres by the course of the planets in them, in accordance to what they observed of the penetration of water by fish swimming in them. This is due to their ignorance that the sublime bodies cannot possibly receive penetration (*ḫaraq*) and are exempt from an inclination to a side through a straight motion, until 'God concludes a thing that was to be done.'[183]

The fact that previous astronomers failed to provide accounts of the physical arrangement of the celestial spheres is, for al-Ḫaraqī, the reason why an unspecified group of people adopted the theory that planets move on their own account and pass through the celestial spheres, which is exactly the same picture described by

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[182] For Kūšyār's account, see MS Alexandria, Baladiyya, 4285 C, ff. 12v:19–13r:1. Note again that the sentence on the planets penetrating the spheres is not transmitted in another important witness, namely MS Istanbul, Süleymaniye Kütüphanesi, Fatih 3418, f. 104r:3–6. For the appendix, see Ibn al-Hayṯam, *On the Configuration*, p. 66:13–15 (Arabic part), and above, pp. 98–99.

[183] See the Arabic edition in Ghalandari, *A Survey*, p. 149:11–18. I also consulted the German translation in Wiedemann and Kohl, 'Beiträge. LXX', pp. 207–08. The last sentence is a quotation from *Qurʾān* 8:44.

Avicenna, Kūšyār, and the anonymous author of the appendix in Ibn al-Hayṯam's *On the Configuration of the World*. Like Avicenna, al-Ḫaraqī uses the planet–fish analogy, which is missing from the other two witnesses. He adopts a similar criticism to the one in the appendix of *On the Configuration of the World*, namely that the heavens should not admit any kind of alteration. As I will highlight shortly, Naṣīr al-Dīn al-Ṭūsī holds the same position. On this basis, and given the lack of a source at our disposal, it remains unclear whether al-Ḫaraqī himself knew of authors who defended such a cosmological theory or whether he relies here on Avicenna. Interestingly, though, al-Ḫaraqī cautiously remarks that such physical rules are true for only as long as God wishes them to. This introduction of God's omnipotence points to the theological tradition, more specifically to another verse from the *Qur'ān*, where it is written that the Sun and the Moon 'each swim in a sphere' (*kullun fī falakin yasbaḥuna*).[184] In fact, the Iḫwān al-Ṣafā' refer to this verse when they describe how every sphere and every planet partakes in the diurnal motion of the all-enclosing sphere (*falak muḥīṭ*), without, however, going into any further details on celestial dynamics.[185] Despite this verse from the *Qur'ān* that uses the terminology of 'swimming', the abovementioned authors rejected a comparison of the motion of a fish in water to the motion of a planet inside a sphere.

It is no different in the case of Naṣīr al-Dīn al-Ṭūsī. If one wants to understand his position within these discussions on celestial motions, his commentary on Avicenna's *Pointers and Reminders* (*al-Išārāt wa-l-tanbīhāt*) is the most important source. In the section on metaphysics, Avicenna touches very briefly on the question of the number of celestial bodies and their movers. As in *The Cure*, the investigation of creation and the First Cause leads Avicenna to the investigation of the separate intellects and their relationship to the celestial bodies. He then begins Chapter 30 of the sixth section on metaphysics with the statement that the celestial bodies are many in number. In his commentary on the *Pointers and Reminders*, al-Ṭūsī divides this chapter into four objects of inquiry, the first being the number of spheres. Al-Ṭūsī uses this opportunity to address Ptolemy's theory of sawn-off pieces. I have discussed these passages in Chapter II and pointed out that the next topic, namely the number of celestial souls, is a 'philosophical investigation'. In the main text of the *Pointers and Reminders*, Avicenna writes that each of these celestial bodies, including homocentric and eccentric spheres, epicycles, and even the planets, have their own 'principle of circular motion', namely a separate mover.[186] This is the

[184] *Qur'ān* 21:33.

[185] See Iḫwān al-Ṣafā', *On astronomia*, pp. 10:1–11:2 (Arabic section). This should be read in the context of other attempts by the Iḫwān al-Ṣafā' to harmonize cosmology with theology. For example, in their epistle *On the Heavens and the World*, they compare the nine main celestial spheres to the eight angels carrying God's throne from *Qur'ān* 69:17. See Iḫwān al-Ṣafā', *On the Natural Sciences*, Epistle 16, Chapter 3.

[186] Avicenna, 'al-Išārāt', Vol. 3, pp. 189–91.

starting point for al-Ṭūsī in referring to the different accounts on the celestial movers, which we already encountered in Avicenna's own descriptions in his other works.

There are, according to al-Ṭūsī, mainly two groups, the first one asserting that 'each of these planets with its spheres' can be compared to:

> one single animal, equipped with one soul that is connected first to the planets and then by mediation of the planets afterwards [also] to its spheres, just like the soul of the animal is connected first to its heart and afterwards by its mediation to the remaining limbs. The moving power is emitted (*munbaʿiṯa*) from the planet, which is like the heart, next to its spheres, which are like the remaining organs and limbs.[187]

Just as Avicenna, al-Ṭūsī does not state here who actually followed this theory. As previously shown, he knew about the content of the *Planetary Hypotheses* but he did not relate the theory of sawn-off pieces explicitly to Ptolemy. In general, however, al-Ṭūsī's description does not contain anything that is not reported already by Avicenna, so it is possible that he depends on Avicenna's other works.

With regard to the second group, however, al-Ṭūsī goes into much more detail than for the first one. First, he presents this second group in a similar fashion to Avicenna, namely that according to this group, every sphere has a moving soul of its own. However, he adds the brief statement that also every planet has a moving soul: 'Others argue that each one of the mentioned spheres possesses a moving soul of its own, and likewise every planet.'[188] The following paragraphs deal with the consequence of this statement. This discussion is triggered by Avicenna's claim that there is a principle of circular motion for the planets, which also occurs in the passage quoted above from *The Cure*. It is, however, difficult to say whether Avicenna believes that the planets have a motion in their own right. In the corresponding passage in *On the Heavens and the World*, Avicenna follows *On the Heavens* II.8, where Aristotle argued that the planets neither roll nor rotate and are simply carried by the sphere. Avicenna adds the argument that we always see the same dark spots on the surface of the Moon (called *maḥw al-qamar*), which he considers as a solid argument against a rolling motion. Against someone insisting that the Moon rotates because these spots can also be explained by other bodies covering parts of the Moon, Avicenna puts forward Aristotle's argument that planets are not equipped with organs for locomotion.[189] In turn, al-Ṭūsī seems to be worried by Avicenna's inclusion of the planets in this picture, as he tries to explain why they should have a moving soul but still be fixed on and carried by a sphere. He alludes to the same example of the dark spots on the Moon that Avicenna used in *On the Heavens and the World* to argue against the Moon's rolling motion, but with the reservation (already made

[187] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 189:8–13.

[188] al-Ṭūsī, 'Šarḥ al-Išārāt', p. 189:17–18.

[189] See Avicenna, 'al-Samāʾ wa-l-ʿālam', pp. 46:16–47:4. There is the further issue of what to make out of his statement at p. 47:13–14: 'And one must also believe that the planet itself necessarily moves on its own, since it is known from the states of the celestial bodies.' Cf. Janos, 'Moving the Orbs', p. 200

by Avicenna) that this is only a valid argument as long as these spots are not merely reflections on the Moon's surface but things existing in reality.[190] However, al-Ṭūsī remarks that a certain judgment on this issue is problematic. His doubt can still be detected in his *Memoir on Astronomy*.[191] Without stating his own preference, al-Ṭūsī closes this part of the discussion by stating that according to this opinion (*ʿalā hāḏā l-raʾy*), the number of separate movers corresponds to the number of spheres and planets combined, and that Avicenna endorsed this view.[192] There is, however, no trace of the motion of the planets themselves in his *Memoir on Astronomy*, in which the complex planetary motions are assigned to the various spheres.

Although the statements on separate movers for the planets remain somewhat obscure, Avicenna makes it rather clear that the planets do not have an independent motion from the spheres in such a way that they would change their position within their carrying sphere. This is what he calls 'being penetrated' (*inḫaraqa*). Although similar statements also appear in Avicenna's other works, as just seen above, it is remarkable that Avicenna addresses the penetration of the celestial spheres in his brief discussion in the *Pointers and Reminders* as well. He states that the planets are carried around the Earth because they are fixed on a carrying sphere and do not penetrate that sphere.[193] Al-Ṭūsī comments on this sentence that Avicenna, by saying that the planets do not penetrate their spheres, aims to argue that they do not behave like fish swimming in water. Avicenna himself does not allude to this example in the *Pointers and Reminders*, but in a passage from his *On the Heavens and the World* that has been discussed above. This passage is repeated here for a direct comparison:

> If [someone] swims in the opposite direction of the stream of the water, then he could be motionless. It would appear that the stream surpasses him and he would remain in his place. And he could do the opposite of that, for if this standstill by him is complete resting, it would be the opposite [case], namely that he flows off with the stream by a motion, while he does not penetrate (*yaḫriq*) the water and what meets him does not depart from him. The same is the case for the planets.[194]

Given that in this passage, Avicenna also speaks of 'penetrating', al-Ṭūsī surely has this passage in mind when he writes the following in his commentary on the *Pointers and Reminders*:

> Then, Avicenna denies the imaginary notion (*wahm*) to which one is taken among the common people, namely that the stars move within the spheres as fish move in water. For the claim about the multiplicity of the motions that is necessary for the multiplicity of

[190] See al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 190:3–7.
[191] See al-Ṭūsī, *Memoir on Astronomy*, p. 159:20–23.
[192] See al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 190:10–13.
[193] Avicenna, 'al-Išārāt', Vol. 3, p. 192:1–2.
[194] Avicenna, 'al-Samāʾ wa-l-ʿālam', p. 46:12–15.

the movers is built on this [denial]. He denies it for two reasons: one of them is the prior general proof, namely that penetration (*al-ḫarq*) and mending of the bodies that possess circular motion by nature is impossible.[195]

Al-Ṭūsī's main argument here is that if we assume that the planets have an independent motion, we would not need to assume a multiplicity of motions and separate movers. In summary, al-Ṭūsī tries to further explain Avicenna's brief assertions in the *Pointers and Reminders* by adding some elements that can already be found in Avicenna's *On the Heavens and the World*. These include the comparison of the planets in their sphere to animals swimming in water, which is rejected both by Avicenna and al-Ṭūsī, and al-Ṭūsī's reference to the lunar spots. Moreover, when al-Ṭūsī presents the dynamic model known from the *Planetary Hypotheses*, he uses the term *inbaʿaṯa* ('being emitted'). Again, this term is not used in this context in the *Pointers and Reminders*, but in *On the Heavens and the World*. Thus, al-Ṭūsī apparently had the cosmological part of *The Cure* at hand while commenting upon Avicenna's *Pointers and Reminders*, and generally followed Avicenna in arguing against a motion by the planets themselves that would be independent from a carrying sphere. Ibn al-Hayṯam saw a similar problem in assigning an independent motion to the planets, as he wondered how it is possible that something could move independently within a sphere but nevertheless take part in its motion.[196] The difference between al-Ṭūsī and Ibn al-Hayṯam, however, is that al-Ṭūsī's argument is embedded in a metaphysical discussion, not in an astronomical one. Thus, al-Ṭūsī relates this argument to the number of separate movers: if the planets move independently from the carrying spheres, there would be no need for several spheres and thus no multiplicity of movers.

In al-Ṭūsī's commentary, there are other interesting passages on the theory of emanation and the separate movers.[197] However, it is also worth looking into al-Ṭūsī's more technical astronomical works. The first book of his *Memoir on Astronomy* contains two propaedeutic chapters. The first is a glossary of important geometrical terms, whereas in the second, al-Ṭūsī lays out the principles that one needs to take from natural philosophy. These physical presuppositions are not many in number and can be compared to the physical principles established by Ptolemy in Book II of the *Planetary Hypotheses*: the distinction between rectilinear sublunar and circular celestial motion, the lack of any alteration in the heavens, and

[195] al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 190:16–20. The second reason omitted in the quotation consists of a long astronomical argument on the regular opposition of the apogee and perigee of the planets, see al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, pp. 191:1–193:11.

[196] See above, pp. 180–81.

[197] See, for example, his citations from Alexander's *On the Cosmos* and from Themistius at al-Ṭūsī, 'Šarḥ al-Išārāt', Vol. 3, p. 182:19–24.

the impossibility of the existence of a void.[198] Al-Ṭūsī further divides self-motion into monoform motion and non-monoform motion. The principle of the first is called 'nature' (*ṭab'*) and is ascribed to the involuntary motion of the sublunar elements as well as to the voluntary motion of the celestial bodies, whereas the principle of the second is called 'soul' and is explicitly ascribed to the motion of plants and animals. This passage seemingly contradicts Avicenna's account, which describes the celestial souls (together with the intellects) as the movers of the celestial bodies and is apparently accepted by al-Ṭūsī in his commentary on *Pointers and Reminders*. However, this account again reflects the problem whether celestial motion should be labelled 'induced by soul' or 'natural', which Alexander of Aphrodisias merged in his own account. In the sublunar realm, the opposition between the natural motion of the elements and the voluntary motion of animals is rather clear, the former being monoform but not the second. Since al-Ṭūsī calls the celestial motions 'voluntary' (*irādiyya*), there also must be some kind of soul involved, while the regularity of their circular motion indicates their dependence on some innate nature. That the celestial motions are thus 'voluntary' and 'natural' reminds of Alexander's merging of 'nature' and 'soul', which seems to be a viable option only for the supralunar realm.

Apart from this notion in the introduction, there is no discussion of celestial movers from a metaphysical or natural philosophical point of view in the *Memoir on Astronomy*. Whenever al-Ṭūsī discusses 'movers' in his *Memoir on Astronomy*, he means spheres that move other spheres or the planets by their own motion.[199] F. Jamil Ragep concludes that 'the philosophical question of the ultimate source of the celestial motion is simply not of concern to him here', i.e. in the *Memoir on Astronomy*.[200] This certainly does not mean that al-Ṭūsī wishes to strictly separate astronomy from physics or metaphysics in general. On the contrary, these sciences depend on each other. As just seen, the number of separate intellects, for example, depends on the number of motions calculated in astronomy, and astronomy needs these physical presuppositions, as presented in the *Memoir on Astronomy*. The exact source of celestial motions does not belong to the presentation of planetary models, because the question whether it is an unmoved mover, a soul, or nature that moves a certain sphere does not have an impact on the resulting planetary motion.

Still, even without a proper discussion of the dynamic models by Avicenna or by al-Ṭūsī in his commentary on the *Pointers and Reminders*, it was very common to consider celestial bodies as ensouled and their motions as voluntary. In this context,

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[198] See al-Ṭūsī, *Memoir on Astronomy*, I.2, Vol. 1, pp. 98–101. For Ragep's valuable comments on these principles, see Vol. 1, pp. 41–46 and Vol. 2, pp. 380–81. In this paragraph, Ragep translates *'alā nahǧ wāḥid* as 'monoform', because the regular motions of the sublunar elements are not of a uniform speed. See also Ragep, 'The Two Versions', pp. 330–31. I follow his terminology in this paragraph.

[199] For example, in Chapter II.4 (al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, II.4, pp. 120–29) and in the chapter on his famous Ṭūsī Couple, II.11 (pp. 194–223).

[200] Cited from Ragep's introduction in al-Ṭūsī, *Memoir on Astronomy*, Vol. 1, p. 46.

the question again arises how an outer sphere moves another sphere within it when they are concentric or rotate about the same axis. Avicenna was concerned with this issue in his additional chapter to his paraphrase of the *Almagest*. One also comes across it in Ptolemy's *Planetary Hypotheses* in the context of his model of sawn-off pieces. There, the so-called 'rest of the aether' is in direct contact with every single set of planetary spheres and thus imparts its diurnal motion to every set. Ptolemy, however, is silent about the exact way in which this transmission happens. According to F. Jamil Ragep, al-Ṭūsī does not provide us with a solution to this problem either. Ragep then quotes the commentary by al-Ǧurǧānī on al-Ṭūsī's *Memoir on Astronomy* as follows:

> [In these latter cases], the moving soul of the enclosing [orb] may have a sufficient faculty to move the contained [orb], and hence will move it, inasmuch as every action is not contingent upon a corporeal instrument, or it may not have [a sufficient faculty] whereupon it will not move [the enclosed orb].[201]

In this account, a moving power stems from a celestial soul and is then imparted not only to its corresponding sphere but also to the next one. This reminds us of Ptolemy's dynamic model from the *Planetary Hypotheses* (though in the other direction: from the planet to the carrying sphere and then to the enclosing spheres) and illustrates again how deeply the idea of celestial motions by a soul penetrated the astronomical tradition. This is, of course, no surprise, since it enabled the astronomers to distinguish celestial motions from the motions of the four sublunar elements. After all, every astronomer could observe that celestial motions do not cease and always come back to their point of departure, and this regularity was accounted for by adopting Aristotle's distinction of sublunar and supralunar physics.

Averroës on Ptolemy's Dynamic Theory in his Commentaries on Aristotle

As shown in Chapter II, we can trace the influence of Ptolemy's *Planetary Hypotheses* in al-Andalus in citations and references in Averroës' commentaries. In this last brief section, I want to discuss the evidence we have that Averroës also engaged with Ptolemy's theory of celestial dynamics, and that he relied on other sources in order to defend Aristotle's cosmology from *On the Heavens* and *Metaphysics* XII.8. I restrict myself to the discussion in his *Epitome of Metaphysics* (*Ǧawāmiʿ Kitāb Mā baʿd al-ṭabīʿa*), as it is there that we find the clearest evidence for an engagement with Ptolemaic cosmology.[202]

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[201] Quoted from Ragep in al-Ṭūsī, *Memoir on Astronomy*, Vol. 2, p. 410.

[202] Averroës' theory of celestial motions can be gathered from a number of works, most importantly his commentaries on *On the Heavens* and the *Long Commentary on Metaphysics*. For modern discussions, see, among others, Carmody, 'The Planetary Theory', Wolfson, 'The Plurality of Immovable Movers', Wolfson, 'The Problem of the Souls', Davidson, *Alfarabi, Avicenna, and Averroes*, pp. 220–57, Endress, 'Averroes' *De Caelo*', and Donati, 'Is Celestial Motion a Natural Motion'.

In his *Epitome of Metaphysics*, Averroës dedicates the last section to questions that arise from *Metaphysics* XII, especially from Chapter 8. With the aid of Aristotle's *Physics*, he quickly summarizes the rationale for unmoved, immaterial principles of celestial motions and then arrives at the question of their kind of existence, their number, and their relation to each other.[203] When he comes to discuss their number, he invokes Aristotle's statements from *Metaphysics* XII.8 (1073b3–5) that one needs to rely on astronomy to answer that question:

> As for the number of these motions and [of] the bodies moved by them, this should be taken for granted here from the discipline of mathematical astronomy. Of these [doctrines] we shall assume here those which are most widely accepted in our days, that is those which are undisputed among the specialists of this discipline, from Ptolemy up to the present time, while we leave [the solution of] that which is disputed among them to the specialists of that discipline. Actually, a lot of what concerns these motions cannot be determined other than by employing generally accepted premises, since the determination of many of these motions requires a span of time many times as long as a man's life. Generally accepted premises of a discipline are those which are undisputed among its specialists, which is why we rely on some of these premises at the present place.[204]

With this remark, Averroës makes it clear that he takes Aristotle's assertion seriously, namely that it is the astronomers' task to provide the necessary number of celestial motions. He does not spare a word for Aristotle's cosmology presented in *Metaphysics* XII.8 and he even disagrees with Aristotle when he writes afterwards that there are 38 (or 39) celestial motions.[205] Instead, he writes that he will start from the theories on which most astronomers agree. Although he considers these as the ones that stem from Ptolemy, he nevertheless makes the restriction that there are aspects that are the subject of ongoing discussions. For Aristotle, the most recent astronomical models were the ones by Callippus and Eudoxus, whereas Ptolemaic astronomy was the most widespread theory in the time of Averroës. In this sense, the approach of Averroës is very much in line with Aristotle's. One must note, however, that Averroës does not make any judgment about the physical status of these theories. After all, his concern here is first the number of celestial movers and how it relates to the number of celestial motions: are these numbers the same or not?

Before he proceeds to this question, Averroës adds a digression on the question of the ninth sphere. He connects it with Ptolemy's theory of precession and Ibn al-Zarqāllūh's theory of trepidation, only to rely in the end on an argument made

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[203] See Averroës, *On Aristotle's 'Metaphysics'*, pp. 138–43. For Arnzen's critique of the extant editions of this text and the use of witnesses for his own translation, see pp. 11–17. In light of these difficulties, I rely solely on Arnzen's translation.

[204] Tr. by Arnzen in Averroës, *On Aristotle's 'Metaphysics'*, p. 146. For another translation and an analysis of this and the following passages from the *Epitome*, see Sabra, 'The Andalusian Revolt', pp. 139–40.

[205] Averroës, *On Aristotle's 'Metaphysics'*, p. 146.

by Aristotle in *On the Heavens* II.12: the highest celestial sphere must be considered as the noblest one, for it is closest to the Prime Mover and encompasses all other celestial spheres. A sign of its nobility is that it carries not a single planet but the entirety of the fixed stars.[206] Therefore, Averroës concludes, there cannot be a starless ninth sphere encompassing the sphere of the fixed stars. This highlights Averroës' approach to astronomy: on the one hand, astronomy provides us with some knowledge that is necessary for certain aspects of metaphysics, such as the number of the celestial immaterial principles; on the other hand, astronomical theories need to be checked not only against the appearances and observational data, but also against the principles established in other disciplines, such as natural philosophy.[207]

As Averroës comes back to the issue in question, namely the number of movers, he faces the question whether every planet needs an own mover for the diurnal motion or whether there is only one celestial mover for this daily rotation, which is then somehow imparted to all planets. Averroës ascribes the first theory to Aristotle and the second to Alexander of Aphrodisias' *On the Cosmos*.[208] In arguing that all planetary spheres are part of the entirety of the cosmos and thus partake in its diurnal rotation, Averroës sides with the view he had ascribed to Alexander and thus suggests that he is in disagreement with Aristotle. This is remarkable, for Aristotle only introduced the counteracting spheres in *Metaphysics* XII.8 (notably the text upon which Averroës comments in these passages) to make sure that all planets indeed partake in the primary diurnal motion without being influenced by the motions of the other planets. This means that one needs only one mover for this diurnal motion, which is obviously the Prime Mover. This raises some doubts about whether Averroës really understood the meaning of the counteracting spheres that came down to him in translation as 'spiral' motions (*lawlabī*).[209] These brief allusions to Alexander, however, nicely bring us back to the beginning of the current chapter, since one can identify the different cosmological works exerting their influence on Averroës: Aristotle's cosmological account from *Metaphysics* XII.8, other Peripatetic cosmological works such as *On the Cosmos* by Alexander, and Ptolemaic astronomy.

Of major importance for the present discussion is the way in which Averroës attempts to argue for the fact that the inner spheres all partake in the motion of the entire cosmos without having a mover essentially imparting this diurnal motion to them. He compares the entirety of the cosmos to an animal that has one major

[206] *Cael.* II.12, 292b25–293a11.

[207] See Averroës, *On Aristotle's 'Metaphysics'*, pp. 146–47. One solution to this problem was offered by ʿAbd al-Laṭīf al-Baġdādī, who argued that the ninth sphere must have even more stars than the sphere of the fixed stars but that we are unable to perceive them. See Neuwirth, *'Abd al-Laṭīf al-Baġdādī's Bearbeitung*, p. 61:6–11.

[208] Averroës might have in mind statements from *On the Cosmos* such as the following: 'Therefore, one should not think about the [impulse] to move from the sphere of the fixed stars to the sphere of the wandering planets that it is coerced', and 'the First Mover [...] is the mover for the first, eternal motion'. See Alexander of Aphrodisias, *On the Cosmos*, Sections 85 and 100, tr. by Genequand.

[209] See above, pp. 125–26.

motion, with the motion of its limbs are the particular motions of the planets.[210] Although this sounds very close to the analogy from the *Planetary Hypotheses*, this comparison by Averroës does not necessarily stem from this source directly. In al-Andalus, we encounter a similar account in Ibn Ṭufayl's *Ḥayy ibn Yaqẓān*, when the protagonist Ḥayy contemplates the arrangement of the cosmos and its motions.[211] In contrast to these accounts by Averroës and Ibn Ṭufayl, in Ptolemy's *Planetary Hypotheses*, as well as in Avicenna and al-Ṭūsī, one finds a more detailed comparison between animals and planetary systems: as the animals' hearts or brains send out impulses to the muscles and limbs, the planets send out impulses to their spheres. This does not result in the analogy of the cosmos as one unique animal, but a comparison of each planetary system to one animal. A little later, Averroës addresses a theory of impulses sent out from the planet. Before we take a look at this passage, one must briefly mention that he also touches on eccentric spheres and epicycles as moving inside this 'celestial animal'. As already stated previously, these remarks are in apparent conflict with his rigorous rejection of non-concentric spheres in the *Long Commentary on Metaphysics* that I have discussed in Chapter II.[212] Part of that story is that Averroës changed his position on the theory of emanation from the *Epitome* to the *Long Commentary on Metaphysics* as well. As argued by Herbert A. Davidson, Averroës first applies a theory of emanation similar to those put forward by al-Fārābī and Avicenna, including the acceptance of minor spheres with their separate movers that are responsible for the complex planetary motions.[213] A complementary aspect that explains why non-concentric spheres feature in the *Epitome* but are rejected in the *Long Commentary on Metaphysics* comes from Averroës' introductory restriction. Admittedly, in the earlier *Epitome of Metaphysics*, he seems more open to the idea of spheres that do not move about the centre of the cosmos and he certainly does not think that this theory has an impact on the determination of the number of celestial movers that are responsible for the diurnal rotation. Nevertheless, he has made it perfectly clear that he relies here only on the astronomical theories that are generally accepted. This does not mean that he accepts them, because he detects some problematic issues with which astronomers should engage. From the point of view of the question at hand, namely whether the number of celestial movers is smaller or higher than or equal to the number of celestial motions, the issue of different astronomical models does not need to

[210] See Averroës, *On Aristotle's 'Metaphysics'*, p. 148. A similar account can be found in the *Epitome of On the Heavens* (see Glasner, 'Gersonides on Simple and Composite Movements', p. 570).

[211] See Ibn Ṭufayl, *Hayy ben Yaqdhān*, p. 80:3–12. In fact, the cosmos–animal analogy goes already back to Plato's *Timaeus*, see *Tim.* 32c5–33b4 and 36b6–37c5.

[212] On this discrepancy, see again Sabra, 'The Andalusian Revolt', pp. 139–42.

[213] See Davidson, *Alfarabi, Avicenna, and Averroes*, pp. 223–31; another example of Averroës' earlier 'Avicennean' phase is the generation of sublunar animals resulting from supralunar influences, for which see Davidson, *Alfarabi, Avicenna, and Averroes*, pp. 232–42, and Freudenthal, 'The Medieval Astrologization'.

be discussed. Still, he writes in the *Long Commentary on Metaphysics* that he had hoped in his youth to find an astronomical model that could better fit Aristotelian physics than the 'new' Ptolemaic one. Thus, he apparently decides at this earlier stage (more Avicennean, we might say following the results of Davidson's study) not to go into the astronomical details in the context of the immaterial principles and save it for a later work after further astronomical studies.

To come back to the question of the number of celestial movers, Averroës also considers a position that sounds much more like the one Ptolemy puts forward in the *Planetary Hypotheses*:

> [One might ask] whether it is possible, as assumed by some people, to posit a number of movers less than this, such that we assume only one mover for each sphere by which first the star [of that sphere] is set in motion, from which star powers then emanate appropriate for the [various] motions peculiar to this star, these [motions] being for the sake of that [single mover]. However, [it is clear] from what has been said before as well as from what follows [that] this is impossible. For when we assume that these spheres are set in motion solely through conceptualizing immaterial things, clearly the remaining movements found in each of the stars originate neither from conceptualizing [this] star nor from desiring it, as is clear from what we said [above]. Furthermore, there are no powers emanating from the star to the remaining parts of its spheres, since the only part of the soul found in them is the kind which consists in intellectual conceptualization.[214]

In this scheme described by Averroës, first the planet desires its unmoved mover and is set in motion in this way.[215] In the next step, the planet sends out impulses to its spheres in order to generate the different simple motions and thus the combined complex motion that is apparent for the planet. Averroës rejects this theory because he has shown earlier that (1) the celestial body is animated and moved by desire and not by nature, (2) that it desires through its intellectual conceptualization and not its sense perception or imagination, and (3) that what is conceptualized cannot be bodily, but must be the immaterial unmoved movers. This train of thought, as shown already by Rüdiger Arnzen, stems from Alexander of Aphrodisias. Here, it leads Averroës to conclude that the spheres do not desire the planet and that in the celestial bodies there is no capacity of the soul other than intellectual conceptualization.[216] An important difference between Alexander of Aphrodisias and Ptolemy is, as shown above, the location of the ensouled body in the heavens. For Alexander, the spheres are ensouled and move the stars and planets along, whereas Ptolemy locates the source of the impulse to move within the planets themselves, which then impart motion

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[214] Tr. by Arnzen in Averroës, *On Aristotle's 'Metaphysics'*, p. 149.

[215] For more details and further literature on Averroës' understanding of the celestial movers, see the research by David Twetten, (e.g. Twetten, 'Averroes on the Prime Mover') and, more recently, Twetten, 'Whose Prime Mover'.

[216] See Averroës, *On Aristotle's 'Metaphysics'*, pp. 142–43, and Arnzen's comment on pp. 305–06 n. 555.

to the various spheres. This is important for Alexander, since in this way, he can be sure not to be in conflict with Aristotle's teaching that the planets do not move by themselves. Ptolemy is, in the end, willing to make the point that if one agrees that the planets impart motion to the spheres, it is also possible for them to have motion on their own. Although Averroës does not tell us who these people that upheld such a theory are, Ptolemy or some other later unknown authors that were influenced by Ptolemy must be the addressees of his critique. There is no other evidence of a similar theory, namely that the planets move by themselves — in Averroës' picture, through their desire for a celestial mover — and that they send out impulses on which the spheres act. In order to find further evidence that Averroës has the *Planetary Hypotheses* in mind here, one can take another look at Chapter II, from which it is clear that he was well acquainted with this text. Thus, here again, the combination of Ptolemy's account of celestial dynamics from Book II of the *Planetary Hypotheses* with the Peripatetic and Neoplatonic theory of celestial bodies that move through their desire for the immaterial unmoved movers comes to light.[217]

Averroës' own stance in his *Epitome of Metaphysics* is the same as Alexander's, namely that each celestial motion comes about by the desire of one celestial sphere for one unmoved mover, whereas the planets are simply carried around by the spheres. This becomes much clearer towards the end of his *Epitome of Metaphysics*, where he discusses the order of celestial movers and the criteria for judging their nobility. Averroës provides the reader with a list of the separate movers and how some of them emanate from others. He closes the list by saying that this list is far from necessary and covers only what is 'most appropriate and fits best'.[218] This is the same notion of probability that surfaced in so many other works discussed in Chapter II, which was also raised by Averroës in the beginning of this section concerning astronomical theories. This underlines Averroës' uncertainty concerning the truth of the astronomical models he adopts because they are the most widely accepted. In fact, it mirrors Aristotle's own remark after his discussion of the number of celestial motions, when he concludes that his account is merely 'reasonable' (*eulogon*) and not necessary.[219] In this light, it becomes even more interesting that Averroës, in the later *Long Commentary on Metaphysics*, claims that one needs to go back to the 'old' astronomy from the time of Aristotle and his predecessors and thus to the account that Aristotle himself had labelled 'reasonable' and not necessary. However, at this earlier stage, Averroës simply acknowledges that his investigation is not a proper astronomical one.

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[217] On this point, see also Janos, 'The Reception of Ptolemy's Theory'. In addition, note that Averroës already rejected the theory of self-moving planets in the previously discussed passage from the *Epitome of On the Heavens* because it would undermine Aristotle's doctrine of a spherical cosmos with a natural circular motion. See Chapter II, p. 118.

[218] See Averroës, *On Aristotle's 'Metaphysics'*, p. 169.

[219] *Metaph.* XII.8, 1074a14–17.

A final illustration of the influence of Alexander's cosmology on Averroës can be seen in the last section of the *Epitome of Metaphysics.* Averroës concludes this work with a discussion of the influence of the rotational motion of the heavens on the sublunar world and subsequently on the role of divine providence.[220] The merging of topics from *Metaphysics* XII with divine providence was very prominent in Alexander's *On the Cosmos*, as shown above. This again highlights Averroës' overall attitude in the cosmological part of the *Epitome of Metaphysics*. As he obviously took his starting point from Aristotle, it can easily be seen that the main source for his cosmological scheme of unmoved movers and how they are desired by the celestial bodies is taken from Alexander's cosmological works, most importantly *On the Cosmos*, but perhaps also *On Providence* and the lost commentary on *Metaphysics*. Averroës also uses arguments that he found in *On the Cosmos* to disprove Ptolemy's theory of planets that conduct their own motions. Interestingly, he ascribes this theory to an otherwise unspecified group of people, which is somewhat similar to the way in which Avicenna and al-Ṭūsī introduced this theory. This could indicate that there were indeed scholars adopting Ptolemy's theory of celestial dynamics — possibly including, as argued above, al-Fārābī — and Averroës turns to Alexander of Aphrodisias to refute it and to come closer to the picture of *Metaphysics* XII.8.

As a final remark, it remains to say that Averroës was not the only one in al-Andalus propagating a theory of celestial dynamics that involved Peripatetic and Neoplatonic concepts such as desire. One example is al-Biṭrūǧī, who develops a curious concept of desire in the celestial spheres: according to al-Biṭrūǧī, this desire somehow diminishes from the highest to the lowest sphere, which is thus one reason for the diversity of celestial motions.[221] Even more important is Averroës' impact on Gersonides (d. AD 1344) who is well-known for his critical assessment of earlier planetary theories. He was very interested in the *Planetary Hypotheses* and its theory of celestial dynamics, since he touches upon it in his major work, more precisely Book V of the *The Wars of the Lord*, as well as in his supercommentaries on Averroës and Aristotle. In fact, we know that he had a copy of Kalonymus ben Kalonymus' Hebrew translation of the *Planetary Hypotheses* in his possession, from which he even quotes literally in *The Wars of the Lord*.[222] Concerning the analogy of the entire cosmos to an animal that Averroës uses to establish that there is only one mover of the diurnal rotation, Gersonides compares this with Ptolemy's account in *Planetary Hypotheses* II.7 and subsequently rejects it.[223] Although the details of Gersonides' engagement with Averroës' commentaries still await more research, we can already see that Averroës and Ptolemy served as important targets of critique in Gersonides' own theory of celestial dynamics.

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[220] See Averroës, *On Aristotle's 'Metaphysics'*, pp. 170–81.

[221] See Samsó, 'On al-Biṭrūǧī', pp. 9–13, and Mancha, 'Al-Bitruji's Theory', p. 148.

[222] See Glasner, 'Gersonides on Simple and Composite Movements', p. 568 and n. 132. For further references concerning his supercommentaries, see Glasner, 'The Early Stages', especially p. 9 n. 31.

[223] Glasner, 'Gersonides on Simple and Composite Movements', pp. 568–74.

Gersonides is the latest author at the present state of knowledge of whom we have direct evidence of the reception of the *Planetary Hypotheses* before its partial Latin translations in the 16th and 17th centuries AD. With him as the last cornerstone, we know about authors reading and discussing this work from the Islamic East via Cairo to al-Andalus, and even to the Jewish community in Provence, from the tenth to the fourteenth centuries AD. As it turns out, Ptolemy's analogy of the cosmos to a flock of birds serves as a valuable fossil index for tracing the reception of the *Planetary Hypotheses*, similar to the famous sawn-off pieces.

IV: Conclusion

Ptolemy wrote the *Planetary Hypotheses* clearly with the layout of the sciences and their epistemological status in *Almagest* I.1 in his mind. It is remarkable how closely he follows the idea of the conjectural knowledge of natural philosophy in the *Planetary Hypotheses*. This becomes apparent from all major theories he develops in this treatise (aside from some astronomical improvements over the *Almagest*): the distances and sizes of the planets; the shape of the celestial bodies; the origin of celestial motions in souls; and the individual motion of a planet independently from a sphere carrying it. In all these instances, Ptolemy explicitly adds that his preferred solutions are only more probable than others since they cannot be proven mathematically and thus with ultimate certainty. The *Planetary Hypotheses* takes the well-established knowledge from the *Almagest* as the starting point for an investigation into topics that need to be considered not only from the mathematical, but also from the physical point of view. In this sense, Ptolemy makes the transition from a purely mathematical account of celestial motions to its physical description, although he himself makes clear that these physical theories cannot be of the same certain nature as the mathematical knowledge from the *Almagest*.

In fact, these key theses turn out to be very helpful for identifying the various traces of an influence of the *Planetary Hypotheses* on later philosophical and astronomical works. In order to fully understand this influence, one must first acknowledge the originality of Ptolemy's cosmology. This does not mean that he established an entirely new approach that is utterly different from his predecessors or contemporaries. In comparison to works such as the pseudo-Aristotelian *On the World*, Alexander of Aphrodisias' cosmological treatises, and to later commentators like Simplicius and Proclus, it becomes clear that issues like the role of celestial souls in the origin and transmission of planetary motion and the relationship between the planets and the spheres are heatedly debated from the time of Plato and Aristotle until late antiquity and beyond. In this sense, Ptolemy is no exception. I have used these other works from the Hellenistic and late ancient tradition in order to better understand the context of Ptolemy's own theories. One of the most important results is the Platonic element of his cosmology. Ptolemy stands within a tradition of authors who try to interpret Plato's or Aristotle's astronomical passages in a way that harmonizes them with more recent astronomical observations and geometrical devices. Through comparing his own theory of sawn-off pieces to Plato's whorls on the one hand and rejecting Aristotle's mechanical cosmology on the other hand, Ptolemy tries to place himself in the Platonic tradition, although his major presentation of celestial physics can safely be called Aristotelian (existence of aether, natural motion of the elements). Ptolemy's agenda, however, is different from these other earlier or contemporary works, insofar as his interest lies in astronomical knowledge. When he introduces his physical positions in order to supply the mathematical calculations from the *Almagest* with an underlying physical theory, his focus still lies on an improved understanding of celestial appearances. For example, when he lays out his theory of planetary distances, he introduces the notion that we can assume that there is no void in the cosmos since nature does nothing in vain. This leads him to conclude a provisional minimum account of planetary distances. However, he does not prove that there is, in fact, no void and he admits instead that the non-existence of void is only most probable. The same strategy can be found in Book II of the *Planetary Hypotheses*, when he argues for the most economic cosmological theory. Here, the astronomical question of the number of spheres is connected to different physical or even metaphysical theories, namely whether the planets are ensouled and as such conduct their own motion and whether celestial motions are transmitted in a mechanical or psychological way. As Ptolemy here relies on arguments from natural philosophy, he restrains a final judgment about which dynamical system is necessarily correct.

Therefore, in the *Planetary Hypotheses* three threads come together to form Ptolemy's cosmology: astronomical questions that cannot be decided solely on the ground of mathematics; physical theories in order to fill this gap left by mathematics; the epistemological framework that these theories which need to rely on non-mathematical arguments are merely most probable or persuasive.

Once one acknowledges these parts of Ptolemy's cosmology as original contributions, a clearer picture about the reception of the *Planetary Hypotheses* emerges. Already in the early Arabic treatises on planetary distances from the ninth and tenth centuries AD, one comes across the idea that the spheres are nested into each other and leave no empty spaces between them. This theory that there are no void spaces in the cosmos is in itself not a clear indication for an influence from Ptolemy as it is a central principle of Peripatetic philosophy. However, the rationale of these astronomers to consider it as necessary requirement for calculating planetary distances strongly resembles Ptolemy's argument in the *Planetary Hypotheses*.

Similarly, one can identify the Ptolemaic influence in the question of the number of celestial motions and movers. As in the case of planetary distances, Ptolemy connects the question of the number of celestial bodies with a non-mathematical investigation. This number does not solely depend on the observed motions, but also on philosophical positions. As Ptolemy tries to show, two assumptions lead to a more economic astronomical system with fewer celestial bodies needed to account for the observed phenomena: (a) that celestial motions do not come about in a mechanical way through the connection of the spheres at their poles, but rather in a psychological way, and (b) that the planets move independently from a carrying body. Therefore, Ptolemy's theory of celestial dynamics is discussed in later times both in astronomical as well as philosophical works and contexts. In the treatises of astronomers like Ibn al-Hayṯam and al-Bīrūnī, one finds direct evidence of a reception of the *Planetary Hypotheses* since they reject Ptolemy's theories briefly, but unanimously. In his metaphysical discussion of celestial movers, Avicenna (and later also al-Ṭūsī) paraphrases theories of an unspecified group of people that resemble the ones by Ptolemy. The fact that Avicenna does so in the context of the number of celestial motions and movers suggests again that it is, in fact, the *Planetary Hypotheses* that is in the background. In the time after Avicenna, there is more evidence of philosophers who argue along similar lines as Avicenna and paraphrase the dynamical ideas of Ptolemy, most importantly the independent planetary motions, in the same fashion. In addition to authors discussed above (namely al-Ḫaraqī, Kūšyār ibn Labbān, and al-Ṭūsī), one can also name Aṯīr al-Dīn al-Abharī and ʿAdud al-Dīn al-Īǧī.[1] The latter author stands for a tradition that I do not include in the present study, namely that of Islamic theology or *kalām*. However, as the example of al-Īǧī shows, this does not mean that the influence of Ptolemy's cosmological idea only pertains to astronomers or *falāsifa*. Certainly, much more material than I was able to cover in the present study awaits proper investigation.

In addition to Ptolemy's account of planetary distances and celestial dynamics, his key doctrine of sawn-off pieces helps in determining that authors are indeed discussing the *Planetary Hypotheses*. These replacements for the usual celestial spheres also come up in the same passages when authors discuss celestial dynamics and the number of celestial bodies and therefore in the same context as in the *Planetary Hypotheses*. Here, it is interesting to note that we only have very scarce evidence of people who actually defended Ptolemy's idea: for instance, there is Ibn al-Hayṯam's dispute with an unknown author of his time. We receive conflicting testimonies from al-Ṭūsī and al-ʿUrḍī, of whom the former claimed that some misguided people argue for this theory, whereas the latter claims that there is virtually no one defending it. Although there is a number of possible explanations, it is possible that al-Ṭūsī refers to earlier discussions (to which he perhaps did not have direct access) and that al-ʿUrḍī talks about his contemporaries or fellow astronomers at the observatory in Marāġa.

In this context, future research must take into account that a serious discussion of Ptolemy's sawn-off pieces together with his notion of independently moving planets begins apparently around AD 1000 onwards in the Islamic world. This shift that I describe in some detail is connected to another very important aspect of Ptolemy's cosmology that turned out to be very pervasive through time. Also starting with authors that lived around AD 1000, one can see various evaluations of Ptolemy's claims concerning the conjectural status of the physical aspects of cosmology. As I lay out in detail, Ptolemy claims that arguments which involve not only mathematical, but also physical reasoning only provide us with the most probable account. In the medieval Arabic tradition, one finds many different replies to that claim and I provide an overview of them in Chapter II. To highlight an important example, one can observe a radical reformulation of Ptolemy's position in al-Bīrūnī's astronomical work. He strongly emphasizes that astronomers must offer mathematical instead of physical arguments and attempts to replace Ptolemy's arguments from natural

[1] For al-Abharī, see the astronomical part of his *Kašf al-ḥaqāʾiq fī taḥrīr al-daqāʾiq*, extant in MS Tehran, Kitābḫāna-yi Maǧlis-i šurā-yi Islāmi, 2752, especially pp. 188:23–198:12, and for al-Īǧī, see Sabra, 'Science and Philosophy', and Morrison, 'Falsafa and Astronomy', pp. 317–18.

philosophy in the first chapters of the *Almagest* with geometrical arguments. On the other extreme, Ibn al-Hayṯam believes that astronomers who only rely on circles and do not provide an account of how geometrical models relate to physical bodies neglect an important aspect of astronomy. This latter approach is further developed by the researchers working at the observatory in Marāġa. Al-Ṭūsī and al-ʿUrḍī are keen to preserve the fundamental claims of Aristotelian natural philosophy against certain innovations in Ptolemaic astronomy, most importantly the motion of spheres rotating about different, non-physical points. One reason for their allegiance to Aristotle may be seen in the dominant role of Avicenna's philosophy in the Eastern tradition. Another important role can be ascribed to logical works, such as the Arabic translation of Aristotle's *Posterior Analytics*, with which the distinction between proofs of the fact and proofs of the cause entered the Arabic tradition. Shortly after this work became available in Arabic, al-Fārābī includes the distinction in his epistemological framework of the sciences, and one can follow this trace up to the time of al-Ṭūsī, who employs the same distinction in order to highlight the difference between mathematics and natural philosophy. While the Eastern tradition in Marāġa focused in their critique of Ptolemaic astronomy mostly on its employment of imaginary points, the Western tradition in al-Andalus around authors such as Ibn Bāǧǧa, Ibn Ṭufayl, and Averroës is much more radical. They extend similar points of critique concerning the supposedly non-uniform motions in Ptolemy's models even to the most basic devices, namely epicycles and eccentric spheres. As in the East, the cosmological work by Ibn Bāǧǧa also starts with an evaluation of logic and how astronomers make use of it. Therefore, one can consider the Andalusian tradition as a similar, but more radical development than the Eastern one, most prominently in form of the vehement rejection of Ptolemaic astronomy in favour of Aristotelian logic and natural philosophy in Averroës and culminating in an entirely new astronomical model by al-Biṭrūǧī.

The present study is certainly not the first to elaborate on the idea of a clash between Aristotelian physics and Ptolemaic astronomy, especially in the context of the Marāġa-school and Andalusian science.[2] However, I want to suggest that Ptolemy's own distinction between the certain knowledge offered by mathematics and the conjectural knowledge by other philosophical disciplines plays a major role in this story. Due to the many references (explicit as well as implicit) to the *Planetary Hypotheses* in the medieval Arabic tradition, it becomes clear that Arabic authors must have been aware of the fact that already Ptolemy himself differentiated between his mathematical proofs from most of his *Almagest* on the one hand and theories that are most probably true on the other hand, such as the eccentric model for the Sun in *Almagest* III and the main cosmological arguments in the *Planetary Hypotheses*.

[2] See for example Sabra, 'Configuring the Universe', Ragep, 'Freeing Astronomy', and Saliba, 'Aristotelian Cosmology'.

As a matter of fact, this awareness can, as I have argued, already be seen in Proclus who apparently refers to this epistemic difference between Ptolemy's arguments.

In addition to the wide reception in classical Arabic cosmology, there might be grounds for an even wider narrative. I argue elsewhere that Ptolemy's epistemology also permeates the Latin tradition in the time of Regiomontanus, Rheticus, Osiander, and Copernicus in the 15th and 16th centuries AD.[3] This means that even in the process of the so-called Copernican revolution, one comes across a debate of the traces which I follow in the present study from the time of Ptolemy through late antiquity until the 13th century AD in the Islamic East and West: which arguments can be considered as generating knowledge of the truth, when mathematical or geometrical proofs are combined with natural philosophy or metaphysics? How do astronomical models relate to philosophical concepts of nature? As the present study suggests, we must consider Ptolemy as an important source of inspiration, not only due to the well-known success of his planetary models, but also in terms of introducing a notion of probabilism to certain aspects of cosmology.

In addition, the present study does not only cast light on the Arabic reception of the *Planetary Hypotheses* in particular, but also develops an overview of the history of Graeco-Arabic cosmology more generally. Surely, this overview is far from being complete. In my restriction to the period and locations in which there are explicit traces of the *Planetary Hypotheses*, I do not cover other important astronomical traditions of the Islamic world, for example the scholars around the observatory in Samarqand or the Ottoman period.[4] These are examples for possible further directions of future research along the lines of the present study. As is abundantly clear from the many examples given above, Ptolemaic cosmology as presented in both the *Almagest* as well as the *Planetary Hypotheses* has a long-lasting impact on later authors. This impact is not only restricted to astronomical works, but is also evident in treatises on physics and metaphysics. In fact, this is mirrored by one of the two main witnesses of this text, as MS London, British Library, Add. 7473 contains, aside from the *Planetary Hypotheses*, both mathematical and psychological texts.[5] One of the reasons for this wide dissemination of the *Planetary Hypotheses* is its combination of astronomical theories with natural philosophy, which made it such an important point of reference for later authors working on the question of how to conceive of geometrical astronomical models in physical terms.

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[3] See Hullmeine, 'Wie sicher ist unser Bild vom Kosmos?'.

[4] As one example, there is the highly interesting figure ʿAlī al-Qūšǧī (15th century AD), who worked at the observatory in Samarqand and later in Istanbul. For his arguments on the independence of astronomy from other philosophical disciplines, see Ragep, 'Freeing Astronomy', pp. 61–63.

[5] See above, pp. 22–23.

V: The Arabic Version of the *Planetary Hypotheses*: Edition and Translation

بسم الله الرحمن الرحيم C2 | B81v | L1v

كتاب بطلميوس القلودي في اقتصاص جمل أحوال الكواكب المتحيّرة

المقالة الأولى

H70 |1:1| إنّا قد وصفنا الأصول التي عليها مبنى الحركات السماوية يا سوري في الأقاويل التي وضعناها في الأمور التعليمية. |1:2| وأتينا في ذلك بقياس برهاني وبيّنّا الشيء الذي يجب أن يكون كلّ واحد منها موافقًا فيه لما يظهر لنا والشيء الذي لا يوافقه فيه لنبيّن بهذا أمر الحركة المستديرة اللازمة ضرورة للأشياء التي تعمّها الطبيعة الثابتة على حال واحدة المستوية النظام. وإنّه لا يمكن فيها قبول الزيادة والنقصان بنوع من الأنواع البتّة.

|1:3| وأمّا في كتابنا هذا فإنّ غرضنا أن نضع فيه جمل هذه الأشياء التي ذكرنا فقط ليكون تصوّرها في أوهامنا وأوهام من أراد أن يعمل لها الآلات سهلًا وكذلك إن أراد مريد أن يحسب باليد فيعلم الموضع الذي انتهت إليه كلّ واحدة من الحركات وكذلك إن أراد أيضًا أن يجمع الحركات بعضها إلى بعض وإلى حركة الكلّ بمذهب المخانيقي وهي الحيل. |1:4| ليس بأن يعمل كرة على المثال الذي جرّت به العادة. فإنّ هذا النوع من C3

كتاب بطلميوس في الهيئة المسمّى بالاقتصاص بسم الله الرحمن الرحيم اللهم [بسم…المتحيّرة **1/2**
L حال [أحوال   om C [كتاب…المتحيّرة **2**   add L يسر رب [الرحيم **1**   B توفيقك لما ترضاه
om BC [قد **4**   add BC من كتاب بطلميوس في الهيئة المسمّى بالاقتصاص قال بطلميوس [الأولى **3**
B وأثبتنا ذلك [وأتينا…ذلك   BC وصفناها [وضعناها **5**   m تبنى [مبنى   om BC [الأصول…السماوية
BC ليبيّن [النبيّن   BC موافقة [يوافقه   om C [الذي   L مواقعًا [موافقًا **6**   sl B [يجب أن **5/6**
C فأنّ [فإنّ **9**   m وأنّه [وإنّه **8**   C أحدة [واحدة   L الثانية [الثابتة   BC تقيمها L يعمها [تعمّها **7**
[بمذهب   om B [أن **12**   L أردنا [أراد   L فتعلم [فيعلم   L تالية [باليد **11**   B ذكرنها [ذكرنا
L حدث [جرّت **13**   BC المجانيقي [المخانيقي   BC مذهب

4 الأصول] Τὰς ὑποθέσεις H   **5** في[1]…التعليمية] τῆς μαθηματικῆς συντάξεως H   **6** والشيء…فيه[2] om H   **7** المستديرة] ὁμαλῆς add H   **10** وكذلك] ἐάν τε H   **11** وكذلك] ἐάν τε H   **12** الحركات] αὐτὰς H   **12/13** بمذهب…الحيل] διὰ τῶν μηχανικῶν ἐφόδων H   **13** يعمل كرة] σφαιροποιεῖν H

In the name of God, the Compassionate, the Merciful

The treatise by Claudius Ptolemy on the report of the summary of the conditions of the wandering stars

Book I

|1:1| We have described the principles on which the heavenly motions rely, oh Syrus,[1] in the account laid down by us about the mathematical issues [i.e. the *Almagest*]. |1:2| In this course, we have brought forward a demonstrative proof and we have shown the aspect in which each of the [motions] is necessarily in agreement with what is apparent to us, and the aspect in which it is not in agreement, in order to show by this the case of the circular motion that necessarily belongs to the things to which the nature is common that stays in one condition and is regularly arranged. For it is not possible that [these things] receive an increase or decrease in any way.

|1:3| In this treatise, it is our aim to lay down only a summary of these things that we mentioned so that it is simple to imagine them in our minds and the minds of those who want to construct instruments for them, both if someone wishes to calculate by hand to know the position in which each of the motions comes to an end, as well as if one wants also to join the motions with each other and with the motion of the universe by the mechanical approach, which is [the approach] of devices. |1:4| [This would not result] from constructing a sphere in the customary way. For in this kind of the spheres – in addition to the fact that some of it is in contradiction to what is laid down and said regarding the motions

[1] Ptolemy also addresses this unknown Syrus in the *Almagest* and other works. See, for example, Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 4:7.

الأكر مع ما فيه من المناقضة لما قد وضع وقيل في الحركات فإنّما يتبيّن فيه ظاهر الشيء
L2r فقط وليس يظهر فيه الوضع الحقيقي حتّى أنّه إنّما يكون به ظهور الصناعة ليس ظهور
الوضع بالحقيقة. |1:5| لكن بأن يعمل ذلك بنوع يقع تحت البصر نظام الحركات
H72 وفصولها والاختلاف الذي يرى لها بنظر الناظرين إليها وهي تتحرّك حركة مستوية مستديرة
وإن كان لا يمكننا أن نركّب الحركات كلّها تركيبًا موافقًا لغرضنا الذي قصدنا له لكنّا
نبيّن بهذا النوع من العمل حال كلّ واحد منها بانفراد.

|2:1| ونحن مصيرون ما نضعه هاهنا من الجمل موافقًا لما حدّدناه في كتاب
السنطكسيس وهو المجسطي. وأمّا ما نضعه من الأشياء الجزئية فإنّا نتبع فيه ما تبيّن لنا
من الأرصاد المتواترة التي رصدناها في مواضع كثيرة وصحّحناها وعلمنا بها وضعها أو
حالها إذا قيّست بسطح من السطوح أو عودات أدوارها. |2:2| ونجعل أيضًا ما نضعها من
C4 الجمل تابعًا لما قدّمنا برهانه. ونقسم ونفصل الحركات المتّصلة المستوية حيث ينبغي أن
نفصلها ونجمع الحركات التي لم نكن جمعناها حتّى تكون مبادئ الحركات وأقسامها
B82r كمبادئ وأقسام منطقة فلك البروج لما في ذلك من السهولة في التجزئة والقسمة.
L2v وليظهر هاهنا أمر كلّ واحدة من الحركات وخواصّها ظهورًا بيّنًا وإن كانت الحركات على
تلك الجهات بعينها التي ذكرنا في غير هذا الموضع. |2:3| ونستعمل أيضًا في وضع
الأفلاك التي من أجلها تكون اختلافات الحركات وترتيبها المذهب الذي هو أبسط

1 يتبيّن] نبيّن L   فيه[2]] om L   **2** الوضع] الموضع BC   إنّما] om BC   **3** الوضع] الموضع BC   **7** حدّدناه] جدّدناه L   **6** بانفراد] بانفراده CM   **5** يمكننا] يمكنّا L   يقع] يوقع m   **8** السنطكسيس...المجسطي] السنطكسيس B السطكسيس C السطكسيس وهو المجسطي L السنطكيسيس وهو المجسطي   فإنّا] فإن C   **9** من الأرصاد] بالأرصاد L   **9/10** وضعها...حالها] ووصفنا أحوالها B   **11** قدّمنا برهانه] قد برهناه L   ونقسم] تقسم L   **12** نفصلها] يفصلها L   نكن] يكن L   **13** وأقسام] أقسام BC   **15** ذكرنا] ذكرناها BC   وإن] فإن BC   وخواصّها] om L   **14** واحدة] واحد BC   السهولة في] سهولة L   المذهب] للمذهب BC   اختلافات] اختلاف C   **16** تكون] يكون BCL و m   أيضًا] om BC   C

2 الحقيقي] om H   **3** بالحقيقة] om H   **6** بهذا...العمل] οὕτως H   **7/8** في...المجسطي] ἐν τῇ Συντάξει H   **9** وعلمنا بها] om H   **10** حالها...السطوح] τῶν ἐπ᾽ εἴδους λόγων H   **12** التي... جمعناها] τὰς ἐκείνῃ H   **13** السهولة...والقسمة] τὴν ἐν τοῖς ἐπιλογισμοῖς εὐχρηστίαν H   **15** التي... الموضع] om H

– rather only the appearance of the thing becomes evident and the true hypothesis[2] does not become apparent, so that through this, rather the artefact and not the hypothesis in truth becomes apparent. |1:5| But [it would result] from constructing it in such a way that before our eyes, there occurs the arrangement of the motions and their divisions and the anomaly, which is seen for them by observing them, whereas they [i.e. the motions] move regularly and circularly, even if we are not able to assemble all of the motions in accordance with our intended aim, but we show by this kind of construction the condition of each of them separately.

|2:1| We bring the general [things] that we lay down here in accordance with what we have settled in the *Syntaxis*, which is the *Almagest*. As for the particular things that we lay down, we thereby follow what is clear to us through successive observations, which we have carried out in several locations and which we have corrected and through which we have learned the hypothesis [of the particular things] or their condition when they are measured with respect to one of the surfaces or the returns of their revolutions. |2:2| We also cause what we lay down as a summary to follow what we have previously proven. We divide and separate the continuous, regular motions where it is necessary to separate them, and we join the motions that we have not joined[3] in order that the principles and divisions of the motions are like the principles and divisions of the belt of the ecliptic, because of the ease regarding the partition and division in [the ecliptic].[4] Thus, here, the affair of each of the motions and their specific properties becomes clearly apparent, even if the motions conform exactly to those directions that we have mentioned in another place. |2:3| We also use for the hypothesis and the order of the circles, because of which there are the anomalies of the motions, the simplest

[2] For the difficulties of translating *waḍʿ*, see above, pp. 26–27, and the commentary to Chapters I.1–2.

[3] Instead of this brief remark, the Greek version has a reference to the *Almagest*.

[4] This sentence reads very differently from the extant Greek version. See the Greek apparatus and the English translation in Hamm, *Ptolemy's Planetary Theory*, pp. 45–46.

