The Demarcation of Physical Theory and Astronomy by Geminus and Ptolemy

Alan C. Bowen
Institute for Research in Classical Philosophy and Science, Princeton

The Hellenistic reception of Babylonian horoscopic astrology gave rise to the question of what the planets really do and whether astrology is a science. This question in turn became one of defining the Greco-Latin science of astronomy, a project that took Aristotle's views as a starting-point. Thus, I concentrate on one aspect of the various definitions of astronomy proposed in Hellenistic times, their demarcation of astronomy and physical theory. I explicate the account offered by Geminus and its subordination of astronomy to arguments made in physical theory about what really is the case. I then show how Ptolemy treats the same topic but maintains that this science is sufficient on its own to determine the realia *it studies. In this way, I identify two moments in an obvious process of intellectual change that had profound consequences for the history of astronomy and cosmology over the next 1500 years. My hope is that this will advance our understanding of the reception of horoscopic astrology in Hellenistic times and also serve to locate Ptolemy more fully in his intellectual context.*

Introduction

Any science may be defined by its demarcation from other sciences and by its articulation into subfields. During the first century BC and later, there were noteworthy attempts to define the Greco-Latin science of astronomy in both these ways. Why this occurred is a question well worth pursuing. One possibility is that thinkers with a philosophical bent found it useful

This paper derives in part from my collaboration with Robert B. Todd on related projects. An earlier version of the paper was presented at the conference, "Natural Philosophy and Mathematics in Antiquity," held at the University of Leiden on 16–18 June 2004. I am very grateful to the participants for their questions at that time, as well as to Bernard R. Goldstein, Geoffrey Lloyd, Robert B. Todd, and the anonymous reader for this journal for their generous, constructive criticism of subsequent versions.

Perspectives on Science 2007, vol. 15, no. 3

to elaborate the remarks on this same subject that Aristotle makes in *Phys.* 2.2. After all, this text is plainly a point of departure.[1] Yet, I doubt that desire to expound Aristotle's text is sufficient *by itself* to account for the concern with the question of demarcation in the form that it actually arises some three centuries after this text was written. My working hypothesis is that the primary occasion for this new effort was the reception of Babylonian horoscopic astrology in the Hellenistic world[2] or, more precisely, the numerous ways in which this astrology challenged traditional Greco-Roman ways of thinking and using information about the heavens.

Specifying how this reception actually took place is difficult, partly because our sources are incomplete and partly because there really was no single, particular (as opposed to general) cause. Rather, what one finds on examining specific documents is a tangle of different considerations in Babylonian horoscopic astrology and its Hellenistic interpretation working together in various, related contexts to produce a new definition of astronomy. Still, it is feasible to tease out at least one thread and to use it to delimit two key moments in this process of broad intellectual change. For, among the considerations confronting those Hellenistic thinkers who reflected on the impact of horoscopic astrology was the idea that the five planets make stations and retrogradations, an idea plainly evident in the arithmetical schemes that the Babylonians and their Hellenistic followers employed in their computations. Indeed, it is striking that the earliest unambiguous references in Greek and Latin to the stations and retrogradations of the five planets typically occur in contexts where horoscopic astrology or divination is mentioned or under discussion;[3] and that, when the question of the demarcation of physical theory and astronomy, a question initially broached by Aristotle, is taken up again in Hellenistic times, there is a typical concern with the motions of the five planets.[4]

As I have argued elsewhere (Bowen 2001, 2002b), this idea that the planets stand still or move sometimes from east to west was news to the Greeks and Romans of the late second and first centuries BC, and they re-

1. See Kidd 1988–1999, F18.1–4; Bowen and Todd 2004, 199nn13, 15.

2. On some differences between Babylonian and Greco-Latin horoscopes, see Rochberg 1998, 1–3: cf. Jones 1996.

3. Thus, e.g., Diodorus, *Bib. hist.* 1.81.3–6, 2.29.2–4, 2.30.1–5; Cicero, *De nat. deor.* 2.51 and *De div.* 2.89; Geminus, *Intro. ast.* cc. 1, 2, 17. Vitruvius (*De arch.* 1.5–13) draws on astrological concepts to explain planetary phases. See Bowen 2001, 2008a.