المذاهب ليكون الطريق في تهيئة الآلات سهلًا ولو خالف ذلك حالها بعض الخلاف. |2:4| ونجعل تأليف الحركات هاهنا بالدوائر بأعيانها وحدها كأنّها مباينة للأكر التي تحيط بها. فنقف بذلك على ما قدّمنا وضعه ويكون منفردًا ظاهرًا مكشوفًا. |2:5| فالنبتدئ في (H74) ذلك من الحركة الكلّية لأنّها أقدم من الحركات الأخر كلّها وهي محيطة بها. فيكون ذلك مثالًا لنا في كثير من أمور هذه الطبيعة العجيبة جدًّا التي تعطي الأشياء الشبيهة بها (C end) ما يشبه حالها. وذلك يتبيّن بما سنبرهنه من بعد.

|3:1| فلنتوهّم دائرة من الدوائر العظام مخطوطة على مركز العالم ثابتة ولتسمّ فلك معدّل النهار. وإذا قُسم الخطّ المحيط بهذه الدائرة بثلاثمائة وستّين قسمًا متساوية فلتسمّ الأقسام باسم خاصّ لها وهو الأزمان. |3:2| ولنخطّ بعد ذلك دائرة يكون مركزها مركز هذا الفلك وتكون هي في سطحه وتتحرّك حول مركزه باستدارة حركة مستوية السرعة من ناحية (L3r) المشرق إلى ناحية المغرب. ولنسمّ هذه الدائرة الفلك المحرّك. |3:3| ولتكن دائرة أخرى من الدوائر العظام يديرها هذا الفلك ولتكن مائلة عنه مخطوطة على مركزه غير منتقلة فيه. ولتسمّ فلك البروج. |3:4| وليكن ميل هذه السطوح بعضها عن بعض محيطًا بزاوية تكون ثلاث وعشرين درجة وإحدى وخمسين دقيقة وعشرين ثانية بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. وإذا قُسم فلك البروج أيضًا بثلاثمائة وستّين قسمًا متساوية فلتسمّ هذه الأجزاء باسم خاصّ لها وهو درج. |3:5| ولتسمّ النقطتان اللتان يتقاطع

2 بأعيانها] اعيانها BC **3** فنقف] فيقف C منفردًا] مفردًا L فالنبتدئ] ولنبتدئ Cm **4** من²] om BC الأخر] للأجزاء BC الاخرى m **5** لنا] om BC تعطي] نعطي L **6** يتبيّن بما] بتبيين ما BC **7** فلنتوهّم] فليتوهّم L متساوية] مستوية الأقسام B **8** بثلاثمائة] ثلثمائة L ولتسمّ] وليسمى L **9** فلتسمّ] فلنسمى L خاصّ لها] لها خاص B **10** مستوية] متسوية L **11** ولنسمّ] ولنسمى L **12** غير] om B **13** ولتسمّ] ويسمى L السطوح] السطح L **14** ثلاث] ثلاثا B ثلاثة L وخمسين] وخمسون B وعشرين²] عشرون B **15** تسعين] تسعون B بثلاثمائة] ثلثمائة L **16** فلتسمّ] فلنسمى L وهو] وهي B ولتسمّ] ولتسمى L ولنسم B **16/8,2** يتقاطع…اللتان] mg B

1 ولو] ἐπακολουθῇ add H **3** على…وضعه] ταῖς τῶν ὑποθέσεων προσβολαῖς H منفردًا…مكشوفًا] ψιλαῖς καὶ ὥσπερ ἀνακεκαλυμμέναις H **5** هذه…جدًّا] τῆς θαυμασιωτάτης φύσεως H **6** حالها] om H **7** دائرة…العظام] μέγιστος κύκλος H مخطوطة] om H مركز العالم] τὸ κέντρον τῆς τοῦ κόσμου σφαίρας H **9** ولنخطّ] περιφερέσθω H, the Arabic later picks up this meaning by adding *bi-stidāra* **9/10** مركزها…الفلك] ὁμόκεντρος αὐτῷ H **11** الفلك المحرّك] φέρων H **12** مخطوطة] om H method so that the way of arranging the instruments is easy, although this is different from their condition by a little bit. |2:4| We carry out the composition of the motions here with the circles themselves and nothing else, as if they were different from the spheres that encompass them. Then, we thereby come upon the hypothesis we have presented previously in a manner that is isolated, clear, and uncovered. |2:5| Let us begin with the motion of the universe, because it is prior to all other motions and encompasses them. Thus, it is an exemplar for us regarding many aspects of this most wondrous nature which imparts things resembling it to what is similar to its condition. This will become evident through what we are going to demonstrate in the following.

|3:1| Let us imagine a circle among the great circles drawn around the centre of the world and fixed and let it be called the 'circle of the equator'. When the circumference of this circle is divided into 360 equal parts, let these parts be called by a specific name, that is 'time-degrees'.[5] |3:2| Afterwards, let us draw a circle whose centre is the centre of that circle and that is in its plane and that moves circularly around its centre with a regular speed from east to west. Let this circle be called the 'moving circle'. |3:3| Let there be another one among the great circles which this circle rotates and let it be inclined to it and drawn around its centre and not be carried away in it. Let [this circle] be called the 'ecliptic'.[6] |3:4| Let the inclination of these planes against each other contain an angle that is 23;51,20 degrees, according to the measure by which the right angle is 90 degrees. When the ecliptic is also divided into 360 equal parts, let these parts be called by a specific name, that is 'degrees'. |3:5| Let the two points in which the moving circle

[5] For this usage of the Greek term *chronoi*, see the introductory remarks by Toomer in Ptolemy, *Almagest*, p. 23.

[6] For a comparison with other descriptions of the main celestial circles in *Almagest* I.8 and *Planetary Hypotheses* II.11, see the commentary to Chapters I.3-4.

عليهما الفلك المحرّك وفلك البروج بنصفين نقطتي الاعتدال. |3:6| ولتسمّ النقطتان اللتان بينهما وبين نقطتي الاعتدال عن جنبتيهما ربع فلك نقطتي الانقلاب والنقطة المائلة إلى الشمال من هاتين النقطتين تسمّى نقطة الانقلاب الصيفي وتسمّى أيضًا منتهى الشمال والنقطة المقابلة لهذه النقطة نقطة الانقلاب الشتوي وتسمّى أيضًا منتهى الجنوب. |3:7| وكذلك أيضًا نقطتا الاعتدال تسمّى النقطة منهما المتقدّمة لنقطة المنقلب الصيفي في حركة الكلّ نقطة الاعتدال الربيعي والنقطة التي تتقدّم المنقلب الشتوي نقطة الاعتدال الخريفي.

H76 |4:1| والعالم يدور دورًا واحدًا إذا ابتدأت نقطة ما من نقط الفلك المحرّك فتحرّكت
L3v من نقطة من فلك معدّل النهار الثابت حتّى يعود إلى تلك النقطة بعينها أوّل عودة. وهو
B82v بيّن أنّ هذه العودة تحوي من فلك معدّل النهار ثلاثمائة وستّين زمانًا. |4:2| ولكن لمّا
كانت عودات حركة العالم ليس وقت تمامها بظاهر وكانت الأيّام والليالي بيّنة التمام لحال الشمس صرنا نعدّ ونقدر بهذه الحركة أوّلًا سائر الحركات. |4:3| واليوم بليلته هو الزمان الذي تدور فيه الشمس معدّل النهار الثابت دورة واحدة بدوران العالم. وهو بيّن أنّ الشمس لو لم تكن لها حركة غير حركة فلك البروج لكان اليوم بليلته هو عودة العالم مرة واحدة. |4:4| ولكن لمّا كان قد جعل لها حركة إلى المشرق صار اليوم بليلته أطول زمانًا من زمان دوران العالم فيحيط اليوم الواحد وليلته بدور واحد وهو ثلاثمائة وستّون زمانًا مزيدًا عليه مقدار ما يصيب مسير الشمس في يوم وليلة في فلك البروج من معدّل النهار إذا جعلنا الحركات مستوية.

1 نقطتي] نقطتين B ولتسمّ] ولتسمى L **2** نقطتي²] نقطتا B **7** الاعتدال] الانقلاب B **8** ما...ابتدأت] ابتدأ من نقطة B نقط] نقطة L فتحرّكت] فتحرك B **9** إلى] على B **10** وستّين] ستون B **11** والليالي الأيّام] الليالي والأيّام L الحال] بحال B **12/14** واليوم...لكان] om L **13** فيه] add m أنّ] add B **14** اليوم] واليوم L **16** دوران] دور B بدور...وهو] بدورة واحدة وهي B **17** عليه] عليها L يصيب...الشمس] تصيب الشمس من مسيرها B

6 حركة الكلّ] τὴν ἐκκειμένην περιφορὰν H **12** صرنا...ونقدر] παραμετροῦμεν H بهذه...أوّلًا] ταύταις πρώταις H **17** يصيب...الشمس] ὁ ἥλιος δίεισι H and the ecliptic cut each other in two halves be called the 'two equinoctial points'. |3:6| Let the two points between which and the two equinoctial points there is a quarter of a circle from both sides be called the 'points of solstice', while the one of these two points that is inclined towards the north is called the 'summer solstice' and also the 'northern limit', and the point opposite to this [first] point is called the 'winter solstice' and also the 'southern limit'. |3:7| Likewise, of the two equinoctial points, the one that precedes the summer solstice with respect to the motion of the universe is called 'vernal' and the one that precedes the winter solstice is called the 'autumnal equinoctial point'.

|4:1| The world revolves once whenever one of the points of the moving circle starts [moving] and then moves from a point of the fixed equator until it returns to this exact point a first [time]. It is clear that this return contains 360 time-degrees of the equator. |4:2| But since the time of the completion of the returns of the world's motion is not apparent – whereas the completion of the days and nights are clear due to the condition of the Sun – we primarily start counting and measuring the other motions through this motion [i.e. the motion of the Sun]. |4:3| A nychthemeron is the time in which the Sun revolves [on] the fixed equator once through the revolution of the world. It is clear that if the Sun did not have a motion other than the motion of the ecliptic, the nychthemeron would be one return of the world. |4:4| But since [the Sun] is assumed to have a motion to the east, the nychthemeron takes a longer time than the time of the revolution of the world, so that one nychthemeron contains one revolution, which is 360 time-degrees, plus the amount of the equator which the course of the Sun reaches on the ecliptic during one nychthemeron, if we assume the motions to be regular.

|5:1| فإذ قد رسمنا هذه الأشياء فإنّا نصير بعدها إلى القول في الكواكب المتحيّرة. ونضع أوّلًا حركاتها البسيطة التي لا تخالطها غيرها وهي التي عنها الحركات الجزئية الكثيرة الأنواع التي أدركناها نحن على أقرب ما يكون من حقيقة عوداتها بما تفكّرنا فيه وصحّحناه وأوضحناه. |5:2| أمّا في ثلاثمائة سنة مصرية وأربعة وسبعين يومًا بلياليها فلنعمل على أنّ الشمس تعود إلى مواضع نقط الانقلابين والاعتدالين من فلك البروج ثلاثمائة مرة |5:3| وأنّ كرة الكواكب الثابتة وأوجات الكواكب الخمسة المتحيّرة تتحرّك L4r جزءًا واحدًا من مائة وعشرين جزءًا من عودة واحدة من هذه العودات وذلك ثلاثة أجزاء بالمقدار الذي يكون به الفلك ثلاثمائة وستّين جزءًا.

H78 |5:4| ففي ستّة وثلاثين ألف سنة من السنين الشمسية التي ذكرنا وهي تكون ستّة وثلاثين ألف سنة وأربع وعشرين سنة من السنين المصرية ومائة وعشرين يومًا أمّا كرة الكواكب الثابتة فإنها تدور دورة واحدة وتفضلها الشمس بخمسة وثلاثين ألفًا وتسعماية وتسع وتسعين دورة وأمّا عودات العالم فإنّها تكون مساوية لعدد ما يحيط به هذا الزمان الذي ذكرنا من الأيّام بلياليها مزيدًا عليه عدد أدوار الشمس التي دارتها في هذا الزمان.

|6:1| وأمّا القمر ففي ثمانية آلاف وخمسمائة وثلاث وعشرين سنة من السنين الشمسية التي هي عودة الشمس إلى نقط الانقلابين والاعتدالين وهي من السنين المصرية ثمانية آلاف وخمسمائة وثمان وعشرون سنة ومن الأيّام بلياليها مائتان وسبعة وسبعون يومًا وعشرون دقيقة وأربع وعشرون ثانية من يوم وليلة يفضل القمر الشمس بأدوار B83r مساوية لعدد جميع الشهور وهي مائة ألف وستّة آلاف وأربعمائة وستّة عشر شهرًا. وأيضًا

1 فإذ] فاذا L **2** عنها] تكون add B **3** بما] om L فيه] فيها L **4** وأوضحناه] om B **5** تعود] يعود L مواضع نقط] نقطة B الانقلابين والاعتدالين] الاعتدالين والانقلابين B **6** الخمسة] om B **8** يكون به] به يكون B وستّين] وستّون B **9** ففي] في B السنين] السنون B ذكرنا] ذكرناها B **10** وثلاثين] وثلاثون B وأربع] وأربعة B **11** ألفًا] الف دورة B **12** وتسع] وتسعة B لعدد ما] لعدادها L هذا] هذه L **14** آلاف] ألف B وثلاث] وثلاثة B **15** نقط] نقطة B من نقطة add m نقط...والاعتدالين] نقط الانقلاب والاعتدال L **16** ثمانية آلاف] ستة ألف L ثمانية...وعشرون] ٩٥٢٨ B **17** وسبعون] وخمسون L **18** مساوية] متساوية B آلاف] ألف L شهرًا] om B

3 الكثيرة الأنواع] ποικίλαι H على...حقيقة] κατὰ συνεγγισμὸν H **4** وصحّحناه وأوضحناه] ἐκ τῆς διορθώσεως H **5** فلنعمل] ὑποκείσθω H **7** من[2]...العودات] περιόδου τῆς ὁμοίας H **17/18** بأدوار...الشهور] τουτέστιν ὅλους μῆνας H

|5:1| Having outlined these things, we begin afterwards the account of the wandering stars. First, we lay down their simple motions which are not mixed with others, and from which the particular, complex motions arise that we have perceived ourselves in a manner closest to the reality of their returns, in light of our reflections, corrections, and clarifications. |5:2| Let us operate on [the assumption] that it is in 300 Egyptian years and 74 nychthemera that the Sun returns to the positions of the points of the two solstices and two equinoxes of the ecliptic 300 times. |5:3| And [let us operate on the assumption] that the sphere of the fixed stars and the apogees of the five wandering stars move one 120th part of one of these returns, that is three parts according to the measure by which the circle is 360 parts.

|5:4| Thus, it is in 36 000 of the mentioned solar years[7] (that is 36 024 Egyptian years and 120 days) that the sphere of the fixed stars revolves once, that the Sun overtakes [the sphere of the fixed stars] by 35 999 revolutions, and that the returns of the world are equal to the number of nychthemera that this mentioned time encompasses, plus the number of the revolutions that the Sun makes in this time.

|6:1| As for the Moon: in 8 523 solar years, which are [defined as] the return of the Sun to the points of the solstices and equinoxes (that is 8 528 Egyptian years and 277;20,24 nychthemera), the Moon overtakes the Sun by revolutions equal to the number of all [lunar] months, and that is 106 416 months.[8] Also, in 3 277

[7] There are two ways to measure a solar year: the tropical year is the revolution of the Sun against the solsticial and equinoctial points, whereas the sidereal year is taken against the apogees and the fixed stars. See Hamm, *Ptolemy's Planetary Theory*, pp. 141–46. By the 'mentioned solar years', Ptolemy refers here to tropical years, as he had previously established the tropical year.

[8] For the correct value of 105 416, see Bainbridge's correction in Ptolemy, *De planetarum hypothesibus*, p. 11:4, and Neugebauer, *A History*, p. 901 n. 3.

فإنه تتمّ للقمر من عودات الاختلاف في ثلاثة آلاف ومائتين وسبعة وسبعين شهرًا ثلاثة آلاف وخمسمائة واثنتا عشر عودة وتتمّ له في خمسة آلاف وأربعمائة وثمانية وخمسين L4v شهرًا من عودات العرض خمسة آلاف وتسعمائة وثلاثة وعشرين عودة.

|7:1| وأمّا كوكب عطارد ففي تسعمائة وثلاث وتسعين سنة من السنين الشمسية الماخوذة من عوداتها إلى الأوجات وإلى مواضعها من كرة الكواكب الثابتة ويكون ذلك من السنين المصرية تسعمائة وثلاث وتسعين سنة ومن الأيّام بلياليها مائتين وخمسة وخمسين يومًا وصفر وأربع وخمسين وصفر وأربع وستّ وأربعين وواحد وخمسين بالتقريب تتمّ له من عودات الاختلاف ثلاثة آلاف ومائة وخمسون عودة.

|7:2| وأمّا كوكب الزهرة ففي تسعمائة وأربع وستّين سنة شمسية من مثل هذه السنين التي ذكرنا وهي من السنين المصرية تسعمائة وأربع وستّون سنة ومن الأيّام بلياليها مائتان وسبعة وأربعون يومًا وأربع وثلاثون واثنتان وخمسة وأربعون وثلاث عشرون وأربعون وثمان وعشرون خامسة بالتقريب تتمّ لها من عودات الاختلاف ستّمائة عودة وثلاث عودات.

|7:3| وأمّا كوكب المرّيخ ففي ألف سنة وعشر سنين شمسية من مثل هذه السنين التي ذكرنا وهي تكون من السنين المصرية ألف سنة وعشر سنين ومن الأيّام بلياليها مائتين وتسعة وخمسين يومًا واثنتين وعشرين وخمسين وستّ وخمسين وستّ عشرة وسبع وعشرين وخمسين بالتقريب تتمّ له من عودات الاختلاف أربعمائة وثلاث وسبعون عودات.

1 تتمّ] يتمّ B   للقمر] القمر L   آلاف] ألف L   **2** واثنتا] اثنا L   وتتمّ] ويتمّ B   آلاف2] ألف BL   **3** آلاف] ألف L   **7** وخمسين3...وصفر1] واحد رابعة وأربعين خامسة وأربع وصفر وخمسين وأربع وصفر   B ٩٢٤ [تسعمائة...وستّين **9** وخمسين B [وخمسون الف L [آلاف **8** L وخمسين ثانية   **10** ذكرنا] ذكرناها B   **12** لها] له B   عودة] om B   **14** ذكرنا] ذكرناها BL   سنة] om L   وعشر] وعشرة B   **16** وثلاث] وثلاثة B

1 شهرًا] ὅλοις add H   **3** شهرًا] ὅλοις add H   **4** وأمّا] ὁμοίως add H   **5** الماخوذة من] om H   **9/10** سنة...ذكرنا] ἔτεσιν ἡλιακοῖς τοῖς ὁμοίοις H, throughout the chapter months, 3 512 returns in anomaly are completed for the Moon, and in 5 458 months, 5 923 returns in latitude.

|7:1| As for Mercury: in 993 solar years that are taken from [the Sun's] returns to the apogees and to its positions on the sphere of the fixed stars (that is 993 Egyptian years and around 255;0,54,0,4,46,51 nychthemera), for Mercury, 3 150[9] returns in anomaly are completed.

|7:2| As for Venus: in 964 solar years like these that we have described (that is 964 Egyptian years and around 247;34,2,45,23,40,28 nychthemera), for Venus, 603 returns in anomaly are completed.

|7:3| As for Mars: in 1 010 solar years like these that we have described (that is 1 010 Egyptian years and around 259;22,50,56,16,27,50 nychthemera), for Mars, 473 returns in anomaly are completed.

[9] Every primary source has 3 150. However, Duke, 'Mean Motions', p. 637, uses 3 130.

|7:4| وأمّا كوكب المشتري ففي سبعمائة وسبعين سنة شمسية من مثل هذه السنين
التي ذكرنا وهي تكون من السنين المصرية سبعمائة وسبعين سنة ومن الأيّام بلياليها مائة L5r
وثمانية وتسعين يومًا وصفر وتسع وثمان عشرة وصفر وستّ وعشرين وسبع وخمسين
بالتقريب تتمّ له من عودات الاختلاف سبعمائة وستّ عودات.

|7:5| وأمّا كوكب زحل ففي ثلاثمائة وأربع وعشرين سنة شمسية من مثل هذه السنين
التي ذكرنا وهي تكون من السنين المصرية ثلاثمائة سنة وأربع وعشرين سنة ومن الأيّام H80
بلياليها ثلاثة وثمانين يومًا واثنتا عشرة وستّ وعشرين وتسعة عشرة وأربع عشرة وخمس
وعشرين وثمان وأربعين بالتقريب تتمّ له من عودات الاختلاف ثلاثمائة وثلاث عشرة
عودة.

|8:1| حال فلك الشمس

فلنتوهّم في كرة الشمس دائرة تكون في سطح فلك البروج وتكون خارجة المركز. وتكون
نسبة الخطّ الخارج من مركزها إلى الخطّ المحيط بها إلى الخطّ الذي بين مركزها ومركز
فلك البروج كنسبة الستّين إلى الاثنين والنصف. |8:2| ويكون الخطّ الذي يجوز على
هذين المركزين وعلى أوج الفلك الخارج المركز يقطع أبدًا من فلك البروج ممّا يلي نقطة
الاعتدال الربيعي على ما يتلو من البروج قوسًا يكون مقدارها خمس وستّين درجة ونصف
درجة. |8:3| ومركز الشمس يتحرّك على الفلك الخارج المركز الذي ذكرنا من المغرب
إلى المشرق حركة مستوية حول مركز هذا الفلك فترى الشمس في خمسين ومائة سنة
مصرية وسبعة وثلاثين يومًا بلياليها تعود إلى أوج الفلك الخارج المركز خمسين ومائة عودة L5v
وكرة الكواكب الثابتة تتحرّك حول مركز فلك البروج وحول قطبيه من المغرب إلى المشرق B83v

1 هذه] om B **2** التي...السنين] om L ذكرنا] ذكرناها B **3** وثمانية] وسبعة add L **5** مثل] om B **6** ذكرنا] ذكرناها B تكون] يكون B **7** يومًا] om L **8** وثلاث] وثلاثة B **11** وتكون²] ويكون B **14** هذين] om B **15** خمس] خمسًا L خمسة B **15/16** درجة...درجة] جزءًا ونصف جزء B **16** ذكرنا] ذكرناه B **17** حركة] وحركة L فترى] وترى Bm **18** وسبعة] sl B وسبع L تعود] يعود L

10 حال...الشمس] om H **11** وتكون²] οὕτως ἔχων, ὥστε H **12** الخطّ¹...بها] τὴν μὲν ἐκ τοῦ κέντρου αὐτοῦ H **14** ممّا يلي] ἀπὸ τῆς ἐαρινῆς ἰσημερίας H **17** حركة مستوية] ἰσοταχῶς H, throughout the text **18** يومًا بلياليها] ἐν ὅλοις πρώτοις νυχθημέροις H, throughout the text

|7:4| As for Jupiter: in 771 solar years like these that we have described (that is 771 Egyptian years and around 198;0,9,18,0,26,57 nychthemera), for Jupiter, 706 returns in anomaly are completed.

|7:5| As for Saturn: in 324 solar years like these that we have described (that is 324 Egyptian years and around 83;12,26,19,14,25,48 nychthemera), for Saturn, 313 returns in anomaly are completed.

|8:1| The condition of the circle of the Sun

Let us imagine in the sphere of the Sun an eccentric circle in the plane of the ecliptic. The ratio of the radius to the line that is between its centre and the centre of the ecliptic is like the ratio of 60 to 2 ½. |8:2| The line that passes through both of these centres and through the apogee of the eccentric circle always cuts off an arc from the ecliptic of 65 ½ degrees from what follows the vernal equinoctial point according to the succession of the signs.[10] |8:3| The centre of the Sun moves regularly on the mentioned eccentric circle from west to east around the centre of this circle so that in 150 Egyptian years and 37 nychthemera, the Sun is seen to return 150 times to the apogee of the eccentric circle, whereas the sphere of the fixed stars moves regularly 1 ½ degrees regularly (according to the measure

[10] This term, *ʿalā mā yatlū min [falak] al-burūǧ*, translates the Greek *eis ta hepomena tou kosmou*, which literally means 'in the direction of the following [parts] of the cosmos'. The motion in reference is the daily east–west rotation of the entire cosmos. The contrary motion is called *eis ta proēgoumena* in Greek and *ʿalā ḫilāf tawālī al-burūǧ* in Arabic, meaning 'in the direction of the leading [parts] of the cosmos'. For the difficulties in translating these terms, see Toomer's remarks in Ptolemy, *Almagest*, p. 20.

بحركة مستوية في الزمان الذي ذكرنا درجة ونصف بالمقدار الذي يكون به فلك البروج ثلاثمائة وستّين درجة.

|8:4| وقد كان بعد الشمس في الفلك الخارج المركز من أوج الفلك الخارج المركز على ما يتلو من البروج في أوّل السنة التي بعد موت الإسكندر البناء في أوّل يوم من شهر ثوث من شهور القبط في وقت نصف النهار بالإسكندرية مائة درجة واثنتي وستّين درجة وعشر دقائق. |8:5| وكان بعد الكوكب الذي على قلب الأسد من نقطة الاعتدال الربيعي على ما يتلو من فلك البروج مائة درجة وسبع عشر درجة وأربع وخمسين دقيقة.

|9:1| حال أفلاك القمر

وأيضًا فإنّا نتوهّم في كرة القمر فلكًا مركزه مركز فلك البروج يتحرّك في سطحه وحول مركزه H82 حركةً مستويةً من المشرق إلى المغرب بمقدار زيادة مسير القمر المأخوذ في فلك البروج على مسير الشمس الأوسط والحركة التي لبعد ما بين النيّرين الوسطى بمجموعتين فيعود هذا الفلك في سبع وثلاثين سنة مصرية وثمانية وثمانين يومًا بلياليها عودتين. وذلك بالتقريب لأنّه يزيد على ما قلنا إذا أُستقصي دقيقة واحدة.

|9:2| وليحرّك هذا الفلك فلكًا آخر مائلًا عنه يكون مركزه هو مركز هذا الفلك ويكون لازمًا لهذا الفلك غير زائل عنه. وليكن ميله ميلًا يحوي زاوية تكون خمسة أجزاء بالمقدار L6r الذي تكون به الزاوية القائمة تسعين جزءًا. |9:3| وليكن في سطح هذا الفلك المائل الذي ذكرنا فلك خارج المركز. تكون نسبة نصف قطره إلى الخطّ الذي بين مركزه ومركز فلك البروج كنسبة الستّين إلى الاثني عشر ونضف.

1 ذكرنا] ذكرناه B   **3/4** الخارج[1]...من[1]] om L   **4** البناء] إلينا m   **5** ثوث] توت B   النهار بالإسكندرية] نهار الإسكندرية L   **6** وعشر] وعشرة B   **8** أفلاك] فلك L   **9** يتحرّك] تتحرّك B   **11** البعد] تبعد B   بمجموعتين] بمجموعين B   **12** سنة] sl B   **14** فلكًا...الفلك[2]] om L   **16** تكون...به] به تكون B   **17** ذكرنا] ذكرناه B   تكون] يكون B   **18** ونضف] والنصف L

4 بعد] om H   **6** وكان] ὁμοίως add H   **10** مسير] κατὰ πλάτος add H   **11** الأوسط] om H   بمجموعتين] om H ἰσοχρονίου add H   **13** على...قلنا] om H, as in the corresponding passages in the following chapters.

by which the ecliptic is 360 degrees) around the centre of the ecliptic and its [i.e. the ecliptic's] two poles from west to east in the aforementioned time.

|8:4| The Sun's distance on the eccentric circle from the apogee of the eccentric circle according to the succession of the signs was 162;10 degrees in the first year after the death of Alexander the Founder [i.e. Alexander the Great] on the first day of the Egyptian[11] month Thoth at noon in Alexandria. |8:5| The distance of the star at the heart of the Lion [i..e. Regulus] from the vernal equinoctial point according to the succession of the signs was 117;54 degrees.

|9:1| The condition of the circles of the Moon

Furthermore, we imagine in the sphere of the Moon a circle whose centre is the centre of the ecliptic, and [this circle] moves in its [i.e. the ecliptic's] plane and around its centre regularly[12] from east to west by the amount of the excess of the course of the Moon, which is taken relative to the ecliptic, over the mean course of the Sun and over the mean motion of the distance of the two luminaries [i.e. the Sun and the Moon] in sum, so that this circle completes two returns in 37 Egyptian years and 88 nychthemera. However, this is [only] approximate, because when it is examined more closely, it exceeds what we have mentioned by one minute.[13]

|9:2| Let this circle move another circle that is inclined to it and whose centre is the centre of this [first] circle, and let it be attached to this circle in a fixed position towards it. Let its inclination comprise an angle of five parts according to the measure by which a right angle is 90 parts. |9:3| In the aforementioned plane of this inclined circle, let there be an eccentric circle. The ratio of its radius to the line between its centre and the centre of the ecliptic is like the ratio of 60 to 12 ½.

[11] The Arabic has *qibṭ*, i.e. Coptic, referring to the Egyptian months. Concerning the Egyptian year, *miṣr* is used. Thoth is the first month of the Egyptian year.

[12] For the first appearance of *isotaxōs*, the translation was *ḥaraka mustawiyat al-surʿa*. From now on, *al-surʿa* is omitted.

[13] According to Neugebauer, *A History*, p. 903, this assertion that reoccurs on similar occasions throughout the following chapters might go back to annotations not by Ptolemy himself.

|9:4| وليتحرّك مركز هذا الفلك الخارج المركز حول مركز فلك البروج حركةً مستويةً من المشرق إلى المغرب من منتهى الشمال مقدار ما يزيد ضعف الحركة الوسطى التي لبعد ما بين النيّرين على مسير العرض في فلك البروج في الأزمان المتساوية ففي سبع عشرة سنة مصرية وثلاثمائة وثمانية وأربعين يومًا بلياليها يعود في فلكه المائل مائتي عودة وثلاث عودات. وذلك بالتقريب لأنّه ينقص عمّا ذكرنا إذا استقصي دقيقتين.

|9:5| ويتحرّك مركز فلك التدوير من المغرب الى المشرق من أوج الفلك الخارج المركز مقدار ضعف الحركة الوسطى التي لبعد ما بين النيّرين ويكون وضعه أبدًا على الفلك الخارج المركز. وهذه الحركة مساوية للحركتين اللتين ذكرنا آنفًا بمجموعتين. ففي تسع B84r عشرة سنة مصرية وثلاثمائة يومًا بلياليها يعود في الفلك الخارج المركز أربعمائة عودة وتسعين عودة. وذلك بالتقريب لأنّه يزيد على ما ذكرنا إذا استقصي أربع دقائق.

H84 |9:6| فيكون مركز فلك التدوير الذي ذكرنا في سطح الفلك المائل وكذلك الخطّ الذي L6v فيما بين مركزه ومركز فلك البروج الذي يدور هذا الفلك حوله أبدًا ويتحرّك حركة مستوية وهذا الخطّ يجوز على نقط من فلك التدوير بأعيانها وهي التي تسمّى الأوج والبعد الأقرب. وتكون نسبة نصف قطر الفلك الخارج المركز إلى نصف قطر فلك التدوير كنسبة الستّين إلى الستّة والثُلث. |9:7| ومركز القمر يسير مسيرًا مستويًا من ناحية الأوج من المشرق إلى المغرب وحركته هي حركة الاختلاف ففي ستّ وعشرين سنة مصرية وتسعة وتسعين يومًا بلياليها يعود في فلك التدوير ثلاثمائة وثماني وأربعين عودة. وذلك بالتقريب لأنّه ينقص إذا استقصي دقيقة واحدة.

|9:8| وقد كان بعد منتهى شمال الفلك المائل من نقطة الاعتدال الربيعي على خلاف توالي البروج في هذه السنة الأولى التي من بعد موت الإسكندر في أوّل شهر

5 عمّا] عن ما L **8** تسع] تسعة B **10** وذلك] om B **11** ذكرنا] ذكرناه B **12** ويتحرّك] أو يتحرّك L
13 يجوز…نقط] يكون على نقطة m BL تسمّى] نسبتها L **14** نصف[1]] om B **16** ففي] وهي B
17 وثماني] وثمانية B

11 فيكون] λοιπὸν add H **13** يجوز…بأعيانها] τὰ αὐτὰ σημεῖα πάντοτε τοῦ κυκλίσκου καταλαμβανούσης H **14** وتكون] ὥστε μέντοι H

|9:4| Let the centre of this eccentric circle move regularly around the centre of the ecliptic from east to west, from the northern limit [according to] the amount [by] which the double mean motion of the distance between the two luminaries exceeds the course in latitude on the ecliptic in equal periods of time, so that in 17 Egyptian years and 348 nychthemera, it [i.e. the eccentric circle] completes 203 returns with respect to its inclined circle. However, this is [only] approximate, because when it is examined more closely, it is less than what we have mentioned by two minutes.

|9:5| Let the centre of the epicycle move from west to east, from the apogee of the eccentric circle by the amount of the double mean motion of the distance between the two luminaries, whereas its position[14] is always on the eccentric circle. This motion is equal to both of the aforementioned motions in sum. Thus, in 19 Egyptian years and 300 nychthemera, it [i.e. the epicycle] completes 490 returns with respect to the eccentric circle. However, this is [only] approximate, because when it is examined more closely, it is less than what we have mentioned by four minutes.

|9:6| Now the centre of the aforementioned epicycle is in the plane of the inclined circle and likewise the line, which is in [the space] between its centre and the centre of the ecliptic, around which this circle [i.e. the epicycle] always rotates and moves regularly, whereas this line passes through exactly these points[15] of the epicycle, namely those which are called the apogee and perigee. The[16] ratio of the radius of the eccentric circle to the radius of the epicycle is like the ratio of 60 to 6⅓. |9:7| The centre of the Moon travels regularly from the direction of the apogee from east to west, whereas its motion is the motion of the anomaly, so that in 26 Egyptian years and 99 nychthemera, it completes 348 returns with respect to the epicycle. However, this is [only] approximate, because when it is examined more closely, it is less than what we have mentioned by one minute.

|9:8| The distance of the northern limit of the inclined circle from the vernal equinoctial point contrary to the succession of the signs was 230 degrees and

[14] Here, *waḍʿ* translates the Greek *thesis*, which is why I do not translate it as 'hypothesis', but rather as 'position'. See above, pp. 26–27.

[15] The translation follows Morelon's reading, which depends on the Hebrew version and corresponds to the Greek text.

[16] One could easily align the Arabic to the Greek version by replacing *wa-takūn* with *fa-takūn*.

ثوث من شهور القبط في وقت نصف النهار بالإسكندرية مائتي درجة وثلاثين درجة وتسع عشر دقيقة وثلاث عشرة. وكان بعد أوج الفلك الخارج المركز من منتهى الشمال إلى المغرب أيضًا اثنين وثمانين درجة وأربعين دقيقة. |9:9| وكان بعد مركز فلك التدوير من أوج الفلك الخارج المركز على ما يتلو من فلك البروج مائتي درجة وستّين درجة وأربعين دقيقة. وكان بعد مركز القمر من أوج فلك التدوير على خلاف توالي البروج خمس وثمانين درجة وسبع عشر دقيقة.

|10:1| حال أفلاك عطارد

L7r وأمّا عطارد فإنّا نتوهّم في كرته فلكًا مركزه مركز فلك البروج يتحرّك في سطحه وحول مركزه حركة مستوية من المغرب إلى المشرق ومساوية لحركة كرة الكواكب الثابتة. |10:2| وليحرّك هذا الفلك بحركته فلكًا آخر مائلًا عنه. وليكن مركزه مركز هذا الفلك ويكون غير H86 زائل عنه. وليكن ميل هذين السطحين كلّ واحد عن الآخر يحوي زاوية تكون سُدس درجة بالمقدار الذي تكون به الزاوية الواحدة القائمة تسعين جزءًا. |10:3| وليكن في سطح الفلك المائل قطر من منتهى الشمال إلى منتهى الجنوب. ونعلّم على هذا القطر نقطتين فيما بين مركز فلك البروج ومنتهى الجنوب ممّا يلي مركز فلك البروج. |10:4| وليتحرّك مركز الفلك الخارج المركز حول أبعد هاتين النقطتين من مركز الأرض على خلاف توالي البروج حركة مستوية من أوج الفلك الخارج المركز الذي هذه النقطة مركزه B84v بمقدار زيادة مسير الشمس على مسير الكواكب الثابتة إذا كانت الحركتان في أزمان متساوية ففي مائة سنة وأربع وأربعين سنة مصرية وسبعة وثلاثين يومًا بلياليها يعود مائة وأربع وأربعين عودة. وذلك بالتقريب لأنّه يزيد إذا استقصي دقيقتين.

1 ثوث] توت B   نصف...بالإسكندرية] نصف نهار الإسكندري L   **2** وثلاث عشرة] om B   **3** اثنين] اثنتين Bm   **4** وستّين درجة] om L   **5** خلاف] om BL   **6** وسبع] وتسع B   **8** كرته] كونه L   **9** ومساوية] مساوية B   كرة] حركة إلى الكواكب B   **10** آخر] om B   **12** ويكون] ويكن B   تكون به] به تكون B   **13** ونعلّم] نتعلم L   **17** بمقدار] مقدار B   إذا] إذ B   **18** وسبعة] وسبع L   **19** وأربع] وأربعة BL

2/3 وكان...دقيقة] om H   **5** على...البروج] εἰς τὰ προηγούμενα τοῦ κόσμου H   **9** حركة مستوية] om H   **10** بحركته] om H, accordingly in the parallel passages in all following chapters

19,13 minutes in this first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the apogee of the eccentric circle from the northern limit to the west was also 82 degrees and 40 minutes. |9:9| The distance of the centre of the epicycle from the apogee of the eccentric circle according to the succession of the signs was 260 degrees and 40 minutes. The distance of the centre of the Moon from the apogee of the epicycle contrary to the succession of the signs was 85 degrees and 17 minutes.

|10:1| The condition of the circles of Mercury

As for Mercury, we imagine in its sphere a circle whose centre is the centre of the ecliptic and that moves regularly in its [i.e. the ecliptic's] plane from west to east, equal to the motion of the sphere of the fixed stars. |10:2| Let this circle by its motion move another circle inclined to it. Let its centre be the centre of this [first] circle, whereas it is in a fixed position towards it. Let the inclination of these two planes against each other comprise an angle of a sixth degree according to the measure by which one right angle is 90 parts. |10:3| In the plane of this inclined circle, let there be a diameter from the northern to the southern limit. Let us indicate[17] on this diameter two points in [the space] between the centre of the ecliptic and the southern limit of what follows the centre of the ecliptic. |10:4| Let the centre of this eccentric circle move regularly around the point of the two aforementioned points that is further away from the centre of the Earth contrary to the succession of the signs from the apogee of the eccentric circle, whose centre is this point, by the amount of the excess of the course of the Sun over the course of the fixed stars, if the two motions are in equal periods of time, so that in 144 Egyptian years and 37 nychthemera, it [i.e. the centre of the eccentric circle] completes 144 returns. However, this is [only] approximate, because when it is examined more closely, it exceeds it by two minutes.

[17] Note that the Arabic translates the Greek eilēphthō.

|10:5| وأمّا مركز فلك التدوير فليتحرّك حول النقطة الأخرى التي هي أقرب النقطتين L7v اللتين ذكرنا إلى الأرض على ما يتلو من فلك البروج من موضع أوج الخروج عن المركز ويكون وضعه أبدًا على الفلك الخارج المركز وتكون حركته مساوية للحركة التي ذكرنا ففي مائة سنة وأربع وأربعين سنة مصرية وسبعة وثلاثين يومًا بلياليها يعود إلى موضع الخروج عن المركز مائة وأربع وأربعين عودة. وذلك بالتقريب لأنّه يزيد على ذلك إذا استقصي دقيقتين.

|10:6| وليكن بعد ما بين مركز فلك البروج وأقرب هاتين النقطتين من الأرض ثلاثة أجزاء وبعد ما بين مركز فلك البروج وأبعد هاتين النقطتين من الأرض خمسة أجزاء ونصفًا بالمقدار الذي يكون به نصف قطر الفلك الخارج المركز ستّين جزءًا وبعد ما بين أبعد هاتين النقطتين من الأرض وبين مركز الفلك الخارج المركز جزئين ونصفًا.

|10:7| وأيضًا فإنّا نتوهّم فلكًا صغيرًا حول مركز فلك التدوير أعني حول مركز كرة فلك التدوير في سطح الفلك المائل. ويكون الخطّ الذي يصل ما بين مركز هذا الفلك وبين أقرب النقطتين اللتين ذكرنا من الأرض وهي النقطة التي يتحرّك حولها هذا الفلك حركة H88 مستوية أبدًا يمرّ من هذا الفلك بنقط بأعيانها وهي التي تسمّى الأوج والبعد الأقرب. |10:8| ونتوهّم أيضًا فلكًا آخر صغيرًا يكون مركزه مركز هذا الفلك الذي ذكرنا. يتحرّك في بسيط الفلك الذي قلنا وحول مركزه حركة مستوية. فإذا تحرّك من موضع الأوج كانت حركته إلى الناحية التي يتحرّك إليها العالم وكانت حركة مساوية لحركة الفلك الخارج المركز الذي ذكرنا أو لحركة فلك التدوير.

|10:9| L8r وليحرّك هذا الفلك بحركته فلكًا آخر مائلًا عنه وعلى مركزه وليكن لازمًا لهذا الفلك غير زائل عنه. وليحو ميله زاوية تكون ستّة أجزاء ونصف جزء بالمقدار الذي تكون

1 فليتحرّك] فيتحرك B **4** وأربع] وأربعة B وسبعة] وسبع L **5** وأربع] وأربعة B **8/10** خمسة... الأرض] om L **10** ونصفًا] ونصف L **11** مركز[2]...فلك[1]] om L **14** يمرّ] تمر BL **15** ونتوهّم] ويتوهّم L الذي] التي B **17** الناحية] خلاف الناحية B صغيرًا] صغير B فلكًا] فلك B **19** فلكًا] فلك B **20** وليحو] وليحوي L جزء] جزءًا B

11/12 أعني...التدوير] om H **18** الذي ذكرنا] τῇ εἰρημένῃ [παρόδῳ] H, similarly in every subsequent chapter

|10:5| As for the centre of the epicycle, let it move around the other point, [namely] that which is the point of the two aforementioned points that is closer to the Earth according to the succession of the signs from the position of the apogee of the eccentricity, whereas its position is always on the eccentric circle and whereas its motion is equal to the aforementioned motion, so that in 144 Egyptian years and 37 nychthemera, it completes 144 returns back to the position of the eccentricity. However, this is [only] approximate, because when it is examined more closely, it exceeds it by two minutes.

|10:6| Let the distance of what is between the centre of the ecliptic and the point of the two points that is closer to the Earth be three parts and let the distance of what is between the centre of the ecliptic and the point of the two points that is further away from the Earth be 5 1/12 parts according to the measure by which the radius of the eccentric circle is 60 parts, and let the distance of what is between the point of the two points that is further away from the Earth and between the centre of the eccentric circle be 2 ½ parts.

|10:7| We also imagine a small circle around the centre of the epicycle (I mean around the centre of the sphere of the epicycle)[18] in the plane of the inclined circle. The line that connects what is between the centre of this circle and between the point of the two aforementioned points that is closer to the Earth (i.e. the point around which this circle always moves regularly), [this line] goes from this circle through these exact points (namely which are called the apogee and perigee). |10:8| Also, we imagine another small circle, whose centre is the centre of the aforementioned circle. It moves regularly in the plane of the said circle and around its centre. Thus, when it moves from the position of the apogee, its motion is in the direction in which the world moves, and the motion is equal to the motion of the aforementioned eccentric circle or to that of the epicycle.[19]

|10:9| Let this circle move through its motion another circle inclined to it and around its centre, and let it be attached to this circle in a fixed position. Let its inclination comprise an angle of 6 ½ parts according to the measure by which a

[18] This addition in the Arabic seems to highlight that the epicycle consists of two spheres in the case of Mercury.

[19] This is very different from the Greek version, cf. the English translation in Hamm, *Ptolemy's Planetary Theory*, p. 54.

به الزاوية القائمة تسعين جزءًا. ونسبة نصف قطر الفلك الخارج المركز إلى نصف قطر هذا الفلك الصغير كنسبة الستّين إلى الاثنين والعشرين والربع. |10:10| ولنتوهّم الكوكب على هذا الفلك وأنّه يسير على مركزه مسيرًا مستويًا من الأوج على خلاف حركة العالم. ولتكن حركته فيه مساوية لحركة مركز فلك التدوير وحركة اختلاف الكوكب بمجموعتين. B85r ففي مائتي سنة وخمسين سنة مصرية ومائة وأربعة وسبعين يومًا بلياليها يعود الكوكب في فلك تدويره المائل ثمانيمائة عودة وخمس وستّين عودة. وذلك بالتقريب لأنّه يزيد على ذلك إذا استقصي الحساب أربع دقائق.

|10:11| وقد كان بعد أوج الفلك الخارج المركز من نقطة الاعتدال الربيعي على توالي البروج في السنة الأولى التي من بعد موت الإسكندر في أوّل شهر ثوث من شهور القبط في وقت نصف النهار بالإسكندرية مائة درجة وخمس وثمانين درجة وأربع وعشرين دقيقة. وكان بعد منتهى الشمال من هذه النقطة خمس درجات وأربع وعشرين دقيقة. وكان بعد مركز الفلك الخارج المركز من أوج موضع الخروج عن المركز على خلاف L8v | H90 توالي البروج اثنتين وأربعين جزءًا وستّ عشر دقيقة. |10:12| وكان بعد مركز فلك التدوير من أوج موضع الخروج عن المركز على ما يتلو من فلك البروج مثل هذه الأجزاء أعني الاثنتين والأربعين الجزء والستّ العشرة الدقيقة. وكان أيضًا بعد منتهى شمال الفلك المائل الصغير من أوج فلك التدوير على خلاف توالي البروج مائة جزء واثنتين وثلاثين جزءًا وستّ عشرة دقيقة. وكان بعد الكوكب من منتهى شمال الفلك المائل الصغير على توالي البروج ثلاثمائة جزء وستّة وأربعين جزءًا وإحدى وأربعين دقيقة.

2 والعشرين] وعشرين B   ولنتوهّم] ويتوهّم L   **3** مسيرًا] سيرًا B   **4** ولتكن] وليكن B   بمجموعتين] مجموعين B   **5** ففي مائتي] اختلاف add B   وسبعين] وتسعين B   **6** وستّين] وستّون L   **9** من¹] om B   ثوث] توت B   **10** في] om B   النهار بالإسكندرية] نهار الإسكندرية L   وخمس] وخمسًا B   وأربع] وأربعة B   **11** وأربع] وأربعًا B   **13** اثنتين] اثنين m BL   وستّ] وستّة B   **15** الاثنتين] الاثنين m BL   **16** واثنتين] واثنين BL   شمال الفلك] الشمال للفلك B   والستّ...الدقيقة] وستّة عشر دقيقة B   **17** وستّ عشرة] وستّة عشر B   واثنتي m

2 ولنتوهّم] κινείσθω H   **3** من] κατὰ H   **4** الحركة...التدوير] τῇ τε τοῦ κέντρου τοῦ ἐκκέντρου ἢ τοῦ ἐπικύκλου H   **8** الفلك...المركز] τῆς ἐκκεντρότητος H right angle is 90 parts. The ratio of the radius of the eccentric circle to the radius of this small circle is like the ratio of 60 to 22 ¼. |10:10| Let us imagine[20] the planet [to be] on this circle and that it travels regularly around its centre from the apogee contrary to the motion of the world. Let its motion on this [course] be equal to the motion of the centre of the epicycle and to the motion of the anomaly of the planet in sum. Thus, in 250 Egyptian years and 174 nychthemera, the planet completes 865 returns with respect to its inclined epicycle. However, this is [only] approximate, because when the calculation is examined more closely, it exceeds this by four minutes.

|10:11| The distance of the apogee of the eccentric circle from the vernal equinoctial point according to the succession of the signs was 185;24 degrees in the first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the northern limit from this point was 5;24 degrees. The distance of the centre of the eccentric circle from the apogee of the position of the eccentricity contrary to the succession of the signs was 42;16 parts. |10:12| The distance of the centre of the epicycle from the apogee of the position of the eccentricity according to the succession of the signs was like these parts, namely 42;16 parts. Also, the distance of the northern limit of the small inclined circle from the apogee of the epicycle contrary to the succession of the signs was 132;16 parts. The distance of the planet from the northern limit of the small inclined circle according to the succession of the signs was 346;41 parts.

[20] The Greek reading in the edition by Heiberg goes back to Bainbridge's emendation of *noeisthō* to *kineisthō*.

|11:1| حال أفلاك الزهرة

وأمّا كوكب الزهرة فإنّا نتوهّم أيضًا أنّ له فلكًا مركزه مركز فلك البروج يتحرّك في سطحه وحول مركزه حركة مستوية من ناحية المغرب إلى ناحية المشرق بمثل حركة كرة الكواكب الثابتة. |11:2| وليحرّك هذا الفلك بحركته فلكًا آخر مائلًا عنه وعلى مركزه وليكن غير زائل عنه. وليحو ميل سطحه زاوية تكون سدس جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. |11:3| وليكن في سطح الفلك المائل قطر من منتهى الشمال إلى منتهى الجنوب. ولنعلّم عليه نقطتين فيما بين مركز فلك البروج ومنتهى الشمال وليكن الخطّ الذي بين هاتين النقطتين مساويًا للخطّ الذي بين مركز فلك البروج وبين النقطة التي تليه من النقطتين.

L9r |11:4| وليكن فلك خارج المركز مخطوطًا على أقرب النقطتين من الأرض غير زائل ولا متحرّك. ولتكن نسبة نصف قطره إلى الخطّ الذي بين مركزه ومركز فلك البروج كنسبة الستّين إلى الواحد. وليتحرّك فلك التدوير حول أبعد النقطتين من الأرض حركة مستوية وليكن وضع مركزه أبدًا على الفلك الخارج المركز على ما يتلو من فلك البروج من القطر B85v الذي ذكرنا بمقدار زيادة حركة الشمس على حركة الكواكب الثابتة في الأزمان المتساوية.

H92 |11:5| وأيضًا فإنّا نتوهّم في كرة فلك التدوير دائرة صغيرة على مركزها وفي سطح الفلك المائل. وليكن الخطّ الذي يمرّ بمركزها وبأبعد النقطتين اللتين ذكرنا من الأرض التي عليها يتحرّك هذا الفلك حركة مستوية يجوز من هذا الفلك الصغير على نقط بأعيانها وهي التي نسمّيها الأوج والبعد الأقرب. |11:6| وأيضًا فإنّا نتوهّم فلكًا آخر صغيرًا يكون مركزه مركز هذا الفلك ويتحرّك في سطحه حركة مستوية من الأوج إلى الناحية التي يتحرّك

1 أفلاك] فلك L **2** وأمّا] أمّا B له] لها B **3** بمثل] مثل B **5** وليحو] وليحوي L تكون به] تكون B **6** تسعين] تسعون B **7** ولنعلّم] ونتعلم L **8** وبين] ومن B تليه] يليه L **10** مخطوطًا] مخطوط L **11** ولتكن] وليكن B **16** وفي] في L **17** وبأبعد] وتابعة L **17/18** التي عليها] الذي عليه BL **19** نسمّيها] تسمى B **20** إلى] التي B

4 بحركته] om H **7** ولنعلّم] om H **10** مخطوطًا] om H **17** بمركزها…الأرض] δι’ ἀμφοτέρων τῶν κέντρων αὐτοῦ τε καὶ τοῦ ἀπογειοτέρου τῶν δύο τῶν εἰρημένων H **20** ويتحرّك] διαστάσεως […] συντελουμένης add H

|11:1| The condition of the circles of Venus

As for Venus, we also imagine that it has a circle whose centre is the centre of the ecliptic, and that it moves regularly in its plane and around its centre from west to east, like the motion of the fixed stars. |11:2| Let this circle move by its motion another circle inclined to it and around its centre, and let it be in a fixed position towards it.[21] Let the inclination of its plane comprise an angle of a sixth part according to the measure by which the right angle is 90 parts. |11:3| In the plane of the inclined circle, let there be a diameter from the northern to the southern limit. Let us indicate on this [diameter] two points in [the space] between the centre of the ecliptic and the northern limit, and let the line between these two points be equal to the line between the centre of the ecliptic and the point of the two points that follows it.

|11:4| Let the eccentric circle be drawn on the point of the two points that is closer to the Earth, in a fixed position and not moving. Let the ratio of its radius to the line between its centre and the centre of the ecliptic be like the ratio of 60 to 1. Let the centre of the epicycle move regularly around the point of the two points that is further away from the Earth and let the position of its centre always be on the eccentric circle according to the succession of the signs from the aforementioned diameter by the amount of the excess of the motion of the Sun over the motion of the fixed stars in equal periods of time.

|11:5| We also imagine in the sphere of the epicycle a small circle around its [i.e. the sphere's] centre and in the plane of the inclined circle. Let the line that goes through its centre and the point of the two aforementioned points that is further away from the Earth, [the point] around which this circle moves regularly, pass through exactly these points of this small circle, namely those which we call the apogee and perigee. |11:6| We also imagine another small circle whose centre is the centre of this circle and which moves regularly in its plane from the apogee in

[21] This sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 51:11–13.

إليها العالم حركة مساوية لحركة فلك التدوير الذي ذكرنا. |11:7| وليحرّك هذا الفلك بحركته فلكًا آخر مائلًا عنه مركزه مركزه وهو غير زائل عن هذا الفلك. وليحو ميل هذا الفلك زاوية تكون ثلاثة أجزاء ونصف جزء بالمقدار الذي تكون به الزاوية القائمة تسعين L9v جزءًا. ولتكن نسبة نصف قطر الفلك الخارج المركز إلى نصف قطر فلك التدوير كنسبة الستّين إلى ثلاثة وأربعين وسدس. |11:8| وليتحرّك الكوكب في هذا الفلك الصغير حول مركز هذا الفلك حركة مستوية من الأوج إلى خلاف الناحية التي يتحرّك إليها العالم حركة مساوية لحركة فلك التدوير وحركة الكوكب بمجموعتين. ففي خمس وثلاثين سنة مصرية وثلاثة وثلاثين يومًا بلياليها يعود سبع وخمسين عودة. وذلك بالتقريب وذلك أنّه يزيد على ما قلنا إذا استقصي دقيقة واحدة.

|11:9| وقد كان بعد أوج موضع الخروج عن المركز من نقطة الاعتدال الربيعي على ما يتلو من فلك البروج في أوّل سنة من بعد موت الإسكندر في أوّل شهر ثوث من شهور القبط في وقت نصف النهار بالإسكندرية خمسين درجة وأربع وعشرين دقيقة. ومثل ذلك كان بعد منتهى الشمال من هذه النقطة. |11:10| وكان بعد مركز فلك التدوير من H94 أوج موضع الخروج عن المركز على ما يتلو من فلك البروج مائة جزء وسبعة وسبعين جزءًا وستّ عشرة دقيقة. وكان أيضًا بعد منتهى شمال الفلك المائل الصغير من أوج فلك التدوير على خلاف توالي البروج سبعة وثمانين جزءًا وستّ عشرة دقيقة. وكان بعد الكوكب من منتهى شمال الفلك الصغير المائل على ما يتلو من فلك البروج مائة جزء وثمانية وستّين جزءًا وخمس وثلاثين دقيقة.

1 مساوية] متساوية L **2** بحركته] om L غير] om B وليحو] وليحوي L **3** جزء] جزءًا L **4** ولتكن] وليكن L نصف[1]] sl L **5** في...الصغير] om BL **8** سبع] سبعًا B **11** ثوث] توت B **12** في] وفي B النهار بالإسكندرية] نهار الإسكندرية L وأربع] وأربعة B **15** عشرة] عشر B شمال الفلك] الشمال للفلك B **17** شمال] الشمال إلى B المائل] om B **18** وخمس] وخمسًا B

2 بحركته] om H **4** فلك التدوير] *τοῦ κυκλίσκου* H **5** في ... الصغير] add H **10** موضع] om H the direction in which the world moves, with a motion similar to the motion of the aforementioned epicycle. |11:7| Let this circle by its motion move another circle inclined to it with the same centre and in a fixed position towards this circle. Let the inclination of this circle comprise an angle of 3 ½ parts according to the measure by which the right angle is 90 parts. Let the ratio of the radius of the eccentric circle to the radius of the epicycle be like the ratio of 60 to 43 ⅙. |11:8| Let the planet move regularly on this small circle[22] around the centre of this circle from the apogee contrary to the direction in which the world moves, with a motion similar to the motion of the epicycle and to the motion of the planet in sum. Thus, in 35 Egyptian years and 33 nychthemera, it completes 57 returns. However, this is [only] approximate, because when it is examined more closely, it exceeds what we have said by one minute.

|11:9| The distance of the apogee of the position of the eccentricity from the vernal equinoctial point according to the succession of the signs was 50;24 degrees in the first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the northern limit from this point was the same. |11:10| The distance of the centre of the epicycle from the apogee of the position of the eccentricity according to the succession of the signs was 177 parts and 16 minutes. Also, the distance of the northern limit of the small inclined circle from the apogee of the epicycle contrary to the succession of the signs was 87 parts and 16 minutes. The distance of the planet from the northern limit of the small inclined circle according to the succession of the ecliptic was 168 parts and 35 minutes.

[22] The translation follows the conjecture from the Greek.

|12:1| حال أفلاك كوكب المرّيخ

L10r وأمّا كوكب المرّيخ فإنّا نتوهّم في كرته أيضًا فلكًا مركزه مركز فلك البروج يتحرّك في
بسيطه وحول مركزه حركة مستوية من ناحية المغرب إلى ناحية المشرق ومساوية لحركة
B86r كرة الكواكب الثابتة. |12:2| وليحرّك هذا الفلك بحركته فلكًا آخر مائلًا عنه مركزه وهو
مركز هذا الفلك وهو غير زائل عنه. وليحو ميل هذا الفلك زاوية تكون جزءًا ونصف وثلث
جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. |12:3| وليكن في سطح الفلك
المائل قطر من منتهى الشمال إلى منتهى الجنوب وليكن على هذا القطر نقطتان فيما
بين مركز فلك البروج وبين منتهى الشمال. وليكن الخطّ الذي فيما بينهما مساويًا للخطّ
الذي بين مركز فلك البروج وبين النقطة التي تليه من هاتين النقطتين. وليكن أقرب
النقطتين من الأرض مركز الفلك الخارج المركز وليكن غير زائل ولا متحرّك. ولتكن نسبة
نصف قطره إلى الخطّ الذي بين مركزه ومركز فلك البروج كنسبة الستّين إلى الستّة.

|12:4| وليتحرّك مركز فلك التدوير حول أبعد النقطتين من الأرض حركة مستوية على ما
يتلو من فلك البروج من موضع القطر الذي ذكرنا بمقدار زيادة حركة الشمس على حركة
هذا الكوكب وحركة كرة الكواكب الثابتة بمجموعتين في الأزمان المتساوية وليكن وضعه
في حركته أبدًا على الفلك الخارج المركز. ففي خمس وتسعين سنة مصرية وثلاثمائة
H96 وإحدى وستّين يومًا بلياليها يعود إحدى وخمسين عودة. وذلك بالتقريب لأنّه ينقص عمّا
L10v قلنا إذا استقصي ثلاث دقائق.

|12:5| وأيضًا فإنّا نتوهّم في كرة فلك التدوير فلكًا صغيرًا على مركزها في سطح الفلك
المائل. وليكن الخطّ الذي يمرّ بمركز هذا الفلك وبالنقطة التي هي أبعد النقطتين اللتين
ذكرنا من الأرض وهي التي يتحرّك حولها فلك التدوير حركة مستوية يجوز على نقط من

1 كوكب] om B **3** ومساوية] مساوية B **4** وهو] om B **5** وليحو] وليحوي L ميل] مثل L جزءًا] جزء L ونصف] ونصف جزء B **6** تكون] يكون B **8** مركز] sl B **9** تليه] بلثة L **10** ولتكن] وليكن BL **11** نصف] om L إلى[1]] التي L **11/12** البروج...فلك] om L **16** وإحدى] واحد L وستّين] ستّون B بلياليها] om BL عمّا] عن ما L **19** وليكن] ولكن L وبالنقطة] بالنقطة B **20** نقط] نقطت B من[2]] om B اللتين] واللتين L

2 أيضًا] om H **4** بحركته] om H **5** هذا الفلك[2]] τῶν ἐπιπέδων H **16** يومًا بلياليها] νυχθημέροις H

|12:1| The condition of the circles of the planet Mars

As for the planet Mars, we imagine in its sphere also a circle whose centre is the centre of the ecliptic, moving regularly in its plane and around its centre from west to east, [its motion] being similar to the motion of the sphere of the fixed stars. |12:2| Let this circle by its motion move another circle inclined to it with the same centre, i.e. the centre of this circle, in a fixed position towards it. Let the inclination of this circle comprise an angle of 1 ½ plus ⅓ parts according to the measure by which the right angle is 90 parts. |12:3| In the plane of this inclined circle, let there be a diameter from the northern to the southern limit, and, on this diameter, two points in the space between the centre of the ecliptic and the northern limit. Let the line in the space between [these two points] be equal to the line between the centre of the ecliptic and the one of the two points that follows it. Let the point of the two points that is closer to the Earth be the centre of the eccentric circle and let it be be in a fixed position and not moving. Let the ratio of its radius to the line between its centre and the centre of the ecliptic be like the ratio of 60 to 6.

|12:4| Let the centre of the epicycle move regularly around the point of the two points that is further away from the Earth according to the succession of the signs from the position of the aforementioned diameter by the amount of the excess of the motion of the Sun over the motion of this planet and the motion of the sphere of the fixed stars in sum in equal periods of time, and let its position in its motion always be on the eccentric circle. Thus, in 95 Egyptian years and 361 nychthemera, it completes 51 returns. However, this is [only] approximate, because when it is examined more closely, it is less than what we have said by three minutes.

|12:5| We also imagine in the sphere of the epicycle another small circle on its [i.e. the sphere's] centre in the plane of the inclined circle. The line that goes through the centre of this circle and the point that is the point of the two aforementioned points that is further away from the Earth and around which the epicycle moves regularly, let [this line] pass through exactly these points of this

هذا الفلك الصغير بأعيانها وهي التي تسمّى الأوج والبعد الأقرب. |12:6| وليكن أيضًا فلك آخر صغير يتحرّك في سطح هذا الفلك وعلى مركزه حركة مستوية من الأوج إلى الناحية التي يتحرّك إليها العالم. وتكون مساوية لحركة مركز فلك التدوير الذي ذكرنا. |12:7| وليحرّك هذا الفلك الصغير فلكًا آخر مائلًا عنه حول مركزه وليكن ثابتًا في هذا الفلك غير زائل عنه. وليحو ميله زاوية تكون أيضًا أربعة أجزاء ونصف وثلث جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. ولتكن نسبة نصف القطر من الفلك الخارج المركز إلى نصف قطر الفلك الصغير كنسبة الستّين إلى التسعة والثلاثين ونصف. |12:8| وليتحرّك الكوكب في هذا الفلك الصغير حول مركزه حركة مستوية فإذا تحرّك من الأوج كانت حركته على خلاف حركة العالم وحركته مساوية لحركة فلك التدوير وحركة
L11r الكوكب بمجموعتين وذلك هو زيادة حركة الشمس على حركة الكواكب الثابتة في الأزمان المتساوية.