4. On Kidd 1988–1999, F18, see below: cf. Seneca, *Ep.* 88.14–15, 26–27. Strabo, *Geog.* 2.5.2 mentions the motions of the planets but only in passing, since his real concern is with the dependence of the geographer on the geometer (or Earth-measurer) and of the geometer on the astronomer.

sponded to it in a number of different ways. Cicero (−102 to −42), for instance, proposed that the planets really do make stations and retrogradations, but that they do so regularly (see *De nat. deor.* 2.51; cf. Bowen 2001, 826)—which means that, as the ancients required, the planets do not really wander (see, e.g., *De div.* 1.17).[5] He also denied the validity and propriety of the Babylonian science of predicting a person's fortune on the basis of the configuration of the heavens at his birth. In sum, Cicero's response was dismissive in its force, if not in its intention: he obviates any pressing concern with the new information about how the planets move by simply affirming it as a regular and, hence, unobjectionable occurrence (cf. Seneca, *Ep.* 88.14–15); moreover, were this not enough, he quarantines the issue by putting the related interest in horoscopic astrology outside the proper confines of Greco-Latin philosophy and science. Understandably, however, Cicero's position gained few adherents as time passed and as the Babylonian celestial science gained devotees.[6] Cicero's response does, however, show concern about whether the astrologer's assumptions about the planetary motions, assumptions made in the course of formulating predictions, are in accord with how the planets really move, and whether astrology rightly counts as a science to be included in astronomy.[7]

In contrast, other writers, Geminus,[8] for example, and his younger contemporary, Vitruvius (cf., e.g., *De arch.* 9.1.11–15), both embraced this new science and attempted to incorporate it into astronomy by addressing the problem that the planetary theory embedded in horoscopic astrology conflicts with traditional Greek views as found, for example, in the works of Plato and Aristotle. Their syntheses constitute two different definitions of what astronomy is. For Geminus, it was necessary to accept that the planets do make stations and retrogradations but only as the *apparent* outcome of constant circular motions; for Vitruvius, one had to suppose that

5. Plato makes a related, but not the same, point when he affirms (*Leg.* 821b3–822d1) that in reality the Sun, Moon, and so forth each travel their own circular paths and, consequently, that it is blasphemy to say that they wander, even though appear to move along many paths. Whatever appearances Plato has in mind, it is not likely that he is alluding to stations and retrogradations, since the Sun and Moon do not exhibit these phenomena.

6. Pliny, writing almost a century later, shares Cicero's sense that reliance on astrology is not consistent with Roman virtue (*Hist. nat.* 2.1–27), but nevertheless offers a survey of astronomy that does include astrological notions and concepts: cf., e.g., *Hist. nat.* 2.64–65, 68–71.

7. For a roughly contemporary *précis* of Greek, Babylonian, and Egyptian astronomy, see Diodorus, *Bib. hist.* 1.81.1–6, 2.29.1–32.10.

8. On Geminus' date, see Bowen 2006, 199n4 or, for a different line of argument, Evans and Berggren 2006, 15–22.

9. Such definitions of astronomy are a mix of description and stipulation; and, when

the planetary direct motions and retrogradations are *real* effects produced by real forces.[9]

Thus, the Hellenistic reception of Babylonian horoscopic astrology gave rise to the question of what the planets really do and whether astrology is a science. And this question in turn became one of defining the Greco-Latin science of astronomy, a project that took Aristotle's views as a starting-point.

On this occasion, I will concentrate on one aspect of the various definitions of astronomy proposed in Hellenistic times, their demarcation of astronomy and physical theory. To begin, I will explicate the account offered by Geminus and its subordination of astronomy to arguments made in physical theory about what really is the case.[10] I will then show how Ptolemy (second century AD) treats the same topic but maintains that this science is sufficient on its own to determine the *realia* it studies. In this way, I propose to identify two moments in an obvious process of intellectual change that had profound consequences for the history of astronomy and cosmology over the next 1500 years. My hope is that this will advance our understanding of the reception of horoscopic astrology in Hellenistic times and also serve to locate Ptolemy more fully in his intellectual context.

The Evidence for Geminus' Views

Our knowledge of Geminus' drawing of the boundary between astronomy and physical theory comes from two sources: his *Introductio astronomiae* and the detailed statement and explanation of this topic offered by Simplicius (Diels 1882, 291.21–292.31)[11] in relaying Alexander's reportedly careful citation of Geminus' summary exposition of Posidonius' *Meteorologica*.[12]

Now, it is customary among classical scholars to treat Simplicius' re-

taken in context, it is often clear that their stipulation is covertly prescriptive. That is, such definitions typically urge a universality that history belies. Thus, to take an earlier example, Plato defines astronomy as the study of solids in motion, but excludes from this the contemporary concern with the risings and settings of the fixed stars, that is, with *parapegmata* (*Resp.* 527d1–e6, 528d5–530c1). In any case, the interest in the definitions advocated by Geminus and Vitruvius is not so much in their factual accuracy, though that certainly merits attention, but in the purposes and contexts of their prescription.

10. See Bowen 2008a on Geminus' articulation of astronomy itself.

11. In what follows, I use the Greek text in Kidd 1988–1999, F18.

12. See note 24 below on Proclus, *In Euc.* prol. 1 (Friedlein 1873, 38.1–42.8). Evans and Berggren (2006, 4 and 250n1) follow Jones 1999, 255 in conjecturing that Simplicius reports the actual title of Geminus' work, namely, *Concise Exposition of the Meteorology of Posidonius.* But this is a strained reading of Simplicius' Greek, and it is contradicted by Priscian's testimony (Kidd 1988–1999, T72) that Geminus wrote a commentary *(comment-*

port as testimony about Posidonius, and I have no real objection to such practice in this case (cf. Bowen 2001, 806–812; 2002b). After all, the view that Simplicius reports is essential to the argument in Cleomedes' *Caelestia,* and this treatise does acknowledge a heavy debt to Posidonius' writings (see *Cael.* 1.8.157–162, 2.6.228–231; Bowen and Todd 2004, 15–17). Yet, as I trust will become clear, the indications of Geminus' understanding of the relation between astronomy and physical theory in the *Introductio* are consistent with the view that Simplicius reports. Further, given the nature of the report and its complicated history, it is impossible to determine how much or little goes back to Posidonius and/or to Geminus.[13] So, since I am on this occasion interested in Geminus' thought and do not wish to prejudge his role in forming the views that Simplicius reports, by identifying only Posidonius as their source—summarizing a treatise *can* be a creative enterprise—I will write either of the author reported by Simplicius or, following Ian Mueller (2004, 66–72) of Posidonius/Geminus.[14]

Geminus' Introductio Astronomiae

As Geminus says,

> [1.19] It is posited (ὑπόκειται)[15] for astronomy (ἀστρολογία) as a whole that the Sun, Moon, and five planets move at a constant speed (ἰσοταχῶς) in a circle,[16] and in a direction opposite to [the daily rotation of] the cosmos. For, the Pythagoreans, who were the first to come to investigations of this sort, hypothesized (ὑπέθεντο) that the motions of the Sun, Moon, and five planets are circular and smooth.
>
> [1.20] The reason is that they did not admit in things that are divine and eternal such disorder that sometimes [these things] move more quickly, sometimes more slowly, and that sometimes they stand still—which they in fact call stations in the case of the

um) rather than an epitome. As for the title of Posidonius' work, this too is uncertain: see Kidd 1988–1999, T72; Todd and Bowen 2007, n13.

13. It seems to me unlikely that any of the substantive views expressed in the report derives from Alexander or Simplicius.

14. Cf. Lloyd, 1991, 265–268; Evans and Berggren 2006, 49–58 which misleadingly treat Geminus as the author reported.

15. The present tense of ὑποτίθημι is often used instead of the perfect passive tense of ὑπόκειμαι, and thus often means (as it does here) "it is assumed as a hypothesis" or "it is hypothesized." Cf. ὑπέθεντο below.

16. *scil.* they each travel equal arcs of their circular paths in equal times (cf. 1.31).