B86v |12:9| وقد كان بعد أوج موضع الخروج عن المركز من نقطة الاعتدال الربيعي على ما يتلو من فلك البروج في أوّل سنة بعد موت الإسكندر في أوّل شهر ثوث من شهور القبط في وقت نصف النهار بالإسكندرية مائة درجة وعشر درجات وأربع وخمسين دقيقة. وكان
H98 بعد منتهى الشمال مثل ذلك. |12:10| وكان بعد مركز فلك التدوير من أوج موضع الخروج عن المركز على ما يتلو من فلك البروج ثلاثمائة جزءًا وستّة وخمسين جزءًا وسبع دقائق. وكان بعد منتهى شمال الفلك الصغير المائل من أوج فلك التدوير على خلاف توالي البروج مائة جزء وستّة وسبعين جزءًا وعشرين دقيقة. وكان بعد الكوكب من منتهى شمال الفلك المائل الصغير على ما يتلو من فلك البروج مائتين وستّة وتسعين جزءًا وستّ وأربعين دقيقة.

1 بأعيانها] om B   **5** زائل] مائل B   وليحو] وليحوي L   **6** ولتكن] وليكن L   نصف…من] قطر L   **7** ونصف] والنصف L   **8** وليتحرّك] ويتحرك B   فإذا] واذا L   **9** وحركته] وحركة L   **13** سنة] إلى add L   ثوث] توت B   **14** النهار بالإسكندرية] نهار الإسكندرية L   وعشر] وعشرة B   وأربع] وأربعة B   **16** ثلاثمائة] بثلاثمائة L   جزءًا¹] جزء L   **17** بعد] om B   شمال الفلك] الشمال للفلك B   **19** شمال] om L   الفلك] om B   **20** وستّ] وستًّا B

2 فلك…صغير] ὁμόκεντρος add H   **2/3** إلى…العالم] ἐπὶ τὰ ἐναντία τῇ τοῦ κόσμου περιστροφῇ H
8 فإذا] ὡς H, not translated in the parallel passages of the preceding chapters

small circle, namely those which are called the apogee and perigee. |12:6| Also, let there be another small circle which moves in the plane of this circle and around its centre regularly from the apogee in the direction in which the world moves. [Its motion] is equal to the motion of the centre of the aforementioned epicycle. |12:7| Let this small circle move another circle inclined to it around its centre and let it be fixed in this circle, not departing from it.[23] Let its inclination also comprise an angle of 4 ½ plus ⅓ parts according to the measure by which the right angle is 90 parts. Let the ratio of the radius of the eccentric circle to the radius of the small circle be like the ratio of 60 to 39 ½. |12:8| Let the planet move regularly on this small circle around its centre so that when it moves from the apogee, its motion is contrary to the motion of the world, and it is equal to the motion of the epicycle and to the motion of the planet in sum,[24] and this is the excess of the motion of the Sun over the motion of the fixed stars in equal periods of time.

|12:9| The distance of the apogee of the position of the eccentricity from the vernal equinoctial point according to the succession of the signs was 110;54 degrees in the first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the northern limit [from the vernal equinoctial point][25] was the same. |12:10| The distance of the centre of the epicycle from the apogee of the position of the eccentricity according to the succession of the signs was 356;7 parts. The distance of the northern limit of the inclined small circle from the apogee of the epicycle contrary to the succession of the signs was 176;20 parts. The distance of the planet from the northern limit of the inclined small circle according to the succession of the signs was 296;46 parts.

[23] These two sentences are cited in Ibn al-Hayṯam, *al-Šukūk*, p. 55:11–17.
[24] Until here, the sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 55:19–22.
[25] Similarly added in Hamm, *Ptolemy's Planetary Theory*, p. 59.

|13:1| حال أفلاك المشتري

وأمّا في كرة كوكب المشتري فإنّا نتوهّم فلكًا مركزه مركز فلك البروج يتحرّك في بسيطه وحول مركزه حركة مستوية من ناحية المغرب إلى ناحية المشرق. وحركته مساوية لحركة كرة الكواكب الثابتة. |13:2| وليحرّك هذا الفلك أيضًا بحركته فلكًا آخر مائلًا عنه مركزه وهو مركز هذا الفلك وليكن غير زائل عنه. وليحو ميل هذين السطحين أحدهما عن L11v الآخر زاوية تكون جزءًا ونصف جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. |13:3| ونتوهّم في سطح هذا الفلك المائل خطًّا مستقيمًا يخرج من مركز فلك البروج إلى النقطة المتقدّمة عن منتهى الشمال بعشرين جزءًا. وليكن على هذا الخطّ نقطتان يكون الخطّ الذي بينهما مساويًا للخطّ الذي بين مركز فلك البروج وبين النقطة التي تليه من هاتين النقطتين. وليكن أقرب النقطتين من الأرض مركز الفلك الخارج المركز غير زائل ولا متحرّك. ولتكن نسبة نصف قطره إلى الخطّ الذي بين مركزه ومركز فلك البروج كنسبة الستّين إلى الاثنين والنصف والربع.

|13:4| وليتحرّك مركز فلك التدوير حول أبعد النقطتين من الأرض حركة مستوية على ما يتلو من فلك البروج وليكن وضع مركز فلك التدوير أبدًا على الفلك الخارج المركز. ولتكن حركته من موضع القطر الذي ذكرنا بمقدار زيادة حركة الشمس على حركة هذا H100 الكوكب وحركة كرة الكواكب الثابتة بمجموعتين في الأزمان المتساوية. ففي مائتي سنة وثلاث عشرة سنة مصرية ومائتين وأربعين يومًا بلياليها يعود ثماني عشرة عودة. وذلك بالتقريب لأنّه يزيد على ما قلناه إذا استقصي دقيقة واحدة.

B87r |13:5| وأيضًا فإنّا نتوهّم في كرة فلك التدوير فلكًا صغيرًا على مركزها في سطح الفلك L12r المائل. وليكن الخطّ الذي يمرّ بمركز هذا الفلك وبالنقطة التي هي أبعد النقطتين اللتين ذكرنا من الأرض وهي التي يتحرّك حولها فلك التدوير حركة مستوية يجوز على نقط من

2 في[1]] om B   كوكب] om B   يتحرّك] ويتحرّك B   **3** وحركته] حركة B   **4** كرة] om B   **5** وهو] om L   وليكن] ولتكن L   **11** الخارج] خارج L   **10** بالمقدار] بالمقدار add L   **6** وليحو] وليحوي L   B   ثماني] ثمانية L   عشرة[1]] عشر BL   وثلاث] وثلاثة B   **17** مركز] sl L   **13** الستّين] الشيسن L   **12** عشرة[2]] عشر B   **18** قلناه] فلنا B   **21** وهي] هي B   نقط] om L

|13:1| The condition of the circles of Jupiter

In the sphere of the planet Jupiter, we imagine a circle whose centre is the centre of the ecliptic and which moves regularly in its plane and around its centre from west to east. Its motion is equal to the motion of the sphere of the fixed stars. |13:2| Let this circle also move by its motion another circle inclined to it, with the same centre, i.e. the centre of this circle, and let it be in a fixed position towards it. Let the inclination of one of these two planes against the other comprise an angle of 1 ½ parts according to the measure by which the right angle is 90 parts. |13:3| We imagine in the plane of this inclined circle a straight line that is produced from the centre of the ecliptic to the point that precedes the northern limit by 20 parts. On this line, let there be two points [so that] the line between them is equal to the line between the centre of the ecliptic and the point of the two points that follows it. Let the point of the two points that is closer to the Earth be the centre of the eccentric circle, in a fixed position and not moving. Let the ratio of its radius to the line between its centre and the centre of the ecliptic be like the ratio of 60 to 2 ½ plus ¼.

|13:4| Let the centre of the epicycle move regularly around the point of the two points that is further away from the Earth according to the succession of the signs, and let the position of the centre of the epicycle always be on the eccentric circle. Let its motion be from the aforementioned diameter by the amount of the excess of the motion of the Sun over the motion of this planet and the motion of the sphere of the fixed stars in sum in equal periods of time. Thus, in 213 Egyptian years and 240[26] nychthemera, it completes 18 returns. However, this is [only] approximate, because when it is examined more closely, it exceeds what we have said by one minute.

|13:5| We also imagine in the sphere of the epicycle a small circle around its [i.e. the sphere's] centre in the plane of the inclined circle. The line that goes through the centre of this circle and through the point which is the point of the two aforementioned points that is further away from the Earth, namely [that] around which the epicycle moves regularly, let [this line] pass through exactly the points

[26] Despite the agreement between the Greek and Arabic version, Bainbridge wanted to change this to 238. See Ptolemy, *De planetarum hypothesibus*, p. 38:8.

هذا الفلك الصغير بأعيانها وهي التي تسمّى الأوج والبعد الأقرب. |13:6| وليكن أيضًا فلك آخر صغير مركزه مركز هذا الفلك وليتحرّك في سطحه وحول مركزه حركة مستوية من الأوج إلى الناحية التي يتحرّك إليها العالم. وتكون مساوية لحركة مركز فلك التدوير الذي ذكرنا. |13:7| وليحرّك هذا الفلك الصغير فلكًا آخر مائلًا عنه حول مركزه وليكن ثابتًا في هذا الفلك غير زائل عنه. وليحو ميله زاوية تكون جزءًا ونصف جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. ولتكن نسبة نصف قطر الفلك الخارج المركز إلى نصف قطر الفلك الصغير كنسبة الستّين إلى الأحد عشر والنصف. |13:8| وليتحرّك هذا الكوكب في هذا الفلك الصغير حول مركزه حركة مستوية من الأوج على خلاف حركة العالم. وحركته مساوية لحركة فلك التدوير وحركة الكوكب بمجموعتين وذلك هو أيضًا زيادة حركة الشمس على حركة الكواكب الثابتة في الأزمان المتساوية.

|13:9| وقد كان بعد أوج موضع الخروج عن المركز من نقطة الاعتدال الربيعي على ما
يتلو من فلك البروج في أوّل سنة بعد موت الإسكندر في أوّل شهر ثوث من شهور القبط L12v
في وقت نصف النهار بالإسكندرية مائة درجة وستّ وخمسين درجة وأربع وعشرين H102
دقيقة. وكان بعد منتهى الشمال منها مائة درجة وستّ وسبعين درجة وأربع وعشرين
دقيقة. |13:10| وكان بعد مركز فلك التدوير من أوج موضع الخروج عن المركز على ما
يتلو فلك البروج مائتي درجة واثنتي وتسعين درجة وثلاث وعشرين دقيقة. وكان بعد
منتهى شمال الفلك الصغير المائل أيضًا من أوج فلك التدوير على خلاف توالي البروج
اثنتي وتسعين درجة وثلاث وأربعين دقيقة. وكان بعد الكوكب من منتهى شمال الفلك

1/2 أيضًا فلك] om B **2** فلك…صغير] فلكًا آخر صغيرًا L وليتحرّك] وليتجرى B **4** وليحرّك] وليجرى B **5** وليحو] وليحوي L جزءًا] جزء L جزء] om L **6** تسعين] تسعون B ولتكن] وليكن L **7** الستّين] الشئن L الأحد عشر] الإحدى عشرة B والنصف] ونصف B **8** حول] وحول L **9** أيضًا] om L **10** الشمس] أيضًا add L **12** ثوث] توت B **12/13** القبط…وقت] المصريين وقت B **13** النهار بالإسكندرية] نهار لإسكندرية L وستّ] وستًّا B **14** وستّ] وستًّا B **16** مائتي] مائتا L وثلاث] وثلاثًا B بعد] sl L **17/38,1** أيضًا…الصغير] om B

1 بأعيانها] *πάντοτε* add H أيضًا] om H **14/15** وكان…دقيقة] om H **17** فلك التدوير] om H على…البروج] *εἰς τὰ ἑπόμενα τοῦ κόσμου* H of this small circle, namely those which are called the apogee and perigee. |13:6| Also, let there be another small circle whose centre is the centre of this circle, and let it move regularly in its plane and around its centre from the apogee in the direction in which the world moves. [Its motion] is equal to the motion of the centre of the aforementioned epicycle. |13:7| Let this small circle move another circle inclined to it around its centre and let it be fixed in this circle, not departing from it. Let its inclination comprise an angle of 1 ½ parts according to the measure by which the right angle is 90 parts. Let the ratio of the radius of the eccentric circle to the radius of the small circle be like the ratio of 60 to 11 ½. |13:8| Let this planet move regularly in this small circle around its centre from the apogee contrary to the motion of the world. Its motion is equal to the motion of the epicycle and to the motion of the planet in sum, and this is also the excess of the motion of the Sun over the motion of the fixed stars in equal periods of time.

|13:9| The distance of the apogee of the position of the eccentricity from the vernal equinoctial point according to the succession of the signs was 156;24 degrees in the first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the northern limit from it [i.e. the vernal equinoctial point] was 176;24 degrees. |13:10| The distance of the centre of the epicycle from the apogee of the position of the eccentricity according to the succession of the signs was 292;23 degrees. Also, the distance of the northern limit of the small inclined circle from the apogee of the epicycle contrary[27] to the succession of the signs was 92;43 degrees. The distance of the planet from the northern

[27] Bainbridge has already noted that the Greek reading is wrong. See Ptolemy, *De planetarum hypothesibus*, p. 41:6.

المائل الصغير على ما يتلو من فلك البروج مائتي جزء وأحد وثلاثين جزءًا وستّ عشرة دقيقة.

|14:1| حال أفلاك زحل

وأمّا في كرة زحل فإنّا نتوهّم فلكًا مركزه مركز فلك البروج يتحرّك في بسيطه وحول مركزه حركة مستوية من ناحية المغرب إلى ناحية المشرق. وحركته مساوية لحركة كرة الكواكب الثابتة. |14:2| وليحرّك هذا الفلك أيضًا فلكًا آخر مائلًا عنه حول مركزه وليكن غير زائل عنه. وليحو ميل هذين السطحين أحدهما عن الآخر زاوية تكون جزئين ونصف جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. |14:3| ونتوهّم أيضًا في سطح الفلك المائل خطًّا مستقيمًا يخرج من مركز فلك البروج إلى النقطة المختلفة عن منتهى الشمال بأربعين جزءًا. وليكن على هذا الخطّ نقطتان. يكون الخطّ الذي بينهما مساويًا للخطّ B87v | L13r الذي بين مركز فلك البروج وبين النقطة التي تليه من هاتين النقطتين. وليكن أقرب النقطتين من الأرض مركز الفلك الخارج المركز غير زائل ولا متحرّك. ولتكن نسبة نصف قطره إلى الخطّ الذي بين مركزه ومركز فلك البروج كنسبة الستّين إلى الثلاثة والثلث ونصف السدس.

|14:4| وليتحرّك مركز فلك التدوير حول أبعد النقطتين من الأرض حركة مستوية على ما يتلو من فلك البروج وليكن وضع مركز فلك التدوير أبدًا على الفلك الخارج المركز. ولتكن حركته من موضع القطر الذي ذكرنا بمقدار زيادة حركة الشمس على حركة هذا H104 الكوكب وحركة كرة الكواكب الثابتة بمجموعتين في الأزمان المتساوية. ففي مائة سنة وسبع عشرة سنة مصرية وثلاثمائة وثلاثين يومًا بلياليها يعود أربع عودات. وذلك بالتقريب لأنّه يزيد على ما قلنا إذا استقصي دقيقة واحدة.

|14:5| وأيضًا فإنّا نتوهّم في كرة فلك التدوير فلكًا صغيرًا على مركزها في سطح الفلك المائل. وليكن الخطّ الذي يمرّ بمركز هذا الفلك وبالنقطة التي هي أبعد النقطتين اللتين

1 جزء] جزءًا B وأحد] وإحدى B عشرة] عشر L **4** يتحرّك] تتحول L **5** كرة] om B **6** حول مركزه] om B **7** وليحو] وليحوي L تكون] وتكون L **8** تكون] يكون B أيضًا] om B **9** المختلفة] المتخلّفة m **10** يكون] add L **12** الخارج] خارج L ولتكن] وليكن BL **13** والثلث] وثلث B **14** ونصف] والنصف BL السدس] سدس B **17** ولتكن] وليكن B **19** وسبع] وتسعة B عشرة] عشر BL limit of the small inclined circle according to the succession of the signs was 231 parts and 16 minutes.[28]

|14:1| The condition of the circles of Saturn

In the sphere of Saturn, we imagine a circle whose centre is the centre of the ecliptic and which moves regularly in its plane and around its centre from west to east. Its motion is equal to the motion of the sphere of the fixed stars. |14:2| Also, let this circle move another circle inclined to it around its centre and let it be in a fixed position towards it. Let the inclination of one of these two planes against the other comprise an angle of 2 ½ parts according to the measure by which the right angle is 90 parts. |14:3| Also, we imagine a straight line in the plane of the inclined circle that is produced from the centre of the ecliptic to the point which is different from the northern limit by 40 parts. On this line, let there be two points. The line between them is equal to the line between the centre of the ecliptic and the point of these two points that follows it. Let the point of the two points that is closer to the Earth be the centre of the eccentric circle, in a fixed position and not moving. Let the ratio of its radius to the line between its centre and the centre of the ecliptic be like the ratio of 60 to 3 ⅓ plus 1⁄12.

|14:4| Let the centre of the epicycle move regularly around the point of the two points that is further away from the Earth according to the succession of the signs, and let the position of the centre of the epicycle always be on the eccentric circle. Let its motion be from the position of the aforementioned diameter by the amount of the excess of the motion of the Sun over the motion of this planet and the motion of the sphere of the fixed stars in sum in equal periods of time. Thus, in 117 Egyptian years and 330 nychthemera, it completes four returns. However, this is [only] approximate, because when it is examined more closely, it exceeds what we have said by one minute.

|14:5| We also imagine in the sphere of the epicycle a small circle around its [i.e. the sphere's] centre in the plane of the inclined circle. The line that goes through the centre of this circle and through the point of the two aforementioned points

[28] These values have also already been corrected by Bainbridge, for which see Ptolemy, *De planetarum hypothesibus*, p. 41:11.

ذكرنا من الأرض وهي التي يتحرّك حولها فلك التدوير حركة مستوية يجوز على نقط من هذا الفلك الصغير بأعيانها وهي التي تسمّى الأوج والبعد الأقرب. |14:6| وليكن أيضًا فلك آخر صغير مركزه مركز هذا الفلك وليتحرّك في سطحه وحول مركزه حركة مستوية من L13v الأوج إلى الناحية التي يتحرّك إليها العالم. وتكون مساوية لحركة مركز فلك التدوير الذي ذكرنا. |14:7| وليحرّك هذا الفلك الصغير أيضًا فلكًا آخر مائلًا عنه حول مركزه وليكن ثابتًا في هذا الفلك غير زائل عنه. وليحو ميله زاوية تكون أيضًا جزئين ونصف جزء بالمقدار الذي تكون به الزاوية القائمة تسعين جزءًا. ولتكن نسبة نصف قطر الفلك الخارج المركز إلى نصف قطر هذا الفلك الصغير كنسبة الستّين إلى الستّة والنصف. |14:8| وليتحرّك الكوكب في هذا الفلك الصغير وحول مركزه حركة مستوية من الأوج على خلاف حركة العالم. وحركته مساوية لحركة فلك التدوير وحركة الكوكب بمجموعتين وذلك هو زيادة حركة الشمس أيضًا على حركة الكواكب الثابتة في الأزمان المتساوية.

H106 |14:9| وقد كان بعد أوج موضع الخروج عن المركز من نقطة الاعتدال الربيعي على ما يتلو من فلك البروج في أوّل سنة بعد موت الإسكندر في أوّل شهر ثوث من شهور القبط في وقت نصف النهار بالإسكندرية مائتي درجة وثماني وعشرين درجة وأربع وعشرين دقيقة. وكان بعد منتهى الشمال منها مائة درجة وثماني وثمانين درجة وأربع وعشرين دقيقة. |14:10| وكان بعد مركز فلك التدوير من أوج موضع الخروج عن المركز على ما B88r يتلو من فلك البروج مائتي جزء وعشرة أجزاء وثماني وثلاثين دقيقة. وكان بعد منتهى شمال الفلك الصغير المائل من أوج فلك التدوير على خلاف توالي البروج سبعين جزءًا وثماني وثلاثين دقيقة. وكان بعد الكوكب من منتهى الشمال من الفك المائل الصغير H end على ما يتلو من فلك البروج مائتي جزء وتسعة عشر جزءًا وستّ عشرة دقيقة.

1 وهي] وبين L يجوز] تجوز B **3** فلك] فلكًا L **4** فلك] om L **5** وليحرّك] وليحول L **6** وليحو] وليحوي L ميله] مثله L جزء] om L **7** ولتكن] وليكن B نصف] sl B **12** نقطة] النقطة التي B **13** ثوث] توت B **13/14** الإسكندر…بالإسكندرية] الإسكندرية L هي B **14** وثماني] ثمانيًا B **15** بعد] sl L وثماني] وثمانية B **16** فلك] om L **18** شمال] الشمال B **18/20** سبعين…البروج] om L **19** وثماني] وثمانية B **20** عشرة] عشر B

2 بأعيانها] πάντοτε add H **4/5** الذي ذكرنا] om H that is further away from the Earth, namely that around which the epicycle moves regularly, let [this line] pass through exactly the points from the small circle, namely those which are called the apogee and perigee. |14:6| Also, let there be another small circle whose centre is the centre of this circle and let it move regularly in its plane and around its centre from the apogee in the direction in which the world moves. [Its motion] is equal to the motion of the centre of the aforementioned epicycle. |14:7| Let this small circle also move another circle inclined to it around its centre and let it be fixed in this circle, not departing from it. Let its inclination also comprise an angle of 2 ½ parts according to the measure by which the right angle is 90 parts. Let the ratio of the radius of the eccentric circle to the radius of this small circle be like the ratio of 60 to 6 ½. |14:8| Let the planet move regularly in this small circle and around its centre[29] from the apogee opposite to the motion of the world. Let its motion be equal to the motion of the epicycle and the motion of the planet taken together, which is also the excess amount of the motion of the Sun over the motion of the fixed stars in equal periods of time.

|14:9| The distance of the apogee of the position of the eccentricity from the vernal equinoctial point according to the succession of the signs was 228;24[30] degrees in the first year after Alexander's death in the first Egyptian month Thoth at noon in Alexandria. The distance of the northern limit from it [i.e the vernal equinoctial point] was 188;24 degrees. |14:10| The distance of the centre of the epicycle from the apogee of the position of the eccentricity according to the succession of the signs was 210;38 parts. The distance of the northern limit of the small inclined circle from the apogee of the epicycle contrary to the succession of the signs was 70;38 parts. The distance of the planet from the northern limit of the small inclined circle according to the succession of the signs was 219;16 parts.

[29] This is where the Greek text ends. Since the remainder of the edition by Heiberg depends on a medieval recension that repeats the last part of Chapter I.13, my Greek apparatus stops here.

[30] In contrast to the remaining following values, Bainbridge's emendation here agrees with the Arabic tradition. See Ptolemy, *De planetarum hypothesibus*, p. 45:25.

L14r |15:1| هذه هيئة الكواكب المتحيّرة في أفلاكها. وعلى حسب ما قلنا يشبه أن يكون السبب الذي من أجله يظهر للحركات السماوية اختلاف غير عارض في كرة الكواكب الثابتة بوجه من الوجوه وذلك أنّ هذه الكرة تتحرّك حركة قريبة جدًّا من حركة الكلّ الذي هو واجب أن يكون طبعه طبعًا بسيطًا لا يخالطه غيره ولا يقبل الحالات المتضادّة البتّة. |15:2| وأمّا الكواكب المتحيّرة كلّها التي هي دون موضع هذه الحركة فإنّها تتحرّك معها من المشرق إلى المغرب وتتحرّك هي بخلاف هذه الحركة من المغرب إلى المشرق وإلى النواحي أعني إلى قدّام وإلى خلف وإلى اليمين وإلى الشمال التي هي جهات الحركة المكانية. |15:3| وذلك أنّ الحركة المكانية هي أوّل سائر الحركات. والأشياء التي طبيعتها طبيعة دائمة ليس يوجد فيها إلّا هذه الحركة وحدها. وهي سبب التغييرات المتضادّة التي في الكيفية والكمّية الكائنة في الأشياء التي ليست بدائمة وليس إنّما هذه التغييرات فيما يظهر لنا منها فقط مثل ما هي في الدائمة لكن وفيها أنفسها وفي جواهرها.

|15:4| وأمّا الشمس فإنّا نظنّ بها أنّ لها اختلافًا واحدًا فقط وهو الذي يرى في حركتها في فلك البروج لأنّه ليس فيما يتحرّك وجدنا في تسخين ما يتحرّك وفي تسخين ما يظهر شيئًا أقوى منها فتقبل منه اختلافًا آخر ثانيًا في مسيرها. |15:5| وأمّا سائر الكواكب المتحيّرة فإنّ لها نوعين من الاختلاف. أحدهما قريب من الذي ذكرنا وهو الذي يكون
L14v على حسب ممرّها في فلك البروج والآخر الذي يكون بحسب عودتها إلى الشمس فتكون لكلّ واحد منها حركة إرادية وحركة يضطرّ إليها. |15:6| وأمّا ما يعرض لها من الحركة التي إلى الناحيتين فإنّه في كرة الكواكب الثابتة وكرة الشمس أيضًا بنوع واحد بسيط وهو الذي من قبل ميل فلك البروج عن معدّل النهار. |15:7| وأمّا في القمر فبنوعين. أحدهما الذي ذكرنا والآخر الذي هو له بميله عن فلك البروج في فلكه المائل. |15:8| وأمّا الخمسة الكواكب المتحيّرة فبثلاثة أنواع فيكون أكثر ما يعرض من

1 هذه...أفلاكها] om L **2** للحركات] في الحركات B **4** البتّة] السببة L **5** وأمّا] فأمّا B **8** وذلك... المكانية²] mg B **11** لكن وفيها] ولكن فيها m **12** فإنّا نظنّ] فإنّما يظنّ L **13** وجدنا...يظهر] om Bm **14** ثانيًا] om B **15** أحدهما قريب] أحدها L **17** فتكون] فيكون B **18** وأمّا] فاما B التي] om L فإنّه] و إنها B بنوع] نوع B **19** وأمّا] ما add L **20** فبنوعين] فنوعين B بميله] فميله B

|15:1|[31] This is the configuration of the wandering stars on their circles. According to what we have said, it seems that the reason for which an anomaly is apparent for the heavenly motions does not occur in any way in the sphere of the fixed stars, for this sphere carries out a motion very close to the motion of the universe, whose nature is necessarily a simple one, not interfering with something else and not receiving opposite states at all. |15:2| As for the wandering stars, all of which are below the position of this motion, they move together with [this motion] from east to west, and they [also] move contrary to this motion from west to east and in the [four] directions, I mean forward and backward, and rightward and leftward [i.e. south and north], which are the directions of locomotion. |15:3| For locomotion is prior to the other motions.[32] In the things with an eternal nature we find only this single motion. This is the reason for the opposite changes in quality and quantity that occur in the non-eternal things. These changes are not only in what is apparent to us of them, as is the case for what is eternal, but [also] in themselves and their substances.

|15:4|[33] As for the Sun, we believe that it has only one anomaly, namely that which can be seen in its motion on the ecliptic, because among the things that move we find nothing stronger than [the Sun] in heating what moves and what is apparent in such a way that [the Sun] would receive from [this stronger thing] another second anomaly in its course.[34] |15:5| As for the other wandering stars, they have two kinds of anomaly. One of them is close to what we have already mentioned, namely that which is according to their path on the ecliptic, the other is that which is according to [the planets'] return to the Sun, so that each of them has a volitional motion and a motion to which it is compelled.[35] |15:6|[36] As for their motion in the two directions, it also [takes place] for the sphere of the fixed stars and for the sphere of the Sun by one simple kind [of anomaly], namely that which is due to the inclination of the ecliptic to the equator. |15:7| As for the Moon, [it] has two kinds [of latitudinal anomaly]. One of them is the aforementioned, and the other is that which it has through its inclination against the ecliptic in its inclined circle. |15:8| As for the five wandering stars, they have three

[31] For the following second part of Book I, I follow Goldstein's division into chapters. See Goldstein, 'The Arabic Version'.

[32] 'Motions' in the sense of 'change'. See Aristotle, *Phys*. VIII.7, 260a26–b15.

[33] Ptolemy deals here with anomalies in ecliptic motion, i.e. longitudinal anomalies.

[34] For the Aristotelian background of the beginning of this chapter, see the commentary to Chapter I.15, p. 360.

[35] These two sentences are cited in Ibn al-Hayṯam, *al-Šukūk*, pp. 44:18–45:3. For the problems that this sentence brings with it, see the commentary to Chapter I.15, p. 361.

[36] At this point, Ptolemy turns towards anomalies perpendicular to the ecliptic, i.e. latitudinal anomalies.

الاختلافات ثلاثة. اثنان منها اللذين ذكرنا والثالث من قبل الأفلاك التي تدور حول الأرض المائلة عن فلك التدوير. وأمر هذه الأفلاك شبيه بأمر سائر أفلاك الميل في جميع أحوالها. |15:9| وإنّما يتوهّم أنّ بينها وبينها اختلافًا لأنّها لا تحيط بالأرض لكن تقع الأرض خارجًا عنها وبذلك السبب صارت الأفلاك المائلة يظنّ بها أنّها تتحرّك وتنتقل إلى جهتين متضادّتين وأنّ حركة هذه الأفلاك أيضًا تكون على موازاة السطوح التي ميلها B88v عنها ميل ثابت كحال فلك البروج عند سطح معدّل النهار.

|15:10| فإنّا إن توهّمنا أنّ القطعة التي فوق الأرض من دائرة نصف النهار ممّا يلي الأوج والتي تحت الأرض منها ممّا يلي البعد الأقرب وأنّ بعد الأفق الذي من الناحيتين جميعًا البعد الأوسط وأنّ ميل فلك البروج واحد بعينه لا يتغيّر فإنّ حركة هذا الفلك المائل عن معدّل النهار هي على أقطابه. |15:11| فإنّ منتهى شمال هذا الفلك وهو النقطة الصيفية يكون أحيانًا على القطعة التي تلي الأوج وأحيانًا على التي تلي البعد الأقرب وأحيانًا في البعد الذي من المشرق وأحيانًا في الذي من المغرب وكذلك أيضًا منتهى الجنوب وهو النقطة الشتوية. |15:12| وأيضًا فإنّ النقطة الربيعية التي هي كعقدة الرأس تكون أحيانًا في القطعة التي ممّا يلي الأوج وأحيانًا في التي تلي البعد الأقرب وأحيانًا في البعد الذي يلي المشرق وأحيانًا في الذي يلي المغرب وكذلك النقطة الخريفية التي كعقدة الذنب.

L15r |15:13| وعلى هذا النحو بعينه يمكننا أن نتوهّم كلّ واحدة من الحالات في الفلك المائل الذي يحيط بالأرض كالفلك القمري إذا جعلنا الأمر فيه مثل الذي ذكرنا آنفًا. ومثل هذا يعرض في الأفلاك التي هي خارجة عن الأرض مثل الذي يعرض لميل أفلاك التداوير.

1 الاختلافات] الاختلاف L   اثنان] اثنين Lm   اللذين] اللتان B   ذكرنا] ذكرناهما B   **2** وأمر] فأمر B   **4** وبذلك] بهذا L   تتحرّك] يتحرّك L   **5** التي] add L التي   **6** النهار] النها L   **7** فإنّا] فاما B   **8** والتي] إلى B التي L   منها] منه L   **9/17** لا...بعينه] om L   **17** يمكننا] يمكنا L   **19** يعرض[2]] عرض L kinds, and three is the highest number of visible anomalies. Two of these have been mentioned [before], whereas the third is due to the circles that revolve around the Earth and that are inclined to the epicycle. The situation of these circles is similar to that of the other circles of inclination in all of their conditions. |15:9| One [can] imagine a difference between them [i.e. these circles and the other circles of inclination] because they do not comprise the Earth, but rather the Earth lies outside them, and it is for this reason that one comes to believe that the inclined circles move and are carried in two opposite directions and that also the motion of these circles is parallel to the planes whose inclination against them [i.e. these circles] is a fixed inclination, just like the condition of the ecliptic with the plane of the equator.

|15:10| If we imagine that the section of the meridian above the Earth belongs to what follows the apogee and [the section] of the meridian below the Earth belongs to what follows the perigee, and that the distance of the horizon from each of the two directions is the mean distance, and that the inclination of the ecliptic is one and the same and does not change, then the motion of this circle [i.e. the abovementioned circle] inclined to the equator is around its poles. |15:11| Thus, the northern limit of this circle, namely the summer point [i.e. solstice], is sometimes on the section which follows the apogee and sometimes on that which follows the perigee, sometimes in the distance from the east and sometimes from the west, and the same also [applies to] the southern limit, namely the winter point. |15:12| Furthermore, then, the vernal [equinoctial] point, which is like the ascending node, is sometimes on the section which belongs to what follows the apogee and sometimes on that which belongs to what follows the perigee, sometimes in the distance to the east and sometimes to the west, and the same also [applies to] the autumnal [equinoctial] point, which is like the descending node.

|15:13| In the very same way, it is possible for us to imagine each of the conditions in the inclined circle which encompasses the Earth, such as the circle of the Moon, once we have dealt with its matter, similar to what we have said above. Similarly, it occurs for the circles that lie outside of the Earth, similar to what occurs for the inclination of the epicycles.

|15:14| وإنّا لا نحتاج إذا نحن أردنا أن ننتقل من الوجه الأوّل إلى الوجه الثاني الذي بعده أن نغيّر شيئًا أكثر من أن نجعل مكان معدّل النهار فلك البروج ومكان الفلك الذي يتحرّك عليه الفلك المائل عن معدّل النهار وهو فلك البروج الفلك الذي يتحرّك عليه فلك البروج ومكان فلك البروج نفسه الفلك المائل نفسه. |15:15| وأمّا في الوجه الثالث من وجوه الميل وهو الذي يكون خارجًا عن الأرض فإنّ معدّل النهار يصير نظيرًا لفلك التدوير الثابت والذي يغيّر الميل عن معدّل النهار نظيرًا للذي يغيّر الميل عن فلك التدوير وفلك البروج نفسه نظيرًا للفلك الصغير المائل نفسه. |15:16| وإنّما يختلف تغيّر الميل فيها هذا الاختلاف الذي أقول فقط وهو أنّا نرى الأفلاك التي تحيط بالأرض تعود مع عودات بعض ما يتحرّك عليها من شمس أو مركز فلك تدوير أو قمر أو كوكب. |15:17| وأمّا التي هي أفلاك تداويرها فإنّها تعود مع عودات مراكز أفلاك التداوير لا مع عودة ما يتحرّك عليها.

|15:18| فهذه حال كل واحدة من الأكر.

|16:1| وأمّا ترتيب وضع بعضها عند بعض فإنّ فيه بعض الشكّ إلى هذه الغاية. |16:2| L15v وأمّا أنّ كرة القمر هي أقرب الأكر إلى الأرض وأنّ كرة عطارد هي أقرب الى الأرض من كرة الزهرة وأنّ كرة الزهرة هي أقرب إلى الأرض من كرة المرّيخ وكرة المرّيخ من كرة B89r المشتري وكرة المشتري من كرة زحل وكرة زحل من كرة الكواكب الثابتة فإنّه يظهر ويتبيّن لنا بما يُرى من سير الكواكب التي أكرها أقرب إلى الأرض للكواكب التي أكرها أبعد من الأرض إذا كانت على خطّ مستقيم يخرج من البصر. |16:3| فأمّا أنّ أكر الخمسة الكواكب المتحيّرة أرفع من كرة الشمس كما أنّها أرفع من كرة القمر أو أنّها أخفض منها أو أنّ بعضها أرفع وبعضها أخفض فليس يمكننا أن نقول ذلك عن يقين.

2 أن^1] وأن L **6** للذي] لذي B **7** للفلك] لفلك BLm **8** أنّا] add لا L **10** تداويرها] تداوير Lm تعود] يعود L **13** وأمّا] فأمّا B وضع] om L **14** وأمّا] om B **15** هي] om L **17** لنا] om B بما] ممّا B يُرى] نرى L سير] ستر m للكواكب] الكواكب B **19** أو] و B **20** أخفض] أخفظ B نقول] add في B يمكننا] يمكنا L ذلك] add شيئًا m

|15:14| If we want to move on from the first to the second kind [of inclination], which comes after it, then we do not need to change more things than to make the place of the equator the [place of the] ecliptic, and the place of the circle about which the circle inclined to the equator moves, namely the ecliptic, the [place of the] circle about which the ecliptic moves, and the place of the ecliptic itself the [place of the] inclined circle itself. |15:15| With respect to the third kind of inclination, namely that outside the Earth, the equator becomes similar to the fixed epicycle, and that which changes the inclination against the ecliptic [becomes] similar to that which changes the inclination against the epicycle, and the ecliptic itself [becomes] similar to the small inclined circle itself. |15:16| However, the change of the inclination in [these circles] differs only in this way that I describe, namely that we see the circles that encompass the Earth returning with the returns of some of [the celestial bodies] which move about them, [namely with the returns] of the Sun or the centre of an epicycle or the Moon or [another] planet. |15:17| As for those that are epicycles, they return with the returns of the centres of the epicycles, but not with the return of what moves about them.[37]

|15:18| This is the condition of each of the spheres.

|16:1| As for the order of the position[s of the spheres] in relation to each other, there has been some doubt about it up to now. |16:2| As for the fact that the sphere of the Moon is the one closest to the Earth, that the sphere of Mercury is closer to the Earth than the sphere of Venus, that the sphere of Venus is closer to the Earth than the sphere of Mars, that the sphere of Mars [is closer to the Earth] than the sphere of Jupiter, that the sphere of Jupiter [is closer to the Earth] than the sphere of Saturn, and that the sphere of Saturn [is closer to the Earth] than the sphere of the fixed stars, this is apparent and clear to us by what is seen of the course of the planets whose spheres are closer to the Earth, against the planets whose spheres are further away from the Earth, if they are along a straight line extending from the [point of] vision. |16:3| As for whether the spheres of the five wandering stars are in a higher [position] than the sphere of the Sun as they are in a higher [position] than the sphere of the Moon, whether they are in a lower [position] than [the Sun], or whether some of them are in a higher and others in a lower [position], we cannot say this with certainty.

[37] On this last sentence, see Hamm, *Ptolemy's Planetary Theory*, pp. 187–88.

|16:4| وذلك أنّ معرفة أبعاد الكواكب الخمسة المتحيّرة ليست في السهولة على مثل ما عليه معرفة أبعاد النيّرين لأنّ النيّرين يدلّ على أبعادهما أكثر الدلالة الاتّصالات الكسوفية. |16:5| فأمّا الكواكب الخمسة فليس يدلّ عليها ذلك ولا يعرض لها عرض آخر يستوجب أن يوثق به في الدلالة على اختلاف المنظر المظنون بها. ولم نر شيئًا منها ستر الشمس عنّا إلى وقتنا هذا. وقد يمكن الإنسان لهذا السبب أن يتوهّم أنّ أكر الخمسة الكواكب أرفع من كرة الشمس. |16:6| فأمّا من كان غرضه وشهوته معرفة الحقّ فإنّ ذلك L16r لا يتبيّن له ممّا قلنا. |16:7| أمّا أوّلاً فلأنّ ما كان في مثل هذا القدر من الصغر إذا ستر ما له هذا القدر من الكبر والضوء لزم ألّا يكون محسوسًا لقلّة ما يستر ولحال الأجزاء التي تبقى مكشوفة من جرم الشمس. فإنّ القمر إذا ستر بعض الشمس بجزء منه مساويًا لقطر جرم كوكب من الكواكب أو أعظم من مقدار قطره فإنّ ستره ما يستر منها غير محسوس. |16:8| وأيضًا فإنّه من الضرورة ألّا يعرض مثل هذا العرض إلّا في الدهر الطويل وذلك أنّ أوجات أفلاك التداوير وبعدها الأقرب وهي التي إذا صارت الكواكب فيها قارنت الشمس إنّما تصير في سطح فلك البروج مرّتين فقط في كل دورة يدورها فلك التدوير وذلك عند تحوّله من ناحية الشمال إلى ناحية الجنوب ومن ناحية الجنوب إلى ناحية الشمال. |16:9| وإذا كان لا بدّ مع ذلك من أن تكون مراكز أفلاك التداوير في مواضع العقد وأن تكون الكواكب في العقد أيضًا وأن تصير الكواكب إلى تلك العقد في الأوج أو في البعد الأقرب فإنّه يعرض من هذا أن يخفي ذلك أيضًا على الذين يستقصون أمر الأرصاد ويتفقّدونها تفقّدًا شديدًا لحال مقدار الزمان الذي ينبغي أن تتمّ فيه عودات هذين جميعًا أعني عودة فلك التدوير وعودة الكوكب ولو اتّفقت الاقترانات أن تكون فوق الأرض. |16:10| أمّا بهذا الضرب من التبيين فليس يقدر أحد أن يحكم حكمًا يقينًا لا في هذين الكوكبين ولا في الكواكب المتّفق على أنّها فوق كرة الشمس أعني المرّيخ والمشتري وزحل.

2 يدلّ] تدل m **4** المظنون] المنظور B شيئًا] شيء L **5** لهذا] بهذا B **7** أمّا] mg B **8** القدر] المقدار L والضوء] ومن الضوء B لزم] اللازم B ألّا] أن لا L الأجزاء] الأخر L **9** مساويًا] مساو B **11** الضرورة] العرورة L ألّا] أن لا L **11/12** وذلك...الأقرب] om L **13** إنّما] فإنّما B **15** وإذا] فإذا B تكون] يكون B التداوير] التدوير L **16** تكون] يكون B العقد[1]] العقدة B وأن] فان Bm الكواكب[2]] الكوكب B أو...البعد] والبعد L **18** تتمّ] يتمّ L **19** الكوكب] الكواكب B ولو] فلو B **20** أحد] أحدًا B

|16:4| For the knowledge of the distances of the five wandering stars is not as easy as it is for the case of the knowledge of the distances of the two luminaries [i.e. the Sun and the Moon], because the conjunctions [producing] eclipses indicate the distances of the two [luminaries] most clearly. |16:5| As for the five planets, there is no such indication, nor does there occur for them anything else that deserves to being trusted, [as] in the case of a parallax, which is supposed of them. Nor we have seen any part of [the five planets] to cover the Sun to this date. For this reason, it is possible for a human to imagine that the spheres of the five planets are higher than the sphere of the Sun. |16:6| [But] for someone who seeks and strives for knowledge of the truth, this is not evident from what has been said. |16:7| Firstly, for if what is of such a small size covers that which has this degree of large size and light, then it follows that it is not perceptible because of the smallness of the covering [body] and because of the condition of the parts of the body of the Sun that remain uncovered. Thus, when the Moon covers a part of the Sun by a part of itself which is equal to the diameter of the body of one of the planets or larger than its diameter, then its covering, namely by that [part of the Moon] which covers something of [the Sun], is not perceptible. |16:8| Another [reason] is that a phenomenon like this necessarily only occurs after a long time, for the apogees and perigees of the epicycles which join the Sun when the planets move in them are only two times in the plane of the ecliptic during each revolution that an epicycle makes, and this is at its transition from north to south and from south to north. |16:9| When despite that, it is necessary that the centres of the epicycles are in the positions of the nodes, that the planets are in the nodes as well, and that the planets move to the nodes in the apogee or the perigee, then from this, it occurs that this is also hidden from those who conduct observations and they mostly miss [these observations] because of the condition of the amount of time in which the returns of each of these two have to come to an end (I mean the return of the epicycle and of the planet) if there happen to be conjunctions above the Earth. |16:10| By this kind of demonstration, one is not able to judge with certainty neither about these two planets [namely Mercury and Venus] nor about the planets on which it is agreed that they are above the sphere of the Sun (I mean, Mars, Jupiter, and Saturn).

L16v |17:1| فأمّا إن جعلنا فحصنا عن ذلك من نسب كلّ واحد من الأبعاد الصغار إلى كلّ واحد من الأبعاد الكبار وممّا يتهيّأ ويستقيم في ترتيب الأكر وممّا لا يتهيّأ فيها B89v وجمعنا في كلّ واحد منها بين أبعد مواضع الكرة القريبة من الأرض وبين أقرب مواضع الكرة التي هي أبعد فإنّا نعلم أنّ كرة عطارد وكرة الزهرة فقط تستقيم أن تكون تحت كرة الشمس وأنّ ما سواهما ليس يمكن أن يكون كذلك. |17:2| فإنّا قد بيّنّا في كتاب السنطكسيس أنّ بعد القمر الأصغر يكون ثلاثة وثلاثين بالمقدار الذي يكون به نصف قطر الأرض واحدًا وأنّ بعده الأعظم يكون بهذا المقدار أربعة وستّين. وذلك إذا نحن جبرنا الكسور وألقيناها وأخذنا ما يقرب من الأعداد التامّة. وأيضًا فإنّ بعد الشمس الأصغر بهذا المقدار ألف ومائة وستّون وبعدها الأكبر ألف ومائتان وستّون. |17:3| ونسبة بعد عطارد الأصغر إلى بعده الأكبر كنسبة الأربعة والثلاثين إلى الثمانية والثمانين بالتقريب وهو بيّن أنّه إن جمع ما بين بعد القمر الأعظم وبعد عطارد الأصغر صار بعد عطارد الأكبر مائة وستّة وستّين بالمقدار الذي يكون به الأصغر أربعة وستّين. |17:4| وأيضًا فإنّ نسبة بعد الزهرة الأصغر إلى بعدها الأكبر كنسبة الستّة عشر إلى المائة والأربعة بالتقريب فهو بيّن أنّه إن جمع ما بين بعد عطارد الأكبر وبعد الزهرة الأصغر صار L17r بعد الزهرة الأكبر ألفًا وتسعة وسبعين بالمقدار الذي يكون به البعد الأصغر مائة وستّة وستّين. |17:5| فإذا كان بعد الشمس الأصغر هو في هذه الألف والمائة والستّين التي ذكرنا وكان هذا المقدار الذي بين هذين البعدين قد يخفى مثله ويذهب علينا في نفس ما وضعنا من البعد فإنّ هاتين الكرتين اللتين ذكرنا لمّا كانتا أقرب إلى الأرض من غيرهما استقام أن تقعا فيما بين كرة القمر وكرة الشمس. |17:6| فأمّا الأكر الباقية فليس يستقيم ذلك فيها وذلك أنّه لا يمكن أن يقع فيما بين بعد الزهرة الأعظم وبعد الشمس الأصغر كرة المرّيخ التي هي أقرب الأكر الباقية إلى الأرض إذ كانت نسبة بعده الأعظم إلى بعده الأصغر نسبة السبعة الأضعاف بالتقريب.

1 فأمّا] وأمّا m **2** وممّا¹] وما L وممّا²] وما L في ترتيب] بترتيب B **5** وأنّ ما] وأمّا B سواهما] سواها L ليس] فليس B يمكن] يستقيم B **6** فإنّا] فلأنّا B السنطكسيس] السيطكسيس BL **7** واحدًا] واحدة L يكون] om L وستّين] وستّون L إذا] لأنّا Lm **9** ألف²] مرّة add B وثلاثين] om L **11** إن] om L القمر…بعد²] om L **13** المائة] مائة B **14** والأربعة] وأربعة B إن] ألف add B **15** ألفًا] ألف L يكون به] به يكون B **16** هو في] هي B والستّين] والستّون BL **18** ما] إذا B وضعنا] وصفنا m كانتا] كانت L **19** تقعا] يقعا BL om B

|17:1| If we make our inquiry about this from the ratios of each of the small[est] distances to each of the great[est] distances and from what is arranged and correct with respect to the order of the spheres and from what is not arranged with respect to them, and if we put together for each of them [the space] between the furthest position of the sphere close to the Earth and between the nearest position of the sphere that is further away, then we know that it is only correct [for] the spheres of Mercury and Venus to be below the sphere of the Sun and that this cannot apply for [spheres] other than these two. |17:2| In the *Almagest*, we have shown that the smallest distance of the Moon is 33 according to the measure by which the radius of the Earth is one, and that its greatest distance is 64 according to this measure.[38] This is the case when we restore and drop the fractions and take what is close to the complete numbers. Furthermore, the smallest distance of the Sun is 1160 [Earth radii] and its greatest distance is 1 260 [Earth radii].[39] |17:3| The ratio of the smallest distance of Mercury to its greatest distance is approximately like the ratio of 34 to 88, and it is clear that if one puts together [the space] between the greatest distance of the Moon and the smallest distance of Mercury, the greatest distance of Mercury becomes 166 [Earth radii] according to the measure by which the smallest distance is 64 [Earth radii]. |17:4| Furthermore, the ratio of the smallest distance of Venus to its greatest distance is approximately like the ratio of 16 to 104, so that it is clear that if one puts together [the space] between the greatest distance of Mercury and the smallest distance of Venus, the greatest distance of Venus becomes 1079 [Earth radii] according to the measure by which the smallest distance is 166 [Earth radii].[40] |17:5| When the smallest distance of the Sun is 1160 [Earth radii], as we mentioned, and when such an amount like it between these two distances is possibly hidden from us and escapes us in the essence of our hypothesis of the distance, then since these two aforementioned spheres are closer to the Earth than the others, it is correct that they lie in [the space] between the sphere of the Moon and the sphere of the Sun. |17:6| As for the remaining spheres, this is not correct, for it is not possible that in [the space] between the greatest distance of Venus and the smallest distance of the Sun, there lies the sphere of Mars, which is of the remaining spheres the one closest to the Earth, since the ratio of its greatest to its smallest distance is approximately seven to one.

[38] In the following, I simply use the term 'Earth radii'.

[39] For the distances of the Moon and the Sun, see Ptolemy, *Syntaxis*, V.11–15.

[40] Up to this point, the calculation is cited literally in Proclus' commentary on Plato's *Timaeus*. See Proclus, *In Tim.*, Vol. 3, pp. 62:24–63:11.

|17:7| وعلى جهة أخرى أيضًا إذ كان يعرض في الجملة أن يكون كلّما زدنا في بعد القمر أن ننقص بعد الشمس وبالعكس أيضًا فإنّا إن زدنا في بعد القمر الذي ذكرنا ولو زيادة يسيرة نقص بعد الشمس الذي يلي بعد الزهرة الأعظم ويتّصل به.

|17:8| فالقول الذي يجب به أن تكون مراتب أكر الكواكب على ما ذكرنا ليس إنّما هو من قبل نسب أبعادها فقط ولكن من قبل اختلاف حركاتها أيضًا. |17:9| فإنّ الأشبه والأولى أن يكون ما كان منها بعيدًا من حال الشمس التي هي في الوسط من جميع الجهات أبعد من الشمس ممّا ليس له بعد من جميع الجهات ولا بعد كثير من حال
L17v الشمس. |17:10| ومن الأولى أيضًا أن تكون كرة عطارد متّصلة بكرة القمر إذ كان يعرض
B90r لفلكي عطارد والقمر الخارجي المركزين فقط أن يتحرك مركزاهما على مثل حركة العالم
وذلك بخلاف حركة فلكي تدويرهما ويلزم أن يصير مركزا فلكي تدويرهما في الأوج وفي البعد الأقرب في كلّ دورة مرّتين. |17:11| فتكون الأكر القريبة من الهواء متحرّكة حركات كثيرة الأنواع وتشاكل في ذلك طبيعة العنصر المتّصل بها. فإنّ الكرة القريبة جدًّا من حركة الكلّ وهي كرة جميع الكواكب الثابتة تتحرّك حركة بسيطة مشاكلة لحركة الشيء المثبوت حولها وتدوم على ذلك أبدًا.

|17:12| فأمّا كمّ أبعاد الكواكب الثلاثة الباقية على هذا الضرب الذي ذكرنا من اتّصال أكرها بعضها ببعض ومن قياس نسب أبعادها البعيدة والقريبة من الأرض بعضها إلى بعض فليس يعتاص علينا أن نتمّمه على مثل هذه السبيل التي سلكنا. |17:13| أمّا على حسب النسبة التي جعلنا لبعدي المرّيخ أحدهما إلى الآخر وهي السبعة الأضعاف إذا جمعنا بين بعده الأصغر وبعد الشمس الأعظم فإنّا نجد بعده الأعظم بعينه ثمانية آلاف وثمانمائة وعشرين بالمقدار الذي يكون به البعد الأصغر ألفًا ومائتين وستّين. |17:14|

1 وعلى…إذ] وعلى وجه آخر إذا B   **2** إن] إذا B   **3** الشمس] القمر B   **4** تكون] يكون B   **5** ولكن من] لكن ومن BL   أيضًا] om L   **8** تكون] يكون B   **9** مركزاهما] مراكزهما B   **10** تدويرهما[1]] تدورهما L   تدويرهما[2]] add فيلزم أن يصير مراكز فلكي تدويرهما L   مركزا] مراكز L   ويلزم] فيلزم L   **11** كلّ دورة] add الدورة B   **14** حولها] add من النفس B   **15** الثلاثة] الثابتة B   **16** ببعض] من بعض B   ومن] add قبل Lm   نسب] ونسب L   بعضها[2]] وبعضها B   **17** فليس] add فليس B   يعتاص] يعتاض B   **19** بعينه] om B   آلاف] ألف BL   **20** ألفًا] ألف L

|17:7| Furthermore, on a different note: since it occurred in general that whenever we increase the distance of the Moon, we [need to] decrease the distance of the Sun, and also vice versa, one would [need to] decrease the distance of the Sun, which is close to and contiguous with the greatest distance of Venus, if we increased the aforementioned distance of the Moon, even if the increase is small.

|17:8| Then, the account by which the order of the spheres of the planets is necessarily such as described is not only from the ratios of their distances but also from the anomaly of their motions. |17:9| It is most likely and most plausible that [the planets] that are far away from the condition of the Sun, which is in the centre from every direction, are further away from the Sun than [the planets] that have no distance from every direction and no great distance from the condition of the Sun. |17:10| Also, it is most plausible that the sphere of Mercury is contiguous with the sphere of the Moon, since it occurred only for the two eccentric circles of Mercury and the Moon that their two centres move in a way that is similar to the motion of the world, namely contrary to the motion of their two epicycles, whereas it is necessary that the two centres of their two epicycles are at the apogee and the perigee twice in every revolution. |17:11| Thus, the spheres closer to the air move by various kinds of motions and thereby resemble the nature of the element that is contiguous with them. The sphere very close to the motion of the universe, namely the sphere of all the fixed stars, moves with a simple motion that resembles the motion of the fixed thing around it [i.e. the sphere] and always endures in this [state].

|17:12| As for the quantity of the distances of the three remaining planets according to the aforementioned method from [the fact that] their spheres are contiguous with each other and from the reasoning of the ratios of their distances, far away from and close to the Earth, in relation to each other, it is not difficult for us to complete it [i.e. the quantity of the distances] following a way similar to this one that we [already] followed. |17:13| On account of the ratio that we established for the two distances of Mars of one in relation to the other, which is seven times as much, we find its greatest distance exactly to be 8 820 [Earth radii] according to the measure by which the smallest distance is 1 260 [Earth radii], if we put together [the space] between its smallest distance and the greatest

ولأنّ بعد المشتري الأصغر جعلت نسبته إلى بعده الأعظم كنسبة الثلاثة والعشرين إلى L18r السبعة والثلاثين فإنّا إذا جمعنا أيضًا بين بعده الأصغر وبعد المرّيخ الأعظم صار بعد المشتري الأعظم أربعة عشر ألفًا ومائة وسبعة وثمانين بالمقدار الذي يكون به بعده الأصغر ثمانية آلاف وثمانمائة وعشرين. |17:15| وكذلك أيضًا إذ كانت قد جعلت نسبة بعد زحل الأصغر إلى بعده الأعظم كنسبة الخمسة إلى السبعة فإنّا إذا جمعنا بين بعده الأصغر وبعد المشتري الأعظم صار بعد زحل الأعظم الذي هو متّصل بكرة الكواكب الثابتة تسعة عشر ألفًا وثمانمائة وخمسة وستّين بالمقدار الذي يكون به البعد الأصغر أربعة عشر ألفًا ومائة وسبعة وثمانين.

|17:16| وفي جملة القول إنّه إذا كان نصف قطر البسيط الكري الذي يحيط بالأرض والماء واحدًا كان نصف قطر البسيط الكري الذي يحيط بالهواء والنار بهذا المقدار ثلاثة وثلاثين ونصف قطر البسيط الذي يحيط بكرة القمر أربعة وستّين ونصف قطر البسيط الذي يحيط بكرة عطارد مائة وستّة وستّين ونصف قطر البسيط الذي يحيط بكرة الزهرة ألفًا وتسعة وسبعين ونصف قطر البسيط الذي يحيط بكرة الشمس ألفًا ومائتين وستّين ونصف قطر البسيط الذي يحيط بكرة المرّيخ ثمانية آلاف وثمانماية وعشرين ونصف B90v قطر البسيط الذي يحيط بكرة المشتري أربعة عشر ألفًا ومائة وسبعة وثمانين ونصف قطر البسيط الذي يحيط بكرة زحل تسعة عشر ألفًا وثمانمائة وخمسة وستّين.

L18v |18:1| ولكنّ نصف قطر البسيط الكري الذي يحيط بالأرض والماء يكون رِبوتَين من الأسطاذي ونصفًا وثلثًا وجزءًا من ثلاثين من ربوة أسطاذيا لأنّا نجد الدور ثماني عشرة ربوة أسطاذيا. فيكون بعد الحدّ الذي يفصل ما بين كرة النار وكرة القمر أربعة وتسعين ربوة من أسطاذيا ونصف وعشر ربوة أسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة القمر وكرة عطارد مائة وثلاث وثمانين ربوة وثلثًا وعشرًا وجزءًا من ثلاثين من ربوة أسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة عطارد وكرة الزهرة أربعمائة وخمس وسبعين ربوة ونصفًا وثلثًا

2 فإنّا] وإنّا B   بين] sl B   **3** يكون به] به يكون B   **4** آلاف] ألف L   وكذلك] وكذ L   إذ] إذا B
7 يكون به] به يكون B   **9** وفي] في B   **11** وثلاثين] وستّين B   **13** ألفًا[1]] ألف L   بكرة] add الزهرة L
ألفًا[2]] ألف L   **14** آلاف] ألف L   وعشرين] وعشرون B   **15** ألفًا] ألف B   **16** البسيط] om L
17 الكري] om B   **18** الأسطاذي] الأسطاذيا B   ونصفًا…وجزءًا] ونصف وثلث وجزء BL
19 وتسعين] سبعين B   **21** وثلاث] وثلاثًا B   وثمانين] وثلاثين B   وثلثًا…وجزءًا] وثلث وعشرة جزء L
22 وسبعين] وسبعون B   **22/56,1** ونصفًا…وجزءًا] ونصف وثلث وجزء L   وثلثًا وعشر وجزء B

distance of the Sun. |17:14| Because the ratio of the smallest distance of Jupiter to its greatest distance was made to be like the ratio of 23 to 37, the greatest distance of Jupiter becomes 14 187[41] [Earth radii] according to the measure by which its smallest distance is 8 820 [Earth radii] if we also put together [the space] between its smallest distance and the greatest distance of Mars. |17:15| Likewise, since the ratio of the smallest distance of Saturn to its greatest distance was made to be like the ratio of 5 to 7, the greatest distance of Saturn, which is contiguous with the sphere of the fixed stars, becomes 19 865 [Earth radii] according to the measure by which the smallest distance is 14 187 if we put together [the space] between its smallest distance and the greatest distance of Jupiter.

|17:16| In summary, the account is [as follows]: If the radius of the spherical surface encompassing earth and water is one, then the radius of the spherical surface encompassing air and fire is 33 according to this measure; the radius of the surface encompassing the sphere of the Moon is 64 [Earth radii]; the radius of the surface encompassing the sphere of Mercury is 166 [Earth radii]; the radius of the surface encompassing the sphere of Venus is 1 079; the radius of the surface encompassing the sphere of the Sun is 1 260 [Earth radii]; the radius of the surface encompassing the sphere of Mars is 8 820 [Earth radii]; the radius of the surface encompassing the sphere of Jupiter is 14 187 [Earth radii]; the radius of the surface encompassing the sphere of Saturn is 19 865 [Earth radii].

|18:1| However, the radius of the spherical surface encompassing earth and water is 2 myriad stades and ½ and ⅓ and 1/30 of a myriad stade, because we find the revolution [i.e. the circumference] [to be] 18 myriad stades. The distance of the border that separates the sphere of fire and that of the Moon is 94 myriad stades and ½ and 1/10 myriad stade. The distance of the border that separates the sphere of the Moon and that of Mercury is 183 myriad stades and ⅓ and 1/10 and 1/30 myriad stades. The distance of the border that separates the sphere of Mercury and

[41] According to Swerdlow, *Ptolemy's Theory*, p. 125, the correct value should be 14 189. See the commentary to Chapters I.16–19, p. 364 n. 49.

وجزءًا من ثلاثين من ربوة أسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة الزهرة وكرة الشمس ثلاثة آلاف وثلاث وتسعين ربوة وعشر ربوة وجزءًا من ثلاثين من ربوة أسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة الشمس وكرة المرّيج ثلاثة آلاف وستّمائة واثنتي عشر ربوة. وبعد الحدّ الذي يفصل ما بين كرة المرّيخ وكرة المشتري ربوتي ربوة وخمسة آلاف ربوة ومائتي وأربع وثمانين ربوة من الأسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة المشتري وكرة زحل أربع ربوات الربوات وأربعة آلاف ربوة وسبعمائة وتسعة وستّين وثلثًا وجزءًا من ثلاثين من ربوة أسطاذيا. وبعد الحدّ الذي يفصل ما بين كرة زحل وكرة L19r الكواكب الثابتة خمس ربوات الربوات وستّة آلاف وتسعمائة وستّ وأربعين ربوة وثلث أسطاذيا.

|18:2| فإن كان الأمر على ما قلنا من أنّه ليس فيما بين الأبعاد الكبار والصغار والبسيطات التي تفصل الأكر بعضها من بعض اختلاف أو فضاء له قدر وهذا هو أشبه الأمور لأنّه لا يجوز أن يكون في طبائع الأشياء خلل كثير وشيء لا يستعمل ولا معنى له فإنّ أبعاد الأكر هي التي ذكرنا وهي تليق بما برهناه فيما سلف. فأمّا إن كان فيما بينها بعد أو فضاء فإنّه بيّن أنّ الأبعاد التي ذكرنا على كلّ حال ليست بأقلّ ممّا قلنا.

|19:1| وقد يمكن أن تقاس أقطار أجرام الكواكب بعضها إلى بعض قياسًا عامًّا لما يرى ويظهر من رؤية أقطارها ولحالها في أنفسها ومساحة أجرامها التي تعلم من الأبعاد التي ذكرنا إذا سلك الإنسان هذه السبيل التي أصف.

|19:2| قال إبرخس إنّ قطر الشمس في الرؤية يعدّه قطر أصغر الكواكب ثلاثين مرّة ويعدّه قطر أعظم الكواكب في الرؤية وهو كوكب الزهرة عشر مرّات بالتقريب. فإنّ أقطار

1 ثلاثين] وجزء ومن ثلاثين add L **2** آلاف] ألف BL وثلاث] وثلاثة BL **3** آلاف] ألف L عشر]
عشرة L **4** ما بين] فيما L وخمسة] وخمس B آلاف] ألف L **5** وأربع] وأربعة L sl B **6** آلاف]
ألف L وستّين...وسبعمائة] وتسعين وتسعًا وتسعمائة B **6/7** وثلثًا وجزءًا] وثلث وجزء L **8** آلاف]
ألف L وستّ] وستّة L وستًّا B ربوة] om B وثلث] ربوة add m **10** الأمر] om L **12** طبائع]
طباع B معنى له] له معنى L **13** سلف] سبق m **14** بعد] بعدًا L بيّن أنّ] بعض B **15** تقاس]
يقاس B **19** عشر] عشرة B

that of Venus is 475 myriad stades and ½ and ⅓ and 1/30 myriad stades. The distance of the border that separates the sphere of Venus and that of the Sun is 3 093 myriads and 1/10 and 1/30 myriad stades. The distance of the border that separates the sphere of the Sun and that of Mars is 3 612 myriad [stades]. The distance of the border that separates the sphere of Mars and that of Jupiter is 2 myriad myriads and 5 284 myriad stades. The distance of the border that separates the sphere of Jupiter and that of Saturn is 4 myriad myriads and 4 769 myriads and ⅓ and 1/30 myriad stades. The distance of the border that separates the sphere of Saturn and that of the fixed stars is 5 myriad myriads and 6 946 and ⅓ myriad stades.

|18:2| If the situation is as we have said, namely that between the great[est] and small[est] distances and the surfaces that separate the spheres from each other, there is no difference or empty space that would have a magnitude – this being the most likely situation since it is not possible that in the nature of the things there is a large interstice and something not used and without a meaning – then the distances of the spheres are as we described and are proper for what we have proven before. But if there is between them a distance or empty space, then it is clear that the distances that we have mentioned for every condition cannot be smaller than we said.

|19:1| It is possible to compare the diameters of the bodies of the planets to each other in a general way due to what is seen and what is apparent from the observation of their diameters and due to their respective condition and the extent of their bodies, which are grasped from the aforementioned distances, if one follows this method that I describe [now].

|19:2| Hipparchus said that one counts the apparent diameter of the Sun approximately 30 times the [apparent] diameter of the smallest planet and 10 times the apparent diameter of the greatest planet, which is Venus. The apparent diameters do not depart from the vision of their true diameters by something per-

ما يرى منها ليست تغادر رؤية أقطارها الحقيقية بشيء محسوس. |19:3| وبهذا القول الذي قاله إبرخس عمل عظم أجرام الكواكب التي لا يمكن أن تكون أقلّ منه واستعمل B91r مع ذلك بعدًا عامًّا تكون نسبة الأرض إليه منزلة النقطة. وأمّا إبرخس فلم يبيّن على أيّ L19v بعد من أبعاد كوكب الزهرة يكون مقدارها هذا المقدار الذي ذكرنا. وأمّا نحن فإنّا جعلنا ذلك في البعد الأوسط من جميع الأبعاد حيث نرصد كثيرًا أقطارها التي نرى ونقيسها لأنّا لو جعلنا أقدارها المأخوذة وهي في الأوج أو في بعدها الأقرب لما كان غير مشكوك فيه لمكان شعاع الشمس وضوئها. |19:4| فنحن نجد أكثر ذلك قطر كوكب الزهرة يأخذ من قطر الشمس مقدار العشر كما قال إبرخس ونجد قطر كوكب المشتري يأخذ من قطر الشمس نصف سدسه وأمّا كوكب عطارد فجزء من خمسة عشر جزءًا من قطر الشمس وأمّا قطر زحل فجزء من ثمانية عشر من قطر الشمس وأمّا قطر المرّيخ وأقطار الكواكب الثابتة التي في العظم الأوّل فجزء من عشرين جزءًا من قطر الشمس وأمّا قطر القمر إذا كان في بعده الأوسط من فلكه مع بعده الأوسط الآخر الذي في الفلك الخارج المركز فإنّه يكون مثل قطر الشمس نحوًا من مرّة وثلث.

|19:5| ولكن لو كانت الأقطار كلّها توتر أبدًا زاوية واحدة فيما يظهر للرؤية إذا كانت في أبعادها الوسطى لكانت نسب أقطارها بعضها إلى بعض كنسب أبعادها الوسطى بعضها إلى بعض لأنّ نسب الخطوط المحيطة بالدوائر بعضها إلى بعض ونسب أنصاف أقطارها التي هي هذه الأبعاد كنسب قسيّها المتشابهة بعضها إلى بعض. |19:6| فبالمقدار الذي يكون به قطر الشمس ألفًا ومائتين وعشرة يكون قطر القمر ثمانية وأربعين L20r وقطر عطارد مائة وخمسة عشر وقطر الزهرة ستّمائة واثنين وعشرين ونصفًا وقطر المرّيخ خمسة آلاف وأربعين وقطر المشتري أحد عشر ألفًا وخمسمائة وأربعة وقطر زحل سبعة عشر ألفًا وستّة وعشرين وقطر الكواكب الثابتة التي في العظم الأوّل إن كانت مماسّة

1 ليست] ليس B   الحقيقية] الحقيقة L   **2** أجرام] om L   التي] الذي L   **3** وأمّا] أمّا B   **5** نرصد] يرصد L   كثيرًا] كثير B   التي] الذي L   ونقيسها] نقيسه L   **6** في[2]] om L   **9** فجزء] فجزءًا B   **10** فجزء] فجزءًا B   **11** الثابتة] om B   الأوّل] add أعني الثابتة B   جزءًا] om L   **12** الأوسط[2]] الوسطي L   **13** نحوًا من] † L   **14** توتر…فيما] † L   للرؤية] للزاوية L   **15** نسب أقطارها] † L   كنسب] كنسبة L   أبعادها[2]] أبعاد L   **16** لأنّ] لا B   ونسب] om BL add m   **16/17** أنصاف أقطارها] om L   **17** كنسب] كنسبة L   **18** به] له L   ألفًا] ألف L   **19** ونصفًا] ونصف L   **20** آلاف] ألف L   أحد] إحدى L ceptible. |19:3| On the basis of this statement, Hipparchus computed a size for the bodies of the planets, such that they cannot be smaller than [this size], and he used thereby a general distance to which the ratio of the Earth is [in the] rank of a point. As for Hipparchus, he does not show at which of the distances of Venus its amount is [equivalent to] this aforementioned amount. We made this with respect to the mean distance of all the distances, where we often observe its [apparent] diameters, which we see and measure, for if we take their diameters while they are at their apogee or perigee, then it would be doubtful because of the location of the rays of the Sun and its light. |19:4| Thus, we find for most cases that the diameter of Venus takes one-tenth of the diameter of the Sun, just like Hipparchus said, and we find that the diameter of Jupiter takes 1⁄12 of the diameter of the Sun; as for Mercury, it is 1⁄15 of the diameter of the Sun; as for the diameter of Saturn, it is 1⁄18 of the diameter of the Sun; as for the diameter of Mars and the diameters of the fixed stars that are of first magnitude,[42] it is 1⁄20 of the diameter of the Sun; as for the diameter of the Moon, it is 1 1⁄3 times the diameter of the Sun if it is at its mean distance of its circle together with its other mean distance which is in the eccentric circle.

|19:5| However, if all of the diameters always form one angle in what is apparent to sight when they are in their mean positions, then the ratios of their diameters to each other would be like the ratios of their mean distances to each other, because the ratios of the circumferences of the circles to each other and the ratios of the [various] kinds of their diameters, which are these distances, are like the ratios of their similar arcs to each other. |19:6| Thus, according to the measure by which the diameter of the Sun is 1 210, the diameter of the Moon is 48, the diameter of Mercury is 115, the diameter of Venus is 622 ½, the diameter of Mars is 5 040, the diameter of Jupiter is 11 504, the diameter of Saturn is 17 029, the diameter of the fixed stars that are of first magnitude is 19 865 or 20 000 in com-

[42] These are the brightest stars. The volumes of the stars of second to sixth magnitude are not calculated by Ptolemy.

لأبعد بعد زحل تسعة عشر ألفًا وثمانمائة وخمسة وستّين أو يكون عشرين ألفًا تامّةً. فأمّا إن لم تكن مماسّة فليس هذا القطر بأقلّ من عشرين ألفًا.

|19:7| ولكن لأنّ أقطارها لا توتر زوايا مساويةً للزاوية التي يوترها قطر الشمس لكنّ قطر القمر يوتر زاوية تكون مرّة وثلث مثلها وأقطار الكواكب توتر الأجزاء التي ذكرنا من هذه الزاوية وهو بيّن أنّ بالمقدار الذي يكون به قطر الشمس ألفًا ومائتين وعشرة يكون قطر القمر أربعة وستّين لأنّها مرّة وثلث مثل الثمانية والأربعين وقطر عطارد ثمانية لأنّها جزء من خمسة عشر من المائة والخمسة عشر بالتقريب وقطر الزهرة اثنين وستّين التي هي B91v عشر ستّمائة واثنين وعشرين ونصف بالتقريب وقطر المرّيخ مائتين واثنين وخمسين التي هي جزء من عشرين من خمسة آلاف وأربعين وقطر المشتري تسعمائة وتسعة وخمسين التي هي نصف سدس الأحد عشر ألفًا وخمسمائة وأربعة بالتقريب وقطر زحل تسعمائة L20v وستّة وأربعين التي هي جزء من ثمانية عشر من السبعة عشر ألفًا والستّة والعشرين بالتقريب وأقطار الكواكب الثابتة التي في العظم الأوّل إمّا أن تكون ألفًا التي هي جزء من عشرين من العشرين ألفًا وإمّا أن لا تكون أقلّ من الألف |19:8| وقد بيّنّا في كتاب السنطكسيس أنّ قطر الشمس يكون خمسة ونصفًا بالمقدار الذي يكون به قطر الأرض واحدًا وهذه الخمسة والنصف تكون من الألف والمائتين والعشرة جزءًا من مائتين وعشرين فإنّ نحن أخذنا من الأعداد التي وضعنا هذا المقدار وجدنا أنّ قطر الأرض إذا كان واحدًا كان قطر القمر ربع ذلك الواحد وجزءًا من أربعة وعشرين وقطر عطارد جزءًا من سبعة وعشرين جزءًا وقطر الزهرة ربعًا وجزءًا من عشرين وقطر الشمس خمسة ونصفًا وقطر المرّيخ واحدًا وسبعًا وقطر المشتري أربعة وثلثًا وجزءًا من أربعين وقطر زحل أربعة وربعًا وحزءًا من عشرين وأقطار الكواكب الثابتة التي في العظم الأوّل إمّا أن تكون أربعة ونصفًا وجزءًا من عشرين وإمّا ألّا تكون أقلّ من ذلك.

1 فأمّا] وأمّا B **3** لأنّ] om m زوايا] زاويًا L مساويةً] متساوية B للزاوية] للزوايا B يوترها] يديرها B توترها L **4** وأقطار] فأقطار B **5** الزاوية] الزوايا B أنّ] أنّه m قطر¹…يكون²] om L **8** مائتين] مائتي B التي] add B **9** خمسة] الخمسة L آلاف] الألف L وأربعين] والأربعين L وخمسين] وخمسون B **11** وأربعين] وأربعون B ألفًا] الألف L **13** ألفًا] الألف L تكون] يكون B وقد] فقد B بيّنّا] بيّناه B **14** السنطكسيس] السيطكسيس BL وقلنا add B ونصفًا] ونصف L **15** والنصف] ونصف L تكون] يكون B **17** وعشرين] سنة add L **18** ونصفًا] ونصف L **19** أربعة²] أربع L **21** ونصفًا] ونصف L وجزءًا] وجزء L plete [numbers], if they are in touch with the farthest distance of Saturn. If they are not in touch, then this diameter is not less than 20 000.

|19:7| But because their diameters do not form angles that are equal to the angle which the diameter of the Sun forms, whereas the diameter of the Moon forms an angle which is 1 ⅓ times than that of [the Sun] and the diameters of the planets form the aforementioned parts of this angle; and [because] it is clear that according to the measure by which the diameter of the Sun is 1 210, the diameter of the Moon is 64, since this is 1 ⅓ times 48; that the diameter of Mercury is 8, since it is approximately 1/15 of 115; that the diameter of Venus is 62, which is approximately 1/10 of 622 ½; that the diameter of Mars is 252, which is 1/20 of 5 040; that the diameter of Jupiter is 959, which is approximately 1/12 of 11 504; that the diameter of Saturn is 946, which is approximately 1/18 of 17 026; that the diameters of the fixed stars that are of first magnitude are either 1 000, which is 1/20 of 20 000 or are not smaller than 1 000; |19:8| and [because] we have shown in the *Almagest*[43] that the diameter of the Sun is 5 ½ according to the measure by which the diameter of the Earth is one, this 5 ½ being 1/220 of 1 210; and [because] we thus took of the numbers that we laid down this measure, we found that if the diameter of the Earth is one, the diameter of the Moon is ¼ of this one and 1/24, the diameter of Mercury is 1/27, the diameter of Venus is ¼ and 1/20, the diameter of the Sun is 5 ½, the diameter of Mars is 1 ⅐, the diameter of Jupiter is 4 ⅓ and 1/40, the diameter of Saturn is 4 ¼ and 1/20, and the diameters of the fixed stars that are of first magnitude are either 4 ½ and 1/20 or are not smaller than this.

[43] See Ptolemy, *Syntaxis,* V.16.

|19:9| وبالمقدار الذي يكون به عظم جرم الأرض واحدًا يكون به عظم جرم القمر جزءًا من أربعين وعظم جرم عطارد جزءًا من تسعة عشر ألفًا وستّمائة وثلاثة وثمانين جزءًا L21r وعظم جرم الزهرة حزءًا من أربعة وأربعين وعظم جرم الشمس مائة وستّة وستّين وثلثًا وعظم جرم المرّيخ واحدًا ونصف واحد وعظم جرم المشتري اثنين وثمانين ونصفًا وربعًا وجزءًا من عشرين وعظم جرم زحل تسعة وسبعين ونصفًا وعظم أجرام الكواكب الثابتة التي في العظم الأوّل إمّا أن يكون أربعة وتسعين وسدسًا وثمنًا وإمّا ألّا يكون أقلّ من ذلك. |19:10| فيكون جرم الشمس على حسب ما وصفنا أعظم من كلّ جرم في العالم. وبعده في العظم أجرام الكواكب الثابتة التي في العظم الأوّل وبعدها في مرتبة ثالثة جرم المشتري وفي مرتبة رابعة جرم زحل وفي مرتبة خامسة جرم المرّيخ وفي مرتبة سادسة جرم الأرض وفي مرتبة سابعة جرم الزهرة وفي مرتبة ثامنة جرم القمر وآخرها جرم عطارد.

|19:11| ونستثني هاهنا أيضًا فنقول إنّه إن كانت أبعادها كلّها على ما ذكرنا فإنّ عظم أجرامها أيضًا يكون على ما قلنا. وإن كانت أبعادها أعظم ممّا وصفنا إذ كان لا يمكن أن B92r تكون أقلّ ممّا قلنا فإنّ عظم أجرامها كلّها أكثر ممّا قلنا وإنّ أبعادها إن كانت على ما حدّدنا فإنّه يكون اختلاف منظر لكوكب عطارد وكوكب الزهرة وكوكب المرّيخ. |19:12| L21v أمّا المرّيخ فيكون له اختلاف منظر وهو في بعده الأقرب مثل الذي يكون للشمس وهي في بعدها الأبعد. وأمّا الزهرة فيكون لها اختلاف منظر وهي في بعدها الأبعد قريبًا ممّا يكون للشمس وهي في بعدها الأقرب. وأمّا عطارد فيكون له اختلاف منظر وهو في بعده الأقرب مثل الذي يكون للقمر وهو في بعده الأبعد. |19:13| وأمّا اختلاف منظر عطارد وهو في بعده الأبعد واختلاف منظر الزهرة وهي في بعدها الأقرب فإنّ نسبة كلّ واحد منهما إلى اختلاف منظر القمر واختلاف منظر الشمس كنسبة بعدهما الذي ذكرنا إلى كلّ واحد من بعدي الشمس والقمر.

2 جزءًا²] جزء L **3** وعظم¹] sl L جرم¹…وعظم²] om L وثلثًا] وثلث جزء L **4** المرّيخ…جرم²] om L ونصفًا…وجزءًا] ونصف وربع وجزء L **5** ونصفًا] ونصف L التي] الذي L **6** وسدسًا وثمنًا] وسدس وثمن L ألّا] أن لا B **8** وبعدها] وبعده L **11** عظم] om L **12** أيضًا] om B قلنا] أيضًا add B **13** فإنّ…قلنا²] om L **15** الذي] الذي add L **18/19** وأمّا…الأبعد] om B **19** وهي] هي L **20** بعدهما] بعدها B

|19:9| According to the measure by which the size of the body [i.e. the volume] of the Earth is one, the size of the body of the Moon is 1/40, the size of the body of Mercury is 1/19, the size of the body of Venus is 1/44, the size of the body of the Sun is 166 1/3, the size of the body of Mars is 1 1/2, the size of the body of Jupiter is 82 1/2 and 1/4 and 1/20, the size of the body of Saturn is 79 1/2, and the size of the bodies of the fixed stars that are of first magnitude is either 94 1/6 and 1/8 or is not smaller than that. |19:10| On account of what we have described, the body of the Sun is larger than every [other] body in the world. After it in size are the bodies of the fixed stars that are of first magnitude; after them in third rank is the body of Jupiter; in fourth rank, the body of Saturn; in fifth rank, the body of Mars; in sixth rank, the body of the Earth; in seventh rank, the body of Venus;[44] in eighth rank, the body of the Moon; and the last of them is the body of Mercury.[45]

|19:11| We may make here also an exception: We say that if all of their distances are as we have said, then the size of their bodies is also as we have said. If their distances are greater than what we have described, then the size of all their bodies is larger than what we have said, since they cannot be smaller than we have said. If their distances are as we have determined them, then there is a [noticeable] parallax for Mercury, Venus, and Mars. |19:12| As for Mars, it has a parallax, namely at its perigee, similar to that of the Sun, namely at its apogee. As for Venus, it has a parallax, namely at its apogee, close to that of the Sun, namely at its perigee. As for Mercury, it has a parallax, namely at its perigee, similar to that of the Moon, namely at its apogee. |19:13| As for the parallax of Mercury, namely at its apogee, and as for the parallax of Venus, namely at its perigee, the ratio of each of the two to the parallax of the Moon and the parallax of the Sun is like the ratio of their [i.e. the two's] aforementioned distance to each of the two distances of the Sun and the Moon.

[44] On the size of Venus and its ranking in comparison to the other planets, see the commentary to Chapters I.16–19, p. 366 n. 60.

[45] This enumeration is quoted (although not literally) in a Judaeo-Arabic copy of Ṯābit's *Simplification of the Almagest*, see Ṯābit ibn Qurra, *Oeuvres d'astronomie*, pp. xl and 14 (note to line 4 in the Arabic apparatus).

|20:1| وأوّل ظهور الكواكب وغيبوبتها تحت شعاع الشمس إذا كانت الكواكب على الأفق وهي تطلع أو تغرب وكانت الشمس ناحية عن الأفق وكان بينها وبينه قوس من الدائرة العظمى التي تخطّ على مركز الشمس وعلى نقطة سمت الرؤوس. |20:2| أمّا في الكواكب الثابتة التي في العظم الأوّل ما كان منها يلي فلك البروج فخمسة عشر جزءًا بالتقريب وأمّا في زحل فثلاثة عشر جزءًا بالتقريب وأمّا في المشتري فتسعة أجزاء وأمّا في L25r المرّيخ فأربعة عشر جزءًا ونصف وأمّا في الزهرة في غروبها بالغدوات وفي طلوعها بالعشيات فسبعة أجزاء وفي غروبها بالعشيات وطلوعها بالغدوات فخمسة أجزاء وأمّا في عطارد فاثنا عشر جزءًا. |20:3| فأمّا ظهور الكواكب التي يمكن أن تبعد عن الشمس البعد كلّه إذا كانت في مقابلة الشمس فإنّه يكون على بعد من الشمس تحت الأرض ينقص عن القوس التي ذكرنا مقدار النصف منها بالتقريب. |20:4| والاختلاف الذي لبعد الشمس إنّما عرض في الزهرة دون سائر الكواكب لأنّ الثلاثة الكواكب أعني المرّيخ والمشتري وزحل إنّما تخفى وتظهر من تحت شعاع الشمس إذا كانت في موضع بعدها الأبعد من فلك التدوير فقط. |20:5| وأمّا عطارد فإنّه إنّما يخفى ويظهر أكثر ذلك إذا كان فيما يلي بعده الأوسط لأنّه إنّما يظهر إذا كان بعده من الشمس بعدًا كثيرًا أكثر من الأبعاد التي تكون له إذا كان فيما يلي الأوج أو البعد الأقرب. ومن أجل ذلك ربّما بطل بعض ظهوراته وغيبوباته. |20:6| وأمّا الزهرة فإنّها تخفى وتظهر إذا كانت في بعدها الأبعد وإذا كانت في بعدها الأقرب فيكون اختلاف عظمها الذي يظهر لها من أجل ذلك سببًا لاختلاف الأبعاد التي عليها يمكن أن تكون أوّل غيبوبتها وظهورها.

L25v |21:1| وأمّا السبب الذي من أجله صار ما يظهر للبصر ويتخيّل إليه من عظم جرمها B92v ليس على مثل نسب أبعادها فينبغي لنا أن نعلم أنّه الغلط الذي يدخل على البصر من قبل اختلاف المناظر. |21:2| وتبيّن اختلاف ذلك في جميع ما يظهر ويرى على بعد كثير. فكما أنّ الأبعاد أنفسها لا تكون كمّيتها معلومة فيما يظهر للعين ولا التفاضل فيما

1 وأوّل] فأوّل B **3** تخطّ] تحيط L الرؤوس] الرأس B في] كرة add L **5** بالتقريب²] om L
6 في¹] om L **7** فخمسة] خمسة BL **11** الكواكب²] العلوية add m **11/12** المرّيخ والمشتري] المشتري والمرّيخ B **12** من] om B شعاع] om B **18** تكون] يكون L **19** للبصر] للنظر B
20 مثل] om B **21** المناظر] المنظر L اختلاف²] om L **22** فيما²] ما L

|20:1| The first appearance of the planets and their disappearance under the rays of the Sun is when the planets are on the horizon, namely when they rise or set, when the Sun is leaving the horizon, and when between it [i.e. the Sun] and [the horizon] there is an arc of the great circle that is drawn about the centre of the Sun and the point of the zenith. |20:2| For the fixed stars that are of first magnitude and that are close to the ecliptic, it is approximately 15 degrees; for Saturn, it is approximately 13 degrees; for Jupiter, it is 9 degrees; for Mars, it is 14½ degrees; for Venus at its setting in the mornings and at its rising in the evenings, it is 7 degrees, and at its setting in the evenings and at its rising in the mornings, it is 5 degrees; and for Mercury, it is 12 degrees. |20:3| As for the appearance of the planets at [their] maximum distance from the Sun, when they are in opposition to the Sun, [the appearance] is at a distance of the Sun below the Earth, which would be less than the aforementioned arc by an amount of approximately half of it. |20:4| A difference for the distance of the Sun only occurs for Venus, not the rest of the planets, since the three planets – I mean Mars, Jupiter, and Saturn – disappear and appear under the rays of the Sun only when they are at the position of their apogee of the epicycle. |20:5| As for Mercury, it disappears and appears more than this when it is in [the space] close to its mean position, for it only appears when its distance from the Sun is a great one, even greater than the distances that it has when it is in [the space] close to the apogee or the perigee. Therefore, sometimes some of its appearances and disappearances happen unnoticed. |20:6| As for Venus, it disappears and appears when it is in its apogee and when it is in its perigee, so that the difference in its size, which is therefore apparent for it, is a reason for the difference of the distances according to which it is possible that it is [at] the first of its disappearances and appearances.

|21:1| As for the reason for which what appears and presents itself to sight of the size of its body [i.e. Venus] is not in agreement with the ratios of its distances, we must know that this is an error that enters sight on account of the parallaxes. |21:2| The difference of that becomes evident in everything that is apparent and can be seen at a great distance. Just as the quantity of the distances themselves are not known with respect to what is apparent for the eye, the difference in [the space] between things of different magnitudes cannot be known on the basis of

بين الأشياء المختلفة الأقدار منها يعلم على التناسب الذي هي عليه لجمع البصر وقبضه إيّاه بتنقيصه له إلى ما هو له أشدّ إلفًا أن يعلم لنقصانها الدائم. |21:3| ولذلك نرى كلّ واحد من الكواكب قريبًا منّا أكثر من حال حقيقته لانحطاط البصر إلى الأبعاد التي قد اعتادها وألفها فيما بيّنّا. |21:4| كذلك الحال في الزيادات والنقصانات التي تعرض للعظم بحسب زيادة الأبعاد ونقصانها فإنّها تكون أنقص من النسبة التي هي لها كالحال في الأبعاد لعجز البصر كما قلنا عن تمييز وإدراك أقدار كمّية تفاضل كلّ نوع ممّا ذكرنا.

|21:5| تمّت المقالة من كتاب بطلميوس القلودي في اقتصاص جمل أحوال الكواكب المتحيّرة.

1 الذي] التي B   الجمع] جمع B   **2** بتنقيصه] تنقيضه BL   له²] om B   أن...الدائم] om L
4 فيما بيّنّا] om L   **5** أنقص] أقلّ B   التي...لها] om B   **6** أقدار] om L   **7/8** تمّت...المتحيّرة] تمّت المقالة الأولى من الاقتصاص لبطلميوس القلودي ولواهب العقل الحمد دائمًا لا ربّ غيره ولا معبود سواه قوبلت بالأصل بحسب الاجتهاد B تمّت المقالة الأولى من الافتصاص لبطلميوس ولواهب العقل الحمد دائمًا لا ربّ غيره ولا معبود سواه قوبلت على الأصل بقدر الاجتهاد C   **7** أحوال] حال L

the proportion according to which they are, for sight collects and contracts [its object] by reducing it to what it is most accustomed to know because of its permanent deficiency. |21:3| Therefore, we see each planet much closer to us than they really are because of the inferiority of sight in relation to the distances to which it is used and with which it is familiar, as we have shown. |21:4| The same [applies to] the condition concerning the increases and decreases that occur for the sizes [of the bodies] in terms of the increase and decrease of the distances, for they fall short of the ratio that they [really] have, as is the case with respect to the distances because of the incapacity of sight, as we said, to distinguish and perceive the magnitudes of the quantity of the difference of any kind of what we have mentioned.

|21:5| Book I of the treatise by Claudius Ptolemy on the report of the summary of the conditions of the wandering stars is completed.

B93r بسم الله الرحمن الرحيم. ربّ يسّر.

المقالة الثانية من هذا الكتاب

L26r |1:1| أمّا ما يدرك من نسب الحركات الفلكية بالأرصاد التي كانت إلى وقتنا هذا فقد وصفنا أكثره. ولكنّا إذ كنّا قد جعلنا المثالات في حركاتها ومراتب وضعها بنوع بسيط في الأفلاك العظام التي نرسمها بحركاتها فقد بقي أن نصف أشكال الأجسام التي فيها نفهم تلك الأفلاك. |1:2| ونتبع في ذلك ما يليق بطبيعة الأجسام الفلكية ويلزم الأوائل التي تشاكل الجوهر الباقي على حالة واحدة دائمًا.

|2:1| فأمّا إحصاء آراء القدماء وأقاويلهم في هذه الأشياء وتصحيح ما يظهر فيها من الخطاء فليس من شأننا. وذلك أنّ هذه أشياء قد وضعت لمن رام أن يقيس الأشياء التي إنّما توضع وضعًا فقط بالأشياء التي هي حقيقية وبما يصحّ ويثبت إذا لزم السبيل التي سلكنا في الحركات الدائمة المستديرة.

|2:2| فأمّا حالات الأجسام التي تكون فيها ما ذكرنا وكيف هي بعضها عند بعض فإنّا نروم أن نضع ذلك هاهنا من بعد أن نقدّم أوّلًا تمييز الأعراض الكلّية التي تعرض لها عامّةً على الجهة الطبيعية والجهة التعليمية.

|3:1| فالقياس الطبيعي يؤدّينا إلى أن نقول إنّ الأجسام الأثيرية لا تقبل الانفعال ولا تتغيّر وإن كانت مختلفة في الزمان كلّه على حسب ما يليق بجوهرها العجيب ويشاكل قوّة الكواكب التي فيها التي تنفذ ضياؤها نفوذًا بيّنًا في جميع هذه الأشياء المبثوثة حولها L26v

1 ربّ يسّر] ثقتي بالله وحده B **2** المقالة...الكتاب] المقالة الثانية من كتاب بطلميوس في الهئة المسمّى بالاقتصاص قال بطلميوس B **4** أكثره] الكثرة L إذ] إذا L **7** تشاكل] نشاكل L حالة] حال B **8** فأمّا] وأمّا B **10** فقط] add † L حقيقية] حقيقة L ويثبت] وتثبت L **12** تكون] يكون B **13** ذلك] add ذلك L **15** فالقياس] والقياس B **16** ويشاكل] تشاكل L **17** المبثوثة] المثبوتة L

In the name of God, the Compassionate, the Merciful. May the Lord make [it] easy.

Book II of this treatise

|1:1| We have described most of the relations of the spherical motions that have been perceived by observations made up to our time. But since we have created the diagrams[46] for their motions and the ranks of their hypothesis in a simple way for the great circles that we draw with their motions, it remains for us to describe the shapes of the bodies, according to which we understand these circles. |1:2| We follow in this respect what is proper for the nature of spherical bodies and what is necessary for the principles that conform to the substance that always endures in a single condition [i.e. aether].[47]

|2:1| We are not concerned with listing the opinions of the ancients and their sayings on these matters and correcting what appears to be wrong in them. For these are things that have [already] been laid down[48] to someone who wishes to compare the things that are laid down only as a hypothesis with the things that are real, and with what is correct and established if he adheres to the way that we pursue regarding eternal, circular motion.

|2:2| As for the conditions of the bodies, in which they are as we have mentioned and how they relate to each other, that is what we seek to lay down here[49] after we have first distinguished the universal properties that occur for them in general, in both the physical sense and the mathematical sense.[50]

|3:1| The physical reasoning leads us to saying that aetherial bodies are unreceptive of alteration and do not change in all time,[51] even if they are different [i.e. from each other], according to what is proper for their wonderful substance and what conforms to the power of the planets that is [inherent] in them. Their brightness pervades in a clear way all of these things spread around them, without

[46] Usually, in the different versions of the *Almagest* and in the *Planetary Hypotheses*, the Arabic term *miṯāl* translates *hypodeigma* or *paradeigma*. Here, it expresses the contrast to the physical shapes of the spheres. Accordingly, the diagrams at the end of Chapters II.11–16 are entitled as *miṯāl*.

[47] The last couple of lines, starting with *fa-qad baqiya*, are cited in Ibn al-Hayṯam, *al-Šukūk*, p. 45:9–12.

[48] See Ptolemy, *Syntaxis*, I.3.

[49] Until here, this sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 45:14–15.

[50] For an upshot of the argument of the following chapters, see the commentary to Chapters II.1–2, p. 369.

[51] Until here, the sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 45:17–18.

بلا منع ولا انفعال. وكذلك ينفذ ما فينا ممّا يجانسها مثل البصر والفهم. |3:2| ويؤدّينا أيضًا إلى القول بأنّ الأجسام الأثيرية لا تتغيّر ما قد قلنا من أنّ أشكالها مستديرة وأنّ أفعالها أفعال أشياء متشابهة الأجزاء. ولكلّ حركة من هذه الحركات المختلفة في الكمّية أو في النوع جسم يتحرّك على أقطاب وفي حيّز ومكان خاصّ له حركةً إراديةً وعلى حسب قوّة كلّ واحد من الكواكب التي منها يكون أوّل ابتداء الحركة التي تنبعث عن القوى الرئيسية التي هي مثل القوى التي فينا وتحرّك الأجسام المجانسة لها التي هي شبه لأجزاء الحيوان الكلّي على قدر النسب التي تليق بكلّ واحدة منها. |3:3| ويكون ذلك فيها بلا قهر ولا ضرورة تلزمها من خارج. وذلك أنّه لا يكون شيء أقوى ممّا لا يقبل الانفعال فيقهره. ولا يكون ذلك فيها أيضًا لحال وزن طبيعي وحركة غير نفسانية مثل ما يعرض للأجسام التي تعلو والتي تهبط لحال حركتها الطبيعية.

|3:4| أمّا أوّلًا فلأنّ هذه الحركات ليست للأجسام التي تتحرّك بها بالطبيعة لكنّ كلّ B93v
واحد منها ثبت وسكن إذا صار في شيء مشاكل له. فإذا انتقل إلى شيء لا يشبهه ولا يشاكله وارتفعت الموانع مال إلى موضعه الخاصّ به. |3:5| وأيضًا فإنّ هذا الجوهر L27r
الموضوع كلّه إذا كان متنفّسًا فإنّه قد سلم من الحركات الجسمانية وهي التي تكون على استقامة وبنوع يتغيّر. وتثبت فيه الحركة المستديرة المستوية محضًا نفسه بإرادة مطلقة لا مانع لها على ما يشبه. وتليق بالعقل العجيب والإرادة التي لا تمنع ولا يعرض فيها تنقّل الرأي وتغيّره وهي حركة على ترتيب تكون في الثلاث الجهات المكانية على التضادّ.

|4:1| فأمّا القياس التعليمي فإنّه لمّا استعمل فيه هذه الأشياء التي وصفنا وقرن إليها ما يظهر لنا من كلّ واحدة من الحركات وجد ذلك يتهيّأ على نوعين من أنواع الاختلافات.

1 فينا] من add L **4** أقطاب] أقطار L حيّز] حين L **5** أوّل] om B عن] om L **6/7** هي[2]... التي] om L **8** تلزمها] يلزمها L ممّا] من ما L **10** للأجسام] الأجسام B الحال] حال L **11** بالطبيعة] الطبيعية L **12** ثبت] يلبث B وسكن] ويسكن B **13** الموانع] المرافع B الجوهر] الجواهر L **14** الحركات] هذه الحركة B التي] النوع الذي B **15** يتغيّر] نغير B وتثبت] وتلبث B نفسه] نقية L hindrance or alteration. [The things] in us that are of the same kind as them, such as sight and understanding, pervade in the same way. |3:2| What also leads us to say that aetherial bodies do not change is what we have already stated, [namely] that their shapes are round and that their actions are actions of things whose parts resemble each other. For each of these motions that differ in quantity or kind, there is a body that moves around poles and in a space and place specific to it with a volitional motion and in accordance with the power of each planet from which the beginning of the initiative to move originates. [This motion] is sent forth by the governing powers that are like the faculties in us and that move the bodies of the same kind as themselves which are similar to the parts of the universal animal[52], in accordance with the relations that are proper for each of them. |3:3| This [occurs] regarding [the aetherial bodies] not by force or necessity, forcing them from outside. For there is nothing stronger than what does not receive alteration[53] so that it could force it. Nor is there such [alteration] in [the aetherial bodies] due to the condition of the natural weight and the motion that is not from soul, as occurs for the bodies that rise and fall due to the condition of their natural motion.

|3:4| For, first, these [elementary] motions do not belong to bodies that undergo [this] motion by nature, but each of them stays [in place] and rests when it comes to be in a thing conforming to it. When it is moved into something that is not similar to it and does not conform to it and when the obstacles are removed, it tends towards its place specific to it. |3:5| Also [second], if this entire underlying substance is animate, then it is free of bodily motions, namely those that are rectilinear and of the kind that changes. In it [i.e. the substance], the regular circular motion remains pure itself through a will which is absolute [in the sense] that there is no obstacle with respect to what is similar. [The circular motion] is proper for the wonderful intellect and the will, which is not impeded and in which no alteration or change of the opinion occurs, namely, [it is free of] a motion ordered such as it is with regard to the three local opposed directions.[54]

|4:1| As for the mathematical reasoning: When these things that we have described are applied in it and when what is apparent to us of every motion is linked to them, it is found that this can be configurated in two different kinds. The first is that a complete sphere is assigned to every motion, either hollow – like

[52] See *Tim*. 32c5–33b4 and 36b6–37c5.

[53] This passage, starting with *li-kull ḥaraka*, is cited in Ibn al-Hayṯam, *al-Šukūk*, pp. 46:2–7 and 46:16–47:2.

[54] Up and down, right and left, back and front.

الأوّل أحدهما أن يقرّر لكلّ حركة كرة تامّة إمّا مجوّفة مثل الأكر التي تحيط بعضها ببعض أو بالأرض وإمّا مصمتة غير مجوّقة مثل التي لا تحيط بشيء محدود على حدته وهي التي تحرّك الكواكب وتسمّى أفلاك التداوير. |4:2| والنوع الآخر ألّا يقرّر لكلّ واحدة من الحركات كرة تامّة لكنّ قطعة من كرة فقط. وتكون تلك القطعة عن جنبتي الدائرة العظمى من الدوائر التي تكون في تلك الكرة وهي التي تكون فيها حركة الطول. ويكون ما تحويه هذه القطعة من الجانبين بمقدار العرض حتّى يكون شكل هذه القطعة إذا كانت L27v من فلك تدوير شبيهًا بالدفّ وإذا كانت من الأكر المجوّفة فشبيهًا بنطاق أو بسوار أو بفلكة كما قال أفلاطن. |4:3| والنظر التعليمي يدلّ على أنّه ليس بين هذين النوعين اللذين وصفنا اختلاف. وذلك أنّ الحركات التي وُضعت في أكر تامّة إذا أُلفت على هذا التأليف وقيست بحركات المنشورات التي ذكرنا على أنّ لها حركات متشابهة أمكنها أن تلزم فيما يظهر منها أمرًا واحدًا بعينه.

|5:1| وأمّا الذين جعلوا ابتداء قياسهم من الحركات الكرية التي تكون عندنا فإنّهم قد قاسوا قياسًا طبيعيًا في وضع الأكر التامّة. |5:2| وذلك أنّهم رأوا فيما يعمل عندنا من الأكر أنّ الحركات الكرية تكون فيها نقطتان ممسكتان للكرة اضطرارًا وهما اللتان تسمّيان قطبين. وتوهّم ذلك في الوضع الذي للمنشورات عسر. وأمّا في الأكر التامّة فيسهل. |5:3| فركنوا إلى القول بذلك كما فعل أرسطوطاليس أيضًا حتّى تكون أقطاب الأكر التي تحاط بها ثابتة على الأكر المحيطة. ثمّ لمّا لم يبقَ شيء من الاتّصال بين الأكر الداخلة وبين الكرة الخارجة الأولى ولم تكن حركة الأكر كلّها متساوية السرعة لكنّ مختلفة اختلافات B94r شتّى اضطرّوا إلى طلب معرفة الوجه الذي به يتحرّك كلّ واحد من الكواكب بالحركة L22r الأولى كما نراه ويظهر لنا. إذ كانت الأكر التي فيما بيننا وبينها مختلفة في وضعها وفي

1 يقرّر] يقرن L **2** وإمّا] أو B **3** ألّا] أن لا L يقرّر] نقرز B يُقرن L واحدة] واحد L **5** فيها] منها B **7** فشبيهًا] om L **8** أفلاطن] أفلاظون L والنظر] فالنظر B **9** وُضعت] وصفت B على] om B **13** رأوا] رأوا add B يعمل] sl B **14** ممسكتان للكرة] تمسكان الكرة B وهما] أو هما L تسمّيان] يسمّيان B **15** عسر] عشر L فيسهل] يسهل L **16** أرسطوطاليس] أرسطاطاليس B **18** تكن] يكن L **20** نراه] ترأه L فيما] فيها L وفي] في B the spheres that comprise each other or the Earth – or solid, [i.e.] not hollow – like those that do not encompass anything determined apart from itself – namely those that move the planets and that are called epicycles. |4:2| The second kind is that not a complete sphere is assigned for every motion, but only a segment of a sphere. This segment is on both sides of the greatest circle in this sphere, namely that [circle] in which there is the longitudinal motion. What this segment comprises from two sides is to the degree of the latitude so that the shape of this segment, when it is from an epicycle, is similar to a tambourine, and when it is from the hollow spheres, it is similar to a belt or a bracelet or a whorl, as Plato said.[55] |4:3| The mathematical investigation indicates that there is no difference between the two kinds that we have described.[56] For when the motions that were laid down in complete spheres are arranged according to this arrangement and are compared with the motions of the already described sawn-off pieces – on the basis of [the fact] that they have similar motions – [then] it is possible for them to adhere to the very same thing with respect to their appearance.

|5:1| As for those who begin their reasoning from the spherical motions in our realm, they used the physical reasoning for the hypothesis of the complete spheres. |5:2| For they held – considering the application of spheres in our realm – that in spherical motions, there are two points that are necessarily in contact with the sphere; these two points are called poles. To imagine this with regard to the hypothesis of the sawn-off pieces is difficult. However, for the complete spheres, this is easy. |5:3| Thus, by that, they trusted the account, just as also Aristotle did, such that the poles of the encompassed spheres are fixed on the encompassing spheres. Then, since no contact between the inner spheres and the first outer sphere remains and since not every motion of the spheres is of equal speed, but differs in many ways, they were forced to seek an explanation of the manner in which each planet moves by means of the first motion, just as we see it [i.e. each planet] and as it is apparent to us. For the spheres between us and [the first

[55] See *Rep.* X, 616d. Al-Bīrūnī explains the terminology of *falak* as deriving from 'the whorl of the spindle' (*falkat al-miġzal*). See al-Bīrūnī, *Kitāb al-Tafhīm*, p. 43:11 (Arabic text). There are a couple of possible vocalizations of the Arabic term for 'whorl' or 'spindle', namely *falka* or *filka* according to Lane (see Lane, *An Arabic–English Lexicon*, Vol. 6, p. 2444), or *falaka* according to Willy Hartner (see Hartner, 'Falak', pp. 761–762). For Ptolemy's reception of Plato's whorls, see above pp. 39–45.

[56] Until here, the beginning of this chapter is cited in Ibn al-Hayṯam, *al-Šukūk*, pp. 47:7–48:5. Instead of 'similar to a belt or a bracelet or a whorl, as Plato said', the version in Ibn al-Hayṯam reads as follows: '[…] similar to a wheel (*ṭār*) and bracelet (*siwār*) and ring (*ḥalaq*) or whorl, as Plato said'.

حركتها. |5:4| ولذلك استعمل أرسطوطاليس الحركات التي تكون شبيهًا بالالتفاف. ولكن ليس ينبغي لنا أن ننسب إلى الجسم الأثيري الأشياء التي يضطرّ إلى وضعها فيما عندنا من الأجسام. ولا أن نتوهّم أنّ الشيء المانع الأشياء التي تكون عندنا قد يمنع مثله الطبيعة الفلكية المخالفة لها كلّ الخلاف في الجوهر والفعل جميعًا. |5:5| وأيضًا فإنّ الأقطاب التي عندنا لا نجدها هي العلّة الأولى لحركة الاستدارة. وذلك أنّه يستقيم أن تتحرّك الكرة بنوع آخر مثل الأكر التي تتدحرج ولا تستند على شيء واحد بعينه من الأشياء التي خارج. فالأقطاب لا تفعل حركة الاستدارة في الموضع الخاصّ لها وإنّما تحمل ثقل الكرة فقط. |5:6| ولا تلك النقط هي سبب ابتداء الحركة وذلك أنّه لا يمكن أن يكون سبب الحركة شيئًا ثابتًا بل السبب إنّما هو شيء آخر غير هذه النقط.

|5:7| فإنّ نحن توهّمنا أيضًا كرة لا تتحرّك ولا تنتقل بالطبيعة أو بشيء يحيط بها له مثل هذه الطبيعة. فإنّا لا نحتاج عند ذلك أيضًا إلى أقطاب لا في أن تتحرّك الكرة ولا في أن تدور وترجع إلى مكان واحد بعينه. وأيضًا |5:8| فإنّ الكرة إن كان لها ابتداء الحركة من ذاتها فالقول بأنّها تستند على شيء آخر وليس ذلك الشيء في وسطها قول ينبغي أن نضحك منه. وذلك مثل الحال في حركة كرة العالم كلّه وذلك أنّ الوسط هاهنا هو L22v الابتداء والوسط. أمّا وسط فلأنّه وسط الجوهر وإليه وحوله تكون الحركة. وأمّا ابتداء فلأنّه ابتداء هذه الحركة التي هي أبدًا دائمة مستديرة والشيء الذي منه تكون. وذلك أنّ العلّة في هذين جميعًا هو أنّ القوّة المحرّكة غير متغيّرة وهي واحدة بعينها. |5:9| وليس هذا فقط لكن وإنّ الأبعاد التي تكون في الجهات التي تصير إليها الأشياء متساوية مثل الأشياء المعلّقة فإنّها تفعل في استواء الميل فعلًا واحدًا إذا كان بعدها من المواضع التي تهوي إليها بعدًا واحدًا.

|5:10| وبالجملة أنّه إن كان يعسر أن يتوهّم أنّ الحركات الفلكية ليست على أقطاب ثابتة فأخلق به أن يكون توهّم ماهية تلك الأقطاب أعسر كثيرًا. وكيف يكون بهذه

1 أرسطوطاليس] أرسطاطاليس B بالالتفاف] بالالتفات L **3** أن] om L أنّ] om B الأشياء] للأشياء B **5** قد] وقد B الاستدارة] الاستدارية L **6** تستند] نستدلّ أيضًا B **7** فالأقطاب] والأقطاب B **8** النقط] النقطة B **9** شيئًا ثابتًا] شيء ثابت L شيء ثابتًا B إنّما هو] أبدًا L آخر] sl B **10** فإنّ] وإنّ L له] sl B **11** أيضًا] om B أقطاب] أيضًا add B **12** تدور] يدور L وترجع] ويرجع L **15** وحوله] وله B وأمّا] فأمّا B **16** أبدًا] om L تكون] يكون B **17** المحرّكة] المتحرّكة L **19** تفعل] يفعل L **21** الحركات] الحركة B sphere] are different with respect to their hypothesis and their motion.[57] |5:4| Therefore, Aristotle used motions which are similar to unwinding.[58] But we should not ascribe to the aetherial body things which one must posit for bodies in our realm. Nor should we imagine that something impeding things in our realm could also impede the celestial nature, which is utterly distinct from it in both substance and action.[59] |5:5| Furthermore, we do not find the poles in our realm to be the first cause for circular motion. For it is correct that the sphere moves with a different kind of motion, such as the spheres which roll and do not depend on any one external thing. Thus, the poles do not cause the circular motion in the position specific to them, but rather they only carry the weight of the sphere. |5:6| Nor are these points the cause of the intiative to move because it is not possible for something fixed to be the cause of motion, but the cause must rather be something other than these points.

|5:7| We [may] also imagine a sphere that does not move and is not moved by nature nor by anything that encompasses it [and] has a similar nature. In this case, we also do not have any need for poles, neither for the sphere to move nor for it to revolve and return to a single particular place. |5:8| Furthermore, if the sphere has an initiative to move from its essence, then the claim that it depends on another thing which is nevertheless not at its centre is a claim at which we should laugh. This is like the condition of the motion of the sphere of the entire world, for the centre here is the initiative and the centre. As for [being] a centre, that is because it is the centre of the substance, and motion is towards it and around it. As for [being] an initiative, it is the initiative of the motions which are always everlasting and circular, and the thing from which [the motion] comes about. For the cause [applies] to both of them, which means that the moving power does not change but is one itself. |5:9| And that is not all, but the distances in all directions to which things proceed are equal like suspended things, for they act in equal inclination in a single manner when their distance from the places to which they strive is the same.

|5:10| In general, if it is difficult to imagine that the spherical motions are not by means of fixed poles, then it ought to be much more difficult to imagine the essence of these poles. How can there be through the poles a simple connection

[57] cf. the similar version of these reasons in the account by Sosigenes preserved in Simplicius, *In Cael.*, p. 498:5–10.

[58] cf. *Metaph*. XII.8, 1073b38-1074a14. On the Arabic term for unwinding motions, see the commentary to Chapter II.5, pp. 372–73.

[59] Compare Ptolemy, *Syntaxis*, XIII.2, Vol. 2, p. 532:16–19.

الأقطاب ارتباط بسيط أعماق الأكر التي تتّصل بها من خارج يجذب الأكر الداخلة؟ وبأيّ شيء تشارك هذه الأقطاب كلّ واحد منها؟ |5:11| فإنّا إن جعلناها نقطًا كنّا قد ربطنا الأجسام بأشياء ليست بأجسام وكنّا قد جمعنا هذه الأشياء التي لها هذا العظم كلّه والقوّة بشيء ليس له عظم ولا هو بشيء. |5:12| وإن نحن جعلناها أجسامًا وكانت هذه الأجسام تشبه عقد الخشب الثابتة أو تشبه الثآليل التي تكون عندنا وكانت غير مخالفة ولا مضادّة للأشياء المثبوتة حولها التي نراها لم يكن لنا سبيل إلى أنّ تنسب هذه الخواصّ التي فيها إلى طبيعة ما.

|5:13| وإن كانت مخالفة لِما حولها بمثل التكاثف الذي يكون في العقد التي في L23r | B94v
الخشب فإنّا عند ذلك لا نجد بدًّا من أن ننفى عنها الثبات في مكانها لأنّ الأجسام التي هي أشدّ تكاثفًا هي أبدًا تهبط أكثر من الأجسام التي أشدّ سخافة وتهوي إلى ناحية وسط العالم. |5:14| والكواكب وإن كانت متنفّسة وكانت تتحرّك حركة إرادية وكانت الحركة الإرادية هي السبب أيضًا في أن تكون للطير من أجناس الحيوان قوّة يتحرّك بها ويدور في العلو ويخالف ما حوله في التكاثف فإنّه لا ينبغي أن نظنّ بالكواكب أنّها تخالف ما حولها من الأشياء بالكثافة. |5:15| لكن إنّما تختلف بالقوّة التي يحفظ فيها الضياء كما أنّ السحاب أيضًا يخالف الهواء الذي حوله ما دام يابسًا باللون فقط وكما تخالف الرطوبات المصبوغة غيرها ممّا ليس بمصبوغ في التكاثف إذا كانت تلك الرطوبات يشبه بعضها بعضًا في التكاثف.

|5:16| وإن نحن أطلقنا لهم أنّ الأقطاب يمكن أن تثبت فبأيّ الأكر ترتبط تلك الأقطاب من الكرتين المربوطتين؟ فإنّه لا يمكن أن ترتبط بهما جميعًا لحال الحركة وإن ارتبطت بواحدة فلمَ صارت ترتبط بها دون أن ترتبط بالأخرى؟ وأيّ شيء في الأقطاب ممّا يحرّك الكرة التي فيها مرسلة؟ فإنّه يقع في هذا ايضًا حيرة.

1 يجذب] نجد به L **2** تشارك] نشارك L **5** الثآليل] الثؤاليل BL **6** مضادّة] مغادرة L المثبوتة] المبثوثة B التي نراها] om L **9** أن] ا L **10** التي²] هي add B وتهوي] ويهوي L **11** والكواكب] إن B وإن] إن B **12** تكون] يكون B **13** ويدور] وتدور L **18** ترتبط] يرتبط L **19** لحال] الحال L **20** ترتبط²] يرتبط L في] من B **21** ممّا] ما من L التي] هي add B هذا] هذه B of the depths of the spheres, with which they are contiguous from the outside, [namely a connection] that attracts the inner spheres? Through which thing do these poles join each of [the spheres]? |5:11| If we make them points, then we have connected the bodies to things that are not bodies, and we have joined these things which have all this size and power with something that has no size nor is it even a thing. |5:12| And if [on the other hand] we make them bodies and if these bodies are similar to fixed wooden knots or warts, which are [examples] of our realm, and if they are not different from or opposed to the things that are spread around them and that we see, [then] it is not possible for us to ascribe these specific properties that are in them to some specific nature.

|5:13| And if they are different from what is around them – like the density of the knots in the wood – we would thus find it necessary to exclude [the possibility] that they remain in their place, because bodies that are of greater density always sink more than the bodies that are thinner and [thus] strive towards the centre of the world. |5:14| Even if the planets are animate and if they move in a voluntary way and if the voluntary motion is also the reason for the [fact] that, among the kinds of animals, birds have a capacity by which they move and revolve in the heights, whereas they are different from what is around them in density, we should not think that the planets are different from the things that are around them through density. |5:15| However, they are different rather through the capacity which preserves brightness in them, just as the clouds are different from the air around them only through colour, as long as they are dry, and as coloured liquids are different from other non-coloured [liquids] in density, [even] if such liquids resemble each other in density.[60]

|5:16| [Even] if we were to concede to them that it is possible for the poles to be fixed [in the sense of unmoved], with which of the two connected spheres are such poles then connected? It is impossible that they are connected to both of them at the same time because of the condition of the motion; and if they are connected to one [of them], then why did it become connected to it and not to the other one? And which thing in the poles is of something that moves the sphere which is set free in them?[61] There is confusion in this matter as well.

[60] The German translation by Nix and Buhl and Heegaard adds a negation (see Ptolemy, 'Hypotheseōn', p. 116). Another solution would be to omit the first instance of *fī l-takāṯuf*, so that the sentence reads as follows: '[…] and as coloured liquids are different from other non-coloured [liquids], [even] if such liquids resembled each other in density.'

[61] In Chapter II.11, Ptolemy describes how an intermediate sphere is 'set free' (*mursila*) between the two adjacent spheres so that it does not transmit its motion to the lower sphere.

L24v |6:1| وصاحب العلم الطبيعي إن قال إنّ سبب ثبات الأجسام التي تتحرّك هو أحد النوعين اللذين ذكرنا أو النوع الآخر لم يكن في ذلك فرق ولا اختلاف. أعني أنّه إن قال إنّ سبب ذلك كلّية الأكر أو القطع التي فيها فيما بينها لم يقع من قبل ذلك فرق ولا اختلاف كما أنّه لا يكون اختلاف أيضًا من قبل أنّ بعضها مجوّف دون بعض وبعضها غير مجوّف.

|6:2| ولصاحب العلم الطبيعي أن يقول أيضًا إن أراد بنوع الحركة التي تكون في قطع تشبه الفِلَك أو الدفوف لأسباب كثيرة. |6:3| أمّا أوّلًا فلأن لا يكون لما في السماء حركات كثيرة لحال الأكر التي يدير بعضها بعضًا. إذ كان ذلك قد يمكن أن يتوهّم حركات قليلة. وذلك أنّ جميع قطع الأجسام الكرية في النوع الذي بمنشورات تكون فيه الحركة التي تكون باستدارة مثل حركة الأثير الذي يكون بالحركة الأولى إذا لم يكن شيء مانع من ذلك حتّى أنّها في كلّ حال تديرها بدورها وبما لها من القوّة على حركاتها الخاصّة لها مثل ما يكون في الأشياء التي تتحرّك حركة واحدة وتخالف هي تلك الحركات خلافات شتّى أو مثل الأشياء التي تسبح في أنهار جارية.

|6:4| وأيضًا فإنّه خليق أن يظنّ أنّه قد جعل في الطبع شيء لا معنى له ولا يحتاج إليه وهو الأكر التامّة في الحركات التي تجري أن تكون في جزء قليل منها وأن يكون ذلك L28r فيها مثل ما هو في الكرة التي تحرّك بخاصّيتها بكلّيتها كواكبها أعني كرة الكواكب B95r الثابتة |6:5| التي يضطرّ إلى القول بذلك فيها لحال ما يقع تحت البصر من أمرها ممّا ليس مضطرًّا إلى ذلك في غيرها. وبمثل هذا السبب رأينا أنّه من الواجب أن لا يكون كوكبا عطارد والزهرة موضوعين فوق الشمس لكن فيما بين الشمس والقمر لئلا يكون هذا الفضاء الكثير جدًا كما يظهر ذلك ويتبيّن من الأبعاد خاليًا مثل شيء قد تركته الطبيعة

2 اختلاف] خلاف B **3** سبب] شيت L كلّية] كلّه B **6** التي] الذي L في قطع] om B **7** أو] و L **9** قطع] om B الذي] تمرّ add B **10** التي…بالحركة] om L **11** تديرها] يديرها BL وبما] وبمهل L من[2]] om L **12** الخاصّة] الخاصّية B **13** أنهار] أنها B **16** بخاصّيتها] om B كواكبها] كواكب B **17** بذلك فيها] فيها بذلك B **18** مضطرًّا] يضطرّ L إلى] om L **19** كوكبا] كوكب B **20** ويتبيّن] ويبيّن L قد] om B

|6:1| If a proponent of the physical science says that the reason for the permanence of the moving bodies is either one or the other of the two aforementioned kinds [i.e. sawn-off pieces or complete spheres], [then] there is no distinction and no contradiction. I mean, if he claims that the reason for this is whole spheres or segments that are [enclosed] in them [and] in [the space] between them, [then] from this no distinction or contradiction arises, as no contradiction occurs from the fact that some of them [i.e. the spheres] are hollow to the exclusion of others, whereas others are not hollow.

|6:2| The proponent of the physical science may also argue – if he so wishes – for the kind of motion which is in the segments that resemble whorls[62] or tambourines for several reasons. |6:3| First, such that there are not so many motions for what is in the heavens because of the condition of the spheres which rotate each other. Since this is so, one can imagine the motions to be few. For in all segments of the spherical bodies according to the kind which is by means of sawn-off pieces, there is the motion that is circular like the motion of aether, which is by means of the first motion, when there is nothing impeding that [motion] such that it [i.e. the motion of the aether], in every condition, rotates them [i.e. the inner sawn-off pieces] by its [own] rotation and by their capacity to [perform] motions specific to them, like what is [the case] for things that move in one way but go against these by [performing] various different [motions], or like things swimming in running rivers.

|6:4| Furthermore, it [would] be appropriate to think[63] that in nature, something is made that has no meaning or use, namely the complete spheres regarding the motions which run [in a way] that they are [only] in a small part of them. [And it would be appropriate] that this is their case, as is the case of the sphere that moves its stars by its specific property and its entirety, I mean the sphere of the fixed stars. |6:5| One is forced to say so concerning [the sphere of the fixed stars][64] because of the condition of what lies before our eyes of its matter; however, [one] is not forced [to say] so concerning [spheres] other than it. By a similar reason, we see that it is necessary that the planets Mercury and Venus are not situated above the Sun, but in [the space] between the Sun and the Moon, so that this very great space, as it is apparent and is evident from the distances, is not empty like something that nature has neglected and rejected and thus did not make use

[62] This plural form of *falka* or *filka* could also be vocalized as *falak* (see again Lane, *An Arabic–English Lexicon*, Vol. 6, p. 2444), but should not be confused with the singular form of 'sphere' or 'circle', *falak*.

[63] Nix and Buhl and Heegaard add a negation, which seems perfectly reasonable. On the other hand, maybe Ptolemy wants to introduce the following discussion with an absurd claim.

[64] Namely that it is a complete sphere.

ورفضته فلم تستعمله. وله إمكان لقبول بعدي هذين الكوكبين اللذين ذكرنا أنّهما أقرب إلى الأرض من غيرهما حتّى أنّ ذلك الفضاء يمتلئ منهما وحدهما.

|6:6| ويلزم هذه الاستحالة والشناعة بعينها في وضع أكر يلتفّ بعضها على بعض سوى ما يلزم من إفراطها في كثرة العدد. وذلك أنّها تأخذ من الأثير فضاء كثيرًا وليس نحتاج إليها في الحركات التي تظهر للكواكب. لكن إنّما تندفع معًا إلى ناحية واحدة حتّى تكون منها حركة واحدة. |6:7| وأعجب ما هاهنا تصييرهم الأكر الأواخر محرّكة للأكر الأول والأكر التي تحاط بها محرّكة للمحيطة بها والأكر الكثيرة الاختلاف للكرة البسيطة على خلاف المذهب الطبيعي. |6:8| وأيضًا فإنّ كلّ واحدة من الأكر تكون L28v عنها حركات جميع الأكر التي فوقها مع حركتها الخاصّة لها فتتحرّك حركات ليست الخاصّة لها فقط لكن والغريبة التي ليست لها. فأيّ شيء نرى أنّ لحركات المشتري من الخاصّة بحركة زحل؟ وأكثر من ذلك بعدًا ما لحركة القمر بحركة زحل من الخاصّة؟

|6:9| وأيضًا فإنّا لا نجد حيلة في وجود القوّة التي تحرّك الكرة الأولى من الأكر التي تلتفّ وتطيف بعضها ببعض في هيئة كلّ الأكر. وذلك أنّ ابتداء الحركة الكائن من الكوكب يمتدّ باتّصال فيحرّك أبعد ما يكون من الأشياء الخاصّة له من خارج ولا يتّصل بأوّل ما تحت الكوكب من الأكر التي يطيف بعضها ببعض. وإن كان مماسًّا لآخر الأكر التي يطيف بها من فوقها فليس يوافق ذلك في حركتها بمثل الحركة الأولى شيئًا بل الأمر على خلاف ذلك لأنّها تتحرّك عليها على أنّه ليس لهذه الأوصاف أيضًا سبب به يكون ابتداء هذه الحركة إذ كان ذلك غير موجود للأكر التي تطيف بها.

|7:1| وإن توهّم متوهّم أنّ الأرض مركز والهوى والنار يدوران مع دَوَران ما يحيط بهما ويضطرّهما إلى الحركة وجعل ما يشاهد من الطائر مثالًا لحركة ما في السماء فخليق ألّا

1 أنّهما] اللذين هما L **3** في] بعض add B **5** تظهر] يظهر L **7** للمحيطة] للمحيط L **9** الخاصّة] الخاصّية B الخاصّة[2]] الخاصّية B **10** نرى] ترى L لحركات] الحركات L **11** ما] om B **13** هيئة] تهيئة L ابتداء] الأكر add B الكائن] الكائنة B **14** يمتدّ] تمتدّ L فيحرّك] فتحرّك B الخاصّة] الخاصّية B **15** مماسًّا] مماسّ L **16** فوقها] فوق L **17** الأوصاف] om B **18** هذه] om B **19** مركز] om L والنار] om L **20** ألّا] أن لا L of. [However, this space] is able to accommodate the distances of these two planets which we said are closer to the Earth than the others such that this space is filled by these two [planets] alone.

|6:6| It [i.e. the empty space] belongs to this exact impossibility and repulsiveness regarding the hypothesis of spheres that unwind each other, not to speak of what follows from their excessive amount. For they take from aether a great [amount of] space and we do not need them for the apparent motions of the planets. But rather, they hurry together to one direction so that there is of them [only] a single motion. |6:7| What is even more astonishing here is that they [held that] the last spheres become movers for the first spheres and [they let] the encompassed spheres [become] movers for the encompassing [spheres] and the more complex spheres [become movers] for the simple sphere, contrary to the physical approach.[65] |6:8| Also, from each of the spheres, there would then be the motions of all the spheres that are above it [i.e. each of the spheres], in addition to its specific motion, so that it does not move only [according to] the motions that are specific to it, but [also] to the foreign [motions] that do not belong to it. Thus, which thing that we see in the specific motions of Jupiter is in the motion of Saturn? And [what is of even] greater distance than that: what in the specific motion of the Moon [do we see] in the motion of Saturn?

|6:9| Furthermore, we do not find an [explanatory] device for the existence of the capacity that moves the first of the spheres that unwind and surround each other in the configuration of all spheres. For the initiative to move which proceeds from the planet extends by contact, such that it moves the most distant of the outside things specific to it, whereas it is not contiguous with the first of the spheres that surround each other below the planet. Even if it were in touch with the last of the spheres which it surrounds from above, then this would not be in accordance, in its motion in the way of the first motion, with anything; but rather, the affair is the opposite, because they move on account of [the first motion], given that these qualities also do not have a cause by which the initiative of this motion is, since this is not found for the spheres which it surrounds.

|7:1| If someone imagines that earth is the centre and that air and fire revolve along with what encompasses them and what compels them to move, and if one takes what is observed in birds as an example of the motion of what is in the heav-

[65] Simplicius paraphrases this passage with reference to Ptolemy in Simplicius, *In Cael.*, p. 506:16–20.

يكون ما مثل من ذلك منكرًا. |7:2| فكما أنّ الطائر ممّا عندنا من الحيوان إذا تحرّك بحركته الخاصّية له كان ابتداء تلك الحركة من القوّة النفسانية التي فيه. ثمّ يحدث عن هذه القوّة الانبعاث ثمّ يصير بعد ذلك إلى العصب ثمّ من العصب إلى رجلَين في المثل أو إلى اليدين أو الأجنحة. وعند ذلك ينتهي ويقف إعطاء هذه الأشياء بعضها لبعض. L29r
وليس يوافق حركاتها الخاصّة لها لا الأشياء التي فيما بينها ولا هي أيضًا توافق حركات ما يحيط بها. وليس شيء يوجب أن تكون حركات الطائر كلّه أو أكثره على مماسّة منه B95v
بعضه لبعض بل الاضطرار في ألّا يماسّ البتّة إن أردنا ألّا يكون بعضه مانعًا لبعض. |7:3| وكذلك ينبغي أن يتوهّم الأمر في الحيوان الفلكي وأن يرى أنّ كلّ واحد من الكواكب في مرتبته له قوّة نفسانية وأنّه يحرّك ذاته. ويعطي الأجسام المتّصلة به بالطبع حركة ابتداؤها ممّا يقرب منه ومصيرها إلى ما يليه مثل إعطائه الحركة أوّلًا لفلك التدوير ثمّ للفلك الخارج المركز ثمّ للفلك الذي مركزه مركز العالم وهذه الحركة التي يعطيها مختلفة في مواضع كثيرة. فإنّ حركة العقل فينا أيضًا ليست مثل حركة الانبعاث بعينها ولا هذه الحركة مثل حركة العصب ولا هذه الحركة مثل حركة الرجل لكن تختلف بعض الاختلاف في ميلها إلى خارج.

|8:1| فأمّا حركة كلّية الأثير المستديرة فإنّها تتّصل بجميع الجواهر المنفصلة عنها. ولكنّها ليست بموافقة لحركات تلك الخاصّة لها ولا تلك توافق هذه في حركاتها الأولى المستديرة. والأجسام التي هي لكلّ واحد من الكواكب تأخذ من الأثير مكانًا واحدًا لأنفسها وللكواكب فقط لكنّ في ذلك المكان القبول لحركتها هذه التي في العلو. L29v
فالأثير يديرها لأنّ مكانها فيه.

2 النفسانية] السياسية L **3** بعد] om B **4** أو²] أم B **5** حركات] del L **6** تكون] يكون B **7** الاضطرار] لاضطرار B ألّا¹] أن لا B يماسّ] تماسّ B ألّا²] أن لا L **8** يرى] نري B في²] om L **9** له] مرتبة L نفسانية] سياسية L **12** فإنّ] وإنّ B العقل] العضل L ليست] ليس B **15** فأمّا] وأمّا B تتّصل] يتّصل L **16** الخاصّة] الخاصّية B الأولى] الأوّل B **18** لكنّ] يمكن L **19** فالأثير] والأثير B ens, one ought not to reject the same sort of thing in this case. |7:2| Then, it is the same as the bird among the animals in our realm: if [the bird] moves through its specific motion, the initiative of this motion is from the capacity of the soul[66] which is in it. From this capacity, then, there arises an emission, which then reaches the nerves, and from the nerves [it reaches] the legs, for example, or the hands or the wings.[67] There, [the emission] comes to an end and stops to transmit some of these things to others. [However,] the motions specific to them are not in accordance with the things between them,[68] nor with the motions encompassing them. And there is nothing that would make it necessary that the motions of each bird, or most of them, are on the basis of them being in touch with each other, but it is a necessity that [the birds] are not in touch at all if we want some of them not to impede the others. |7:3| One must imagine the case of the celestial animal in the same way and see that each planet in its rank has a capacity of the soul and that it moves itself. [Further,] it gives to the bodies that are by nature contiguous with it a motion, beginning with what is close to it [i.e. one of the planets] and proceeding to what comes next. Accordingly, it [i.e. one of the planets] gives the motion first to the epicycle, then to the eccentric sphere, then to the sphere whose centre is the centre of the world; and this motion, which it [i.e. one of the planets] gives, is different in many places. So too, the motion of the intellect in us is also not similar to the motion of the emission itself, this motion is not similar to the motion of the nerves, and this motion is not similar to the motion of the legs. Rather, they are different in some sense with regard to their inclination towards the outside.

|8:1| As for the circular motion of the entirety of aether, it is contiguous with all substances that are distinct from it. However, it [i.e. the motion of the aether] is not in accordance with these motions specific to them, and these are not in accordance with that [i.e. the aether's motion] with regard to their circular first motions. The bodies belonging to each planet take only a single place of the aether for themselves and for the planets, but [being] in this place, they receive its motion, which is above. Thus, aether rotates them because their place is in [aether].

[66] Note the variant reading in L of *quwwa siyāsiyya* instead of *nafsāniyya*. This reading would put more emphasis on the driving force of this faculty.

[67] Simplicius seems to refer to this passage in Simplicius, *In Cael.*, p. 506:20–22.

[68] See *Phys*. VIII.4, 254b13–21.

|8:2| وأمّا أجزاؤها فإنّها مطلقة مرسلة لتنتقل وتدور في مكان بكلّية ذلك الجسم على أنواع مختلفة وفنون شتّى إلّا أنّ حركتها كلّها مستوية مستديرة شبهة بحلقة الدستبندا وشبهة بحلقة قوم يلعبون بالسلاح وبعضها يعين بعضًا في الفعل وتتّصل قواها بعضها ببعض من غير أن تتّصل أجسامها لئلا تمنعها من الفعل ولا تمتنع هي بها من أن تفعل. |8:3| وهما يمكن أن يبيّن به هذا المذهب وأن يكون سهلًا أن يعمل له آلة تتبيّن بها حركات الأفلاك الخارجة المراكز وأفلاك التداوير التي توضع لأمر الحركات التي تظهر لها. |8:4| وإن استعمل مستعمل في الحركات أقطابًا ولزم وضعها الخاصّ لها لم يمكنه أن يفهم ابتداء هذا الشيء ولا الوجه في عمله ولا في ترتيبه. ويمكن أن يعلم ذلك من رامه. |8:5| وأمّا إن وضع لذلك قياس من الدوائر البسيطة أو من حركات الأشياء التي أشكالها أشكال الدفوف في سطح فلك البروج وإن يقاس بها مواضع الكواكب على الوِلاء فإنّه يجعل ذلك أمرًا واضحًا بيّنًا لجميع الناس ويعلم به هل هو موافق لما يظهر لنا وللحساب الذي وضع على حسب الأصول التي قلنا أم لا.

|8:6| أمّا الأشياء التي كان ينبغي لنا أن تقدّم ذكرها ممّا نختار على حسب النظر الطبيعي الصحيح من الأشياء التي وضعنا آنفًا. فهذا ما يكتفي به فيها.

L30r |9:1| ولنصر الآن إلى القول في إيضاح أمر وضع الأجسام التي لكلّ واحدة من
B96r الحركات وترتيبها. فنقول قولًا واحدًا عامًّا لئلا نحتاج إلى إعادة القول وتكراره ولا إلى أن نقول قولًا مختلطًا فيما نروم من وضعه في الحركات وأقدار الأبعاد والميل والخروج عن المركز وأفلاك التداوير. ونجعل مذهبنا في ذلك مذهبًا تابعًا للطرفين جميعًا ليكون قد فهمنا أيضًا من اختلافاتها الجزئية وكثرة الحركات التي نفحص عنها ومذهبها البسيط.

1 لتنتقل وتدور] لينتقل ويدور L بكلّية] كلّية B **2** حركتها] حركاتها L **3** وشبهة] وشبيه L **4** تتّصل] يتّصل L تمنعها] يمنعها L تفعل] يفعل L **5** يبيّن] تبيّن B تتبيّن] يتبيّن B بها] من add L **6** لأمر] لا من L تظهر] يظهر L **7** ولزم] ولزوم L لها²] بها L **8** ترتيبه] سيه L **9** قياس] قياسًا L أم لا] أوّلًا B **10** وإن] om L يقاس] فقياس L **11** الوِلاء] الولا B الولى L **12** حسب] حساب B **13** الأشياء] الأسباب B واحدة] واحد B **14** الصحيح] om L **15** ولنصر] فلنصر B أمر] om B **16** عامًّا] عامّيًا B نحتاج] يحتاج B **17** نروم] يروم L الحركات] الحركة L **18** للطرفين] للطرفتين L **19** من] أمر B نفحص] تفحص B

|8:2| As for the parts [of aether], they are unrestricted and set free, so that they move about and revolve in a place by means of the entirety of this body according to different kinds and various branches, except that their motion is, in its entirety, regular and circular, similar to a group of dancers[69] and similar to people playing with weapons, assisting each other in the action and their capacities being contiguous with each other, without their bodies being contiguous so that they do not impede them from acting and that they are not impeded by them from acting. |8:3| It[70] is possible that this approach is explained through it and that it is easy to make for it an instrument through which the motions of the eccentric spheres and the epicycles are evident, which are laid down regarding the apparent motions. |8:4| If someone uses poles for these motions and if their specific hypothesis follows, then he is not able to understand the initiative of this thing, nor the manner of its action or its order. This can be known by anyone who seeks it. |8:5| But if one lays down for that a reasoning from the simple circles or the motions of the things whose shapes are the positions of tambourines in the plane of the ecliptic, and if by means of them the places of the planets are derived from the sequence, then it makes this a clear, obvious matter for most people and one can learn through it whether it is in accordance with what is apparent to us and with the calculation laid down according to the aforesaid principles or not.

|8:6| We had to mention all of this first [in order] to decide which of these things laid down previously are in accordance with sound physical investigation. As for these things, this should suffice.

|9:1| Let us go on now with clarifying the matter of the hypothesis of the bodies that each of the motions has and their order. We give one general account so that we do not need to reiterate and repeat it, and so that we do not need to give a mixed account about what we want of its hypothesis concerning the motions and the magnitudes of the distances and the inclination and eccentricity and the epicycles. We make our method on this a method that follows the two options[71] in order that we also understand [the bodies'] particular differences and the multiplicity of the motions, into which we inquire, and their simplified path. |9:2| We start by this from above – I mean from the account on the sphere of the fixed stars

[69] This Persian loanword, *dastabandā*, designates a type of game or dance, in which people 'turn round in a circle, as though imitating the revolutions of the "host of heaven"', see Lane, *An Arabic–English Lexicon*, Vol. 3, pp. 878–79. See also the the commentary to Chapters II.7–8, p. 380 n. 107.

[70] It is unclear to me how one can make sense of the introducing *wa-humā* or *wahman*.

[71] i.e. the options of complete spheres and sawn-off pieces.

|9:2| ونبتدئ بذلك من فوق أعني من القول في كرة الكواكب الثابتة لأنّها أوّل ما يتحرّك حركة محسوسة ولا يستقيم أن يكون فيها إلّا الواحد من النوعين اللذين ذكرنا للحركة فقط. وذلك أنّ الكواكب متفرّقة متبدّدة في جميعها وهي تحفظ وتلزم على حالة واحدة ليس وضع بعضها عند بعض ومراتبها فقط لكن والقوّة التي يجب أن تكون ممتدّة في الكرة التي تحيط بها وتحرّكها.

|10:1| ويسمّى ما كان من الأجسام المتحرّكة من المشرق إلى المغرب على أقطاب فلك معدّل النهار وكان يذهب بجميع ما يحيط به إلى ناحية حركة الكلّ بالضرورة باسم عامّ له وهو المحرّك. وأوّل هذه الأجسام هو الذي يحرّك كرة الكواكب الثابتة والثاني هو الذي يحرّك كرة زحل الخارجة والثالث الذي يحرّك كرة المشتري الخارجة وكذلك ما يتلوا هذا على الوِلاء. |10:2| ويسمّى كلّ واحد من الأجسام التي تحت هذا الجسم بحسب L30v ما يعرض في كلّ واحد منها من الأعراض أعني من قياس وضعها إلى وضع فلك البروج. |10:3| وذلك أنّ بعض الذي يحيط بالأرض منها تدور على سهم فلك البروج نفسه وتسمّى المتشابهة المراتب. وبعضها مركزها مركز هذا الفلك ولكنّها لا تدور على سهمه وتسمّى الأفلاك المائلة. |10:4| وبعضها ليست على مركزه ولا تدور على سهمه. وبعض هذه تدور على سهم يوازي سهم فلك البروج وتسمّى باسم خاصّ لها أفلاك خارجة المراكز. وبعضها تدور على سهم ليس يوازي سهم فلك البروج وتسمّيها باسم خلاف اسم الأولى وهو ضد المتشابهة المراتب. |10:5| وأمّا التي لا تحيط بالأرض وهي التي تسمّى باسم عامّ لها وهو فلك التدوير فإنّ بعضها تتحرّك على سهم يوازي الفلك المائل الذي ذكرنا وتسمّى غير مائلة. وبعضها تتحرّك على سهم غير موازٍ وتسمّى مختلفة الميل. |10:6| وما كان منها محيطًا بالأجسام المضئة يسمّى محرّك الكواكب.

1 من القول] om L   كرة] أكر B   **2** يستقيم] تشقيص L   ذكرنا] ذكرناه L   **3** وذلك…جميعها] om L   حالة] om L   **6** المتحرّكة] متحرّكًا B   **7** يحيط] يحتاط L   **8** هو²] om L   **10** التي] الذي L   **12** الذي] التي L   تدور] يدور B   نفسه] om L   **13** مركزها] مركزه BL   ولكنّها] ولكنّه BL   تدور] يدور BL   **14** وتسمّى] ويسمّى L   تدور] يدور L   **15** وتسمّى] ويسمّى B   **15/16** وتسمّى…البروج] om L   **16** وتسمّيها] ونسمّيها L   **18** تسمّى] نسمّيها B   لها] om B   الفلك] للفلك L   **19** ذكرنا] ذكرناه B   وتسمّى¹] ويسمّى BL   مائلة] وبعضها يتحرّك على سهم غير موازٍ ويسمّى غبر L   وتسمّى²] ويسمّى L   مائلة add B

– because it is the first [thing] that moves with a perceptible motion, and it is correct that there is [in it] only one of these two aforementioned kinds of motion. For the stars are dispersed and spread in [the sphere's] entirety, while they are preserved and stay permanently in one condition, not only the position of some of them to others and their ranks, but [also] the capacity that is necessarily spread over the sphere, which encompasses and moves them [i.e. the stars].

|10:1| Those of the bodies that move from east to west according to the poles of the equator and that go necessarily with everything that they encompass in the direction of the motion of the universe are called by a general name, namely 'movers'. The first of these bodies is that which moves the sphere of the fixed stars; the second is that which moves the outer sphere of Saturn; the third is that which moves the outer sphere of Jupiter; and likewise this goes on according to the sequence. |10:2| Each of the bodies below this body is called according to the properties that occur for each of them (I mean from the reasoning of their position to the position of the ecliptic). |10:3| For some of them, which surround the Earth, revolve around the axis of the ecliptic itself, and they are called 'the similarly ordered'. Others [have] as their centre the centre of this sphere but do not revolve around its axis, and they are called 'inclined spheres'. |10:4| Others are not [relying] on its centre and do not revolve around its axis. Some of these revolve around an axis that is parallel to the axis of the ecliptic, and they are called by a specific name, [namely] 'eccentric spheres'. Others of these revolve around an axis that is not parallel to the axis of the ecliptic, and they are called by a name contrary to the name of the first, namely 'the dissimilarly ordered'. |10:5| As for those that do not surround the Earth and that are called by a general name, namely epicycle: some of these move around an axis parallel to the aforementioned inclined sphere, and they are called 'the non-inclined'. Others of these move around an axis not parallel, and they are called 'the differently inclined'. |10:6| What encompasses the shining bodies is called the 'mover of the planets'.

|11:1| فإذ قد قدّمنا وضع هذه الأشياء فإنّا نخطّ أوّلًا أربعة أفلاك مركزها مركز العالم وهي اب وجد وهز وحط. ونتوهّم نقط ا ح وط ب على سهم معدّل النهار وخطّي جه وزد المستقيمين على سهم فلك البروج. ونتوهّم أيضًا أنّ الكرة التي تحيط بها دائرتا ا ج B96v هي التي تحرّك كرة الكواكب الثابتة والتي تحيط بها دائرتا ج ه هي التي للكواكب الثابتة والكرة التي تحيط بها دائرتا ه ح هي التي تحرّك الكرة الخارجة التي لزحل. |11:2| L31r وليماسّ اج جه على ج ود ويماسّ جه هح على ه وز. وإذا كان اج يتحرّك من المشرق إلى المغرب على نقطتي ا ب الثابتتين فإنّ النقط الأخر التي فيه ممّا ليس على سهم اب تتحرّك مثل هذه الحركة التي ذكرنا حتّى أنّ نقطتي ج د أيضًا والكرة المتّصلة بهما التي للكواكب الثابتة وهي جه تتحرّك على مثل ذلك. وتتحرّك كرة جه على سهم جد على خلاف حركة اج إلى ناحية المشرق وتتحرّك بحركتها هح إلى تلك الجهة بعينها ومثل حركتها في السرعة. ولكنّها حينئذ لا تحفظ الوضع الذي لاج الذي هو أمر اضطراري في أن تحرّك الكرة الخارجة من أكر زحل كما كانت تحرّكها اج.

|11:3| لو كانتا متّصلتين وكان يحتاج إلى أن تكون حركة هح التي صارت مع حركة جه على خلاف ذلك وأن تكون مثل حركة تلك في السرعة فإنّه على هذا الوجه ليس أنّها تكون نقطتا ج د ونقطتا ه ز من الكرتين الطرفين باقية على عمود واحد بعينه وهو سهم فلك البروج فقط لكنّ وا ب ح ط الذي هو سهم معدّل النهار. وهو من البيّن أنّ جميع ما في كرة اج مع ما في كرة هح يحفظ وضعًا واحدًا بعينه.

|11:4| فأمّا أنّ القول بأكر تطيف وتلتفّ بعضها على بعض فضل لا يحتاج إليه في هذه الاتّصالات أعني في التي تكون فيها أقطاب الكرتين على سهم واحد. |11:5| فإنّه L31v يتبيّن بهذا القول الذي أنا قائله وهو أنّ قطبي كرة هح إن لم يكن لهما وضع على ه ز لكن يكونان على نقط أخر من النقط التي تتحرّك من كرة جه فإنّه ينبغي أن تتحرّك هي

2 وهز] وهو L   3 وزد] زد B   4 والتي...الثابتة[2]] om L   5/6 اج[1]...ح] om L   5 هي] هي B   6 وليماسّ] ولتماس B   ود] om B   وإذا] فإذا L   7 الثابتتين] الثابتين L   11 ولكنّها] والكنها L   13 حركة[2]] كرة B   14 تكون] يكون B   أنّها] إنّما B   15 تكون] يكون B   الكرتين الطرفين] الكرة B   15/16 واحد...فقط] om L   17 مع ما] معما L   18 بأكر] بأنّ أكرًا B   عمود] عموده L   القصوى B   فضل] فصل BL   20 يتبيّن] يبيّن B   قطبي] نقطي L   21 نقط] نقطة B   هي] هي B

|11:1|[72] Now that we have laid down these matters, we first draw four circles, with their centre being the centre of the world, namely AB, CD, EF, and GH. We imagine the points A, G, H, and B on the axis of the equator and the two straight lines CE and FD on the axis of the ecliptic. Moreover, we imagine that the sphere that is encompassed by the two circles of A and C is the one that moves the sphere of the fixed stars and that [the sphere] that is encompassed by the two circles of C and E is for the fixed stars, and that the sphere that is encompassed by the two circles of E and H is the one that moves the outer sphere belonging to Saturn. |11:2| Let AC[73] touch CE at C and D, and let CE touch EH at E and F. When AC moves from east to west around the two fixed points A and B, the other points on it that are not on the axis of AB move like the aforementioned motion so that the two points C and D as well as the sphere that is contiguous with them and that belongs to the fixed stars, namely CE, move like this. The sphere CE moves around the axis of CD contrary to the motion of AC eastwards and EG moves by its motion [i.e. the motion of CE] in the very same direction with the same speed. However, then [EG] would not preserve the position of AC, which is necessarily the case for moving the outer sphere of the spheres of Saturn as if it was moved by AC.

|11:3| If the two [spheres] are contiguous [i.e. AC and EG] and if this demands that the motion of EG, which came to be together with the motion of CE, is contrary to it [i.e. CE] and of the same speed as that [i.e. AC], then according to this picture, it is not the case that only the two points C and D and the two points E and F of the two outer spheres remain on one and the same pillar, namely the axis of the ecliptic, but [it is the case] that A, B, G, and H [lie on the axis] which is the axis of the equator. It is clear that all of what lies on the sphere AC together with what lies on the sphere EG preserves one and the same position.

|11:4| Now [we come] to the argument that the spheres surround and unwind each other: This is an excess that we do not need regarding these connections – I mean regarding these [instances] at which the poles of the two spheres are on one axis. |11:5| This becomes evident through what I am about to say: if the two poles of the sphere EG do not lie on EF but on other points of it that move from the sphere CE, then it is necessary that it and its poles also move together with the

[72] I provide a detailed analysis of this chapter as an example for all planetary models of Book II in the commentary to Chapters II.11–16.

[73] This means the sphere encompassed by the two circles on which A and C lie.

أيضًا وأقطابها مع حركة كرة جه وتحتاج إلى الحركة التي تكون بالتفاف. لكن إذا كانت نقطة ه ونقطة ز ثابتتين فليس كرة هح بمضطرّة إلى أن تتحرّك مع كرة جه ولا بمثل حركتها وذلك أنّه يمكن إذا تحرّكت كرة جه ممّا يلي اج أن تكون هي ثابتة وتكون النقطتان الثابتتان مشتركتين لكلتي الكرتين وهما نقطتا ه ز وهذه الحال هي مثل حالها.

|11:6| لو كان السهم الذي يمرّ ب ج ه وز د متّصلًا بالكرتين اللتين في الطرفين وكان مطلقًا مرسلًا في الكرة الوسطى فكان يحفظ تينك الكرتين على هيئتهما بعضهما بعضهما عند بعض أبدًا وكانت تتحرّك هذه الوسطى إلى جانب تينك كلتيهما حركة على الخلاف B97r حتّى أنّ الأمر الأولى كان أن تسمّى هذه الأكر ثابتة مكانَ تسميتها الملتفّة. |11:7| وهي في هيئة الأكر كلّها كرة كرة حالها هذه الحال وهذه هي الكرة الأولى الخارجة من التي تلتفّ بعضها على بعض. وينبغي أيضًا أن تكون هذه الكرة موضوعة في الوجه الآخر من الوجهين اللذين ذكرنا ولكن لا يكون كالملتفّية لكن كالتي تقارن التي هي خارجة عنها بكرة واحدة بنوع من الأنواع كما يقارن هاهنا كرة هح كرة اج. L32r

|11:8| فبحسب القول بأكر تامّة فإنّ الأكر المتحرّكة تكون ثلاثة وهي هذه الكرة الأولى من الأكر المحرّكة وكرة الكواكب الثابتة والكرة الثانية من الأكر المحرّكة وتكون هذه أيضًا منفصلة ومحيطة بأكر زحل فقط. |11:9| وأمّا بحسب القول بالمنشورات فإنّ الكرتين اللتين ذكرنا تبقيان على حالهما والكرة الثالثة تكون مشتركة للأثير الذي تحيط به كرة الكواكب الثابتة كلّها ويحيط هو بجميع الأكر الباقية ويحويها. |11:10| ولهذا السبب إن أراد مريد ألّا يسمّى أثير أو سماء جوهرًا واحدًا بعينه فالواجب أن يصير اسم السماء واقعًا على الكرة التي تحيط بالكواكب الثابتة التي تنظر إليها بالضياء الكثير العدد جدًا. وأمّا سائر الأجسام فإنّها إمّا أن لا تكون قابلة لشيء من هذا وإمّا أن تكون قابلة لشيء واحد فقط أيّ بأنّ فيها كوكبًا واحدًا فقط.

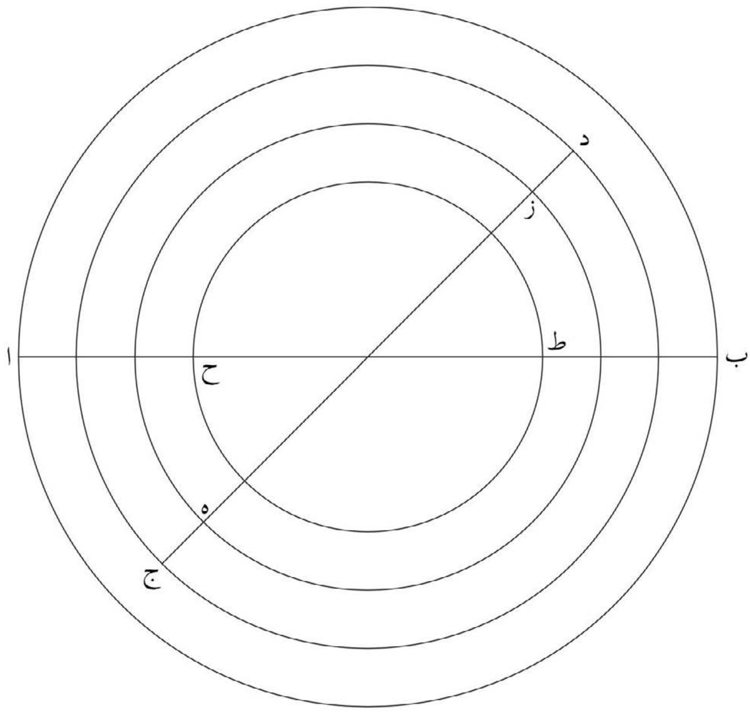
1 كرة] om L بالتفاف] بالتفات L **2** إلى] om B **4** حالها] حالهما L **6** فكان] وكان L تينك] تيك B **7** تينك] تيك B كلتيهما] كلّيتهما B **8** الملتفّة] الملبقة B **8/9** وهي في] وفي L **9** كرة²] om L وهذه هي] وهي L **10** وينبغي] فينبغي B أيضًا] sl L تكون] يكون L **11** يكون] تكون B كالملتفّية] كالملبثة B تقارن] تفارق L **13** بأكر] إنّها كرة B **14** المحرّكة¹] om B الثانية] الثابتة L وتكون] ويكون L **15** وأمّا] فأمّا B **16** تبقيان] يبقيان L الثالثة] الثانية B **18** ألّا] أن لا L أثير...واحدًا] أثيرًا وسماءً الجوهر الواحد B فالواجب] فبالواجب B **19** واقعًا] وافقًا B العدد] om B **20** لا] om L قابلة²] add له L **21** الشيء] بشيء L أيّ...فقط²] om L motion of the sphere CE and it needs a motion that comes about through unwinding. However, if the points E and F are fixed, then the sphere EG is not obliged to move together with the sphere CE nor [to move] by a similar motion, for it is possible that if the sphere CE moves from what follows AC, it is fixed, and that the two fixed points belong to both spheres, namely the two points E and F, and the condition of the one is like that of the other.

|11:6| If the axis that goes through C, E, F, and D is contiguous with the two outer spheres and if it is loose and set free from the intermediate sphere, then [the axis] always preserves these two spheres in their configuration in relation to each other, and this intermediate [sphere] moves with a contrary motion aside from these two, so that the more plausible thing to do is to call these spheres 'fixed' instead of calling them 'unwinding'. |11:7| In the configuration of the spheres, this is each sphere whose condition is like this, and this is the first outer sphere of those that unwind each other.[74] It is also necessary that this sphere is laid down in the other of the two aforementioned ways, [this other one] not being like the unwinding, but like that which is joined with that outside of it by one sphere [and] by a kind, just like here the sphere of EG is joined to AC.

|11:8| Thus, on account of the assumption of complete spheres, the spheres in motion are three, namely the first of the moving spheres, the sphere of the fixed stars, and the second of the moving spheres, the latter also being disjunct and only comprising the spheres of Saturn. |11:9| But on account of the assumption of sawn-off pieces, the two aforementioned spheres remain in their condition [i.e. as in the case of complete spheres], while the third sphere belongs to aether which the sphere of the fixed stars, in its entirety, encompasses, and it [i.e. aether] encompasses and comprises all the remaining spheres. |11:10| Therefore, if one does not want to call aether or heaven a single substance in itself, then the name 'heaven' must be applied to the sphere that encompasses the fixed stars, which can be perceived through the lights that are very great in number. As for the rest of the [heavenly] bodies, they either receive nothing from this, or they receive only one thing, namely through the fact that there is only one planet in them.

[74] Here, this term seems to refer to connected homocentric spheres in general and not specifically to the unwinding spheres. For a similar usage in Simplicius, see Bowen, *Simplicius on the Planets*, p. 135 n. 113. See the commentary to Chapter II.5, p. 373.

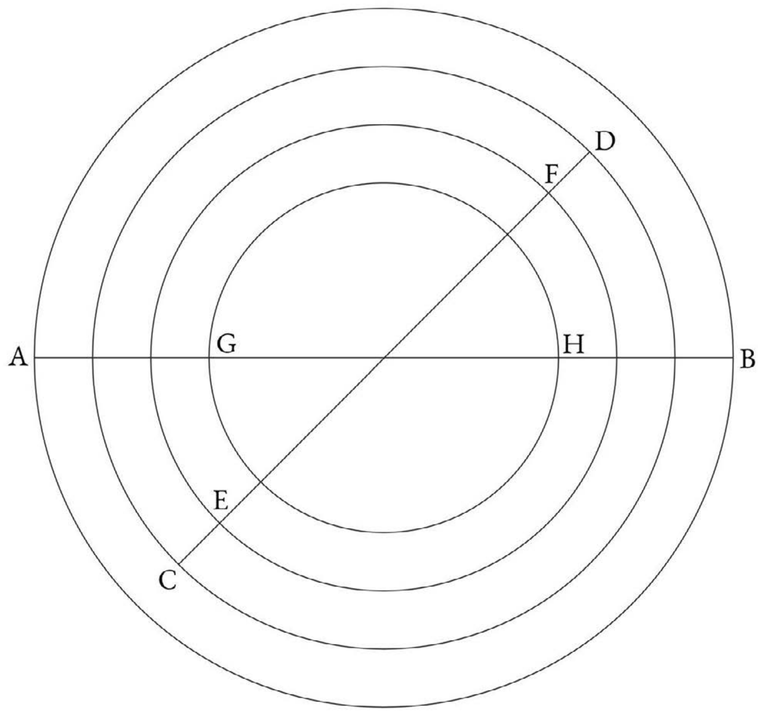
L32v |11:11| مثال عامّ للحركة الأولى الكلّيّة وكيف تحرّك أفلاك الكواكب.



L33r |12:1| أمّا في هذه الأشياء فإنّ فيما قلناه منها بعض القنوع. فلنبيّن بعد هذا ما يلزم في وضع وترتيب أكر زحل. |12:2| فليكن حول ا الذي هو مركز فلك البروج الكرة الثانية من الأكر المحرّكة وهي التي تحيط بدائرة بج كما كأن يكون المحرّكة حولها أو محيطًا بها لو نقلناها من موضعها الأعلى فجعلناها في أكثر ما يكون خروجًا ممّا هو دونه. |12:3| ونجيز على نقطة ا في سطح فلك البروج خطّ دا ونجيز عليها أيضًا في سطح الفلك المائل الذي يحيط بالأرض وعلى مركز الفلك الخارج المركز خطّ هزا. ونتوهّم عليه مركز الفلك الخارج المركز الذي عليه يتحرّك فلك التدوير نقطة ز ومركز كرة فلك التدوير ح. ونخطّ على مركز ح دائرتي طك ولم ونخرج في سطح الفلك المائل عن فلك التدوير

3 في[1]] بعض add L **4** فليكن] فليكون BL الكرة] للكرة B الثانية] الثابتة BL **5** المحرّكة[2]] المحرّك BL أو محيطًا] ومحيطًا B **6** ممّا] من ما L هو] om L **7** خطّ] حط L دا] جا B عليها أيضًا] أيضًا عليها B **8** خطّ] حط L **8/9** خطّ…المركز] om B **9** عليه] sl L

|11:11| General diagram for the first motion of the universe and how it moves the spheres of the planets.



|12:1| What we have already said about these things [might] be in some way convincing. Now, after this, let us show what belongs to the hypothesis and the order of the spheres of Saturn. |12:2| Let there be around A, which is the centre of the ecliptic, the second of the moving spheres, namely that which encompasses the circle BC, just as if the [first] moving [sphere] was around it and encompassing it if we transferred it [i.e. the first moving sphere] from its utmost position, so that we put it into the most extreme [position], where it is [still] outside of what is below.[75] |12:3| Through the point A in the plane of the ecliptic, we let the line DA pass, and also through [this point] and through the centre of the eccentric sphere, we let the line EFA pass in the plane of the inclined sphere that encompasses the Earth. On this line, we imagine the point F, the centre of the eccentric

[75] His point seems to be that the motion of the second moving sphere is the same as that of the first, which is the same as if we put the first moving sphere into a lower position.

خطّ لحم. ونخطّ على مركز ز الأشكال التي تحيط بأفلاك التداوير وهي نهس وعفق.
ونخطّ على مركز ا دائرة رشت والدائرة التي دونها. ونتوهّم نقط ن ز ب ج على السهم
الذي يمرّ بنقطة ا الذي هو سهم فلك البروج. ونتوهّم نقط ن ع ق س على السهم الذي
يمرّ بنقطة ز الذي هو سهم حركة فلك الخروج عن المركز المستدير. وأيضًا فإنّا نتوهّم L33v
نقطتي ث خ على السهم الذي يمرّ بمركز ح القائم على هف على زوايا قائمة ونتوهّم
تقطتي ذ ض على السهم الذي يمرّ بنقطة ح القائم على لم على زوايا قائمة. ونتوهّم B97v
نقطة ل على الكوكب. |12:4| ولتكن الخطوط التي تحدّ نسب الكوكب الخاصّة له از
زح والخطّ الذي بين نقطة ح ومركز الكوكب. |12:5| فهو بيّن ممّا قدّمنا أوّلًا أنّ الكرة
التي تحيط بدائرة بج إذا تحرّكت من المشرق إلى المغرب حرّكت أيضًا الكرة التي
تحيط بها دائرة بج ودائرة نس التي هي أوّل أكر زحل. ولأنّ هذه الكرة المحرّكة تتحرّك
على سهم معدّل النهار وقطبا كرة بنجس اللذان هما ب ج هما موضوعان على سهم
فلك البروج فإنّ كرة بن إذا تحرّكت بالقرب من الكرة التي تحرّكها من ناحية المغرب
إلى ناحية المشرق بالحركة التي هي لأوج الفلك الخارج المركز تحرّكت معها أيضًا الكرة
التي تحيط بها دائرتا نس وعق. |12:6| ولأنّ هاهنا أيضًا قطبان آخران وهما ن س وهما
موضوعان على سهم آخر سوى السهم الذي يمرّ ببج فإنّها هي أيضًا تتحرّك إلى جانب
بن إلى ناحية المشرق بمثل حركة فلك التدوير. |12:7| وليس تتحرّك الكرة التي تحيط بها
عق ورت مع حركة كرة نع لكن تبقى على الوضع الذي لبن لأنّ قطبي كرة نع وهما ن
س وقطبي كرة عق اللذين هما ع ق هي أيضًا على سهم واحد. وتتحرّك مع كرة عر الكرة L34r
التي تحيط بها رت لأنّ قطبي كرة عر اللذان هما ع ق لا يقعان مع نقطتي ر ت على

1 خطّ] حط L لحم] لجم B وهي] add نهس L نهس] نهش B **2** ونخطّ] نخط B رشت] زشت B ج] add تمرّ L **4** الخروج] البروج L **5** ث خ] تح L نح B بمركز ح] كزح L **6** ذ ض] دص BL **7** ولتكن] وليكن L التي] الذي L نسب] بسبب BL **8** زح] وح L فهو] وهو L **9** حرّكت] حركة L **10** نس] يس L الكرة] الحركة B **12** تحرّكها] تحرّكهما L **14** وعق] عق B ولأنّ] فلأنّ B أيضًا] om B قطبان] قطبين B آخران] آخرين B ن س] ي س L **15** آخر] أخرى L **16** بن] بق L تتحرّك] تحرّك B **17** عق] عف B ورت] ورث B نع[1]] بع B لأنّ] لا B كرة[2]] كز B **17/18** ن س] ي س L **18** عق] عن B عر] عز B **19** رت] رث B قطبي] sl B كرة] om L عر] عرق L عز B اللذان] اللذين B ت] رث B sphere on which the epicycle moves, and [the point] G, the centre of the epicyclic sphere. We draw around the centre G two circles, HK and LM. We produce the line LGM in the plane of the sphere that is inclined to the epicycle. We draw around the centre F the figures that encompass the epicycles, namely NES and OPQ. We draw around the centre A the circle RŠT and the circle below it. We imagine the points T, R, B, and C on the axis going through point A and being the axis of the ecliptic. We imagine the points N, O, Q, and S on the axis going through the point F and being the axis of the motion of the circular eccentric sphere. Furthermore, we imagine the two points Ṯ and U on the axis that goes through the centre G at a right angle on EP, and we imagine the two points V and W on the axis that goes through the point G at a right angle on LM. We imagine the point L on the planet. |12:4| The lines that determine the ratios[76] of the planet specific to it are AF, FG, and the line which is between the point G and the centre of the planet. |12:5| Thus, it is clear from what we have presented previously that if the sphere that encompasses the circle BC moves from east to west, it also moves the sphere which is encompassed by the circle BC and the circle NS, and which is the first of the spheres of Saturn. Because this moving sphere moves around the axis of the equator and because the two poles of the sphere BNCS, namely B and C, lie on the axis of the ecliptic, the sphere that is encompassed by the two circles NS and OQ also moves together with the sphere BN, if [BN] moves close to the sphere that moves it from west to east through the motion which belongs to the apogee of the eccentric sphere. |12:6| Because here are also two other poles, namely N and S, whereas they lie on another axis apart from that one which goes through BC, this [sphere] also moves towards BN to the east, just as the motion of the epicycle. |12:7| The sphere that is encompassed by OQ and RT does not move together with the motion of the sphere NO, but it remains in the position which BN has because the two poles of the sphere NO, namely N and S, and the two poles of the sphere OQ, which are O and Q, are also on one axis. Together with the sphere OR, the sphere that is encompassed by RT moves because the two poles of the sphere OR, which are O and Q, do not lie together with the two points R and T on one axis. |12:8| And if the sphere that is encom-

[76] This emendation was already suggested by Nix and Buhl and Heegaard. See Ptolemy, 'Hypotheseōn', p. 127. Instead of 'ratios' (*nisab*), the manuscripts have 'because of' (*bi-sabab*).

سهم واحد. |12:8| وإن دارت الكرة التي تحيط بها رت حول هذه المواضع التي هي على العمود الذي عليه بج من المشرق إلى المغرب بمثل المقدار الذي يتحرّك به من المغرب إلى المشرق كرة بن التي تتحرّك مع المحرّك فإنّه يكون للكرة التي تحيط بدائرة بج وللتي تحيط بها دائرة رت وضع واحد. |12:9| وقد كانت الكرة التي تحيط بدائرة بج هي الثانية من الأكر المحرّكة وهي من أكر زحل. فتصير الكرة التي تحيط بها رت هي الكرة الثالثة من الأكر المحرّكة وهي من أكر المشتري.

|12:10| وأمّا من أفلاك التداوير فإنّ كرة فلك التدوير التي تحيط بها دائرتا طك ولم التي هي مجوّفة تتحرّك على سهم ثخ حركة مساوية لحركة الكرة التي تحيط بها التي هي هف إلّا أنّها تتحرّك على الخلاف. وذلك أنّها تحرّك القطعة التي تلي الأوج إلى المغرب والتي تلي البعد الأقرب إلى المشرق. |12:11| والكرة التي تحيط بها دائرة لم التي هي متّصلة بالكوكب الذي عليه ل تحرّكها كرة ثذ إلى الناحية التي تتحرّك إليها لأنّ أقطابها ليست على سهم تلك وتتحرّك هي مع الكوكب حركة مخالفة لتلك على سهم ضذ. L34v أعني أنّ القطعة منها التي تلي الأوج تنقلها إلى المشرق والتي تلي البعد الأقرب إلى المغرب.

|12:12| فجميع ما يجب من حركة الأكر المحيطة وحركة الكوكب نفسه يجعل لنا أكر زحل خمسًا ثلاثًا منها الأكر التي تحيط بالأرض. وهي كرة بن التي هي مشابهة في B98r المرتبة لفلك البروج لأنّها تدور على سهمه وكرة نع التي هي غير مشابهة في المرتبة لفلك البروج لأنّها لا تدور على مركزه ولا على سهم موازٍ لسهمه وكرة عر التي يكون أبدًا وضعها موافقًا لوضع كرة بن التي منها ترجع الكرة الثالثة المحرّكة إلى وضع ما قبلها من الأكر المحرّكة. |12:13| وليس ينبغي أن نعدّ هذه الأكر المحرّكة مع الأكر التي تفصل

1 رت] رث B   هي] om L   **2** من¹…المغرب] من المغرب إلى المشرق sl L   به] om BL   **3** كرة] وكرة L   للكرة] الكرة B   **4** وللتي] والتي B   رت] زث B رت L   **5** هي الثانية] هي الثابتة L الثانية هي B   المحرّكة] المتحرّكة B   **6** المحرّكة] المتحرّكة B   رت] زث B   **7** وأمّا] فأمّا B   دائرتا] دائرة L   **8** تتحرّك] يتحرك L   ثخ] بج B   بها] به L   **9** تلي] يلي L   **10** تلي] يلي L om B   **11** ل] ا L   ثذ] تد L ند B   تتحرّك] يتحرّك L   **12** ضذ] ند B   **13** تلي¹] يلي L   تلي²] يلي L   الأقرب] corr sl L   **16** خمسًا ثلاثًا] خمسة ثلاثة L   ثلاثًا] ثلثًا B   منها] منه B   بن] بز L   مشابهة] متشابهة B   **17** نع] تع L   غير] عير L   مشابهة] متشابهة B   **18** لا] om B   عر] عز B   يكون] تكون B   **19** ترجع] يرجع منها L   **20** وليس] فليس B passed by RT revolves around these positions, which are on the pillar on which BC is, from east to west by the same amount by[77] which the sphere BN moves from west to east, which moves together with the moving [sphere], then the sphere that encompasses the circle BC and the one that encompasses the circle RT have one position. |12:9| The sphere that encompasses the circle BC is the second of the moving spheres and belongs to the spheres of Saturn. The sphere which is encompassed by RT becomes the third of the moving spheres and belongs to the spheres of Jupiter.

|12:10| As for [the case] of the epicycles: the sphere of the epicycle that is encompassed by the circles HK and LM and that is hollow moves around the axis ṮU equally to the motion of the sphere which encompasses it, which is EP, except that it moves in the contrary [direction]. For it moves the segment which follows the apogee to the west and [the segment] which follows the perigee to the east. |12:11| The sphere that is encompassed by the circle LM and that is contiguous with the planet, on which is L, is moved by the sphere ṮV in the direction in which it moves, because its poles do not lie on the axis of that [sphere, i.e. ṮV], and it moves together with the planet in the opposite [direction] of the other around the axis VW. I mean that the segment of it that follows the apogee moves it to the east and the [segment] that follows the perigee [moves] it to the west.

|12:12| Thus, everything necessary for the motion of the encompassing spheres and the motion of the planet itself makes us [posit] five spheres of Saturn. Three of these are the spheres encompassing the Earth. They are the sphere BN, which is similarly ordered in relation to the ecliptic because it revolves around its axis; the sphere NO, which is not similarly ordered in relation to the ecliptic because it does not revolve around its centre nor around an axis parallel to [the ecliptic's] axis; and the sphere OR, whose position is always in agreement with the position of the sphere BN, from which the third moving sphere returns to the position that belongs to the [first two] moving spheres before it. |12:13| We should not

[77] For this addition in the Arabic text, see Rashed and Penchèvre, 'Ibn al-Hayṯam', p. 123:14.

فيما بينها لأنّها ليست بخاصّية لشيء من الكواكب. فأحرى إذًا ألّا نعدّ معها مرّتين. ولا ينبغي أن نفعل ذلك بها لأنّها تحيط وتحاط بها فإنّ هذا قد يعرض أيضًا لغيرها من الأكر ولا لأنّها متقدّمة لبعض الكواكب متأخّرة عن بعض لأنّ كلّ واحدة منها واحدة في النوع والعدد. وأمّا في القوّة فكلّها واحدة. |12:14| وتكون لنا أيضًا من أفلاك التداوير كرتان كرة فلك تدوير طك وهي مجوّفة لا ميل لها وذلك أنّ سهم ثخ يوازي سهم نس والكرة التي L35r تحيط بها هذه الكرة وهي الحاملة للكوكب وهي مائلة عنها لأنّ سهم ذض ليس بموازٍ لسهم نس.

|12:15| فأمّا في وضع المنشورات الكرية فنتوهّم على دائرة بج وتحت دائرة رت كرة الأثير متّصلة. ونتوهّمها تدير بدورانها القطع الكرية التي تحيط بها دَوَرانًا من المشرق إلى المغرب. |12:16| وليكن المنشور الأوّل في هذا الموضع هو منشور من الكرة التي تحيط بها دائرتا بج ورت وليكن هذا المنشور مأخوذًا فيما بين دب وضدّها في الوضع وليكن قائمًا على سهم بج الذي هو سهم فلك البروج على زوايا قائمة. |12:17| وليكن المنشور الثاني منشورًا آخر من الكرة التي تحيط بها دائرتا نس وعق وليكن هو أيضًا فيما بين هج وضدّها في الوضع وليكن قائمًا على سهم نس على زوايا قائمة وليكن قد أحاط بجميعته المنشور الأوّل. |12:18| وليكن أيضًا منشور ثالث في داخله وليكن هذا المنشور من كرة فلك التدوير المجوّفة التي تحيط بها دائرتا ثخ وذض وليكن هو أيضًا في وسط طك وليكن قائمًا على سهم ثخ على زوايا قائمة. |12:19| وليكن أيضًا منشور رابع يحيط بكلّيته هذا المنشور الذي ذكرنا. وليكن قطعة من الكرة المحرّكة للكوكب التي هي مصمتة وليكن هو أيضًا في وسط لم وليكن قائمًا على سهم ذض على زوايا قائمة.

1 إذًا] إذن B **2** وتحاط] ويحاط L هذا] add أيضًا B أيضًا] om B **4** وتكون] ويكون L **5** ثخ] نح B نس] لس BL **6** ذض] دض B **8** رت] رث B زت L **9** تدير] add تدير L بدورانها] بدوراتها L **10** وليكن] فليكن B **10/11** الأوّل...بها] om L **11** ورت] رث B مأخوذًا] مأخوذ B دب] دج B **13** آخر] om L نس] نس B **14** في] om L نس] سن B بجميعته] بجميعة BL **16** ثخ] ثج L بج B وذض] ودص B **17** ثخ] يج L بج B رابع] راجع L **18** وليكن] ولتكن L ذض] دص B وسط] سطح B **19** مصمتة] مضمنة L للكوكب] للكواكب L count these moving spheres together with the spheres that are separated between them because they are not specific to any of the planets. Thus, it is more appropriate not to count them together with [the spheres of Saturn] twice. We should not do this with them because they encompass and are encompassed, for this may also occur for spheres other than them, nor because they precede some planets and fall behind others, for each of them is one in species and number. In potentiality, all of them are one.[78] |12:14| Furthermore, there are for us two spheres of the epicycles: the sphere of the epicycle HK, which is hollow and has no inclination, for the axis Ṯ U is parallel to NS; and the sphere which is encompassed by this sphere and which carries the planet and which is inclined to it, because the axis VW is not parallel to the axis NS.

|12:15| As for the case of the hypothesis of the spherical sawn-off pieces,[79] we imagine around the circle BC and below the circle RT the sphere of aether as being continuous. We imagine it to rotate the spherical segments which it encompasses by its own revolution from east to west. |12:16| Let the first sawn-off piece in this position be a sawn-off piece of the sphere that is encompassed by the two circles BC and RT. Let this sawn-off piece be taken to be in [the space] between DB and its opposite in position, and let it be at a right angle to the axis of BC, which is the axis of the ecliptic. |12:17| Let the second sawn-off piece be another one from the sphere which is encompassed by the two circles NS and OQ, and furthermore, let it be in [the space] between EC and its opposite in position, and let it be at a right angle on the axis of NS, and let the first sawn-off piece encompass its entirety. |12:18| Let there also be a third sawn-off piece inside of it and let this sawn-off piece be from the hollow sphere of the epicycle that is encompassed by the two circles ṮU and VW, and furthermore, let it be within HK and at a right angle to the axis of ṮU. |12:19| Let there also be a fourth sawn-off piece encompassed in its entirety by this aforementioned sawn-off piece. Let it be a segment from the sphere moving the planet which is solid and let it be within LM and at a right angle to VW. |12:20| On account of this hypothesis, only four sawn-off pieces are sufficient for us, three of which are similar to whorls, and one of them, namely the last one, is similar to a tambourine. |12:21| One should understand the motion in each of them according to the approach that is under-

[78] On this aspect, see the commentary to Chapters II.11–16, p. 384.

[79] Here, Ptolemy means that the sawn-off pieces are taken out of complete spheres, as is apparent from the formulation in later chapters.

|12:20| فبحسب هذا الوضع تجزينا أربعة منشورات فقط ثلاثة منها شبيهة بالفِلَك L35v وواحد منها وهو آخرها شبيه بالدفّ. |12:21| وينبغي أن تفهم الحركة في كلّ واحد منها على المذهب الذي فُهم في الأكر التي هذه هي قطع لها وأن يفهم عرضها عن جنبتي السطوح المتوسّطة لها بمقدار ما يجزي في الإحاطة بالقطع التي تحاط بها كانت القطع موازية لفلك البروج أو كانت مائلة. |12:22| فتصل القطع بذلك إلى التي تحاط بها أبدًا فتتحرّك مع الحركة المحيطة وتصل من خارجها إلى الأثير. وحدّ العرض أمّا في شكل B98v الدفّ الصغير وفي وسط مل فبمقدار عظم الكوكب الذي يحاط به. وأمّا الذي يحيط بهذا ويلي طك فبمقدار عظم ميل دفّ لم. |12:23| وأيضًا فإنّ حدّ القطعة التي تحيط بهذا وهي فيما بين هف عظم هذا الميل وذلك أنّ وضع هاتين القطعتين وضع متوازٍ وعلى سطح واحد متوسّط لهما. وأمّا حدّ القطعة الخارجة عن الجميع وهي فيما بين بش فبمقدار عظم ميل منشور هف.

|12:24| فقد تبيّن أنّا إن لم يحرك الكوكب أيضًا بكرة أو منشور سيبطل جسم واحد من الأجسام الموضوعة لذلك الكوكب وهو الذي يلي دائرة لم المخالف في حركته لحركة فلك التدوير الأوّل. فأمّا أنّ قبول الوجه الآخر أولى بنا فقد تمكّنّا أن نتوهّمه من قبل الأشياء التي قبلت في سائر الأجسام حتّى يكون الكوكب أيضًا محتويًا على مكانه L36r كاحتواء كلّ واحد من تلك الأجسام ولا يحتوي على مكان لغيره احتواء متّصلًا كأنّما يتدحرج أو كأنّه يدفع شبيهًا بما يساق بعضها بعضًا. |12:25| فإنّ ما كان من الحركات على مثل هذه الحال فإنّه يستدلّ بذلك على أنّ ابتداء حركته من شيء آخر وبضرورة. وأمّا التدحرج فإنّه يخرج عن حدّ الحركة الدائمة حول الوسط. فالأولى إذًا أن يحرّك كلّ واحد من الكواكب أيضًا شيئًا لأنّ هذا هو قوّة الكوكب وفعله في موضعه الخاصّ له

1 تجزينا] يجزينا L أربعة] أربع L شبيهة] شبيه L **2** منها¹] om L تفهم] يفهم L **3** الأكر] الكرة B هي] om L يفهم] نقيم B **4** لها] add وأن يفهم عرضها عن جنبتي السطوح المتوسّطة لها L **5** فتصل] فيصل B **6** فتتحرّك] فيتحرّك L الحركة] حركة L وتصل] ويصل L **10** بش] دهر L **12** أنّا] لنا B سيبطل] فنبطل B **14** تمكّنّا] تمكّننا B **15** سائر] add † B **17** أو] و L يساق] يشاق B بعضها] om L **18** أنّ] om B وبضرورة] لضرورة B **19** إذًا] إذن B stood concerning the spheres for which these are segments, and one should understand their width on the two sides of the planes connected to them by the amount of that which is enough for encompassing the segments that they encompass,[80] may the segments be parallel to the ecliptic or inclined. |12:22| Thus, by this [approach], the segments always reach what encompasses them so that they move together with the encompassing motion, and they reach the aether from the outside. As for the case of the shape of the small tambourine and the interior of ML, the boundary of the width is [set] by the amount of the size of the planet which it encompasses. As for [the case of] what encompasses this and follows HK, [the boundary of the width] is [set] by the amount of the size of the inclination of the tambourine LM. |12:23| Furthermore, the boundary of the segment which encompasses this and which is in [the space] between EP is the size of this inclination, for the hypothesis of these two segments is a parallel hypothesis and on one intermediate plane connected to both. As for the boundary of the segment which is external to all others and which is in [the space] between BŠ, it is [set] by the amount of the size of the inclination of the sawn-off piece EP.[81]

|12:24| It is evident that if the planet does not also move by a sphere or by a sawn-off piece, one of the bodies laid down for that planet becomes obsolete,[82] namely that which follows the circle LM and which, in its motion, is contrary to the motion of the first epicycle. As for the case that it is more plausible for us to accept the other option, it is possible for us to imagine it as being part of the things that have been accepted in the case of the other bodies, so that the planet also occupies its place, just as each of these bodies occupies [its place], and so that it does not continuously occupy the place of another, just as what rolls or pushes is similar to what drives another. |12:25| From motions which are in such a condition, it can be inferred that the initiative of its motion comes from something else and [does so] necessarily. As for rolling, it goes beyond the definition of eternal motion around the centre.[83] Thus, it is more plausible that each planet also moves something, for this is the capacity of the planet and its action in a place that is specific to it and around its centre, namely by a continuous[84] and circular

[80] This sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 49:7–10.

[81] Basically, the width of each sawn-off piece depends on what it contains: it must provide enough space for the size of the planet in the first case, and then, in every other case, for the inner sawn-off piece, which is sometimes inclined to it. These two sentences are paraphrased in Ibn al-Hayṯam, *al-Šukūk*, p. 49:10–13.

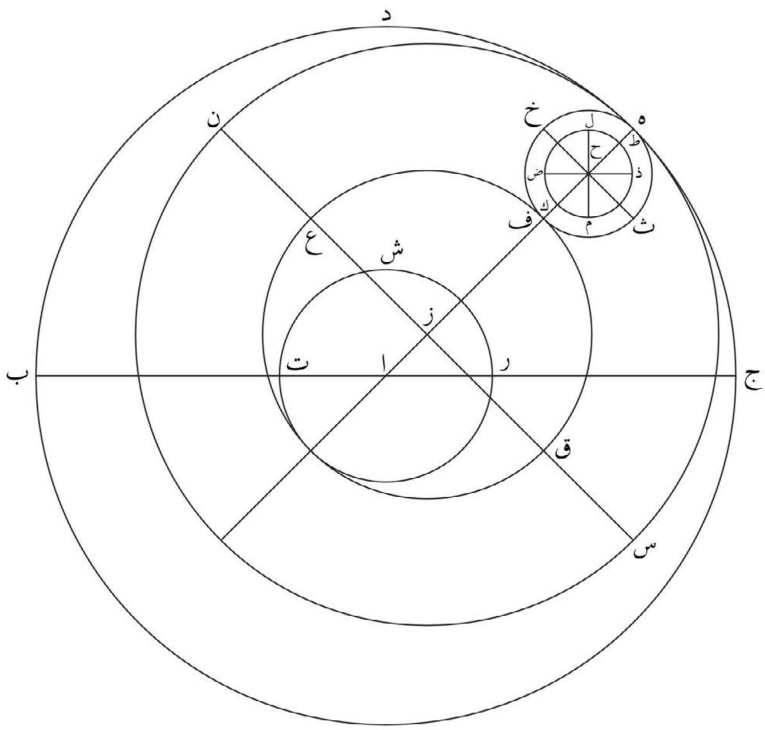
[82] Until here, this sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 60:12–13.

[83] This sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 61:16.

[84] Simplicius, *In Cael.*, p. 456:26: *homalōs*.

وعلى وسطه أعني الحركة المتّصلة المستديرة. فقد يجب أن يكون للكوكب أوّلًا الشيء الذي يفعله بالأجسام التي تحيط به.

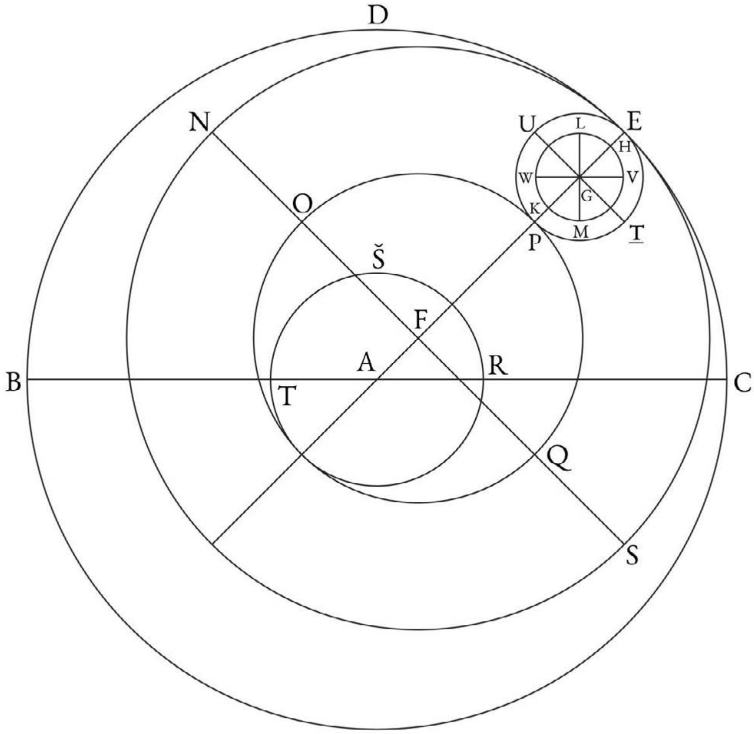
|12:26| مثال لأفلاك زحل ويعمّ المشتري والمرّيخ والزهرة.



L36v |13:1| فإذ كنّا قد وصفنا وضع الأشياء التي ذكرنا في كوكب زحل فينبغي أن نثبت ونحفظ هذا الوضع وهذا الترتيب بعينه في الأكر أو المنشورات التي لكوكب المشتري وكوكب المرّيخ وكوكب الزهرة. وأمّا النسب الخاصّة لكلّ واحد منها فإنّا نترك ذكرها إذ كانت قد ذكرت مع غيرها |13:2| ونأخذ في ذكر أشياء عامّية تستحقّ أن يذكر منها أنّ الأكر أو المنشورات التي تشبه جسم نَعَ مركزها أبدًا نقطة زَ. وليس يتمّ به لا استواء

3 ويعمّ] ونعمّ L **5** وصفنا] فصلنا B **6** أو] و B **7** الخاصّة] الخاصّية B **8** ذكرت] قد ذكرت add L ذكر] om B **9** أو] و B زَ] نَ B motion. It is necessary that the thing which the planet imparts to the bodies encompassing it primarily belongs to the planet.[85]

|12:26| Diagram for the spheres of Saturn, which also applies to Jupiter, Mars, and Venus.[86]



|13:1| Since we have described the hypothesis of the aforementioned things with respect to the planet Saturn, we now should establish and bring to mind this very same hypothesis and order with respect to the spheres or the sawn-off pieces belonging to the planets Jupiter, Mars, and Venus. As for the ratios specific to each of them, we refrain from mentioning them, since this has [already] been done together with the other [planets].[87] |13:2| We start by mentioning the general things, of which it is noteworthy that the spheres or sawn-off pieces that are similar to the body NO always have their centre at the point F. By this, neither

[85] This is preserved in Greek, for which see Simplicius, *In Cael.*, p. 456:22–27. The last sentence is also cited in Ibn al-Hayṯam, *al-Šukūk*, p. 61:18–19. In the commentary to Chapters II.11–16 (pp. 382–84), I explain some aspects of Ptolemy's additional remarks to the model of Saturn.

[86] The diagram is missing in L.

[87] Nix and Buhl and Heegaard refer to *Almagest* X and XI, see Ptolemy, 'Hypotheseōn', p. 131 n. 1.

الحركة ولا ميل فلك التدوير لكن كما قلنا وبيّنّا من أمر الأفلاك وأنّ ذلك إنّما يكون في نقطة على اح بعدها من ا كبعدها من ز وأنّ مركز فلك التدوير إذا كان في منتهى شمال ميل الفلك الذي يحيط بالأرض فعند ذلك يكون منتهى شمال الميل عن فلك التدوير B99r في زحل والمشتري والمرّيخ في البعد الأقرب من فلك التدوير. وأمّا في الزهرة وعطارد ففي نقطة بعدها من أوج فلك التدوير إلى ناحية المشرق تسعين جزءًا وهي ربع دائرة.

|14:1| فالنصر الآن إلى القول في الشمس ووضعها على هذه الصفة. نخطّ على ا وهو مركز فلك البروج دائرتي بج وده. ونخرج خطّ ازح في سطح فلك البروج ونتوهّم نقطة ز على مركز فلك الشمس الخارج المركز. ونرسم حول هذا المركز دائرتي كط ولم. ونعمل على مركز ح دائرة نس للشمس. |14:2| ونتوهّم الكرة التي تحيط بها بج كرة تحرّك L37r الشمس وهي الكرة الخامسة من الكرة الأولى المحرّكة والكرة التي تحيط بها دائرة ده هي الكرة التي تحرّك الزهرة وهي الكرة السادسة من الكرة الأولى. |14:3| ونجعل أيضًا نقطتي ب ج على سهم فلك البروج الذي يمرّ بنقطة ا ونجعل ط وك ول وم على سهم الفلك الخارج المركز الذي يمرّ بنقطة ز الذي هو موازٍ لسهم فلك البروج. ولتكن النسبة الخاصّة له نسبة از إلى زح. |14:4| فإذا تحرّكت كرة بط من المشرق إلى المغرب تحرّكت معها كرة طل لأنّ كرة بط تتحرّك على سهم معدّل النهار وكرة طل تتحرّك على سهم موازٍ لسهم فلك البروج. فإذا تحرّكت هذه الكرة حركة على الخلاف وحرّكت الشمس حركتها الخاصّية من المغرب إلى المشرق على السهم الذي يمرّ بطل ومك فإنّ كرة لد تبقى مقارنة لكرة بط لأنّ قطبيهما اللذين هما ل م هما ط ك على سهم واحد وهو سهم كرة طل حتّى أنّ وضع لد يكون كوضع بط وكوضع الكرة الأولى من الأكر المحرّكة.

2 ز] ن B **4** في[1]...التدوير] om L **8** ونرسم] ويرسم L ونعمل] ويعمل L **9** بج] بج L **10** الكرة[1]] الحركة B بها دائرة] بدائرة BL **11** الكرة[1]] om L **12** وك] و ك L **13** ز] ن B **14** الخاصّة] الخاصّية B از] ان B زح] نح B **15** كرة[1]] om L لأنّ...طل[2]] om L **16** مواز] يوازي L السهم] سهم L الكرة حركة] الحركة B **17** ومك] مد B مل L **18** لد] از B الكرة] om L بط] ل بط L لبط B قطبيهما] قطبها L ل] ا L ك] هما ل B **19** طل] طل B بط] بط L the regularity of motion nor the inclination of the epicycle is completed, but [it is] just as we have said and shown in the case of the spheres, namely that it is in one point on AG whose distance from A is like its distance from F, and that if the centre of the epicyle is on the northern limit of the inclination of the sphere that encompasses the Earth, then, upon that, the northern limit of the inclination against the epicyle is on the perigee of the epicycle in the case of Saturn, Jupiter, and Mars. As for the case of Venus and Mercury,[88] [it] is on a point whose distance from the apogee of the epicycle is 90 parts in the eastern direction, namely a quarter of a circle.

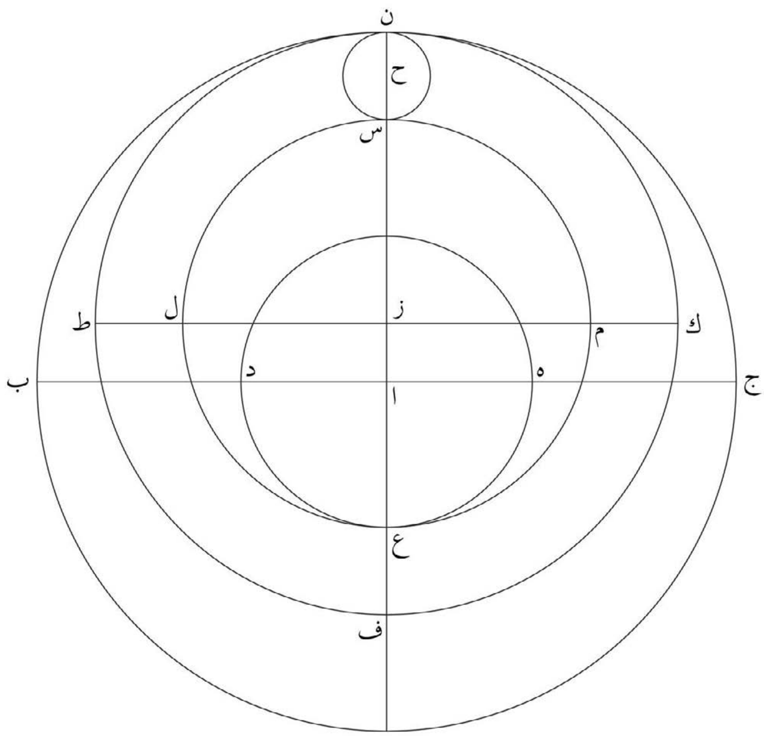
|14:1| Now, let us get to the discussion about the Sun and its hypothesis in this manner. We draw around A, which is the centre of the ecliptic, the two circles BC and DE. We produce the line AFG in the plane of the ecliptic, and we imagine the point F to be on the centre of the eccentric sphere of the Sun. Around this centre, we draw the two circles KH and LM. Around the centre G, we produce the circle NS for the Sun. |14:2| We imagine the sphere that is encompassed by BC to be the sphere moving the Sun, being the fifth sphere [counted] from the first moving sphere[89], and [we imagine] the sphere that is encompassed by the circle DE as the sphere that moves Venus, being the sixth sphere [counted] from the first [moving] sphere. |14:3| Further, we make the two points B and C [lie] on the axis of the ecliptic, which goes through point A, and we make H, K, L, and M [lie] on the axis of the eccentric sphere which goes through point F and which is parallel to the axis of the ecliptic. Let the ratio specific to it be the ratio of AF to FG. |14:4| If the sphere BH moves from east to west, the sphere HL moves together with it because the sphere BH moves around the axis of the equator, and the sphere HL moves around an axis parallel to the axis of the ecliptic. If this sphere moves contrary and if the Sun moves by its specific motion from west to east around the axis that goes through H, L, M, and K, the sphere LD remains joined to the sphere BH because the two poles of both of them, namely L and M and H and K, are on one axis, namely on the axis of the sphere HL, so that the position of LD is like the position of BH and like the position of the first of the moving spheres.

[88] This might be a mistake, given that Ptolemy will devote a chapter to the hypothesis of Mercury later.

[89] Namely after those moving the fixed stars, Saturn, Jupiter, and Mars.

|14:5| وكذلك أيضًا الأمر في وضع المنشورات الكرية فإنّ أبعاد بط ولد نتوهّمها متّصلة بكرة الأثير وتتحرّك معه مع القطعة الكرية التي تحويها من المشرق إلى المغرب. فتكون هاهنا الكرة كلّها واحدة والقطعة الموجودة هي من الكرة التي تحيط بها دائرتا كط ولم والموجودة فيما بين نس وعف وهي قائمة على سهم بج الذي هو سهم فلك البروج على زوايا قائمة وعرضها بمقدار ما يحيط بجرم الشمس. |14:6| فينبغي أن نجعل الفلك الذي للشمس جسمًا واحدًا على الوجهين جميعًا مجوّفًا غير زائل وهو خارج عن المركز لأنّ سهمه موازٍ لسهم فلك البروج.

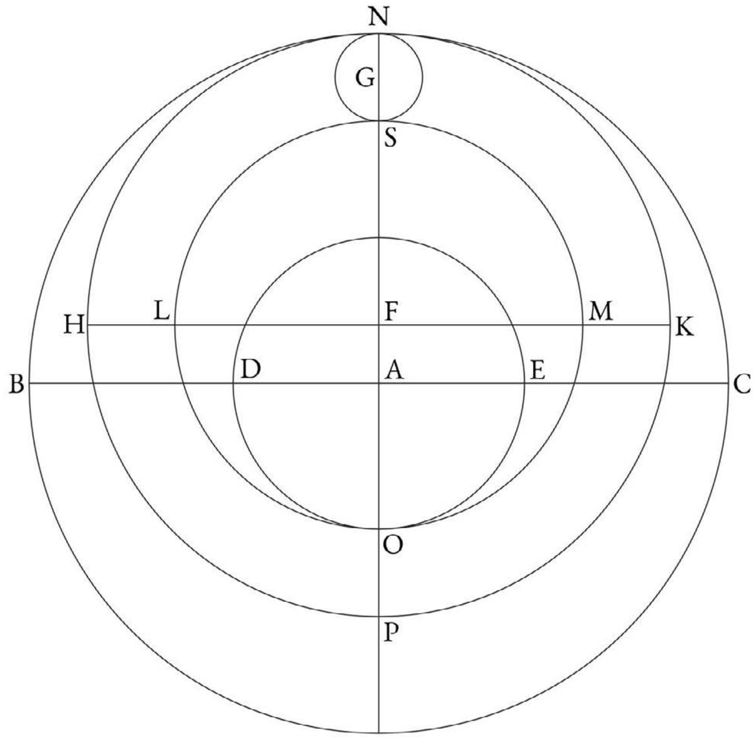
L37v |14:7| مثال لفلك الشمس.



1 نتوهّمها] يتوهّم L نتوهّم B **3** الموجودة] om L **4** والموجودة] والمأخوذة B **5/7** وعرضها...البروج] om L **5** الفلك] السهم B

|14:5| Furthermore, the same is the case for the hypothesis of the spherical sawn-off pieces, for we imagine the distances of BH and LD as continuous with the sphere of aether and to move together with it [and] with the spherical segment that it comprises from east to west. Thus, here the entirety of the sphere is one and the piece that can be found is from the sphere which the two circles KH and LM encompass and which can be found in [the space] between NS and OP, which is at a right angle to the axis BC, which is the axis of the ecliptic, and its width is [set] by the amount of what encompasses the body of the Sun. |14:6| We should make the sphere[90] belonging to the Sun one body, according to both options [i.e. complete spheres and sawn-off pieces], entirely hollow, in a fixed position, and eccentric, for its axis is parallel to the axis of the ecliptic.

|14:7| Diagram for the sphere of the Sun.[91]



[90] I follow the emendation of 'axis' to 'sphere' that was proposed by Nix and Buhl and Heegaard. See Ptolemy, 'Hypotheseōn', p. 133 n. 2.
[91] The diagram is missing in L.

B99v |15:1| القول في أفلاك عطارد.

L38r وأمّا في وضع كرة كوكب عطارد فإنّا نجعل أيضًا الكرة السابعة من الأكر المحرّكة الكرة التي تحيط بدائرة بج على مركز ا. ونجيز على نقطة ا جطّ دا في سطح فلك البروج ونجيز عليها أيضًا خطّ ها في سطح الفلك المائل الذي يحيط بالأرض. ونعلّم عليه مركز الفلك الخارج المركز وهو ز وليتحرّك هذا المركز حول مركز ح. وليكن مركز أكر أفلاك التداوير نقطة ط. ونخطّ على مركز ط دائرتي كل ومن. ونخرج في سطح فلك التدوير المائل الذي فيه يتحرّك الكوكب الذي عليه ن خطّ مطن. ونخطّ على مركز ز الدائرتين اللتين تحيطان بأكر أفلاك التداوير وهما سهع وفقر. ونرسم على مركز ح دائرتين تحيطان بالدائرتين اللتين ذكرنا وهما شت وثخ. ونعمل على مركز ا دائرة ذص والدائرة التي تحتها. وليكونا تحت الدوائر التي ذكرنا كلّها. ونتوهّم نقط ب ذ ض ج على سهم فلك البروج ونقط ش ث خ ت على سهم الفلك المائل الذي يحيط بالأرض الذي يمرّ بنقطة ح. ولتكن نقط س ف ر ع على سهم الفلك الخارج المركز الذي يمرّ بنقطة ز وهو موازٍ للسهم الذي يمرّ بنقطة ح. ونتوهّم نقطتي ص ظ من النقط التي في فلك التدوير على
L38v السهم الذي يمرّ بط ويكون قائمًا على كل على زوايا قائمة. ونتوهّم نقطتي ي غ على السهم الذي يمرّ بنقطة ط القائم على من على زوايا قائمة. ولتكن النسب الخاصّية للكوكب موجودة في خطوط اح وحز وزط والخطّ الذي يخرج من نقطة ط إلى مركز الكوكب. |15:2| فلهذه الأسباب معما تقدّم ذكره تكون الكرة التي تلي دائرة بج إذا حرّكت ما تحيط به من المشرق إلى المغرب فإنّ كرة بش التي هي على سهم فلك البروج الذي هو بج تتحرّك إلى ما يتقدّمها أعني إلى المشرق بمثل حركة الأوج. وتحرّك

1 القول...عطارد] om L **2** كرة كوكب] فلك B **3** ونجيز] ويُجيز L **4** ونعلّم] نتعلّم L عليه] على B **5** ز] ن B **6** ط¹] طا L **7** ن خطّ] زحط B زخطّ L ز] ن B **8** وفقر] فقر B ونرسم] ويرسم L ح] ه B **9** شت] شت B وثخ] نح B ذص] دص B والدائرة] الدائرة B **10** نقط] نقطة L ذ] د BL ض ج] ص ح B **11** ث] ب B ت L خ] ح B ت] ب B **12** ولتكن] وليكن L ف] ق BL على...المركز] om L ز] ن B **13** للسهم] الذي يمرّ على سهم حركة الفلك الخارج المركز add L ظ] ط BL **14** بط] يط L كل] كلّ L ي غ] دع B نع L **15** من] مز L مر B ولتكن] وليكن L **16** وحز] حن B وحز L وزط] زط B ورط L **17** معما] مع ما B معما خذ L الكرة] الأكر B **18** بش] نش B **19** بمثل] وبميل B بمثل L

|15:1| The discussion of the spheres of Mercury.

As for the hypothesis of the sphere of Mercury, we also make the seventh of the moving spheres the sphere that encompasses the circle BD around the centre A. We let the line DA pass through point A in the plane of the ecliptic and we also let the line EA pass through it in the plane of the inclined circle, which encompasses the Earth. On [this line], we indicate the centre of the eccentric circle, namely F, and let this centre move around the centre G. Let the centre of the epicyclic spheres be point H. We draw around the centre H the two circles KL and MN. In the plane of the inclined epicyle in which the planet moves, on which N is, we draw the line MHN. We draw around the centre F two circles that encompass the epicyclic spheres, namely SEO and PQR. We draw around the centre G two circles that encompass the two aforementioned circles, namely ŠT and UV. We produce around centre A the circle WX and the circle below it. Let both of them be below all of the aforementioned circles. We imagine the points B, W, X, and C to be on the axis of the ecliptic, and the points Š, U, V, and T to be on the axis of the inclined circle, which encompasses the Earth, and [the axis of] which goes through the point G. Let the points S, P, R, and O be on the axis of the eccentric circle, which goes through the point F and which is parallel to the axis that goes through the point G. We imagine the two points Y and Z of the points that are on the epicycle to be on the axis that goes through H and that is at a right angle to KL. We imagine the two points a′ and b′ on the axis that goes through H and that is at a right angle to MN. Let the ratios specific to the planet be found with respect to the lines AG, GF, FH, and the line that is drawn from point H to the centre of the planet. |15:2| From these reasons, together with what has previously been said, [it follows that] if the sphere that follows the circle BC moves what it encompasses from east to west, then the sphere BŠ, which is around the axis of the ecliptic, namely BC, moves in the direction of what precedes it, this is to the east, similar to the motion of the apogee. It moves ŠS together with it because of the difference of the axes, and this sphere moves in the direc-

معها شس من أجل اختلاف السهام وتتحرّك هذه الكرة إلى ما يتقدّمها وهو إلى ناحية المغرب على سهم شت بمثل حركة فلك البروج وتحرّك معها سف واختلاف أقطابها اختلاف واحد. وأمّا سف فإنّها تتحرّك بخلاف هذه الحركة إلى المشرق على سهم سع بمثل الحركة التي تحرّكتها شس مع زيادة حركة مساوية لهذه الحركة التي تحرّكها شس وهي ضِعف الحركة المستوية. وميل فلك التدوير ليس يكون نحو نقطة ز التي هي مركز الفلك الخارج المركز لكنّ نحو ح. وكرة سف لا تحريك معها بحركتها كرة فث إذ كان سهماهما متّفقين لكن تحفظ فث وتثبت على وضع واحد تقارن به وضع شس.

|15:3| وأمّا كرة ثذ فإنّها لحال اتّصالها بكرة ثف تتحرّك هي أيضًا معها إلى المشرق L39r بمثل حركة شس مع حركة بش إلى المغرب على سهم بج. وهو أبدًا السهم بعينه الذي B100r يمرّ بش ت فيحفظ كرة ثذ على وضعها كوضع بش. وكذلك أيضًا الكرة التي تحيط بها دائرة ذض تتحرّك إلى جانب ثذ إلى المغرب على سهم ذض الذي هو السهم الذي يمرّ بب ج بمثل حركة شب إلى ما يتقدّمها أعني إلى المشرق حتّى أنّ هذه الكرة أيضًا تحفظ الوضع الذي للكرة التي تحيط بدائرة بج التي هي الكرة السابعة من الأكر المحرّكة فتكون هذه الكرة هي الثامنة من الأكر المحرّكة.

|15:4| وكذلك أيضًا أمر أفلاك التداوير. أمّا الكرة التي تحيط بها دائرتا كل ومن التي هي أيضًا مجوّفة فإنّها تتحرّك على سهم صظ مع الكرة التي تحويها حركة مساوية لحركة فلك التدوير وتحرّك الناحية التي تلي الأوج منها إلى المغرب والتي تلي البعد الأقرب منها إلى المشرق.

1 معها…وتتحرّك] om L   شس] شس B   **2** شت] ست B   البروج] التدوير L   سف] سو B   **3** وأمّا] فأمّا B   **4** تحرّكتها] تحركة B   **5** وهي] وهو B   يكون] om B   **6** تحريك…بحركتها] معها تحرّك بحركها B   فث] om L بث B   إذ] إذا B   **7** فث] بث B   شس] سس B   **8** ثذ] تد BL   فإنّها] وإنّها B   ثف] تف L نف B   **9** شس] شس L سس B   بش] بش L   **10** ت] بشت L   **11** ذض^{1}] دص BL   بش^{2}] نش B   على…كوضع] وضعًا لوضع L   ثذ] تد B   فيحفظ] فتحفظ L   تتحرّك…ذض^{2}] om L   ثذ] تد B   **12** ذض^{2}] دص B   يتقدّمها] يتقدّم B   **13** الكرة] للكرة L   **14** الثامنة] التامة L   **15** دائرتا] دائرة B   **16** تتحرّك] يتحرّك L   صظ] ضط B صط L   **17** تلي^{1}] يلي L   منها^{2}] om L   تلي^{2}] يلي L tion of what precedes it, that is, to the west around the axis ŠT, similar to the motion of the ecliptic, and it moves SP together with it, the difference of their poles being one. As for SP, it moves contrary to this sphere to the east around the axis SO, similar to the motion by which ŠS moves, with an additional motion that is equal to the motion that ŠS moves, that is the double regular motion. The inclination of the epicycle is not with respect to point F, which is the centre of the eccentric circle, but with respect to G. Together with it, the sphere SP does not move the sphere PU by its [own] motion, since both their axes fall together, but PU is held and fixed in one position in which it is joined to the position of ŠS.

|15:3| As for the sphere UW, because of the condition of its connection to the sphere PU, it also moves together with it to the east, similar to the motion of ŠS with the motion of BŠ to the west around the axis BC. It is always one and the same axis, namely that going through Š and T, which holds the sphere UW in its position like the position of BŠ.[92] Similarly, the sphere that is encompassed by the circle WX also moves next to UW to the west around the axis of WX, which is the axis going through B and C, similar to the motion of ŠB in the direction of what precedes it (I mean to the east) so that this sphere also holds the position of the sphere that encompasses the circle BC and which is the seventh of the moving spheres, so that this sphere [i.e. the one encompassed by WX] is the eighth of the moving spheres.

|15:4| The same is the case for the epicycles as well. As for the sphere which is encompassed by the two circles KL and MN and which is also hollow, it moves around the axis YZ, together with the sphere that comprises it, equally to the motion of the epicycle, and it moves the area that follows the apogee from it to the west, and [the area] that follows the perigee from it to the east.

[92] BŠ and UW must move in the same way, for they are actually one sphere, separated by the sphere ŠT, but they are later joined again in the model of sawn-off pieces. The same is true in the next case, namely WX and the moving sphere of Mercury. How the axes ŠT or BC, respectively, accomplish this, is not entirely clear.

|15:5| وأمّا الكرة التي تحيط بها دائرة من التي هي متّصلة بالكوكب الذي عند نقطة ن فإنّ كرة كم تحرّكها بحال اختلاف أقطابها وتتحرّك هي على خلاف هذه الحركة مع الكوكب. وذلك أنّ القطعة التي تلي الأوج تتحرّك إلى المشرق على السهم الذي يمرّ بنقطتي يغ بمثل الحركة التي تحرّكها بها الكرة التي تحيط بها مع كرة الكوكب مجموعتين.

|15:6| فتكون لنا أكر كوكب عطارد سبع. خمس منها هي التي تحيط بالأرض وهي كرة بج الشبيهة الترتيب وذلك أنّها تتحرّك على سهم فلك البروج وكرتا شس وسف وهما
L39v ضدّ المتشابهة المراتب لأنّ سهميهما وإن كانا متوازيين فإنّهما ليسا على مركز فلك البروج ولا بموازيتين لسهمه وكرة فث أيضًا المقارنة لكرة شس وكرة ثذ المقارنة لكرة بش. |15:7| وكرتان أيضًا لفلكي التدوير وهما كرة كم المجوّقة التي ليست بمائلة وذلك أنّ سهمها الذي يمرّ بنقط ص ط ظ موازٍ لسهم الفلك المائل الذي يحيط بالأرض والكرة التي تحيط بها هذه الكرة وتحرّك الكوكب. وميلها مخالف لميلها وذلك أنّ سهم هذه هو الذي يمرّ بي غ وليس بموازٍ لسهم الفلك المائل الذي ذكرنا.

|15:8| فأمّا في وضع منشورات من أكر فإنّا نتوهّم كرة الأثير متّصلة أبدًا حول دائرة بج وتحت دائرة ذض وأنّها تدير معها قطع الأكر التي تحيط بها بالحركة التي من المشرق إلى المغرب. |15:9| وأوّل المنشورات التي في هذا المكان هو منشور الكرة المجوّقة التي تحيط بها دائرتا بج وذض. وهو محاط به فيما بين د ه وما يقابلها وهو قائم على السهم الذي يمرّ بب ج على زوايا قائمة. |15:10| والمنشور الثاني الذي بعده هو كلّه في داخل المنشور الأوّل وهو منشور من الكرة المجوّفة التي تحيط بها دائرتا شت وبج. وهو محاط به فيما بين د ه وما يقابلها وهو قائم على السهم الذي يمرّ بنقطتي ش ت على زوايا

1 الذي] التي هي B 4 يغ] نع B بها¹] إليها L بها²] om B الكوكب] الكرة B 6 خمس] سبع B خمسة] سبعة BL هي] om L 7 كرة] ك ر ه B 8 المراتب] om B فإنّهما ليسا] فليسا B 9 بموازيتين] موازيين B فث] بث B ثذ] تد B ثد L الكرة²] om B بش] بج BL 10 الفلكي] لفلك B 11 سهمها] سهمهما B بنقط] بنقطة B ص...ظ] صضط B صطط L 11/12 التي...يحيط] om B 12 هو] وهو L 13 وليس] ليس L 14 من أكر] مراكز B متّصلة] حولها add B 15 ذض] دص L تدير] يدير L 16 التي¹] الذي B 17 وذض] دص L د ه] ده BL 18 الثاني] om L 19 شت] ش ت شث B 20 يمرّ] تمرّ L ت] ث B

|15:5| As for the sphere that is encompassed by the circle MN and that is contiguous with the planet, which is at point N, the sphere KM moves it through the condition of the difference of its poles, and it moves contrary to that motion together with the planet. For the segment that follows the apogee moves to the east around the axis which goes through the two points a′ and b′, similar to the motion by which the sphere that encompasses it moves it together with the sphere of the planet in sum.

|15:6| Thus, we have seven spheres of the planet Mercury. Five of them encompass the Earth, namely the sphere BC, which is similarly ordered, for it moves around the axis of the ecliptic; [next,] the two spheres ŠS and SP, which are dissimilarly ordered, since both of their axes, even though they are parallel to each other, are not on the centre of the ecliptic and are not parallel to its axis; [next,] also the sphere PU, which is joined to the sphere ŠS; and the sphere UW, which is joined to the sphere BŠ. |15:7| Furthermore, there are two spheres for the two epicycles, namely the sphere KM, which is hollow and not inclined, for its axis, which goes through the points Y, H, and Z, is parallel to the axis of the inclined circle encompassing the Earth; and the sphere which is encompassed by this sphere [i.e. KM] and which moves the planet. Its inclination is contrary to the inclination of [KM], for the axis of that one is that which goes through a′ and b′ and is not parallel to the axis of the aforementioned inclined circle.

|15:8| As for the case of the hypothesis of the pieces sawn out of the spheres, we imagine the sphere of aether around the circle BC and below the circle WX as always being continuous, and that it rotates the segments of the spheres which it encompasses together with it through the motion from east to west. |15:9| The first of the sawn-off pieces in this place is the sawn-off piece of the hollow sphere that is encompassed by the two circles BC and WX. It is encompassed in [the space] between D and E and that which is opposite to it, and it is at a right angle to the axis that goes through B and C. |15:10| The second sawn-off piece, whose distance is entirely inside the first sawn-off piece, is sawn out of the hollow sphere that is encompassed by the two circles ŠT and BC. It is encompassed in [the space] between D and E and that which is opposite to it, and it is at a right angle

قائمة. |15:11| والمنشور الثالث الذي يتلو هذين فهو بأجمعه في داخل الثاني منشور الكرة المجوّقة التي تحيط بها دائرتا سع وفر. وهو محاط به فيما بين هف وما يقابلها وهو قائم على السهم الذي يمرّ بنقطتي س ع على زوايا قائمة. |15:12| والمنشور الرابع أيضًا B100v بأجمعه في داخل الثالث وهو منشور فلك التدوير المجوّف الذي يحيط به دائرتا لك ومن في جوف دائرة كل التي تحيط به. وهو قائم على السهم الذي يمرّ بنقطتي ص ظ على زوايا قائمة. |15:13| والمنشور الخامس هو أيضًا بأجمعه داخل في المنشور الرابع وهو من الكرة المتّصلة بالكوكب المحرّكة له وهي التي تحيط بها دائرة من وهي فيما بين من. وهو قائم على السهم الذي يمرّ بنقطتي يغ على زوايا قائمة.

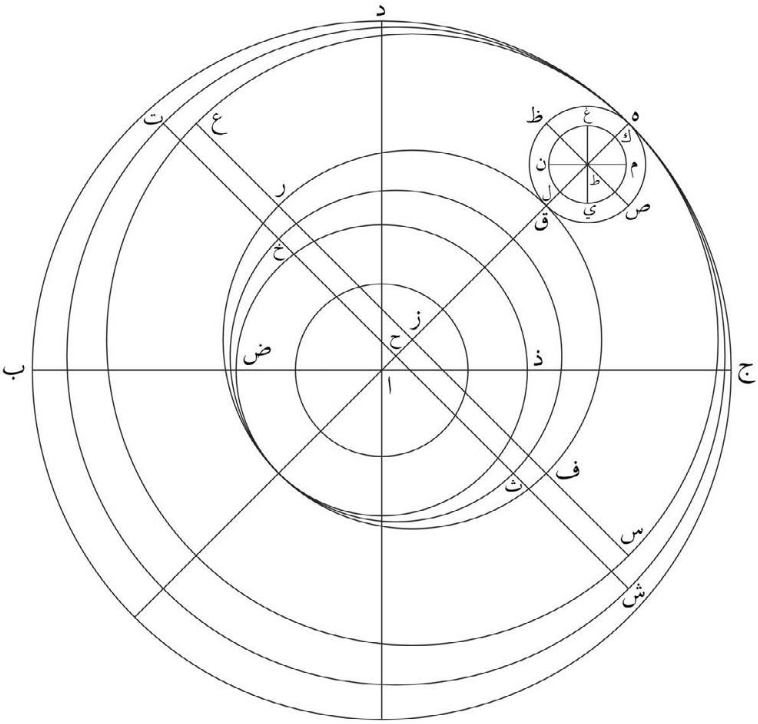
|15:14| فيكون لنا على هذه الجهة من جهات الوضع خمسة أقسام فقط أربعة منها شبيهة بالفِلَك وواحد شبيه بالدفّ. وذلك إذا جعلت حركات كلّ واحد من المنشورات شبهة بحركات الأكر التي هذه المنشورات قطع منها في الجهات والأسماء ومساواة الحركة كما ذكرنا في الأكر وفي العرض الذي عن جنبتي السطوح في كلّ واحده من الجهتين كما بيّنّا فيما تقدّم من القول.

1 هذين] هاذين B   فهو] وهو L   **2/116,1** التي…عطارد] om L   **2** وفر] فن B   **4** منشور] منشو B
5 ظ] ط B   **8** يغ] بع B   **10** المنشورات] المنشوراث B

to the axis that goes through the two points Š and T. |15:11| The third sawn-off piece following these two is entirely inside the second sawn-off piece [and] it is sawn out of the hollow sphere which is encompassed by the two circles SO and PR. It is encompassed in [the space] between E and P and that which is opposite to it, and it is at a right angle to the axis which goes through the two points S and O. |15:12| The fourth sawn-off piece is also entirely inside the third one and it is sawn out of the hollow epicycle which is encompassed by the two circles LK and MN, in the hollow [inner] of the circle KL which encompasses it. It is at a right angle to the axis which goes through the two points Y and Z. |15:13| The fifth sawn-off piece is also entirely inside the fourth one and it is sawn out of the sphere that is continuous with the planet moving it, and is encompassed by the circle MN, located in the space between M and N. [The sawn-off piece] is at a right angle to the axis which goes through the two points a′ and b′.

|15:14| Thus, on account of this one of the options of the hypothesis, we have only five divisions: four of them are similar to whorls and one of them is similar to a tambourine. And this is if the motions of each of the sawn-off pieces are made analogous to the motions of the spheres from which these sawn-off pieces are segments with respect to the directions, the names, and the regularity of the motion as we discussed regarding the spheres and the width, which [results] from the two sides of the planes in each of the two options, as we have previously shown.

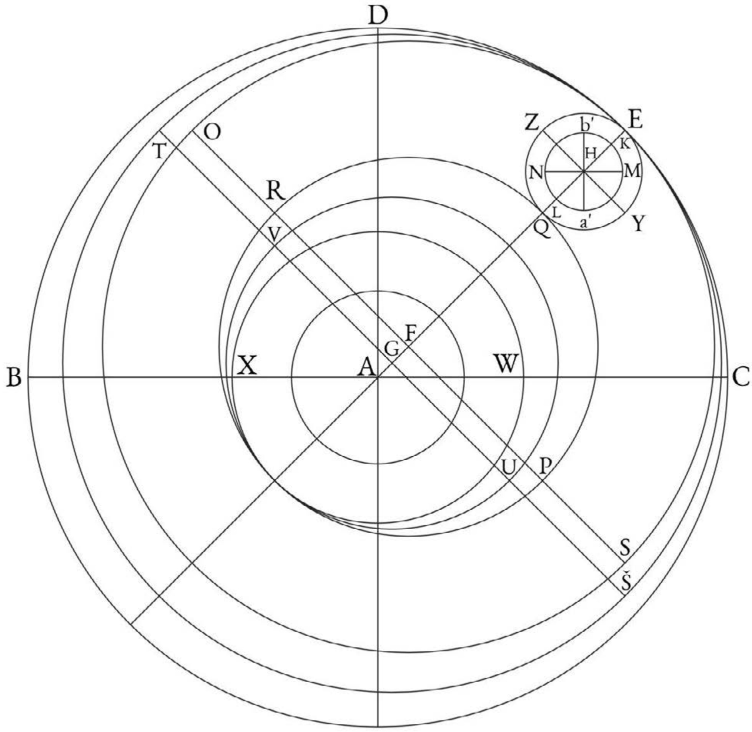
|15:15| مثال لأفلاك عطارد.



L40r |16:1| فقد بقي أن نذكر أمر وضع هذه الأشياء في القمر. فنجعل وضع الكرة الثامنة من الأكر المحرّكة حول نقطة ا التي هي مركز فلك البروج. وهي الكرة التي تحيط بدائرة بج. ونجيز على نقطة ا في سطح فلك البروج خطّ اد وفي سطح الفلك المائل خطّ ها. ونعلّم عليه مركز الفلك الخارج المركز وهو ز ومركز كرة فلك التدوير وهو ح. ونعمل على مركز ح فلك تدوير طك ونتوهّم القمر على نقطة ط. ونعمل على ز الدائرتين اللتين تحيطان بفلك التدوير وهما دائرتا لمن وسعف. ونعمل على مركز ا الدائرتين اللتين تحيطان بهاتين وهما دائرتا قهر وشت. ونتوهّم نقطتي ب ج على سهم فلك البروج الذي يمرّ بنقطة ا ونتوهّم نقطتي ق ر على سهم الفلك المائل الذي يمرّ بنقطة ا. ونتوهّم نقط

3 أمر] om B **4** مركز] من كز L **5** ونجيز] يجيز B خطّ[1]] حط L **5/6** الفلك…المائل] om L **6** ز] ن B **7** ونعمل] ولنعلم B ز] ر B **8** المن] امن B وسعف] شعف B ا] om B **9** قهر] فهذ B **10** يمرّ[1]] om B ونتوهّم[2]] ويتوهّم L

|15:15| Diagram for the spheres of Mercury.[93]



|16:1| It remains for us to describe the case of the hypothesis of these things regarding the Moon. Thus, we make the hypothesis of the eighth of the moving spheres around centre A, which is the centre of the ecliptic. It is the sphere that encompasses the circle BC. We let the line AD pass through the point A in the plane of the ecliptic, and the line EA in the plane of the inclined circle. On [the line EA], we indicate the centre of the eccentric circle, namely F, and the centre of the epicycle, namely G. We produce around the centre G the epicycle HK and we imagine the Moon to be on point H. Around F, we produce the two circles that encompass the epicycle, namely the circles LMN[94] and SOP. We produce around centre A the two circles that encompass these two, namely QER and ŠT. We imagine the two points B and C to be on the axis of the ecliptic, which goes through the point A, and we imagine the two points Q and R to be on the axis of the inclined circle, which goes through the point A. We imagine the points L, S, P, and N to be on the axis of the eccentric circle, which goes through the point F,

[93] The diagram is missing in B and L.

[94] In my diagram, the point M should be in the same position as E and H, except that it belongs to the larger eccentric circle.

ل س ف ن على سهم الفلك الخارج المركز الذي يمرّ بنقطة ز ونقطتي ث خ على السهم الذي يمرّ بنقطة ح ويوازي سهم الفلك المائل. ويحيط بالنسب التي للقمر خطوط از وزح والخطّ الذي يخرج من ح إلى مركز القمر. |16:2| وأمّا الكرة التي تحيط B101r بدائرة بج وتحرّك ما يحيط به من المشرق إلى المغرب تحريكًا شبيهًا بالحركة الأولى فإنّها تحرّك كرة بق معها إلى ناحية المغرب على سهم فلك البروج الذي يمرّ بب ج وتتخلّف عنها بمقدار حركة العقد فقط. وتحرّك معها كرة قل بحال اختلاف السهام وكرة قل هي أيضًا تتحرّك إلى جانب بق إلى ناحية المغرب على السهم الذي يمرّ بنقطتي ق ر حركة هي حركة أوج الفلك الخارج المركز من العقد. وتحرّك معها كرة لس بحال اختلاف السهام. ولس أيضًا تتحرّك إلى جانب قل إلى ناحية المشرق على السهم الذي يمرّ بل س L40v بالحركة التي لمركز فلك التدوير من أوج الفلك الخارج المركز. وتحرّك معها كرة طك التي لفلك التدوير وتتحرّك هذه الكرة أيضًا مع القمر من موضع الأوج على سهم ثخ بمثل حركة القمر نفسه فتكون نقلة الأوج إلى المغرب ونقلة البعد الأقرب إلى المشرق. |16:3| ولا يدور معها الأثير الذي تحت كرة لس لأنّه لا يحتاج إلى أن يكون قطبا كرة لس اللذين عند نقطتي سف متّصلتين بها وذلك أنّا لا نحتاج هاهنا إلى أن تكون أكر تلتفّ على ما فوقها لأنّ كرة الهواء تماسّ الأثير على دائرة شت. ويكون هاهنا استواء حركة كرة لس. |16:4| وميل فلك التدوير ليس على نقطة ز التي هي مركز شكل هذه الكرة أيضًا لكن على نقطة ا كما يعرض لغيرها عامّة.

|16:5| فتكون لنا في القمر أيضًا أربع أكر. ثلاث منها محيطة بالأرض وهي كرة بق التي هي شبيهة الترتيب وذلك أنّها تتحرّك على سهم فلك البروج وكرة قل المائلة وذلك

شبيه [شبيهًا **4**   B رح [وزح   B ان [از **3**   B نح [ث خ   BL ونقطة [ونقطتي   B ن [ز   L ز [ن **1**
[ق ر   B بن [بق **7**   om L [وكرة…السهام **6/9**   L وتحوّل [وتحرّك   sl L [فقط **6**   B نق [بق **5**   B
L بفلك [الفلك **11**   L بلسق [ب ل س   B فل [قل   B فليس [ولس **9**   B ليس [لس **8**   B فن
B متّصلين [متّصلتين   B سف [سف **14**   om B [لأنّه…لس² **13**   B مثل [بمثل   B بج [ثخ
L ثلاثة B ثلاثًا [ثلاث   om B [أيضًا **18**   BL ر [ز **16**   B شت [شت **15**   BL يكون [تكون
التي تمرّ بنقطتي فن حركة هي حركة أوج الفلك الخارج المركز من العقد [بالأرض   B محيطًا [محيطة
بالترتيب [الترتيب **19**   add B وتحرّك أيضًا معها لس لحال اختلاف السهام وليس ايضًا تتحرّك إلى جانب
B فك [قل   L يتحرّك [تتحرّك   B

and the points U and V to be on the axis that goes through the point G and that is parallel to the axis of the inclined circle. The lines AF and FG and the line that extends from G to the centre of the Moon encompass the ratios belonging to the Moon. |16:2| As for the sphere that encompasses the circle BC and that moves what it encompasses from east to west similar to the first motion, it moves the sphere BQ with it towards the west around the axis of the ecliptic, which goes through B and C, and it falls behind it by only the amount of the motion of the nodes. It [i.e. BQ] moves the sphere QL together with it by means of the condition of the difference of the axes, whereas the sphere QL also moves close to BQ towards the west around the axis that goes through the two points Q and R by a motion that is the motion of the apogee of the eccentric sphere from the nodes. It moves along with it the sphere LS by means of the condition of the difference of the axes. LS also moves close to QL towards the east around the axis that goes through L and S by the motion that belongs to the centre of the epicycle from the apogee of the eccentric circle. Together with it, it moves the sphere HK that belongs to the epicycle, and this sphere also moves together with the Moon from the position of the apogee around the axis UV, similar to the motion of the Moon itself, such that the progression of the apogee is to the west and that of the perigee to the east. |16:3| The aether, which is below the sphere LS, does not revolve together with it, since there is no need for the two poles of the sphere LS, which are at the two points S and P, to be contiguous with it [i.e. aether]. For we do not need [to assume] here that there are spheres that unwind what is above them, because the sphere of the air touches the aether at the circle ŠT. It is here that the motion of the sphere LS becomes regular. |16:4| The inclination of the epicycle is not with respect to the point F, which is the centre of the shape of this sphere as well, but with respect to the point A, just as it occurs for the other, in general.

|16:5| Thus, we also have four spheres in the case of the Moon. Three of them encompass the Earth, namely the sphere BQ, which is similarly ordered, for it moves around the axis of the ecliptic; [next,] the inclined sphere QL, for it moves

أنّها تتحرّك على مركز فلك البروج ولكنّها لا تتحرّك على سهمه وكرة لس ليست شبيهة الترتيب لأنّها لا تتحرّك على مركز فلك البروج ولا على سهم موازٍ لسهمه وكرة واحدة هي كرة فلك التدوير وهي كرة كط المصمتة التي ليست بمائلة وذلك أنّه لا يلزم القمر من أجل هذه شيء من الميل.

L41r |16:6| فأمّا في وضع منشورات الأكر فإنّا نتوهّم على دائرة بج كرة الأثير متّصلة ذاهبة إلى دائرة شت وهي التي تتّصل بالهواء كما قلنا. |16:7| فأوّل المنشورات التي تحيط بها هذه الكرة وتديرها معها هو منشور الكرة المجوّفة التي تحيط بها دائرتا بج وشت. وهذا المنشور محاط به فيما بين د ه وما يقابلها. وهو قائم على السهم الذي يمرّ بنقطتي ب ج على زوايا قائمة. |16:8| والمنشور الثاني أيضًا هو كلّه في داخل المنشور الأوّل. وهو منشور الكرة المجوّفة التي تحيط بها دائرتا قر والدائرة التي ترسم على مركز هذه وهي أعظم من دائرة شت بشيء يسير مثل دائرة ذض. وهذا المنشور أيضًا هو فيما بين ه د وما B101v يقابلها. وهو قايم على السهم الذي يمرّ بنقطتي ق ر على زوايا قائمة. |16:9| والمنشور الثالث يحيط به أجمع المنشور الثاني وهو منشور الكرة المجوفة التي تحيط بها دائرتا لن وسف. وهو فيما بين ه د وما يقابلها. وهو قائم على السهم الذي يمرّ بنقطتي لز على زوايا قائمة. |16:10| والمنشور الرابع هو كلّه في داخل الثالث وهو منشور الكرة التي تحيط بها طك من كرة فلك التدوير. وهو أيضًا فيما بين ط ك وهو قائم على السهم الذي يمرّ بنقطتي ث خ على زوايا قائمة.

L41v |16:11| فيكون أيضًا على هذه الجهة من الوضع أربعة منشورات من هذه الأكر بأعيانها لأنّه لم يحتج في هذه كما أحتيج في تلك إلى شيء ممّا يلتفّ بعضه على

1 تتحرّك¹] يتحرّك L تتحرّك²] يتحرّك L **2** لأنّها] ولكنّها L تتحرّك] لا add L **3** كط] كط B بمائلة] يماثله L **6** فأوّل] وأوّل L **7** وتديرها] تديره B وشت] شت B **8** المنشور] لا add B ه] ش BL **9** داخل] كرة add B **10** قر] فق B ترسم] يوسم L **11** شت] شت B ذض] دص L **12** ر] قن B **13** لن] لر B **14** وسف] سف B **16** من كرة] مركزه B **17** خ] ح B **18** الوضع] الموضع L أربعة] أربع BL **19** يحتج] يحتاج L around the centre of the ecliptic but not its axis; [next,] the sphere LS, which is dissimilarly ordered, for it does not move around the centre of the ecliptic and not around an axis parallel to its axis; and one sphere is the sphere of the epicycle, namely the solid sphere HK that is not inclined, for nothing of an inclination adheres to the Moon due to this [sphere].

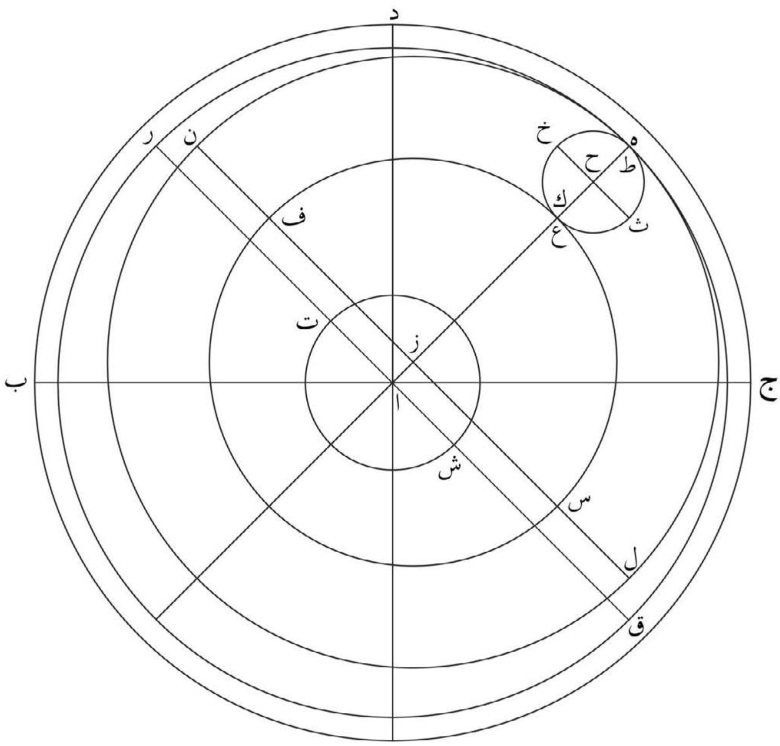
|16:6| As for the case of the hypothesis of the pieces sawn out of the spheres, we imagine the sphere of the aether around the circle BC to be continuous and reaching the circle ŠT, which is contiguous with the air, as we have said. |16:7| Thus, the first of the sawn-off pieces that are encompassed by this sphere and that are rotated by it is sawn out of the hollow sphere, which is encompassed by the two circles BC and ŠT. This sawn-off piece is encompassed in [the space] between D and E and what is opposite to them. It is at a right angle to the axis that goes through the two points B and C. |16:8| Further, the second sawn-off piece is entirely inside the first sawn-off piece. It is sawn out of the hollow sphere that is encompassed by the two circles QR and the circle that is drawn around the centre of this and is greater than the circle ŠT by something insignificant, just like the circle XW[95]. This sawn-off piece is also in [the space] between E and D and what is opposite to them. It is at a right angle to the axis that goes through the two points Q and R. |16:9| The third sawn-off piece is encompassed by the entirety of the second sawn-off piece and it is sawn out of the hollow sphere that is encompassed by the two circles LN and SP. It is in [the space] between E and D and what is opposite to them. It is at a right angle to the axis that goes through the two points L and F. |16:10| The fourth sawn-off piece is entirely inside the third one and is sawn out of the sphere that is encompassed by [the circle] HK of the sphere of the epicycle. It is also in [the space] between H and K and it is at a right angle to the axis that goes through the two points U and V.

|16:11| Thus, on account of this option of the hypothesis, there are also four pieces sawn out of the exact same spheres, and in their case, there is no need for something that unwinds something else, just as is needed in [the case of the

[95] These points were not introduced before.

بعض. ثلاثة من هذه المنشورات شبهة بالفِلَك وواحد شبيه بالدفّ. وحال الحركات أيضًا في الأجسام على الوجهين جميعًا غير مغادرة.

|16:12| مثال لأفلاك القمر.

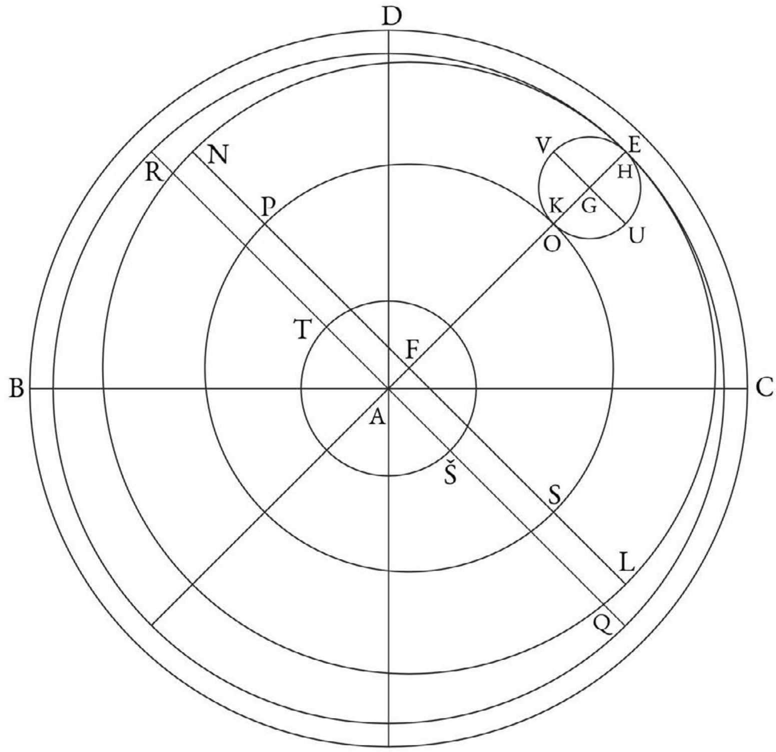


L42r |17:1| فجميع الأكر على الوجه الأوّل إحدى وأربعون. كرة من ذلك ثمان أكر محرّكة وكرة للكواكب الثابتة وكرة الشمس وأربع للقمر ولكلّ واحد من زحل والمشتري والمرّيخ والزهرة خمس أكر. وفي هذه الأكر في كلّ واحد من الكواكب كرة مقارنة وكرة تتحرّك على خلافها. ولعطارد سبع أكر فيها واحدة مقارنة وواحدة تتحرّك على خلافها. فجميع ذلك إحدى وأربعون كرة.

1 شبهة] شبيه L   وحال الحركات] والحال التي للحركات B   **2** جميعًا] om B   **6** وكرة الشمس] om L
7 مقارنة] مقارّ L   وكرة] وكيف B   **8** فيها] om L   مقارنة وواحدة] om B

spheres].[96] Three of these sawn-off pieces are similar to whorls, one to a tambourine. The condition of the motions concerning the bodies is, on account of both options, a single one, not departing [from another].

|16:12| Diagram for the spheres of the Moon.[97]



|17:1| Thus, on account of the first option, all the spheres are 41. Of these, eight are moving spheres, one is for the fixed stars, one for the Sun, four for the Moon, and five spheres each for Saturn, Jupiter, Mars, and Venus. Among these spheres, for each planet, there is one joined sphere and one that moves contrary to it. Mercury has seven spheres; among them are one joined and one that moves contrary to it. Therefore, all of these are 41 spheres.

[96] Given that Ptolemy just wrote that there is no need for unwinding spheres in the case of complete spheres, this statement is puzzling.

[97] The diagram is missing in L and B.

|17:2| وأمّا على الوضع الثاني فإنّ جميع الأجسام تكون تسعة وعشرين جسمًا. من ذلك ثلاث أكر مجوّفة وهي الكرة المحرّكة للكواكب الثابتة وكرة الكواكب الثابتة وكرة ما يبقي من الأثير وستّة وعشرون منشورًا من منشورات الأكر. وكذلك أيضًا يكون للشمس منشور واحد وللقمر أربع منشورات ولكلّ واحد من زحل والمشتري والمرّيخ والزهرة أربعة ولعطارد خمسة. فجميع ذلك تسعة وعشرون جسمًا. |17:3| وإن نحن توهّمنا أنّ حركات الكواكب هي لها أنفسها لا لأجسام أخر محركة لها فإنّ عدد ما ذكرنا من الأجسام سينقص في كلّ واحدة من الجهتين واحدًا واحدًا في كلّ واحد من الكواكب المتحيّرة فيكون ما ينقص من عدد الجميع سبعة. |17:4| فتجتمع على الجهة الأولى أربع وثلاثون كرة وعلى الجهة الثانية تكون الأكر أيضًا ثلاث أكر والمنشورات تسعة عشر منشورًا فجميع الأجسام اثنان وعشرون جسمًا. L42v

|17:5| وليس يظهر ولا يعرض أمر مخالف لما يظهر البتّة إن لم يتوهّم على الجهة الثانية أنّ الأجسام التي تحيط بالحركات شبيهة بالفِلَك لكنّ شبيهة بالأسورة أو شبيهة B102r بالأهلّة من بعد أن يحفظ هاهنا أيضًا أنّ الأشياء المحيطة التي هي أكبر تحيط بجميع ما هو أصغر منها ليس إن كان وضعها وضعًا موازيًا فقط لكن وإن كانت خارجة المراكز وإن كانت مائلة على ما قلنا فيها. |17:6| وإنّما نختار أحد هذين الأمرين اختيارًا طبيعيًا فقط إمّا الشبيهة بالفِلَك فلأنّها تحيط بقطع كرية وإن لم تكن الأضلاع التي تمرّ بالجهة العميقة مستديرة من كلّ جهة وإمّا الشبيهة بالأسورة فلأنّا قد وضعنا أيضًا أنّها مستديرة وإن لم تكن محيطة بكلّية منشورات أكر مجوفة بل إنّما تحيط بأشياء من القطع شبيهة بآثار الخرط كأنّ أشكالها شبيهة بما تحيّل من قوس قزح. وقد تكون في الهواء أشكال مثل هذه كثيرة. |17:7| وأمّا أنّ أجسام أفلاك التداوير التي تحيط وتحرّك الكواكب أنفسها فقد يمكن أن نتوهّم مصمتة وأن نتوهّم أيضًا مجوّفة وأنّ ما في داخلها وما يحيط بها كلّه

1 تسعة] سبعة B   وعشرين] وعشرون L   **2** وكرة[1]...الثابتة[2] om B   **6** فإنّ] om B   **9** ثلاث] ثلاثة B   **10** وعشرون] وثمانون add L   **11** وليس] فليس B   يظهر ولا] om L   **12** أو شبيهة] وشبيهة L   **13** بالأهلّة] بالاهلود B   **14** منها] فيها B   **15** وإنّما] وأيضًا B   الأمرين] الآخرين L   **16** الشبيهة] شبيهة L   **17** من...مستديرة[2] om B   بقطع] قطع B   الشبيه L   **18** شبيهة] شبيه B   **19** كأنّ] om B   تحيّل] يتحيل L   تكون] يكون L   **20** تحيط وتحرّك] تحرّك L   **21** فقد] قد L   نتوهّم[1] يتوهّم B

|17:2| On account of the second hypothesis, all the bodies are 29. Of these, three are hollow spheres, namely the sphere moving the fixed stars, the sphere of the fixed stars [itself], and the sphere of what remains of the aether; 26 are pieces sawn out of the spheres. Accordingly, the Sun has also one sawn-off piece; the Moon four; Saturn, Jupiter, Mars, and Venus have four each; and Mercury has five. Therefore, all of these are 29 bodies. |17:3| If we imagine that the motions of the planets [arise] from their own and not from other bodies moving them, the number of bodies that we just mentioned will be smaller in either of the two options, respectively, by one for each wandering star, so that the [amount] by which the number of the sum decreases is seven.[98] |17:4| Therefore, on account of the first option, 34 spheres come together, and on account of the second option, the spheres are three as well, and the sawn-off pieces are 19, so that all bodies together are 22.

|17:5| Nothing at all is apparent, nor does there occur something that is contrary to what is apparent, if one does not imagine, on account of the second approach, that the bodies that encompass the motions are similar to whorls, but that they are similar to bracelets or crescent moons, after one also bears in mind here that the encompassing things, which are greater, encompass everything that is smaller than them, not only if their position is parallel but also if they are eccentric and inclined, following what we have said about them. |17:6| We rather choose one of these two principles only by a physical choice: either they are similar to whorls, for they encompass spherical segments, even though the sides that go through the depth are not circular from every viewpoint, or they are similar to bracelets, for we also just laid down that they are circular, even though they do not encompass the entirety of the pieces sawn out of the hollow spheres, but rather they encompass the things of the segments that are similar to the traces of turning, just as their shapes are similar to what is practised of the rainbow.[99] It is possible for many shapes like these to exist in the air. |17:7| As for the fact that the bodies of the epicycles, which encompass and move the planets, are the same, we can imagine [on the one hand] that [they] are solid and [on the other hand] that [they] are hollow, and that what is inside them and what encompasses them

[98] This sentence is cited in Ibn al-Hayṯam, *al-Šukūk*, p. 60:15–18.

[99] Through the analogy to the work of a turner, Ptolemy illustrates that a bracelet-shaped segment does not encompass anything inside it because it is not a complete ring. The reference to the rainbow is, however, odd. In order to make sense out of this passage, one either needs to read *yataḫayyil* ('what is imagined of the rainbow'), or to assume a mistake in the transmission of the text. For one could also omit *quzaḥ*, so that it is a reference to how the turner constructs a bow (*qaws*) on a lathe, and the remainings (*āṯār*) of this process look like bracelets. For references to the process of turning in constructing astronomical instruments in the *Almagest*, see above, p. 21.

يصير واحدًا متّصلًا. قد يجوز في المنشورات إذا نحن توهّمنا أشكالها في العمق شبيهة بفِلَك وتوهّمنا أشكالها إذا كانت مصمتة شبيهة بدفوف. وهو بيّن. |17:8| وأمّا في الأشكال الشبيهة بالأسورة فليس يجوز ذلك لأنّ هذه الأشكال فيها هذا الشيء الواحد L43r وهو أن نتوهّم مجوّفة وإن لم تحوِ في جوفها شيئًا لأنّ هذا هو حدّ هذه الأشكال التي ذكرنا.

|18:1| وأمّا إنّا قد استعملنا اختلاف حركات أبسط وأقلّ ممّا فعل من كان قبلنا كثيرًا فيما وضعنا من أسباب ما يظهر فإنّه يتبيّن إذا قيس بأقاويلهم وما استعملوا في ذلك. وأمّا أنّ الذي يجب فيه إنّما يتمّ بما وضعنا وحده أعني أنّه يتمّ به ما يعرض في حركات الكواكب من الأعراض الكلّية والجزئية فيما نتوهّم وفيما يظهر من ذلك فإنّه يمكن الفاحص عنه أن يفهمه وأن يعلمه إذا هو جمع وقاس ما يتوهّم من وضعها إلى الأرصاد التي لا شكّ فيها إن كان قياسهم فيما يفحصون عنه بالمثالات التي تكون بالآلات وإن كان بمذهب بخطيط الجداول التي تستعمل في القوانين.

|18:2| ولكيما يكون حساب الحركات المستوية التي تستعمل في الآلات الشبيهة بالدفوف سهلًا على من عسى أن يبتدئ في التعليم وضعنا في الزيج الذي يتلو كتابنا هذا حركات كلّ واحد من الكواكب المتحيرة على ما يتّبع الأصول والمذاهب التي سلكنا وما يجتمع من هذه الحركة في السنين المجموعة التي هي خمس وعشرون خمس وعشرون سنة وأوّلها من بعد موت الإسكندر على استواء الأيّام والليالي وفي السنين وفي الشهور وفي الأيّام وفي الساعات. |18:3| أمّا الشمس ففي جدول واحد وامّا لما سواها L43v ففي أربعة أربعة جداول لكلّ واحد منها من بعد أن تجمع الأبواب التي للسنين

1 شبيهة] شبيه B **2** وهو] فهو L **3** فيها] om B **4** لم تحوِ] لم تحوي B تجري L **6** وأمّا] أمّا L أبسط] أسبط B فعل] فصل B **7** وضعنا] وصفنا B يتبيّن] تبيّن B وأمّا] فأمّا B **8** أنّ] om B يجب] نحن L إنّما] فإنّما B **9** الكواكب] حركات الكواكب ما يعرض في add B **10** يفهمه وأن] om L يعلمه] يعلم B **11** شكّ] نشكّ L بالآلات] بآلات L **12** بخطيط الجداول] يحيط به الحذاق B **13** الشبيهة] الشبهة B **14** على...أن] غير عسر ولكنّا B التعليم] في add B **15** يتّبع] نتبع L والمذاهب التي] والمذهب الذي B **17** وفي[1]] في L **18** أمّا] في add L سواها] سواه L **19** أربعة أربعة] أربع أربع BL لكلّ] ولكلّ B للسنين] للسنن B becomes in its entirety one and continuous. It is possible concerning sawn-off pieces when we imagine their shapes in the depth as being similar to whorls and when we imagine their shapes, if they are solid, as similar to tambourines. This is clear. |17:8| As for the shapes that are similar to bracelets, this is not possible because in these shapes, there is this single thing: namely that we imagine them as hollow even though they do not contain anything in their inside, because this is the definition of these aforementioned shapes.

|18:1| As for the fact that we have applied the anomaly of motions in a much simpler and more economical[100] way than our predecessors did with respect to what we laid down as the causes for what appears, [this] becomes evident when one compares their sayings and what they have applied with respect to this. As for the fact that what is necessary in that regard is [only] satisfied by what we have presented alone (I mean that by it, what occurs for the motions of the planets universally and particularly is satisfied, both with respect to what we imagine and what is apparent), it is possible for someone who inquires into [that] to understand and know it when he adds together and compares their imagined hypothesis with the observations about which there is no doubt, if their reasoning regarding what they inquire about is [made] by figures that are by means of instruments and by means of a method of drawing tables that are used for the canons.

|18:2| In order to ease the calculation of the equal motions which are used in the instruments similar to tambourines[101] for one who may like to begin the study, we have laid down in the table that follows this treatise of ours the motions of each wandering star according to what follows the principles and methods that we have pursued and what is added together of this motion, in the collected years [in steps of] 25 years, the beginning of which is [at the time of] equinox after the death of Alexander, in years, months, days, and hours. |18:3| As for the Sun, [they are] in one table, and as for [the planets] other than [the Sun], [they are] in four tables for each of them after the basic quantities are added together [that are] for the assumed years , including the current year in which we live and [for] the

[100] My translation of *aqall*, mirroring the idea that Ptolemy claims that he needs fewer spheres than anyone before him.

[101] It is not entirely clear whether this refers to an instrument that makes use of Ptolemy's sawn-off pieces and that looks like a tambourine or whether Ptolemy refers here to an instrument for timekeeping. I was only able to find a reference to an instrument called *dabbat al-sāʿāt* in al-Ḫwārizmī's *Keys of the Sciences* (*Mafātīḥ al-ʿulūm*). See the quote in King, *In Synchrony with the Heavens. Volume Two*, p. 318. I owe this reference to Benno van Dalen.

B102v المفروضة مع سنتنا التي نحن فيها والشهور والأيّام. ونأخذ أيضًا الساعات المعتدلة التي مضت من نصف نهار يومنا. فإنّا في الشمس إذا جمعنا العدد الذي بحيال هذه الأبواب وجدنا بعد مركزها من أوج فلكها الخارج المركز على ما يتلو من فلك البروج. |18:4| وأمّا في القمر فإنّ الذي يجتمع من الجداول الأول يحدّ به بعد منتهى شمال الفلك المائل من نقطة الإعتدال الربيعي على ما يتقدّم من فلك البروج. والذي يجتمع من الجداول الثانية هو بعد أوج الفلك الخارج المركز من منتهى شمال الفلك المائل على ما يتقدّم من فلك البروج. والذي يجتمع من الجداول الثالثة هو بعد مركز فلك التدوير من أوج الفلك الخارج المركز إلى ما يتلو من فلك البروج. والذي يجتمع من الجداول الرابعة هو بعد مركز القمر من أوج فلك التدوير على ما تقدّم من فلك البروج في القوس العليا. |18:5| وأمّا في الخمسة الكواكب المتحيرة فإنّ العدد الذي يجتمع من الجداول الأوّل هو لبعد أوج الفلك الخارج المركز من نقطة الإعتدال الربيعي إلى ما يتلو من فلك البروج. L44r والذي يجتمع من الجداول الثانية هو لبعد مركز فلك التدوير من أوج الفلك الخارج المركز إلى ما يتلو أيضًا من فلك البروج وأمّا في عطارد منها فإنّه يجتمع مع ذلك بعد مركز الفلك الخارج المركز من أوج الخروج عن المركز إلى ما تقدّم من فلك البروج. والذي يجتمع من الجداول الثالثة هو بعد منتهى شمال الفلك المائل عن فلك التدوير من أوج فلك التدوير إلى ما يتقدّم من القوس العليا. والذي يجتمع من الجداول الرابعة هو بعد مركز الكوكب من منتهى شمال الفلك المائل عن فلك التدوير إلى ما يتلو من القوس العليا.

1 المفروضة] المفروضة التي للسنتين من بعد أن تجمع الأبواب add L   سنتنا] سنينا L   التي[2]] الذي B   **2** فإنّا] وإنّا B   **4** يجتمع] يجمع B   الجداول] الحذاول B   يحدّ] تجد B   **5** من[1]] عن B   يجتمع] يجمع B   الجداول] الحذاول B   **6/7** الجداول...الثانية] om L   **6** هو] هي B   بعد] أبعد B   **7** يجتمع] يجمع B   الجداول] الجذاول B   **8** الجداول] الحذول B   الرابعة] الرابع B   **9** على] إلى L   **10** وأمّا] فأمّا B   الجداول] الحدول B   **12** الجداول] الحذاول B   **13** وأمّا] فأمّا B   يجتمع] يجمع B   **15** الجداول] الحذاول B   الثالثة] الثانية B   هو] وهو B   **16** الجداول] الحذاول B months and days. We also take the equal hours that have passed since the noon of the present day. In the case of the Sun, when we have added together the number that arises from these basic quantities, we find the distance of its centre from the apogee of its eccentric circle according to the succession of the signs. |18:4| As for the Moon, one determines by what is added together from the first [set of] tables the distance of the northern limit of the inclined circle from the vernal equinoctial point contrary to the succession of the signs. What is added together from the second [set of] tables is the distance of the apogee of the eccentric circle from the northern limit of the inclined circle contrary to the succession of the signs. What is added together from the third [set of] tables is the distance of the centre of the epicycle from the apogee of the eccentric circle according to the succession of the signs. And what is added together from the fourth [set of] tables is the distance of the centre of the Moon from the apogee of the epicycle contrary to the succession of the signs in the uppermost arc. |18:5| As for the case of the five wandering stars, the number that is added together from the first [set of] tables is for the distance of the apogee of the eccentric circle from the vernal equinoctial point according to the succession of the signs. What is added together from the second [set of] tables is for the distance of the centre of the epicycle from the apogee of the eccentric circle, also according to the succession of the signs; in contrast, as for the case of Mercury from [the second set of tables], the distance of the centre of the eccentric circle from the apogee of the eccentricity is added together contrary to the succession of the signs. What is added together from the third [set of] tables is the distance of the northern limit of the circle that is inclined to the epicycle from the apogee of the epicycle contrary to the succession of the uppermost arc. What is added together from the fourth [set of] tables is the distance of the centre of the planet from the northern limit of the circle that is inclined to the epicycle according to the succession of the uppermost arc.

|18:6| تمّت المقالة الثانية من كتاب بطلميوس القلودي في اقتصاص جمل أحوال الكواكب المتحيّرة. وهي تمام الكتاب.

1/2 الكتاب...تمّت] زمان سنة الشمس المأخوذة من عودتها إلى أوجات الكواكب التحيّرة و إلى الكواكب الثابتة على ما يدلّ عليه ما بيّنه بطلميوس في هذا الكتاب من أزمان الحركات ثلاثمائة وخمسة وستّون يومًا وربع يقع وجزء من مائة وسبعة وأربعين جزءًا من يوم بالتقريب add L كتاب من الثانية المقالة تمّت بطلميوس في الهيئة المسمّى بالاقتصاص وتمّ الكتاب بتمامها ولواهب العقل الحمد والشكر دائمًا لارب غيره B **1** أحوال] حال L

|18:6| Book II of the treatise by Ptolemy on the report of the summary of the conditions of the wandering stars is completed. It is the end of the treatise.

VI: Commentary

I.1–2

The first important thing to clarify is what Ptolemy means by *hypothesis*. With the curious exception of the very first appearance of this word, where the Arabic translation reads *aṣl* (which I translate as 'principle'), *hypothesis* and *hypokeimenon* are usually translated as *waḍʿ*. Both the Greek and the Arabic words have a similar literal meaning, namely that something 'is laid down' or 'put below'. Ptolemy uses this word not only in the *Planetary Hypotheses* but also in the *Almagest* to refer to 'things that have been shown' or 'models'.[1] The Arabic term *waḍʿ* (sometimes also translated as 'position') that is used to render the Greek word *hypothesis* throughout Book I also comes up in the same contexts in Book II. Thus, in the context of Ptolemy's astronomy, this term refers not only to the mathematical abstraction of planetary motions but also to the physical reality behind these geometrical calculations. For the present study, this means two things: first, *hypothesis* does not have the modern meaning of 'hypothesis' (i.e. an unverified theory) and second, by using the word 'hypothesis', I mean Ptolemy's mathematical and physical representation of planetary motions. Thus, although Ptolemy already states in the first sentence of the *Planetary Hypotheses* that he has dealt with the *hypotheseis* (translated as *uṣūl* in the Arabic version) in the *Almagest*, the hypotheses of the planets, namely the physical foundations of the geometrical models, are the main subject of this treatise.

Ptolemy commences his book by reminding the reader what he has already achieved in the *Almagest*. This first passage of the *Planetary Hypotheses* echoes *Almagest* IX.2:

> Now it is our purpose to demonstrate for the five planets, just as we did for the Sun and Moon, that all their apparent anomalies can be represented by uniform circular motions, since these are proper to the nature of divine beings, while disorder and non-uniformity are alien [to such beings].[2]

Both the quoted passage as well as *Planetary Hypotheses* I.1 unequivocally reflect Ptolemy's wish to present the apparent irregular planetary motions only by a combination of regular circles, which can be seen as an answer to Plato's demand to 'save the appearances' (if we believe Simplicius' famous report). In any case, Ptolemy conforms to the fundamental idea of a regularly constructed heavenly

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[1] See the brief remarks by Toomer in the preface of Ptolemy, *Almagest*, pp. 23–24, and on the Arabic translation by Moureau, 'Note'. Compare this also with Alan C. Bowen's conclusion that Ptolemy uses *hypothesis* for a 'quantified geometrical model', see Bowen, 'Hypothesis', p. 90.

[2] Ptolemy, *Syntaxis*, IX.2, Vol. 2, p. 208:4–9, tr. by Toomer in Ptolemy, *Almagest*, p. 420.

realm, in accordance with both Plato and Aristotle.[3] The only difference between *Almagest* IX.2 and *Planetary Hypotheses* I.1 is that aether is called 'divine' in the former but not in the latter. The *Planetary Hypotheses* does not speak of a deity or a divine nature at all, whereas in *Almagest* I.1, we find a brief allusion to the divine First Cause of the diurnal rotation of the cosmos, which seems to be close to Aristotle's Prime Mover.[4] This will be of some importance when one looks at the question whether there is any room for a deity in Ptolemy's theory of celestial motions.[5]

Very quickly, however, Ptolemy turns to the agenda of the present work. The main aim of the *Planetary Hypotheses* is to enable two groups of people to conceptualise (*katanoeō/taṣawwara*) these models. The first group is referred to as 'us', by which he presumably means theoretical philosophers (including mathematicians and natural philosophers), as opposed to the second group, namely the instrument-makers.[6] Thus, the aim of the *Planetary Hypotheses* is a physical description of the various mathematical models from the *Almagest*: it serves as a description of how the different spheres work together to bring about planetary motion so that (a) astronomers can learn how they have to conceive of the spheres, and (b) instrument-makers can know how they should represent these in their device. An important point for Ptolemy, however, is that an instrument should allow the observer to understand the process of how the planets actually move. In this way, Ptolemy's model of sawn-off pieces is not only preferable because of certain physical suppositions, as Ptolemy will explain in Book II, but also because it allows one to better understand the inner workings of the spherical model, since one can see into the device itself when it is not a solid globe.[7] This might raise the question whether Ptolemy was inspired by the idea of an astronomical instrument inside of which you can see the interaction of the spheres, and thought of sawn-off pieces only afterwards. An answer to this question remains speculative.[8]

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[3] See Simplicius, *In Cael.*, p. 488:10–24. On the history of this demand and modern discussions about its authenticity, see (among others) Duhem, *Σῴζειν τὰ φαινόμενα*, Mittelstrass, *Die Rettung*, Goldstein, 'The Status', pp. 133–37, and, more recently, Bodnár, 'Sozein ta phenomena'.

[4] Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 5:13–16. Of course, it is still possible that a reference to the divine nature was changed or suppressed in the Arabic version (as is the case in the translation of Alexander's cosmological treatises within the translation circle around al-Kindī. See Fazzo and Wiesner, 'Alexander of Aphrodisias', p. 128). However, Ptolemy also talks in the extant Greek part about aether and does not call it divine there.

[5] See above, pp. 160–62.

[6] cf. Jones, 'Theon of Smyrna and Ptolemy', pp. 84–86, especially p. 84 n. 17.

[7] Basically, this chapter has been sufficiently dealt with in Murschel, 'Structure and Function', pp. 36 and 55–57, Hamm, *Ptolemy's Planetary Theory*, pp. 72–96, Hamm, 'Modeling', and Evans and Carman, 'Mechanical Astronomy', with respect to the question whether such a device could actually be made in Ptolemy's time. For a description of the various meanings of the word *sphairopoiia*, see the comments by Evans and Berggren on their translation in Geminus, *Introduction*, pp. 51–53.

[8] cf. Murschel, 'Structure and Function', p. 40, and Feke, *Ptolemy's Philosophy*, pp. 192–93. A similar question has been discussed in a broader form by Evans and Carman, 'Mechanical Astronomy'.

The second chapter again connects this aim to the *Almagest*. In general, the physical representation should not violate its results. Nevertheless, Ptolemy admits that he deviates from the *Almagest* in two aspects. First, he states that he made some corrections based on further observations. Second, Ptolemy claims that he would use a 'simpler method' for the arrangement of the spheres in order to facilitate the arrangement of the instrument, and that this 'simpler method' required some deviations from the *Almagest*. As Elizabeth Anne Hamm already noted, the only change within the planetary models themselves is the new latitude theory from the *Planetary Hypotheses*. However, as Swerdlow pointed out, this new latitude theory is a definite improvement over the one from the *Almagest* (for example, it gives the correct inclination for Mars).[9] If, in this 'simpler method', Ptolemy has his new latitude theory in mind, he would be very cautious about it.

Ptolemy then closes the introductory chapters. He states that he will start the investigation with the diurnal motion of the cosmos because it is the simplest one and serves as a good introduction to aethereal motion. Here, he ascribes a 'most wondrous nature' (*thaumasiōtatē physis*/*ṭabīʿa ʿaǧība ǧiddan*) to aether for the first time. He gives a glimpse into the particularity of aether: it gives similar things to what is similar to it, which means that it transmits circular motion throughout the aethereal world. In this way, aether is made responsible for imparting the diurnal rotation to the supralunar world.

The methodology that is proposed in *Planetary Hypotheses* I.2 and then carried out in the following chapters mirrors the presentation of the argument in *Almagest* I.2. After the presentation of the fundamental principles, which has no analogous part in the *Planetary Hypotheses*, in the *Almagest*, Ptolemy first discusses the ecliptic (*Almagest* I.12–16), then the Sun and the Moon (Books III–VI), the fixed stars (VII–VIII), and finally the five wandering planets (IX–XIII). This applies to the models of the *Planetary Hypotheses* in a similar way. First, Ptolemy presents the diurnal revolution (*Planetary Hypotheses* I.3), then the Sun (I.4), the fixed stars (I.5) — presented here before the Moon (I.6), unlike in the *Almagest* — followed by the revolutions of the wandering planets (I.7).

I.3–4

As promised at the end of Chapter I.2, the third chapter presents the mathematical abstraction of the diurnal rotation. One can find all aspects mentioned here in the first book of the *Almagest* as well. The value given for the inclination between the ecliptic and the equator (23;51,20°) is the same as in *Almagest* I.12.[10] These two

[9] See Hamm, *Ptolemy's Planetary Theory*, p. 93, Swerdlow, 'Ptolemy's Theories', pp. 66–67, and Jones, 'Theon of Smyrna and Ptolemy', pp. 91–92. Most recently, Ptolemy's latitude theory both in the *Almagest* and the *Planetary Hypotheses* has been discussed in detail by Sajjad Nikfahm-Khubravan, see Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories*, pp. 53–114.

[10] See Britton, 'Ptolemy's Determination', and Neugebauer, *A History*, p. 901.

circles are divided into 360 degrees and Ptolemy adds a so-called 'moving circle' (*falak muḥarrik*) or 'carrier' (*pherōn*) between them. The circle of the equator itself is motionless and is the reference for the inclination of the ecliptic, which rotates through the motion of this 'carrying' or 'moving' circle. In the course of establishing these circles, Ptolemy also explains (as in *Almagest* I.8) the points of the solstices and equinoxes.[11]

This picture deviates to some extent from the account in *Almagest* I.8.[12] There, the equator is called the 'greatest of these circles'; however, it moves from east to west and it has the function of the moving sphere:

> [...] there are two different primary motions in the heavens. One of them is that which carries everything from east to west: it rotates them with an unchanging and uniform motion along circles parallel to each other, described, as is obvious, about the poles of this sphere which rotates everything uniformly. The greatest of these circles is called the 'equator' [...][13]

And later:

> We can imagine the first primary motion, which encompasses all the other motions, as described and as it were defined by the great circle drawn through both poles [of equator and ecliptic] revolving, and carrying everything else with it, from east to west about the poles of the equator. These poles are fixed, so to speak, on the 'meridian' circle, [...][14]

The diurnal motion comes about and is transmitted to the inner circles in the geometrical account of *Almagest* I.8 through the interaction of the following circles: the circle of the equator moves around the northern and southern celestial poles from east to west. The meridian circle goes through these poles as well as through the poles of the third circle, the ecliptic, which is inclined to the equator. Since the poles of the ecliptic are also fixed on the meridian circle, the ecliptic is carried diurnally from east to west, but it nevertheless has its own motion from west to east around its own poles.[15] This account is different from that in *Planetary Hypotheses* I.3. Here, Ptolemy first describes the fixed equator, which serves merely as a measurement for the inner diurnal motion, then a 'carrying' or 'moving' circle in the same plane that moves itself from east to west and which also moves the third circle, the ecliptic, from east to west. This ecliptic is, of course, inclined to the equator. Thus, the main difference between *Almagest* I.8 and *Planetary Hypotheses* I.3 is that the second primary motion in the heavens,

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[11] Compare this with Ptolemy, *Syntaxis*, I.8, Vol. 1, p. 29:3–16.

[12] For a discussion of this chapter on the 'two primary motions', see Pedersen, *A Survey*, p. 45, and Taub, *Ptolemy's Universe*, pp. 100–03.

[13] Ptolemy, *Syntaxis*, I.8, Vol. 1, p. 26:14–20, tr. by Toomer in Ptolemy, *Almagest*, p. 45.

[14] Ptolemy, *Syntaxis*, I.8, Vol. 1, p. 29:17–23, tr. by Toomer in Ptolemy, *Almagest*, p. 47.

[15] For the second primary motion, see Ptolemy, *Syntaxis*, I.8, Vol. 1, p. 30:7–17.

the one the planets perform from east to west, is ascribed to the ecliptic circle containing all planetary circles in *Almagest* I.8, whereas the ecliptic circle itself only has a motion from east to west in *Planetary Hypotheses* I.3. On the other hand, if one considers the second primary motion from *Almagest* I.8 as a summary of the eastward motion that all planets share, the difference between the *Almagest* and the *Planetary Hypotheses* might not be considered to be that important. Whether it is the ecliptic, as the circle containing all remaining circles, or another circle for every sphere below it that is responsible for the eastward motion of the planets is, geometrically speaking, not a major problem for establishing the revolutions of the planets. The reason why Ptolemy distinguished between the two primary motions in *Almagest* I.8 in the first place was to preclude any irregularity from the celestial motion so that the planets move by certain retardations of the primary motion.[16] This is still precluded in the *Planetary Hypotheses*. It is simply a different way to approach the motions of the heavens. In the introduction to the *Almagest*, the motions are briefly summarized. In the planetary models of both the *Almagest* and *Planetary Hypotheses*, however, the complex motion of every planet is generated by a set of circles. Accordingly, in *Planetary Hypotheses* I.4, Ptolemy writes that the Sun has a motion to the east in addition to the motion of the ecliptic, which is to the west. It is the motion of the Sun against which the following planetary motions will be measured, because this motion is visible through the rhythm of day and night.[17]

Subsequently, we come across a third account of the diurnal motion when Ptolemy establishes the physical models of his cosmos in *Planetary Hypotheses* II.11. This shows that in the first part of Book I, Ptolemy has not yet entirely departed from the rather mathematical approach of the *Almagest*. The difference between *Planetary Hypotheses* I.3–4 and II.11 is more evident than the one between *Almagest* I.8 and *Planetary Hypotheses* I.3–4. In the physical model of the cosmos, for example, Ptolemy does not need what he called the 'great circle', the purpose of which in *Planetary Hypotheses* I.3 is to divide the heavens into 360 degrees. This indicates the abstract geometrical nature of the models that Ptolemy presents in Book I of the *Planetary Hypotheses* in comparison with the representation of the physical reality of the cosmos in Book II.

Chapter I.4 serves to establish how the motions of the following models are measured. Since the diurnal rotation of the intermediate carrying sphere cannot be observed, Ptolemy measures the planetary motions by the daily solar motion.[18] Because of the slight additional eastward motion of the Sun, this solar revolution is not the same as the diurnal revolution of the cosmos.

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16 See Taub, *Ptolemy's Universe*, pp. 101–02. Taub also suggested that Ptolemy might have been influenced by the motions of the Same and the Different from Plato's *Timaeus* when claiming that there are two primary motions in the heavens. See *Tim.* 36b6–d7 and Taub, *Ptolemy's Universe*, pp. 102–03.

17 Compare this also with Ptolemy, *Syntaxis*, I.8, Vol. 1, p. 26:21–23.

18 See Ptolemy, *Almagest*, p. 23 for Toomer's explanation of the term *nychthemeron*.

I.5–7

Chapter I.5 marks the beginning of the presentation of planetary motion. Ptolemy distinguishes 'simple' and 'complex' motions and presents the former in Chapters I.5–7. These simple motions basically indicate the time that the planets, stars, or apogees need for a certain number of revolutions. In Chapter I.5, Ptolemy gives the number of returns that the fixed stars, the apogees of the planets, and the Sun cover in 300 tropical years with respect to the solstitial and equinoctial points of the ecliptic. The returns of the Moon (with respect to the Sun, in anomaly and in latitude) are given in Chapter I.6. Finally, Chapter I.7 provides us with the planetary restitutions in anomaly in sidereal years.

These chapters and the parameters (i.e. the numerical values that appear here) have been studied in detail by Otto Neugebauer, Dennis Duke, and Elizabeth Anne Hamm, including an explanation of how Ptolemy arrived at these numbers.[19] Some of these parameters are already known or derive from the *Almagest*, whereas others are newly observed or based on new calculations. For the history of the text, the often diverging parameters between the different versions might be of some interest. In some cases, the Arabic tradition has the correct parameter as opposed to the Greek tradition. In other cases, the Arabic has similar mistakes to the Greek. John Bainbridge corrected many of the mistakes he found in the Greek.[20] They are mostly collected in the footnotes accompanying Hamm's English translation, to which I refer for a comparison between the values found in the Greek and Arabic versions.[21] I highlight in the notes to my translation those parameters that are wrongly transmitted in the Arabic manuscripts.

These simple periods are prerequisites for Ptolemy's arrangement of the planetary models that follow in Chapters I.8–14. He uses them to establish the inclination and returns of each circle needed to account for the apparent mean motion.

I.8–14

Ptolemy now proceeds to the description of the 'complex' motions, as promised in Chapter I.5. By 'complex', he means the combination of the motions of the various circles responsible for the apparently irregular motions of the planets. For example, regarding the upper planets, the returns in anomaly which are basically generated by the rotation of the epicycle are added to the motion of the eccentric that carries the epicycle. Ptolemy starts with the Sun (Chapter I.8), perhaps because it needs the smallest number of circles. He continues to the Moon (I.9), then proceeds to

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[19] See Neugebauer, *A History*, pp. 901–02, Duke, 'Mean Motions', pp. 637–43, and Hamm, *Ptolemy's Planetary Theory*, pp. 140–67.

[20] See his own list of corrections in Ptolemy, *De planetarum hypothesibus*, p. 52.

[21] See Hamm, *Ptolemy's Planetary Theory*, pp. 44–64.

the remaining five planets, from the lowest (Mercury, I.10) to the highest (Saturn, I.14). The corresponding passages from the *Almagest* are Chapter III.4 for the solar model, Book IV for the lunar model, and Books IX–XI for the five planets. The most striking feature is the new latitude theory. Major research on these chapters has been conducted by Neugebauer, Duke, Hamm, and most recently Nikfahm-Khubravan.[22]

To each planet belongs a 'sphere' (*sphaira* in Greek and *kura* in Arabic). These spheres contain a number of 'circles' (*kyklos* in Greek and *falak* in Arabic). The brief chapter on the model of the Sun (Chapter I.8) already makes it clear what Ptolemy intends to do for every planet. He gives the relative position of the centre of the eccentric circle and establishes the speed of the Sun's revolution on this eccentric circle. Although the models of the remaining planets and the Moon differ from each other, Ptolemy's method is always the same: he first establishes the position and motion of the deferent circles and then adds the position and motion of the epicycles. The combination of these motions for every planet is the reason why Ptolemy calls these models from Chapters I.8–14 'complex' in comparison with the 'simple' periods of Chapters I.6–7. At the end of each of these chapters, Ptolemy gives the positions at a certain epoch date, namely the first day of the Era Phillip (Thoth 1), which corresponds to 12th November 323 BC in the Julian calendar.[23]

Again, one should bear in mind the question why Ptolemy deals with these issues here in the *Planetary Hypotheses*. First, we already find an account of planetary models in the *Almagest*. As Ptolemy himself announces in the beginning, and as Duke has sufficiently shown, we are faced with a number of changes and differences between these two works. Thus, what we find in the first 14 chapters of the *Planetary Hypotheses* is an abridged and updated version of what we find in the *Almagest*. Ptolemy used these results for a (lost) table that he mentions in Chapter II.18. There, he also states that whoever studies astronomy should deal with both the physical models of Book II as well as with observations and calculations of planetary motion. Although the physical models of Book II do not contain similar mathematical calculations, the connection between these two books is quite clear. In the *Almagest* and Book I of the *Planetary Hypotheses*, Ptolemy establishes how one can mathematically present planetary motions and how many and which geometrical bodies are necessary for that. The physical models that we subsequently find in Book II rely on these geometrical models. However, there are again some changes between these two accounts, mostly because Ptolemy wishes to bring the seven models of the planets, the Sun, and the Moon together into one coherent system of the cosmos. By doing so, as we are going to see, he wishes to reduce the

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22 Neugebauer, *A History*, pp. 902–13, Duke, 'Mean Motions', pp. 643–53, Hamm, *Ptolemy's Planetary Theory*, pp. 168–80, and Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories*, pp. 99–114 and especially pp. 565–81 for his edition of the Arabic version of Chapters I.10–15.

23 For a summary of these circles, see Jones, 'Theon of Smyrna and Ptolemy', pp. 90–91, and for an overview of the different eras, see Neugebauer, *A History*, pp. 1064–67.

total number of physical bodies in the heavens, so that there are in the end fewer physical spheres than geometrical circles.

I.15[24]

With this chapter, the second part of Book I begins. This part has been rediscovered and translated by Bernard R. Goldstein.[25] Indeed, it forms a discussion in its own right. At the beginning of this chapter, Ptolemy writes explicitly that the 'configuration of the wandering planets with respect to their circles' has now been sufficiently dealt with. The result of the previous chapters is that the fixed stars move 'in a way very close to the motion of the universe', that the Sun has one anomaly, the Moon two, and the wandering planets three. This leads to two main questions that Ptolemy addresses here.

First, Ptolemy apparently worries about the physical implications of the anomalistic motions of the planets. The fixed stars move 'very close' (but only very close because of precession) to the motion of the cosmos from east to west, this motion being simple and unmixed. This is an indication of its eternal nature. However, the anomalistic motions could suggest that the planets are not eternal, since the eternity of the celestial bodies is usually inferred from their perfect circular motion. The following remarks go back to Aristotle's *Physics* and *On Generation and Corruption*. Ptolemy argues that there are three kinds of change or motion: locomotion, change in quality, and change in quantity. Therefore, even when we observe forward and backward or southward and northward motion by the planets, this still belongs only to the category of locomotive change. This does not entail any change in the substances, as is the case for sublunar bodies. In the same passage on the different kinds of change from *Physics* VIII.7, Aristotle also briefly alluded to the process of heating, which Ptolemy now picks up in his explanation of why the Sun has only one anomaly.[26] Here, Ptolemy follows Aristotle's description of how the Sun influences the sublunar changes: the Sun's motion in anomaly ensures the passing away and coming to be of sublunar bodies, whereas its regular daily rotation is responsible for the fact that these changes happen constantly.[27]

After Ptolemy explained that it is conceivable for even eternal things to have different kinds of locomotion, he discusses the differences between the three kinds of inclinations that generate these kinds of anomaly. After describing the longitudinal anomalies, Ptolemy presents the three different kinds of latitudinal anomalies for planetary motion. The first

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[24] I am grateful to Jan P. Hogendijk for valuable comments on this and the following chapters.

[25] See Goldstein, 'The Arabic Version'. A detailed analysis of this part can be found in Hamm, *Ptolemy's Planetary Theory*, pp. 185–213. The current chapter is summarized on pp. 185–88. In addition, see Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories*, pp. 107–13.

[26] See *Phys.* VIII.7, 260a26–b15. Note, however, that both Morelon and Nikfahm-Khubravan omit this sentence from their editions. See Ptolemy, 'La version arabe du *Livre des Hypothèses*', p. 57 (note to Line 14), and Nikfahm-Khubravan, *The Reception of Ptolemy's Latitude Theories*, p. 579 n. 10.

[27] *Gen. et Corr.* II.10, 336a15–336b18. See also *Metaph.* XII.6, 1072a9–18 and XII.7, 1072a21–24, Jones, 'Theon of Smyrna and Ptolemy', pp. 84–85, and Bowen, *Simplicius on the Planets*, p. 277.

is the inclination of the equator to the ecliptic, the second is the inclination between the planet's circle and the ecliptic, and the third is between the planet's epicycle and the deferent. Subsequently, Ptolemy describes how the different astronomical points, namely the summer and winter solstices and the vernal and autumnal points, change their position because of the first latitudinal inclination of the ecliptic to the equator. The second and third inclinations are afterwards compared with this first one. As in the previous chapters, these kinds of inclination are clear to every reader of the *Almagest*.

Nevertheless, in describing the first two kinds of inclination, Ptolemy gives a somewhat strange account of two kinds of motion according to these two inclinations: 'each of them [i.e. the planets] has a volitional motion and a motion to which it is compelled (*yaḍṭurr ilay-hi*).'[28] What makes this sentence so curious is the fact that he directly opposes this view in the third chapter of Book II: 'this [occurs] regarding [the aethereal bodies] not by force (*qahr*) or necessity (*ḍarūra*), forcing them from outside. For there is nothing stronger than what does not receive alteration so that it could force it.'[29] This contradiction within the *Planetary Hypotheses* has already been criticised by Ibn al-Hayṯam.[30] If we take Ptolemy's statement from I.15 as an allusion to Aristotle's division of motion into natural and coerced (*bia*) motion, this indeed goes directly against Ptolemy's overall conception of celestial and aethereal motion.[31] One solution could lie in the way in which we read *yaḍṭurr ilay-hi*, 'to which it is compelled'. Here, in I.15, Ptolemy might simply state that the planets move by their volition but this motion is led by the way in which the different spheres are arranged. In that case, *yaḍṭurr ilay-hi* would instead mean something like 'accidentally'. Since this accidental motion is also circular, as is natural for aether, one could still consider this accidental motion as being in accordance with nature.[32] However, there still remain serious problems. First, it is not clear why Ptolemy seems to assume that one of the first two inclinations (probably the first one) is voluntary but the other is accidentally (or compelled from outside). This is at least what the Arabic version suggests. Second, a form of the same Arabic root *ḍ-r-r* is used in II.3 to refer to a motion that is excluded from planetary motion. Without the Greek text, this problem is hard to resolve.[33]

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28 *Plan. Hyp.* I.15, p. 262:17.
29 *Plan. Hyp.* II.3, p. 290:7–9.
30 See Ibn al-Hayṯam, *al-Šukūk*, p. 47:3–5.
31 cf. *Phys.* IV.8, 215a1–2.
32 This would be similar to al-Ṭūsī's definition of accidental motion (*ḥaraka ʿaraḍiyya*). See al-Ṭūsī, *Memoir on Astronomy*, p. 101:10–11.
33 cf. Hamm, *Ptolemy's Planetary Theory*, p. 186.

I.16–19

Chapter I.16 starts by repeating some claims already made in *Almagest* IX.1.[34] Both in the *Almagest* and in the *Planetary Hypotheses* I.16, Ptolemy begins by stating what most astronomers agree upon concerning the order of the planets. The sphere of the fixed stars is farthest away from the Earth, the next below it is Saturn, then Jupiter and Mars, and the Moon is closest to the Earth. In the *Almagest*, Ptolemy then ascribes the view that Mercury and Venus are below the Sun to the 'most ancient' astronomers, whereas 'some of their successors' held the position that the Sun is below Mercury and Venus.[35] In the *Planetary Hypotheses*, Ptolemy simply writes that this problem cannot be solved 'with certainty' (*ʿan yaqīn*). To the remark in the *Almagest* that this uncertainty is caused by the lack of observed parallaxes,[36] Ptolemy adds in the *Planetary Hypotheses* that the reason why no (partial) occultations of the Sun by Mercury or Venus have been observed might be the brightness of the Sun. In the end, these doubts lead Ptolemy to say that the positions of not only Venus and Mercury but of all planets are not certainly proven.

Nevertheless, Ptolemy opts in both treatises for one of the two options, namely Earth — Moon — Mercury — Venus — Sun — Mars — Jupiter — Saturn. The reason for preferring this order in the *Almagest* was that Mercury and Venus always move near the Sun. In this way, Ptolemy separated these two from the remaining three planets that have greater distances from the Sun.[37] Here, in *Planetary Hypotheses* I.17, Ptolemy gives another indication of the correct order of the planets, namely their actual distances from the Earth. For the Moon and the Sun, Ptolemy had already computed these distances in the *Almagest*.[38] The methods involved in calculating these distances, however, could not be transferred to determining the distances of the remaining planets. Instead, Ptolemy introduces two other principles by means of which one can obtain the celestial distances.[39] First, the ratios of the relative distances from the geometrical models are like the ratios of the true distances. Here, the Arabic version draws the distinction between something that is 'arranged' (*yatahayyaʾ*), referring to the true distances, and what is not

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[34] Summaries of Ptolemy's discussions on the order of the planets can be found in Goldstein, 'The Arabic Version', p. 4, Swerdlow, *Ptolemy's Theory*, pp. 99–106, Hamm, *Ptolemy's Planetary Theory*, pp. 188–91, and Pedersen, *A Survey*, pp. 393–96.

[35] Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:2–6, tr. by Toomer in Ptolemy, *Almagest*, p. 419. For possible candidates for these two models, see Neugebauer, *A History*, pp. 690–93.

[36] Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:13–16.

[37] Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:16–20.

[38] See Ptolemy, *Syntaxis*, V.11–13 for the Moon and V.14–15 for the Sun. For reconstructions of these values, see Swerdlow, *Ptolemy's Theory*, pp. 41–52 and 58–72, Neugebauer, *A History*, pp. 101–03 and 109–11, Carman, 'Rounding Numbers', and Loizelet, *Mesurer et ordonner*, Chapter 3.

[39] See, most importantly, Goldstein, 'The Arabic Version', p. 4, and Swerdlow, *Ptolemy's Theory*, pp. 95–96 and 121. For concise summaries, see Goldstein and Swerdlow, 'Planetary Distances', pp. 138–43, and Goldstein and Hon, 'The Nesting Hypothesis', pp. 209–11. A more detailed account can be found in Loizelet, *Mesurer et ordonner*, Chapter 4.

'arranged', referring to the relative distances.[40] Second, the maximum distance of a planet should coincide with the minimum distance of the planet above in order to exclude any void space between two planetary spheres.[41] These two principles, taken together with the calculated distances of the Sun and Moon, allow Ptolemy to infer the true distances (but not calculate them mathematically, as he did in the cases of the Moon and the Sun). The table below summarizes the values that can be found in *Planetary Hypotheses* I.17.[42]

From the true distances of the Moon and the Sun, Ptolemy finds it only logical to assume that the spheres of Mercury and Venus fill the void space between the Sun and the Moon, but also that this space is, on the other hand, not large enough to accommodate any other planet. Still, Ptolemy acknowledges the problem that there remained a small space of 81 Earth radii between Venus and the Sun. Ptolemy suggests getting rid of this gap by adjusting the lunar distance. However, this remains only a suggestion and Ptolemy does not engage with it any further.[43]

In Chapter I.18, these absolute distances are transferred into stades.[44] Ptolemy adopts the same circumference for the Earth as in his *Geography*, namely 180 000 stades.[45] This allows Ptolemy to infer the distances of the planets in stades. For the following table, which includes the distances in Earth radii and in stades, I generally follow the calculations by Swerdlow.[46]

	Minimum distance (Earth radii)	**Maximum distance (Earth radii)**	**Minimum distance in stades**	**Maximum distance in stades**
Moon	33	64	946 000	1 834 666;40
Mercury	64	166[47]	1 834 666;40	4 758 666;40

[40] Regarding the relative distances, see Swerdlow, *Ptolemy's Theory*, pp. 107–20, especially the table of the relative distances of the planets between pp. 118 and 119.

[41] Carman, 'Rounding Numbers', especially pp. 225–38, argued that Ptolemy had this idea of strictly nested spheres in the back of his head in the *Almagest*.

[42] A recomputation of these values can be found in Goldstein, 'The Arabic Version', pp. 9–11, and Swerdlow, *Ptolemy's Theory*, pp. 121–27.

[43] See Swerdlow, *Ptolemy's Theory*, pp. 123–25. Goldstein, 'The Arabic Version', pp. 10–11, provides such a computation.

[44] The Greek stade was not fixed and thus varied. We do not know how long Ptolemy's stades actually are. See Diller, 'The Ancient Measurements', pp. 7–9.

[45] Ptolemy, *Handbuch der Geographie*, Vol. 2, VII.5.12:8, and Diller, 'The Ancient Measurements', p. 7.

[46] Swerdlow, *Ptolemy's Theory*, pp. 127–28.

[47] According to the calculation by Hartner, 'Medieval Views', pp. 268–69, this value should be 177 on the basis of the values from the *Almagest*. Based on the account of Proclus in his commentary on the *Timaeus*, he rightly concluded that the value of 166 comes from the *Planetary Hypotheses* and supposed that Ptolemy did a mistake there. Part of this mistake can be explained by new values for Mercury's model in the *Planetary Hypotheses*, see Goldstein, 'The Arabic Version', pp. 9–10, and Carman, 'Rounding Numbers', pp. 227–28.

Venus	166	1079	4758666;40	30931333;20
Sun	1160	1260	–[48]	36120000
Mars	1260	8820	36120000	25284000
Jupiter	8820	14189[49]	25284000	406751333;20[50]
Saturn	14189	19865	406751333;20	509463333;20

This cosmological system that results from these two principles is often called the theory of 'nested spheres'. For example, the greatest distance of the Moon equals the smallest distance of Mercury, and therefore the spheres in which these planets move must be in direct contact with each other. In this way, all the planetary spheres are tightly packed around each other like the skins of an onion.[51]

Ptolemy concludes this chapter with another remark on this system of nested spheres. Since it is naturally impossible, as Ptolemy writes, that there is an amount of space that is 'useless' and 'meaningless', namely the void, Ptolemy holds that this account is 'most likely' (*as̆bah al-umūr*). This concept — namely that 'nature does nothing in vain' — is, of course, very prominent in the Aristotelian corpus and is adduced by Aristotle not only in his biological treatises but also in *On the Heavens*.[52] Nevertheless, Ptolemy remains very cautious about this issue of the order of the planets. He explicitly writes that 'if the situation is as we have said', then the distances are as calculated. However, if there is indeed empty space between the spheres, as Ptolemy adds, then the distances should not be smaller than calculated before. Thus, Ptolemy provides us with the smallest possible planetary distances and only this can safely be determined. This cautious note mirrors the beginning of the discussion on planetary distances in Chapter I.16 where Ptolemy stated that one cannot know the planetary order 'with certainty' (*'an yaqīn*), as well as the first chapter of the *Almagest*. Although Ptolemy 'calculated' these distances, he did not do so on the basis of observations or of geometrical proofs, but on physical grounds such as his assumption that there is no empty space between the spheres. Given his statement in *Almagest* I.1 that physics is 'guesswork' and that only mathematics can generate true knowledge, his hesitation about the question of the order and distances is nothing but consistent. Moreover, he is also very consistent in marking

[48] Ptolemy gives the distances in stades for the border of two adjacent spheres and the value for the border of the spheres of Venus and Sun are calculated from the value of the maximum distance of Venus. He did not calculate the value for the minimum distance of the Sun in stades.

[49] I adopt the correction by Goldstein, 'The Arabic Version', p. 11, and Swerdlow, *Ptolemy's Theory*, p. 125 n. 24, instead of 14,187, which is preserved in the manuscripts.

[50] Following Swerdlow, *Ptolemy's Theory*, p. 128 n. 25, who calculated this from the corrected value for the maximum distance of Jupiter in Earth radii.

[51] See again Goldstein and Hon, 'The Nesting Hypothesis'.

[52] See, for example, *Cael.* I.4, 271a32–33, and *Inc. Anim.* 2, 704b15.

the limits of safe knowledge and the beginning of conjectural knowledge.[53] It should also be noted that the Greek word for 'guesswork', *eikasia*, is translated as 'more likely and appropriate', *ašbah wa-aḥrā*, in the Isḥāq-Ṯābit version of the *Almagest*.[54]

These chapters (together with the subsequent one, I.19) are of particular importance for understanding the *Planetary Hypotheses*. Before the discovery of this second part of Book I, the *Planetary Hypotheses* merely consisted of 'a summary of planetary theory followed by curious spherical models', as Swerdlow rightly commented.[55] These chapters on cosmic dimensions make it clear that Ptolemy is serious in his attempt to give the best possible reconstruction of the physical reality of the cosmos.[56] As discussed above, Ptolemy also addressed his work to instrument-makers. However, for them, the relative planetary distances should have been enough to construct an instrument. When Ptolemy transfers the relative distances into true ones, this signifies a shift within his work, which is also dedicated to astronomers and natural philosophers, who want to understand not only how to compute the celestial phenomena but also how to explain the celestial motions in reality.

Next, Chapter I.19 closely follows the agenda of the previous chapters, namely to give true values for the cosmic models. The issues at stake here are the diameters and volumes of the planets. Basically, Ptolemy uses the mean distances, the apparent diameters of the planets in relation to the Sun, and the apparent diameters of the Sun.[57] From these, Ptolemy calculates the true diameters of each planet in relation to the Earth and subsequently calculates the planetary volumes.[58] Ptolemy distinguishes between stars of six different magnitudes in his star catalogue in the *Almagest*.[59] Here, he only provides the sizes of the brightest stars, namely those that are of the first magnitude.

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53 See also Hamm, *Ptolemy's Planetary Theory*, pp. 38–43. For physics as a conjectural science, see Feke, *Ptolemy's Philosophy*, Chapter 3, and Chapter II of the present study.

54 See MS Tunis, Dār al-kutub al-waṭaniyya, 7116, f. 2^r:9. I consulted the transcription by Pouyan Rezvani, available on the website of *Ptolemaeus Arabus et Latinus* at https://ptolemaeus.badw.de/text/M971 (last consulted on 20.01.2021).

55 Swerdlow, *Ptolemy's Theory*, p. 20.

56 See also Pedersen, *A Survey*, p. 395.

57 The latter is already known from the *Almagest*, as Ptolemy states, and it is 5.5 times the diameter of the Earth (Ptolemy, *Syntaxis*, V.16).

58 For the details of these calculations, see Goldstein, 'The Arabic Version', pp. 11–12, and Swerdlow, *Ptolemy's Theory*, pp. 168–72. Swerdlow's recalculations offer some adjustments, see such as in his Table 4.2 between pp. 170 and 171.

59 See Neugebauer, *A History*, pp. 291–92.

	Volume (compared with the Earth)
Moon	1/40
Mercury	1/19683
Venus	1/44[60]
Sun	166 ⅓
Mars	1 ½
Jupiter	82 ½ + ¼ + 1/20
Saturn	79 ½
fixed stars of first magnitude	94 ⅙ + ⅛

Ptolemy concludes Chapter I.19 on the sizes of the celestial bodies with two statements. First, he again emphasizes that these values are only correct if the planetary distances are also correct, which is basically the same as what he had to say about the true diameters themselves. Again, it becomes clear that Ptolemy does not consider his values to be ultimately proven, although these values might be a good guess. The second statement concerns parallaxes. Previously, in the *Almagest*, on the topic of the uncertainty of any theory of planetary order, he argued that there are no parallaxes observed for the planets.[61] Ptolemy calculated the lunar parallax in *Almagest* V.12–13.[62] In the *Planetary Hypotheses*, he writes that there should be observable parallaxes for Mercury, Venus, and Mars, but introduces this statement by the now well-known formula: 'if their distances are as we have determined them'. Indeed, if the distance of Mercury's perigee is the same as the Moon's apogee, then they should have the same parallax at these points.[63]

60 Goldstein, 'The Arabic Version', p. 12 notes that the values for the diameters of Venus are wrongly attested in the manuscripts, as these do not result in the volume given in the manuscripts. Swerdlow, *Ptolemy's Theory*, p. 171 n. 2, and p. 172 agrees but also notes that there is a further complication. Ptolemy concludes the passages on the volume of the planets by ordering the planets according to their volume and Venus is said to be larger than the Moon, which is in contradiction to the given values. As Goldstein has argued, there might be a mistake in the given diameters, but then the mistake in the order of the planets according to their sizes remains. Thus, Carman, 'Rounding Numbers', pp. 229–32, suggests that Ptolemy might have taken these values from previous calculations. Carman provides also a list of how this error was dealt with by authors in the Arabic tradition. See Carman, 'Rounding Numbers', p. 232 n. 41. In addition, one should consider Ibn al-Ṣalāḥ, who writes in the commentary to the star table of the *Almagest* that in the *Planetary Hypotheses*, Ptolemy gives the ratio as 1/44, whereas the correct ratio is 1/37. See Ibn al-Ṣalāḥ, *Zur Kritik der Koordinatenüberlieferung*, pp. 48 and 150:14–18.

61 Ptolemy, *Syntaxis*, IX.1, Vol. 2, p. 207:13–17.

62 See Pedersen, *A Survey*, pp. 204–06.

63 Following Hamm, *Ptolemy's Planetary Theory*, p. 204.

I.20–21

The last two chapters of Book I are somewhat unconnected to the previous discussions. Chapter I.20 deals with the *arcus visionis*, the angle between the Sun and the horizon at which the planet in question is visible. These arcs were calculated by Ptolemy in *Almagest* XIII.7.[64] The parameters given here in the *Planetary Hypotheses* are not in agreement with those from the *Almagest*, but rather with those from the *Handy Tables*, Ptolemy's treatise originally containing astronomical tables and a manual for their application.[65] Thus, the reason why this chapter is included in the *Planetary Hypotheses* is not so much as a physical representation of the cosmos but to add more corrections to the values from the *Almagest*, as Ptolemy promised in the first chapter.

The last chapter of Book I concerns optical illusions that might impede correct observations. The problem described here is that planets seem to be much closer than they really are because, as Ptolemy describes, the eyes are used to see things that are much closer. Hamm has compared this last paragraph with passages on the optical problems of observations in the *Almagest* and the *Optics*, but could not find similar statements.[66]

II.1–2

Ptolemy finishes the first part of Book I as follows: 'This is the configuration (*hay'a*) of the wandering stars on their circles.'[67] In the beginning of Book II, he concludes that he has described 'most of the relations of the spherical motions that have been perceived by observations made up to our time.'[68] What is left is the discussion of the shapes of the heavenly bodies. Ptolemy aims at harmonizing their nature and the principles of aethereal motion with the previous discussion. Although he is going to lay out these principles in more detail, we are already acquainted with the most important of them from the *Almagest*. The first chapters of Book I of the *Almagest* presented the foundations of the Ptolemaic cosmos, and in Chapter III.3, Ptolemy established that all celestial motions, even the apparently irregular motions of the

64 See Neugebauer, *A History*, pp. 234–38.

65 Discussed by Goldstein, 'The Arabic Version', p. 4, and Hamm, *Ptolemy's Planetary Theory*, pp. 206–08.

66 See Hamm, *Ptolemy's Planetary Theory*, pp. 208–13. In addition, note that there are doubts concerning the authenticity of the extant version of the *Optics*. See Siebert, *Die ptolemäische Optik*.

67 *Plan. Hyp.* I.15, p. 262:1.

68 *Plan. Hyp.* II.1, p. 288:3–4. Note that at the end of *Almagest* I.1 Ptolemy had already stated that he would give 'everything which we think we have discovered up to the present time' (Ptolemy, *Syntaxis*, I.1, Vol. 1, p. 8:6–7). This shows that Ptolemy indeed believes that astronomical knowledge advances more and more because of ongoing observations, and that recent observations may call for a correction of the astronomical values based on older observations.

wandering planets, are, in fact, uniform.[69] Given that Ptolemy will argue against Aristotle's cosmology, his claim that he does not deal with incorrect previous accounts might sound strange. An explanation of this might be that he has in mind theories of completely different shapes of the cosmos or its motions, as they were already refuted in *Almagest* I.3.

The second chapter closes with two announcements by Ptolemy. First, before he lays out the individual spheres for every planet (starting with Chapter II.9), he plans to provide a more general account of the possible shapes of the celestial bodies. This is similar to what Ptolemy does in the *Almagest*. At the end of *Almagest* I.2, Ptolemy introduces the topics of 'general' nature (*katholou*) from Chapters I.3–8, whereas at the beginning of Chapter I.2, he writes that the subsequent investigations concern the 'particular aspects' (*tōn kata meros*).[70] Thus, the methodology is the same for both the *Almagest* and the *Planetary Hypotheses*.

Second, Ptolemy distinguishes two disciplines by which one can approach the questions that are to be answered in Book II, namely the mathematical and the physical (*ǧiha taʿlīmiyya* and *ṭabīʿiyya*, literally 'mathematical' and 'physical side'; in the following chapters, the Arabic has *qiyās*, 'reasoning', instead of *ǧiha*). Again, we have already encountered this dichotomy in the *Almagest*, though in a different context. The question at stake in *Almagest* III.1 is the definition of a solar year. Ptolemy concludes that both approaches agree that one should consider a solar year to be the time from one solstice or equinox to the same again. As he explains, the mathematical viewpoint implies the return of the Sun to the same position, and the most suitable positions for observation are the equinoxes and solstices. From the physical viewpoint, one wants to measure the Sun's return to a 'similar atmospheric condition and the same season', and since the solstices and equinoxes mark the beginnings and endings of the seasons, these points are again most suitable.[71] Both approaches arrive at the same conclusion. This is not the case for the present question of the shape of the spheres.

It has now been stated a couple of times that the *Planetary Hypotheses* mark the beginning of a new discussion, namely the presentation of the physical shape of the spheres. However, it is not the case that Ptolemy was not concerned with physical arguments in the *Almagest*. This is indicated by the argument above from *Almagest* III.1, and it has already been pointed out by Alexander Jones. In order to show that Ptolemy had indeed already applied physical principles in the *Almagest*, Jones points to not only the often cited first chapters of Book I but also

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[69] See Ptolemy, *Syntaxis*, I.1–8 and III.3, Vol. 1, especially p. 216:3–7.

[70] Ptolemy, *Syntaxis*, I.2, Vol. 1, p. 8:20 and 9:17.

[71] See Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 192:22–193:11. For the terminology, I have followed Toomer's translation. See Ptolemy, *Almagest*, p. 132. The Isḥāq-Ṯābit-version of the *Almagest* also has *waǧh taʿlīmī* for *mathēmatikōs* ('mathematical viewpoint') and *al-waǧh allaḏī huwa ašbaha bi-l-ʿilm al-ṭabīʿī* for the Greek *physikōteron* [...] *to oikeion* ('physical viewpoint'). See MS Tunis, Dār al-kutub, 7116, f. 38r:7 and 10. This makes it probable that Ptolemy used the same terminology in *Almagest* III.1 as in *Planetary Hypotheses* II.2.

to Chapter III.3, where Ptolemy argued for the necessity for all celestial motions to be regular and uniform, as well as to XIII.2 on the simplicity of the models.[72] In this second chapter of Book II of the *Planetary Hypotheses*, Ptolemy's attempt to harmonize the observations and the mathematical proofs with physical principles becomes manifest again.

As the following commentary shows, Book II of the *Planetary Hypotheses* follows a coherent line of argument in order to establish an account of the physical representation of the cosmos. This coherency was doubted by Andrea Murschel but defended by Régis Morelon. Murschel writes that the first part of Book II, supposedly Chapters II.1–8, do 'not follow a logical order, as if the Greek passages were translated out of sequence.'[73] In contrast, one can detect a clear train of thought. First, Ptolemy wishes to transform the geometrical account into an account of the underlying reality (II.1–2). For that reason, he introduces the important physical foundations that need to be taken for granted for such an enterprise (II.3). On the basis of the mathematical account, there are two possible shapes for the celestial spheres, and since mathematics does not allow us to decide between these two options (II.4), we need to investigate the physical consequences of each option (II.5–8). Ptolemy shows that one of the two options leads to problematic physical consequences (II.5), whereas the other better fits the physical principles laid out in Chapter II.3 (II.6). Lastly, Ptolemy explains how celestial motions arise in physical and psychological terms (II.7–8). For this reason, I believe that there is no ground for assuming that the Arabic translation available to us is not faithful to the original Greek version.

II.3

This chapter offers a concise overview of the physical principles that Ptolemy seems to take for granted for the following discourse. Here, the Arabic version uses terminology that is different from the previous chapter, where the physical and mathematical approach or viewpoint was labelled by the term *ǧiha*. Now (and the same holds true for the following chapter on the mathematical approach), the Arabic version uses the term *qiyās*, which generally means 'reasoning' (or even 'syllogism' in a more technical sense). Lacking the Greek original, there is an opposition in the Arabic between *arṣād* (the plural of *raṣd* or *raṣad*, 'observation') and *qiyās*. In *Planetary Hypotheses* II.1, Ptolemy announces that the investigation of the celestial motions that are perceived by observations (*yudrak* […] *bi-l-arṣād*) is finished. In fact, no mathematical parameters are given for the rest of the treatise. These two terms (*arṣād* and *qiyās*) seem to have been set against each other in the later Arabic

72 See Jones, 'Ptolemy's Mathematical Models', pp. 27–32.

73 Murschel, 'Structure and Function', p. 37, and Morelon, 'Le Livre des hypothèses', p. 98. See above, pp. 15–22.

tradition quite often, always with the meaning of observations (either with the naked eye or astronomical instruments) and reasoning, frequently implying conclusions drawn from physical principles.[74] Once more, this highlights the shift in the object of the present investigation.

What is indicated by this physical reasoning? Ptolemy presents a theory of elementary motion that draws on the opposition of the rectilinear motion of the sublunar elements and the circular and uniform nature of the celestial element: aether itself is unchanged and uniform, and it is called a 'wonderful substance' (*ǧawhar ʿaǧīb*).[75] For every celestial motion, there is an aethereal body moving in a circular manner. These bodies do not move in this way because of an external, separate mover. Instead, celestial motions are voluntary. Ptolemy also ascribes 'governing powers' to the planets, as well as a 'brightness [that] pervades in a clear way all of these things spread around them'.[76] The relationship between these two is not explained. These voluntary aethereal motions are contrasted with the soulless motions of the four elements earth, water, air, and fire. The down- and upward motions do not naturally belong to them, but they have an inclination (*mayl*) to move back whenever they are forced outside of their natural place. Ptolemy explicitly states that what is 'ensouled' or 'animate' (*mutanaffis*) does not move rectilinearly.[77] A brief passage in *Almagest* XIII.2 on the simplicity of the planetary theories seems to foreshadow the idea of aethereal powers passing through the celestial realm and not influencing or hindering each other:

> For provided that each of the phenomena is duly saved by the hypotheses, why should anyone think it strange that such complications can characterize the motion of the heavens when their nature is such as to afford no hindrance, but of a kind to yield and give way

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[74] For example, Averroës distinguishes among *baṣar* (observation with the naked eye), *arṣād* (observations over a longer period of time with the help of instruments), and *qiyās*, which denotes reasoning with the help of physical principles. See Averroës, *Tafsīr Ma baʿd al-Ṭabīʿa*, p. 1655:3–10.

[75] In Chapter I.2, the term 'wonderful' (*aǧīb*) was used to translate the Greek word *thaumasiōtatos*. In the *Almagest*, Ptolemy usually called the aethereal bodies 'divine' (*theios*). See, for example, Ptolemy, *Syntaxis*, I.3, Vol. 1, p. 14:9, IX.2, Vol. 2, p. 208:8, and XIII.2, Vol. 2, p. 532:15. Cf. *De mundo* 5, 396a33–b7 where, in response to the question why the cosmos has not been destroyed because of the different qualities in the cosmos, it is answered that the harmonious collaboration in a city (or, of course, the cosmos) is 'most wonderful' (*thaumasiōtatos*).

[76] *Plan. Hyp.* II.3, p. 288:17. In the *Tetrabiblos*, Ptolemy speaks of rays that are the transmitters of the planets' powers in an astrological framework. However, as Feke points out, there is no detailed analysis of what these rays actually are or consist of. See Feke, *Ptolemy's Philosophy*, pp. 176–87. The connection of the theory of rays with the *Planetary Hypotheses* goes back to a mistranslation of the word 'brightness' (*ḍiyāʾ*) as 'Strahlen' in the German translation by Nix. See Ptolemy, 'Hypotheseōn', p. 112:5. This Arabic term simply denotes the light emitted by the stars, also in a philosophical context. See, for example, al-Fārābī, who characterizes light (*ḍiyāʾ*) as a sublime quality of the stars (al-Fārābī, *On the Perfect State*, Chapter III.7, p. 122:18).

[77] This chapter is briefly addressed in Murschel, 'Structure and Function', p. 38, Taub, *Ptolemy's Universe*, pp. 113–14, Feke, *Ptolemy's Philosophy*, pp. 188–90. For an analysis of the fragments of Ptolemy's theory of elementary motion from other works, see Rashed, 'Contre le mouvement'.

> to the natural motions of each part, even if [the motions] are opposed to one another? Thus, quite simply, all the elements can easily pass through and be seen through all other elements, and this ease of transit applies not only to the individual circles, but to the spheres themselves and the axes of revolution.[78]

This dichotomy between the natural motion of the sublunar elements and aether probably leads Ptolemy to label the aethereal motions as belonging to the physical argument, although at one point in *Almagest* I.1, he makes the aethereal bodies the objects of theology.[79] Here in the *Planetary Hypotheses*, Ptolemy makes no allusion to theology and surely has Aristotle's *On the Heavens* in mind when he speaks of the argument of natural philosophers concerning the natural motions of the elements.

Given that I devote Chapter III to Ptolemy's celestial dynamics and its historical background, it suffices here to underline that this chapter provides us with some preliminary statements on the nature of the celestial element. In contrast to the following chapters, these doctrines are not questioned or discussed in any way, but they are simply presented and subsequently referred to. Ptolemy uses technical philosophical terms such as 'intellect' and 'will' without any further definition or even a slight indication of how to understand these terms in the present context. Thus, in this chapter, Ptolemy apparently summarizes the fundamental cosmological principles of his time that seem unambiguous to him. When Ptolemy again comes back to the 'physical reasoning' in Chapters II.5–6, he has another issue to talk about, namely the shape of the spheres and whether they are complete spheres or only slices. Some ideas expressed in Chapter II.3 come up again there, such as the voluntary motion and the power of the planets. The fact that he starts to discuss the initially promised issue only after Chapter II.3 also indicates that this chapter is supposed to lay a common, unambiguous ground for the following discussion.

II.4

Despite its brevity, this chapter is fundamental for an understanding of Ptolemy's aim in Book II. He claims that there are two possible ways to imagine the shape of the spheres. Either they are complete like a globe or they are just segments like slices sawn out from a trunk of a tree. This suggestion originates in the fact that the planets can only be observed in a certain latitude around the ecliptic. However, Ptolemy does not explain this reason before Chapter II.6.

The important thing to note here is that Ptolemy acknowledges the mathematical equivalency between these two models. Both could equally well account for the

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[78] Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:22–533:10, tr. by Toomer in Ptolemy, *Almagest*, pp. 600–01.

[79] cf. Feke, *Ptolemy's Philosophy*, p. 18.

apparent motions of the planets. Thus, when mathematics cannot give an answer to the question about which model we should prefer, how do we attain knowledge about the shape of the spheres? Ptolemy had faced the same problem already in *Almagest* III.3–4. The Sun's motion can be represented either by an eccentric model or by an epicycle. His solution lies in a decision for the former theory because it is the simpler of the two models. Thus, Ptolemy applies the physical principle of preferring the simpler model if that is mathematically possible. Ptolemy establishes this principle in *Almagest* III.1 and refines it in XIII.2.[80] To put it in general terms, whenever mathematics does not provide certain knowledge, one should turn to physics (although it is labelled 'guesswork' in *Almagest* I.1).[81] The same methodology applies to the *Planetary Hypotheses*: since mathematics does not resolve the question whether the spheres are actually complete spheres or only slices, Ptolemy will turn to physical arguments in the following two chapters. Thus, this chapter justifies why Ptolemy starts a discussion on physics, although he considers it to be 'guesswork'.

At first glance, it might be strange that the previous chapter (Chapter II.3) offers a positive account of what physics indicates. In this chapter, we only find the negative assertion that mathematics is not decisive regarding the shape of the spheres. This divergence can easily be explained by the different objects of these two chapters. Chapter II.3 treats the general physical principles of the elements and their motion and thus simply gives the frame for everything that follows. It is in Chapter II.4 that Ptolemy starts to discuss the question that he promised to address at the beginning of Book II (Chapter II.2), namely the shape of the spheres.

II.5

Before Ptolemy criticizes Aristotle's cosmological setup, he reconstructs the line of reasoning that could lead one to assume a homocentric system of complete spheres. The principal mistake, in Ptolemy's view, is that natural philosophers (Ptolemy again picks up the notion of the 'physical reasoning', *qiyās ṭabīʿī*) transfer the motion that they observe in globes, for example, to the celestial realm.[82] A difficulty in reading this passage lies in the double usage of *kura* (as is the case for its Greek equivalent, *sphaira*) as 'ball' or 'globe' and as 'celestial sphere'. The former meaning is used here, together with the Arabic term *ʿinda-nā*, which I chose to translate as 'in our realm'.[83] In the example of the globes that we still know today, we usually have two points or 'poles',

[80] Regarding the model of the Sun, see Ptolemy, *Syntaxis*, III.4, Vol. 1, p. 232:5–17. For Ptolemy's account of his principle of simplicity, see Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 201:18–22 and XIII.2, Vol. 2, pp. 532:12–534:6. The mathematical equivalence of both theories was probably established by Apollonius (see Neugebauer, 'The Equivalence').

[81] For a full discussion, see Chapter II above, especially pp. 31–38.

[82] As pointed out by Murschel, 'Structure and Function', p. 38.

[83] In this respect, I follow Liba Taub, see Taub, *Ptolemy's Universe*, p. 115.

where the globe is fixed and around which a globe can rotate. This, as Ptolemy argues, has led natural philosophers to believe that we need similar poles for the celestial spheres. Poles, however, are easier to imagine in the case of complete spheres. Ptolemy then presents the Aristotelian cosmos as follows: the poles of one sphere are attached to the sphere above it so that the upper motion is transferred to the lower sphere. Ptolemy says that in order to make sure that the inner spheres still partake in the diurnal rotation of the outermost sphere and have their proper position and speed, and in order to avoid having all spheres moving with the same speed and in the same direction, Aristotle introduced his system of counteracting spheres.[84] Although the Arabic term *iltaffa* is ambiguous, here, it clearly refers to these counteracting spheres, *anelittousai* in Greek. The two reasons which Ptolemy ascribes to Aristotle for introducing the counteracting spheres appear in a very similar fashion in a quotation from Sosigenes preserved by Simplicius.[85] As Alan C. Bowen has pointed out, the Greek term *anelittousai* sometimes refers to Aristotle's homocentric cosmology, in general. Accordingly, the term *iltaffa* or *multaffa* seems to be used in reference to a system of complete spheres entirely enclosing each other in later chapters of the *Planetary Hypotheses*.[86]

Ptolemy's attack against Aristotle's homocentric cosmos and his counteracting spheres serves a specific goal. If he wants to argue for sawn-off pieces from which the region around the poles is cut off, he first must show that poles are unlikely to be the cause of motion. Ptolemy's first, very brief objection is directed against the comparison of human-made globes and the celestial realm in general: 'but we should not ascribe to the aetherial body things which one must posit for bodies in our realm.'[87] Apparently, Ptolemy draws a distinction between the nature of aether and the nature of things 'in our realm' (*'inda-nā*). He uses this expression three times in this chapter of the *Planetary Hypotheses*. Directly afterwards, Ptolemy goes on to say the following:

> Furthermore, we do not find the poles in our realm to be the first cause for circular motion. For it is correct that the sphere moves with a different type of motion, such as the spheres which roll and do not depend on any one external thing. Thus, the poles do not cause

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[84] The reconstruction of Aristotle's homocentric cosmos and that of his forerunners, Eudoxus and Callippus, has been a matter of debate in modern scholarship. An important contribution still is Schiaparelli, *Le sfere omocentriche*. For more recent research, see Yavetz, 'On the Homocentric Spheres', Mendell, 'Reflections on Eudoxus', Mendell, 'The Trouble', and Beere, 'Counting the Unmoved Movers'. Ptolemy's critical engagement with Aristotle has already been touched upon by Taub, *Ptolemy's Universe*, pp. 115–17, and Feke, *Ptolemy's Philosophy*, pp. 189–90.

[85] See Simplicius, *In Cael.*, p. 498:4–10.

[86] For the Greek, see Bowen, *Simplicius on the Planets*, p. 135 n. 113. For the Arabic term in the *Planetary* Hypotheses, see for example *Plan. Hyp.* II.11, p. 310:10 and II.16, p. 340:19. We also see that al-Bīrūnī uses *iltaffa* in order to compare the structure of nested spheres to the layers of an onion. See al-Bīrūnī, *Kitāb al-Tafhīm*, p. 43:8–9 (Arabic text), and also Sabra, 'Ibn al-Haytham's Treatise'.

[87] *Plan. Hyp.* II.5, p. 294:1–3.

> the circular motion in the position specific to them, but rather they only carry the weight of the sphere.[88]

Already before, in the beginning of this chapter, he writes:

> Concerning those who begin their reasoning from the spherical motions in our realm, they used the physical reasoning for the hypothesis of the complete spheres.[89]

These three citations which contain the first objections against counteracting spheres and poles pose two problems. First, what does Ptolemy mean by referring to bodies, spherical motions, or poles 'in our realm'? A possible answer might be given in the *Almagest*. When Ptolemy presents his models for the planetary motion in latitude, in Book XIII he admits that his models might look rather complicated at first sight. To allay this worry, he states the following:

> Now let no one, considering the complicated nature of our devices, judge such hypotheses to be over-elaborated. For it is not appropriate to compare human [constructions] with divine, nor to form one's beliefs about such great things on the basis of very dissimilar analogies. For what [could one compare] more dissimilar than the eternal and unchanging with the ever-changing, or that which can be hindered by anything with that which cannot be hindered even by itself? Rather, one should try, as far as possible, to fit the simpler hypotheses to the heavenly motions, but if this does not succeed, [one should apply hypotheses] which do fit. For provided that each of the phenomena is duly saved by the hypotheses, why should anyone think it strange that such complications can characterize the motions of the heavens when their nature is such as to afford no hindrance, but of a kind to yield and give way to the natural motions of each part, even if [the motions] are opposed to one another? Thus, quite simply, all the elements can easily pass through and be seen through all other elements, and this ease of transit applies not only to the individual circles, but to the spheres themselves and the axes of revolution. We see that in the models constructed on Earth the fitting together of these [elements] to represent the different motions is laborious, and difficult to achieve in such a way that the motions do not hinder each other, while in the heavens no obstruction whatever is caused by such combinations.[90]

Even without the Greek text of Book II of the *Planetary Hypotheses*, it is clear that Ptolemy uses exactly this argument from the *Almagest* again in the *Planetary Hypotheses*, without reference to the simplicity of models this time but in the context of the comparison between models or devices as humans use them and the real nature of celestial aether.[91] In the *Almagest*, Ptolemy argues that although

[88] *Plan. Hyp.* II.5, pp. 294:4–8.

[89] *Plan. Hyp.* II.5, p. 292:12–13.

[90] Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:12–533:15, tr. by Toomer in Ptolemy, *Almagest*, pp. 600–01.

[91] Ptolemy might also have in mind Plato's *Philebus*, where Socrates compares inaccurate 'human' circles with the perfect celestial spheres, cf. *Phil.*, 62a7–b2.

the human depictions of celestial motion might appear to be too complex, they are the simplest kind of motion in reality. He explicitly writes that the interaction of the various circles within one sphere (by which he refers to the set of epicycles and eccentric and homocentric circles one needs for each planet) is difficult to achieve by physical models or even instruments constructed by humans. In the celestial realm, however, these difficulties do not occur. According to this passage from the *Almagest*, even if the different parts of the celestial element, namely the spheres, move in different ways, these motions do not influence each other in a way that would be against their nature. In *Planetary Hypotheses* II.5, Ptolemy reiterates these claims. Obstacles or similar influences that occur 'in our realm' do not occur in the same way in the celestial realm. When we transfer this claim to the argument against Aristotle's counteracting spheres, Ptolemy's argument is along the following lines: when we construct physical instruments of nested spheres, we face the exact mechanical problems Aristotle tried to account for. They interfere with each other and in order to make sure that the inner spheres take part in the diurnal rotation transmitted from the outermost orb without being influenced by the intermediate spheres, one needs to add these counteracting spheres. However, the matter is completely different with respect to the celestial element. When such combinations of a number of spheres occur, all with different motions, there is no interference between these parts, Ptolemy argues.[92]

Ptolemy adds another argument, namely that something fixed cannot be the cause of motion (*sabab ibtidā' al-ḥaraka*).[93] This is a direct objection against Aristotle's unmoved movers from *Physics* and *Metaphysics* XII. Ptolemy does not add any argument or proof to this claim. Apparently, this was a position widely held in Hellenistic times before the time of Alexander, and apparently Ptolemy did not feel the need to refute this doctrine here in detail.[94] Even so, this short complementary argument is not free from further difficulties. When describing the celestial spheres, he writes that they move like 'rolling spheres' (*al-kura allatī tatadaḥriǧ*). The Arabic term *daḥraǧa* or the reflexive form *tadaḥraǧa*, as is found here, is usually used to translate the Greek term for 'rolling' (*kylisis*).[95] *Daḥraǧa* is again used in *Planetary Hypotheses* II.12, where Ptolemy suggests that celestial motion comes about from the star. This passage is quoted by Simplicius, and although he does not quote the discussion of *daḥraǧa* motion in this passage, he includes this quotation in his discussion of *On the Heavens* II.8.[96] In this chapter, Aristotle argues that the stars neither rotate (*dinēsis*) nor roll (*kylisis*). This indicates that Ptolemy also talks about the rolling motion (*kylisis*) in this context whenever the

[92] Very briefly in Murschel, 'Structure and Function', p. 38.

[93] *Plan. Hyp.* II.5, p. 294:8–9.

[94] See, for example, Menn, 'Aristotle's Theology', pp. 431–32. Menn points to Theophrastus and Eudemus as supporters of Aristotle, and cites Sextus Empiricus as one opponent.

[95] See Sabra, 'The Andalusian Revolt', pp. 146–47 n. 7.

[96] Simplicius, *In Cael.*, p. 456:22–27. See Bowen, *Simplicius on the Planets*, pp. 29–32.

term *daḥraǧa* occurs in the Arabic translation. What Ptolemy means by 'rolling' in *Planetary Hypotheses* II.5 is that a rolling sphere does not need external poles to move. Instead, in this case the poles 'only carry the weight of the sphere', by which Ptolemy must mean that the two poles define the axis and thus the direction of rotation.[97] One can perhaps compare this with the brief statement in the pseudo-Aristotelian treatise *On the World*, where the poles are responsible only for holding the sphere in position.[98]

Ptolemy then makes the transition to the celestial realm. Even if we assume that the spheres do not move by nature or by something outside of the same nature, we still do not need to assume poles. The alternative solution is that the motion originates from inside the sphere. By stating that 'this is like the condition of the motion of the sphere of the entire world',[99] Ptolemy makes the transition from the previous terrestrial examples to the celestial realm perfectly clear. The centre of the world is both the centre of celestial motion and the starting point. It is the centre, since the elemental motion goes around it and towards it (one might wonder why Ptolemy does not mention the motion away from it here, but he might consider 'around it and towards it' as a sufficient reference to rectilinear and circular elemental motion). It is also the beginning, since it is from the centre that the everlasting circular motion arises. Both of these principles together form the one cause for the motion of the outermost sphere in this example, and of circular heavenly motion in general, as one can suppose. To put it differently, motion around a centre fits the aethereal substance of the heavens and is a sign is that it is never-ceasing. The last short remarks of this passage concern the natural place of the elements and why the celestial sphere that consists of aether is held in position even without fixed poles. Although Ptolemy is not entirely clear, his argument seems to be that all points on a circle have the same distance to the centre, which then can be applied to the sphere. They all have the same inclination, as Ptolemy puts it, towards moving around the centre and therefore do not displace each other.

The last passages of Chapter II.5 are again dedicated to the refutation of poles. Ptolemy claims that the nature of the poles cause more trouble than dropping them as the causes of motion. The first problem lies in the question whether these poles are mere points or bodies. Both of these options lead to serious problems. Ptolemy dismisses the former right away because points — because of their lack of physical existence — cannot be considered as being connected to bodies. However, the poles cannot be bodily either for two reasons: if they were of the same element as the spheres, namely aether, then the question arises as to what makes them different from the sphere itself so that they cause motion. On the other hand, if they were

[97] Andrea Murschel took this statement to be a *reductio ad absurdum*, see Murschel, 'Structure and Function', p. 39.

[98] See *De mundo*, 391b24–392a2. For a discussion of the cosmology presented in *On the World*, see above pp. 164–67.

[99] *Plan. Hyp.* II.5, p. 294:14.

of a different element, they would tend toward their natural place and would not persist in the aethereal realm. The first of these two objections begs the question what the difference is between the planets and the spheres, because in Ptolemy's scheme, it is the planets that emit the impulse to move towards their surrounding spheres. Ptolemy's answer is that they are not different in density but only in their capacity to preserve light. However, he does not provide a complete argument that explains this special capacity. The reader only learns that one should not think that the planets and the spheres differ substantially.

In the background of these arguments stands Aristotle's excursus on the celestial sphere in *On the Movement of Animals* 3–4. There, one comes across rejection of the idea that celestial poles which are part of the sphere can be the source of its motion on the basis of similar reasons on the non-bodily nature of mathematical entities. In contrast to Ptolemy, however, this argument leads Aristotle to assume that the necessary support for the motion of the cosmos must lie outside of it.[100] Surely, Ptolemy has this account in mind when he argues that one should look for the cause of celestial motion within the sphere itself and not for an external support. In fact, this solution might go back to Aristotle's *On the Movement of Animals* as well, as Aristotle explains that animals, as opposed to the cosmos, have an internal support (in addition to the external one).[101] Since Ptolemy later compares the entire cosmos to a flock of birds and suggests voluntary powers as the cause of celestial motions, it seems reasonable to assume that he does not want to distinguish between animals and the cosmos in this way and thus adopted the view that the motion of the cosmos somehow originates inside it. The last point Ptolemy makes in this chapter concerns the difficulty of how we can think of poles as unmoved movers. The assumption that they have the function of unmoved supports (as described in *On the Movement of Animals* 3) leads to the difficulty that they are nevertheless driven away by the sphere to which they are attached so that they are ultimately not unmoved.

II.6

These are the different arguments Ptolemy uses against the theory of celestial poles as movers or transmitters of motion.[102] At the beginning of Chapter II.6, Ptolemy refers twice to the 'natural philosopher' (*ṣāḥib al-ʿilm al-ṭabīʿī*). However, this chapter does not proceed in the same way as Chapter II.5. Instead, Ptolemy now turns to physical reasons why one should rather adopt his theory of slices of spheres instead of complete spheres. First, Ptolemy compares the apparent difference between complete spheres and sawn-off pieces with hollow and solid spheres. Because it is

[100] *Mot. An.* 3, especially 699a20–24 for the argument on the celestial poles.

[101] *Mot. An.* 4, 700a6–10.

[102] In Chapter III, pp. 151–53, I briefly discuss whether this is a fair rendering of Aristotle's cosmology.

commonly accepted in astronomy that there are hollow and solid spheres, the natural philosopher should also not worry that the assumption of complete spheres renders the existence of sawn-off pieces impossible.

Since one still wants the inner spheres to partake in the diurnal rotation of the entire cosmos, it would be easier to think of sawn-off pieces that are embedded within aether. In that case, every inner sphere could be in direct contact with the surrounding aether and would be equally taken away by its rotation similar to how things are taken away by the motion of a river. This argument exhibits Ptolemy's attempt to arrive at an economical system of the greatest possible simplicity, as already expressed in the *Almagest*.[103] The same striving is evident by his allusion to the Aristotelian doctrine that 'nature does not do anything in vain'. We have already seen this argument at work in Chapter I.18 concerning the non-existence of an empty space between the celestial spheres. The fixed stars are spread out throughout the entire heaven. Thus, there needs to be a complete sphere for the fixed stars. However, the wandering planets are only observed within a certain degree of latitude, as is apparent from the Sun's motion along the ecliptic. According to Ptolemy, one does not need the rest of the spheres in which the planets are never seen. He compares this to the question of the position of Mercury and Venus that had already been discussed in Chapter I.17: as there should be no empty space within the cosmos, it seems to be most natural to assume that Mercury and Venus are between the Moon and the Sun. The same argument also applies to Aristotle's entire homocentric system with its excessive amount of spheres, as Ptolemy goes on to say. Again, he expresses his wish to arrive at a simpler system with fewer spheres than Aristotle postulated after introducing his counteracting spheres. In addition, Ptolemy criticizes the idea that the encompassed spheres become the movers for the encompassing ones. The reason for this critique is that the counteracting spheres are usually ascribed to the planet whose motion they cancel.[104] Ptolemy further ridicules this notion with the sarcastic claim that in that case, the spheres of the Moon would, in some way, belong to the motion of Saturn.[105] Apparently, he does not think of the counteracting spheres as removing the motions specific to one planet but as adding more motions to it (although, effectively, their motions are opposed to the specific motions of one planet and the resulting motion can be considered as a less complex motion). For example, there are four spheres for the specific complex motion of Saturn. Each of the three following counteracting spheres add another motion and Ptolemy emphasizes that they (a) still belong to Saturn and thus partake in Saturn's motion, and (b) they are more complex than

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103 See again Ptolemy, *Syntaxis*, III.1, Vol. 1, p. 201:18–22, and XIII.2, Vol. 2, pp. 532:12–534:6.

104 See the brief remark in Judson, 'Aristotle's Astrophysics', p. 182 n. 93.

105 cf. Murschel, 'Structure and Function', pp. 38–39, who has a different reading of this passage. She understands it to say that Ptolemy criticizes the notion that the planets have motions from the planets above, not below. See also the reference in Simplicius' commentary on *On the Heavens* (Simplicius, *In Cael.*, p. 506:17–20) and the analysis in Bowen, *Simplicius on the Planets*, pp. 278–83.

the sphere that actually carries Saturn (although, again, their resulting motion is less complex). Apparently, Ptolemy then thinks that if motion is transmitted throughout the entire system, not only the counteracting spheres belonging to the planet above but also all the encompassed spheres add another motion, and thus there is no separation between the different sets of spheres for each planet. As the motions of the counteracting spheres are not specific to the planet to which they belong, the motions of each sphere below them do not belong to the specific motion of that planet. For Ptolemy, this means that if they consider the counteracting spheres as belonging to the planet above, the same should apply to all spheres below them, a conclusion that he finds ridiculous.

The last paragraph of Chapter II.6 anticipates Ptolemy's own solution to the question of how celestial motion is initiated and transmitted. Its goal seems to be to show that Ptolemy's own idea about the transmission of the diurnal motion, which he is going to lay out in the following two chapters, cannot be harmonized with a cosmos of complete homocentric spheres. Ptolemy introduces here the 'power' that moves the spheres, as well as the initiating impulse from the planets and the extension of this initial moment to the adjacent spheres. He explains this impulse from the planets in Chapter II.7 and explains right at the beginning of Chapter II.8 how the sawn-off pieces partake in the diurnal motion of the 'entirety of aether'. The point of the argument here at the end of Chapter II.6 is — due to the difficult reading of this passage — far from clear. However, Ptolemy's main point seems to be that only the most superior planet can partake in the first motion, since it is in direct contact with the outermost diurnal sphere. Instead, the system of spheres belonging to the next planet is cut off from the first motion.

Even though Ptolemy argues strongly against complete spheres and in favour of sawn-off pieces, he nevertheless sticks to the principle he had set out in the beginning of the *Almagest*, namely that physics does not provide us with true knowledge but only with a good guess at the truth. This is evident from the fact that he is going to give an account of his system of the spheres in the cosmos with respect to both options.

II.7–8

In the previous chapters, Ptolemy dismissed Aristotle's mechanical approach to celestial motion. In short, the basis of his alternative explanation is a particular psychological power that is emitted by the planets to their surrounding spheres. Thus, driven by his wish to reduce the number of celestial spheres that are needed in Aristotle's mechanical system, Ptolemy introduces a completely different concept to his cosmology. Chapter II.7 is devoted to the analogy of a flock of birds and planets.[106] The motion of the bird through the air is induced by the capacity of its soul (*quwwa nafsāniyya*). Through this capacity, an emission (*inbiʿāṯ*) is sent out to the nerves and then to the various limbs. Two things are important for Ptolemy: (1) that the motion of the different limbs or nerves are different from each other, and (2) that the birds do not interfere with or influence each other. In this picture, every bird as a whole and all the limbs perform their proper function. The limbs act on behalf of the impulse from the bird's soul, but they react to this impulse in the way specifically belonging to them. Thus, Ptolemy explains the various motions within one bird as well as within a flock of birds. This picture is then transferred to the planets: they are ensouled, their souls have the same capacity, and they send an impulse to the surrounding spheres that act in the same way as the animals' limbs. Ptolemy highlights that the motions of the various spheres responsible for moving the planet are different from each other.

As Ptolemy writes in the beginning of the next chapter, the 'circular motion of the entirety of aether' is also different from the spherical motions that belong to a planet. However, since they are embedded within aether, as is the case for the sawn-off pieces in particular, they partake in its general diurnal rotation. The other analogy that is briefly mentioned, namely the one concerning the groups of dancers, is supposed to show — as the analogy of the flock of birds did previously — that the dancers perform their individual motions within a larger choreography. The same should apply to the planetary motions: all the planets partake in the diurnal rotation of the cosmos.[107] However, all of them have their individual motions that arise through the proper functioning of their spheres (the limbs in the case of humans and animals). In doing so, they are completely independent from each other. The analogy of a flock of birds or a group of dancers is of eminent importance for Ptolemy because he considers this as a definite rebuttal of the Aristotelian scheme. Aristotle had to introduce counteracting spheres in order to make sure that the inner planets were not taken away by the motions of the upper planets. By putting emphasis on the independence of the planets from each other, Ptolemy gets rid of this problem immediately.

Chapter II.8 closes with three different brief remarks. The first is a repetition that one can construct an instrument that illustrates the independent motions of the different celestial bodies. The next comment is perhaps related in some way: Ptolemy claims that one can draw an analogy between the 'simple circles' on the

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106 This analogy has already been described in the following studies: Sabra, 'The Andalusian Revolt', pp. 150–51 n. 29, Langermann's introduction to Ibn al-Hayṯam, *On the Configuration*, p. 20, Murschel, 'Structure and Function', p. 39, Taub, *Ptolemy's Universe*, pp. 117–18, and Feke, *Ptolemy's Philosophy*, pp. 197–200.

107 The comparison of celestial motions to a dance is quite common. See, among other sources, Plato's *Timaeus* (*Tim.* 40c3–5), the pseudo-Platonic *Epinomis* (*Epin.* 982e3–6), and also later in Plotinus (Plotinus, *Opera*, Vol. 2, IV.4.33). The Persian loanword used in the Arabic version, *dastaband*, translates the Greek *xoros* and *rhapsōdia* in the Arabic version of Aristotle's *Poetics*, see Tkatsch, *Die arabische Übersetzung*, pp. 222:6 and 228:4–21, and also the Graeco-Arabic apparatus by Tarán and Gutas in Aristotle, *Poetics*, pp. 314–15 and 334.

one hand — probably referring to the geometrical models from the *Almagest* and Book I of the *Planetary Hypotheses* — and the sawn-off pieces on the other hand. More important, however, is the last sentence. There, Ptolemy's methodology becomes quite clear. He writes that he has laid down these things '[in order] to decide which of these things laid down previously are in accordance with sound physical investigation'. By the 'sound physical investigation' (*naẓr ṭabīʿī ṣaḥīḥ*), Ptolemy has the physical principles from Chapter II.3 in mind. This investigation, therefore, consists of an unchanging aether with a circular motion and of ensouled planets that are endowed with a certain capacity to move themselves voluntarily. He concludes his own account of how planetary motion comes about by claiming that this, taken together with the acceptance of slices of spheres, better fits these physical presuppositions (and, in a way, Aristotle's own physics as well). The details of Ptolemy's account in these chapters are given in Chapter III of the present study.

II.9–10

Chapter II.9 marks the transition to the final investigation of the *Planetary Hypotheses*. Ptolemy had promised in Chapter II.2 to discuss the conditions of the celestial bodies and their relationship with each other after a presentation of the 'universal appearances' (*aʿrāḍ kulliyya*). Since he brought the general account of his cosmology in Chapter II.8 to an end, it is now the time to actually present the arrangement of the particular bodies. As in Book I, Ptolemy starts from above, namely from the sphere of the fixed stars. In Chapter I.2, he put forward as a reason the fact that the first motion of the universe precedes the other motions and paves the way, because of its comparable simplicity, for the investigation into more complex motions. Similarly, Ptolemy says in Chapter II.9 that he starts with the sphere of the fixed stars because it is the first visible motion and he refers again to its simplicity, since the stars carried around by it do not change their relative position to each other or their distance to the Earth.

In Chapter II.10, we see another signal that Ptolemy undertakes a new investigation. This chapter is basically a glossary of astronomical terms. This is remarkable, as some of the terms (such as 'inclination' and 'eccentricity') have already been used throughout the geometrical models in Book I of the *Planetary Hypotheses*, not to mention the *Almagest*. However, these terms are explained with respect to the physical arrangement of the spheres and, apparently, Ptolemy feels the need to put these terms properly in this new context. For example, he does not define the term 'inclination' in general. Instead, he explains that in the following chapters, 'inclined sphere' relates to spheres whose centres are the Earth but whose axes are inclined to the axis of the ecliptic.

The most interesting term is the first one that Ptolemy defines: 'mover'. In the rest of the *Planetary Hypotheses*, as Ptolemy explains, 'mover' is not used in its general meaning of something that moves something else. Only bodies that both move themselves and the encompassed spheres in the direction of the diurnal rotation of the cosmos (from east to west) are called 'movers'. This will be important in the following chapter when Ptolemy enumerates these 'moving spheres'.

II.11–16

Ptolemy is now able to present the planetary models. The first part of Book I, taken together with the more detailed account in the *Almagest*, lays the mathematical foundation. The second part of Book I establishes the order, distances, and sizes of the planets. The first part of the Book II addresses some physical questions that need to be considered before one can establish the nature of the spheres and their interactions. In Chapters II.11–16, Ptolemy presents his models of the planetary spheres and their motions. We have seen that Ptolemy argued that — mathematically speaking — there is no difference between assuming either complete spheres or only slices. We have also seen that he strongly argues for the latter option. Nevertheless, Ptolemy now gives two models for each planet. First, he provides the planetary model with complete spheres and, in the next step, he goes on to adapt this model to sawn-off pieces. The reason for this methodology is clear: physics is only guesswork in Ptolemy's eyes. It might be that we have good physical reasons to prefer one of two different models. Nevertheless, these reasons remain uncertain. His cautious remarks about the order and distances of the planets throughout the *Almagest* and the *Planetary Hypotheses* serve as a perfect object of comparison.[108] One might be tempted to compare Ptolemy's methodology here with the development of Ptolemy's lunar model in *Almagest* IV–V. However, the case of the *Almagest* is different insofar as Ptolemy explicitly rejects the earlier attempts through which he takes the reader in order to show the process of how he came across the ultimate, correct version.[109] In contrast, such a final judgment is missing from the account in the *Planetary Hypotheses* concerning the shape of the celestial bodies.

One must pay particular attention to Chapter II.11. Since Ptolemy provides the first model here, namely the model of the fixed stars, he explains for the first time how the spheres move without attached poles or counteracting spheres. Three homocentric spheres are involved: the first two for the fixed stars and the third belonging to the outermost planet, Saturn. The first sphere is responsible for the daily rotation from east to west, whereas the sphere of the fixed stars itself has the opposite motion to account for precession. The third sphere also needs to move in the diurnal direction to make sure that Saturn also partakes in that motion. Ptolemy is faced with the problem of how the third sphere can move in the same way as the first one, whereas the inner sphere has an independent motion, in the sense that it does not influence the motion of the inner (i.e. third) sphere. First, he describes how

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108 See the comments on Chapters I.16–19.

109 See the brief summary in Jones, 'Ptolemy's Mathematical Models', pp. 28–31. For the technical details, see Pedersen, *A Survey*, pp. 159–202.

this system would work if one assumed that the inner sphere is always attached to the outer sphere by its poles.[110] This would lead to the abovementioned problem, namely that the third sphere (since it would be attached to the second sphere) would partake in its motion and would not move in the same way as the first one. In order to avoid that, Ptolemy suggests that the inner sphere is not attached to its two adjacent spheres, namely the first and the third one. These two outer spheres share their axis, namely the axis of the equator, and have the same (diurnal westward) motion. The important point is the lack of any connection between the second inner sphere to the first or third sphere. According to this interpretation, the following sentence is of extreme importance:

> [...] it is not the case that only the two points C and D and the two points E and F of the two outer spheres remain on one and the same pillar, namely the axis of the ecliptic, but [it is the case] that A, B, G, and H [lie on the axis]which is the axis of the equator.[111]

This means that the points C and D belong to the outermost sphere, and E and F to the third sphere. They are not attached to the intermediate sphere. Ptolemy adds that it is not necessary to posit additional counteracting spheres. This would only be necessary if one assumes that the third sphere has its poles attached to the intermediate sphere. Additionally, if the points E and F were on the axis of the equator, and if they connected the second with the third sphere, then all three spheres would have the same motion. Consequently, in order to avoid (a) the false consequence that all three spheres moved in the diurnal westward direction, (b) the third sphere moving along with the precessional motion of the second, and (c) the need to posit counteracting spheres, Ptolemy emphasizes again explicitly:

> If the axis that goes through C, E, F, and D is contiguous with the two outer spheres and if it is loose and set free from the intermediate sphere, then [the axis] always preserves these two spheres in their configuration in relation to each other, and this intermediate [sphere] moves with a contrary motion aside from these two, [...][112]

Although Ptolemy himself does not further elaborate on that point, the independent motion of the intermediate sphere can then be generated by the governing power of the stars, as explained for the planets in Chapters II.7–8.

He concludes Chapter II.11 by a comparison between the theories of complete spheres and sawn-off pieces. There is no difference between the two concerning the first two spheres, because the fixed stars are scattered throughout the entire heaven and thus the sphere of the fixed stars needs to be complete. However, when we follow

110 This cannot directly compared with the model of Eudoxus and Aristotle, since they did not know about precession and thus did not need to propose another sphere for moving the fixed stars.

111 *Plan. Hyp.* II.11, p. 308:14–16.

112 *Plan. Hyp.* II.11, p. 310:5–7. Compare my interpretation of this chapter with Murschel, 'Structure and Function', pp. 42–43. She focuses on the principle that an outer sphere moves an inner one of their mathematical axes are not collinear.

Ptolemy in assuming only slices of spheres for the planetary spheres, then 'the third sphere belongs to aether, [...] and it [i.e. aether] encompasses and comprises all the remaining spheres.'[113] Since all the lower spheres are only sawn-off pieces, they all can be included in a single complete sphere, which would be simply aether, not belonging to any planet but moving in a way natural to aether. In contrast, in the case of complete spheres, we would need to assume a complete moving sphere for every set of planets to make sure that the planets partake in the diurnal rotation of the cosmos.

The first planet for which the model is given in detail is the highest one, Saturn (Chapter II.12). Since its model is close to that of Jupiter, Mars, and Venus, these three are described together in Chapter II.13. These are followed by the models for the Sun (II.14), Mercury (II.15), and the Moon (II.16).[114] Although the model of Saturn is not the most complex one, it is the longest chapter because Ptolemy uses the opportunity to add some general statements that also apply to the other models. Before Ptolemy turns to the model of sawn-off pieces, he counts the spheres belonging to Saturn, namely five. The moving spheres should not be counted together within the set of spheres of Saturn. Instead, Ptolemy counts them separately, because they are also in the models that are not connected to the other spheres, in the sense that the planets do not influence their motion. The final result of the number of spheres is, of course, the same, but this again highlights that these moving spheres are moved by the simple motion of aether or, in other words, by a different impulse than the spheres of a single planet.

In addition to the psychological explanation of why the spheres move as they do, namely on account of their reaction to the planet's impulse, Ptolemy also makes use of the geometrical axes of the spheres in order to argue that two spheres that have the same axis do not change their relative position to each other. Although such an explanation might seem superfluous from a geometrical point of view in an attempt to formulate the physical dynamics of celestial motions, this theory is more useful in the case of sawn-off pieces. As Ptolemy shows for each planetary model, the parecliptic sphere (i.e. the sphere with the same centre and in the same plane as the ecliptic) is divided into two spheres in the case of complete spheres but is joined to one sawn-off piece in the theory of sawn-off pieces (as I will also explain the commentary on Chapter II.17). In these cases, therefore, Ptolemy needs to make use of his theory of geometrical axes only in the case of complete spheres, because in the theory of sawn-off pieces, he only talks about a single sphere, in which case it is clear that it moves only about one axis.[115]

[113] *Plan. Hyp.* II.11, p. 310:16–17.

[114] See Murschel, 'Structure and Function', pp. 43–50, for a detailed analysis of the models. Another analysis of the Ptolemaic models, albeit through the lens of Ibn al-Hayṯam's criticism, can be found in the commentary by Don L. Voss in Ibn al-Hayṯam, *Doubts*, pp. 147–71.

[115] Murschel, 'Structure and Function', pp. 41–50 puts more emphasis on this theory of mathematical axes.

Ptolemy closes the discussion of Saturn's model with a final general suggestion. If the planets have a motion of their own, then we could assume one sphere less. In the case of Saturn, this is the smaller of the two epicycles. Ptolemy suggests that Saturn, instead of being motionless and carried by the smaller epicycle, moves freely within the larger epicycle.[116] This part is again not easy to understand, but apparently, Ptolemy argues that if indeed the motion originates within the planets, one should not think that the planets themselves are motionless and fixed in a certain place. The idea that planets are carried by a sphere rather applies, according to Ptolemy, when the motion is induced from outside. When the moving principle comes from the planet itself, however, it should also be thought of moving in a circular fashion, since this is what it gives to the adjacent spheres. In this context, Ptolemy also rejects rolling motion for the planets, since it 'goes beyond the definition of eternal motion around the centre',[117] probably implying that rolling motion has a double motion around another centre and the planet's own centre.

II.17

	First count: carried planets		**Second count: self-moving planets**	
	Complete spheres	Sawn-off pieces	Complete spheres	Sawn-off pieces
Fixed Stars	1	1	1	1
Saturn	5	4	(4)[118]	(3)
Jupiter	5	4	(4)	(3)
Mars	5	4	(4)	(3)
Sun	1	1	(0)	(0)
Venus	5	4	(4)	(3)
Mercury	7	5	(6)	(4)
Moon	4	4	(3)	(3)
Moving spheres	8	2	(8)	2
Total	**41**	**29**	**34**	**22**

This table shows the calculation of the number of spheres. The first thing to notice is that Ptolemy succeeded in his attempt to reduce the number of spheres in comparison to Aristotle. The first count mirrors the number of spheres that Ptolemy laid out in the previous chapters for every model. There are two reasons

[116] *Plan. Hyp.* II.12, p. 320:12–13.
[117] *Plan. Hyp.* II.12, p. 320:19.
[118] The numbers in parentheses are not explicitly given in the text.

why the system of sawn-off pieces needs fewer bodies. The first is that a complete sphere is divided into an outer and an inner sphere if another hollow sphere is placed inside it. In Ptolemy's theory of sawn-off pieces, this intermediate hollow body is, however, only a ring that moves inside the solid tambourine. This single solid tambourine, in the theory of sawn-off pieces, corresponds to two spheres in the theory of complete spheres.[119] Thus, in the case of Saturn, Jupiter, Mars, and Venus, for which Ptolemy supposes the existence of parecliptic bodies, he needs one sawn-off piece fewer than the number of complete spheres. For the same reason, he needs two bodies fewer in the case of Mercury, since it has a more complicated model than the others. Given that Ptolemy assumes no change for the Sun and Moon, this adds up to six bodies.[120] The remaining six bodies that Ptolemy can eliminate are the moving spheres. In the case of complete spheres, he introduced one moving sphere for every set of spheres that belong to one planet. He still needs a complete moving sawn-off piece for the sphere of the fixed stars. However, since all the remaining bodies are sawn-off pieces, he only needs one moving sawn-off piece that encompasses all of these shells directly. Thus, he only needs two moving sawn-off pieces, the outermost one and what he calls 'what remains of the aether'.

Regarding this first count, already Andrea Murschel raised some serious questions, mostly concerning the way in which Ptolemy counts the parecliptic spheres.[121] In most cases, he counts them as two spheres in the model of complete spheres and as one piece in the model of sawn-off pieces. There is, however, no change regarding the number of spheres of the Sun and Moon; the Sun has only one sphere assigned to it. As Ptolemy explains in the end of Chapter II.14, he apparently thinks that since the two axes of the parecliptic bodies are parallel to each other, they should be considered to be one body. There is also another curious difference from the previously presented model of Saturn. In Chapter II.12, Ptolemy writes twice that the moving sphere of Saturn is the one outside the presented model: 'the sphere that encompasses the circle BC is the second of the moving spheres.'[122] In the model of the Sun, however, 'the sphere that is encompassed by BC [is] the sphere moving the Sun, being the fifth sphere [counted] from the first moving sphere'.[123] Thus, it seems to be the case that the eccentric circle that carries the Sun is directly embedded in the 'moving sphere', which is possible, since the two axes described in the Sun's model are parallel. In the model of the Moon, we also find such parallel axes.

In the second count, Ptolemy claims that we even need fewer spheres when assume that the planets' motions arise from 'themselves' (*anfusu-hā*). Since we have seven planets (the five wandering planets plus the Moon and Sun), he claims that seven additional spheres can be omitted. Clearly, by this, Ptolemy does not refer to the

119 See the figure in Murschel, 'Structure and Function', p. 51.
120 See Murschel, 'Structure and Function', pp. 50–51.
121 Murschel, 'Structure and Function', p. 50.
122 *Plan. Hyp.* II.12, pp. 312:4–5 and 316:4–5.
123 *Plan. Hyp.* II.14, p. 324:9–10.

spheres that he labelled as 'moving spheres' earlier, because in the model of sawn-off pieces, we only have two in the first count. This means that Ptolemy thinks that we can get rid of the last sphere carrying the planet if we think that the planet induces its own motion. These last spheres are described by Ptolemy as 'moving the planet' as well.[124] In that case, the planets do not only send out impulses to the surrounding spheres to conduct their motion (as described in Chapter II.7). Moreover, they move themselves and are not simply carried by the smallest sphere of their sets. In the case of the Sun, this would mean that there is actually no sawn-off piece and that the Sun moves freely within this 'rest of aether' between the spheres of Mars and Venus. Ptolemy described this possibility only in the case of the first model that he presented, namely for Saturn. He now suggests that if we accept this for every planet, we will reduce the number of spheres by seven in total.

Interestingly, Ptolemy did not properly prepare this last step to reduce the number of spheres again. A suitable place to discuss the question whether the planets are carried by spheres and are themselves motionless or not would have been the first part of Book II. The claim that the planets have a motion of their own has some serious implications, the most important of which are perhaps the following two: (1) how a planet moves within a celestial sphere without the existence of an empty space[125] and (2) how the planet still partakes in the motion of the remaining spheres. Ptolemy does not give an account of motion in general in any of his works, and thus we cannot get an idea of how he thought motion would occur without a void. Concerning Problem (2), this arises because the planetary motions are still complex and therefore must arise from a number of combined motions. Perhaps Ptolemy gives a glimpse of a solution earlier in *Planetary Hypotheses* II.6. There, he compares the motion of a sawn-off piece within the sphere, which he calls the 'rest of aether', to something that swims in a river. As a fish, for example, has a motion of its own but nevertheless is also taken away by the stream, in the same way, the sawn-off piece can be thought of as being driven in the direction of the daily rotation. In *Almagest* XIII.2, Ptolemy emphasizes the unhindering nature of aether, with the effect that every celestial sphere can move inside the aether according to its own proper motion.[126] This picture could also easily be ascribed to the planets, although Ptolemy does not address this issue at all.[127]

In the last section of Chapter II.17, Ptolemy refers back to the introduction of shapes for the celestial bodies other than complete spheres given in Chapter II.4. In Chapter II.4, he suggested not only Plato's whorls but also bracelets. Apparently, he thinks of bracelets in the form of a crescent moon, which would accordingly be of a different shape from whorls. Again, he notes that there is no observational

124 See the models of Saturn, the Moon, and Mercury, where the epicycles 'move' the planets.

125 As already put forward by Ibn al-Hayṯam, see Ibn al-Hayṯam, *al-Šukūk*, p. 61:1–5.

126 See Ptolemy, *Syntaxis*, XIII.2, Vol. 2, pp. 532:22–533:10.

127 For a more detailed discussion and the Arabic reception of this idea, see Chapter III of the present study, especially pp. 197–98.

criterion in order to decide whether these pieces are whorls or bracelets. Thus Ptolemy turns to the 'physical choice' (*iḫtiyār ṭabīʿī*) and admits that both shapes bring certain problems with them. First, the whorl is not entirely spherical, and second, the bracelet does not encompass the entirety of the sawn-off piece. This latter problem is the reason why Ptolemy adopts the whorls, because it is necessary that the inner sawn-off pieces are encompassed in their entirety, which is not the case for celestial bracelet-shaped segments. He does not go into much detail at this point, but he probably intends to claim that the lower sawn-off pieces only take part in the motion of the outer pieces if they are completely encompassed. This passage is, therefore, another example of Ptolemy's methodology, namely to turn to 'physical considerations' whenever mathematics fails to provide a definite answer.

II.18

An important issue in Book II of the *Planetary Hypotheses* is the reduction of the number of celestial bodies needed to account for the appearances. Ptolemy takes this up by claiming that he has found a system that is more economical than that of his predecessors. He explicitly refers to the 'causes of the appearances', which echoes *Almagest* I.7.[128] Although in the *Almagest*, Ptolemy considered an investigation into the causes as 'superfluous' once the appearances are firmly established, Book II of the *Planetary Hypotheses* deals exactly with the causes of celestial motion in order to decide how many spheres there really are and what these spheres look like. However, Ptolemy also makes it clear that a student of astronomy should always combine these models with mathematical figures and astronomical tables.[129] This is why Ptolemy informs us that he had attached some tables to the work. Unfortunately, these tables are lost. However, we have a good idea about their content, since we are in possession of the data from Book I. On this basis, there are some descriptions in modern research of what these tables probably looked like.[130]

128 Ptolemy, *Syntaxis*, I.7, Vol. 1, p. 21:14–19.

129 On this emphasis on the value of astronomical instruments and tables for teaching, see Jones, 'Theon of Smyrna and Ptolemy', pp. 86–87. In fact, the first paragraph of Chapter II.18 can be compared with similar conclusions in other works, such as the pseudo-Platonic *Epinomis*, see *Epin.* 991d5–992a1.

130 See Neugebauer, *A History*, p. 913, Murschel, 'Structure and Function', pp. 52–53, and Duke, 'Mean Motions', pp. 650–53.

Glossary

The glossary contains terms from the Arabic and Greek versions of the *Planetary Hypotheses*. In general, references are made to Book, Chapter, and Section according to the present edition. For example, 'II.10:3' means Book II, Chapter 10, Section 3. In the Arabic text and the English translation, the Chapter and Section is given between vertical strokes ('|10:3|'). For the Greek terms, page and line numbers to the Heiberg edition are added.

The glossary took its starting point from the online glossary of astronomical terms on the website of *Ptolemaeus Arabus et Latinus*, the beta version of which was published some years ago (see: https://ptolemaeus.badw.de/glossary). The main aim of this glossary is to provide an online database of (mostly technical) terms and the way they have been translated from Greek into Arabic and Latin. Therefore, my preliminary work for the online glossary of terms from the *Planetary Hypotheses* focused on the first part of Book I, for which we not only have the Arabic, but also the Greek text. This focus on technical terms, both in the Greek and Arabic versions of the first part of the *Planetary Hypotheses*, can still be detected in the glossary printed on the following pages through mainly two points. First, I decided to include more than 200 Arabic entries just from this small part, namely Chapters I.1–14, in order to illustrate the translation process from Greek into Arabic. Second, references to the occurrences of technical terms such as 'epicycle', which come up abundantly in the entire text, are given mostly for these early chapters, for which we have a corresponding Greek term. These are often the first occurrences of the respective terms. I include additional references to later chapters if a concept is again defined or put into a new context. Of course, the glossary also includes terms that only come up from Chapter I.15 onwards and thus in the part for which we do not have the Greek original. I followed the same rationale just described, namely that the selection of the provided occurrences focuses on places of definition or first occurrences if a term comes up too frequently to provide all its occurrences. This means that the glossary is not a complete index of all occurrences of (technical) terms, but rather provides the reader with an overview of the overall terminology.

I followed a special method for the geometrical terms that come up in Chapters II.11–16, in which Ptolemy describes the construction of the figures for his planetary models. Those terms that show up frequently in these chapters, such as 'point', 'draw', and 'circle', are indicated as occurring in 'II.11–16:*passim*'. In other cases, when *passim* follows only the reference to a single chapter (for example, 'II.10:*passim*'), the such denoted term comes up in this single chapter in nearly every section.

The Arabic-Greek-English glossary is followed by a Greek-Arabic glossary. Arabic or Greek terms that are discussed in this book outside of the edition are given in the index of concepts.

Arabic–English–Greek

	Hipparchus	إبرخس I.19:2–4
	trace	أثر II.17:6
	aether	أثير II.6:3; II.6:6; II.8:1; II.11:9; II.12:22; II.15:8; II.16:3
	aethereal	أثيري II.3:1–2; II.5:4
ἐκβάλλω I.9:1, 82:2	to take	أخذ I.9:1
μεταλαμβάνω I.7:1, 78:18	to take	أخذ I.7:1
	Aristotle	أرسطوطاليس II.5:3–4
	Earth	الأرض II.6:5; II.10:3; II.10:5; II.11–16:passim
	earth (element)	أرض I.17:16; I.18:1; II.7:1
	stade	أسطاذيا I.18:1
ὑπόθεσις I.1:1, 70:3	principle	أصل I.1:1
	principle	أصل II.8:5; II.18:2
	Plato	أفلاطن II.4:2
μαθηματικὴ σύνταξις I.1:1, 70:4	mathematical issues (*Almagest*)	الأمور التعليمية I.1:1
ἀπόγειον I.5:3, 76:29	apogee	أوج I.5:3
	apogee	أوج I.11–16:passim

τὸ ἀπόγειον τῆς ἐκκεντρότητος I.9:5, 82:25; I.10:4, 86:8	apogee of the eccentric circle	أوج الفلك الخارج المركز I.9:5; I.10:4
	apogee of the eccentric circle	أوج الفلك الخارج المركز II.12:5; II.16:2; II.18:3–5
τὸ ἀπογειότατον τῆς ἐκκεντρότητος I.12:9, 96:29	apogee of the position of the eccentricity	أوج موضع الخروج عن المركز I.12:9
τὸ ἀπογειότατον τῆς ἐκκεντρότητος I.13:9, 100:30	apogee of the position of the eccentricity	أوج موضع الخروج عن المركز I.13:9
	beginning	أوّل II.3:2; II.18:2
	principles	أوائل II.1:2
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Indexes

Persons and Works

Concepts

This index only covers (technical) terms that are discussed in the philosophical analysis. For astronomical terminology from the *Planetary Hypotheses*, with which I do not deal in particular outside of the edition, see the glossary. Arabic and Greek terminology is only included here in case I discuss the meaning or interpretation of this term in my philosophical analysis.

Ptolemy's *Almagest* (2nd century AD) is the most influential work of ancient and medieval astronomy. This work, however, does not tell us the full story about its author's views of the heavens. After completing the *Almagest*, Ptolemy turned his attention to a physical investigation of celestial motions. The result is the *Planetary Hypotheses,* a bold attempt to provide a celestial physics that coheres with the mathematical account of astronomical observations in his *Almagest*.

This book provides the first complete critical edition and English translation of the Arabic version of the *Planetary Hypotheses*, which is lost for the most part in its original Greek. It furthermore provides an extensive commentary on the whole work, which situates the *Planetary Hypotheses* within the context of its time and investigates philosophical ideas central to the work. These include the epistemic value of mathematics relative to natural philosophy, and the shape, number, and dynamics of the celestial bodies. The book also investigates the influence of the *Planetary Hypotheses* on a wide range of medieval Arabic astronomical and philosophical works from the 9th to the 13th century AD. The upshot is to establish the *Planetary Hypotheses* as a crucial text for understanding the history of philosophy and science from Greek antiquity to the Arabic Middle Ages

Paul Hullmeine is a historian of philosophy and science. His research focuses on Greek natural philosophy and astronomy and its reception in the Arabic Middle Ages. He received his PhD from the LMU Munich and currently holds a postdoctoral position at the same university, funded by the DFG.

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