> five planets. For, not even in the case of a man who is well behaved and orderly would one accept such unsmoothness of motion in his modes of progression (πορεῖαι).[17]
>
> [1.21] For, the necessities of life are often causes of slowness and speed for men; but, in the case of the imperishable nature of the celestial bodies, no cause of speed and slowness can be introduced. For which reason they have proposed the following question: How can the phenomena be explained by means of circular, smooth motions?
>
> [1.22] Accordingly, we will give the explanation concerning the other celestial bodies elsewhere;[18] but right now we will show concerning the Sun the reason why, though it moves at a constant speed, it traverses equal arcs in unequal times. (*Intro. ast.* 1.19–22)[19]

Geminus' position will hardly surprise anyone who has read Plato's *Timaeus* or Aristotle's *De caelo,* two important works enunciating fundamental assumptions of the Greek understanding of the heavens. If the heavens are the domain of the divine and the eternal, then there is but one sort of motion they can make, circular motion at a constant speed.[20] So, the planetary stations and retrogradations must be apparent only. Consequently, the critical task for astronomers is to explain (ἀποδίδεσθαι) these phenomena.

There are two points to bear in mind when interpreting this passage. First is that we should not simply suppose that in assigning this project of explaining (or in other terminology, saving) these phenomena to "the Pythagoreans," Geminus means the *early* Pythagoreans.[21] There is, after all, no good evidence dating from the fifth and fourth centuries warranting the claim that the early Pythagoreans (or any early Greek for that matter)

17. Cf. Aristotle, *Eth. Nic.* 1125a12–16.

18. Geminus does not return to this in the *Intro. ast.* Perhaps this was a topic to be taken up in a treatise for more advanced students: cf. Bowen 2008a.

19. For the Greek text I have consulted both Manitius 1898 and Aujac 1975.

20. Geminus' adoption of a geometric model for the motion of the Sun (1.31–41) is in accord with 1.19–22, but his adaptation of Babylonian arithmetic models to account for the Moon's motion (c. 18) is not (see Bowen and Goldstein 1996, 179–181). So, what is one to make of this? One possibility is that Geminus simply did not accept the Pythagorean challenge to explain how the planets move by recourse to constant circular motions. This would certainly be unexpected, given *Intro. ast.* 1.22 (which appears to offer the case of the Sun as the sort of argument to be made for the other planets) and cc. 9–12. Another possibility is that there was at the time no geometrical lunar theory which could serve him in explicating the *exeligmos;* or again, that, though there was such a theory available, he deemed its exposition appropriate to a more advanced treatise (see below).

21. As does van der Waerden (1988, 107–108), for example: cf. Evans and Berggren 2006, 49–50.

were aware of such characteristic planetary motions as their stations and retrogradations. That is, there is no good evidence that they were aware of such planetary phases or phenomena as were computed in the Babylonian ephemerides (see Neugebauer 1975, 386–387; Bowen 2001, 2002b). In fact, there are more likely alternatives. For example, it would be more in line with what we actually know to suppose that these Pythagoreans to whom Geminus refers were intellectuals of the late second and first centuries BC who revived Pythagoreanism by adopting what they took to be Pythagorean views, since they coupled this philosophical stance with a keen interest in astrology. Nigidius Figulus was, apparently, a leading figure in this movement.[22] Alternatively, there is the possibility that Geminus is alluding to views expressed in the pseudepigraphic literature written in the late second and first centuries BC, when planetary stations first became known to the Greeks, which purports to relate the thought of earlier Pythagoreans (cf. Kahn 2001, 72–85).

The second point is that this project of explaining or saving these phenomena is predicated on an understanding of the natural world that is considered epistemically prior to astronomical theorizing. Indeed, for Geminus, proper astronomical theorizing about the planetary motions will alleviate any concern that the planets are really doing what they appear to do, by demonstrating these apparent motions as the observable outcome of their real motions. In effect, his construal of the project of explaining the phenomena instantiates the thesis that what astronomers assert is subject to the tenets of physical theory. The particular argument that Geminus offers in support of the proposition that the celestial bodies are limited to smooth, circular motions, a proposition which astronomers are plainly to receive and hold as a hypothesis, comes in two parts. The first (1.20) is dialectical and amplifies the thesis that the planets are immortal beings of supreme moral worth. The second (1.21) is, I think, likewise dialectical and contends that since it is the imperishable nature of the planets to travel in circles at a constant speed, and since there is no (observable) external body acting on them, there is neither an internal nor an external cause to make the planets depart from their motion at a constant speed.[23]

In any event, the basic thesis of the subservience of astronomy to physical *realia* and theory about them is clear enough; and it was certainly a

22. Figulus was friend of Cicero. Nothing survives of his work except citations in contemporary and later writers: see Hornblower and Spawforth 1996, *s.v.* Nigidius Figulus, Publius. See Getty 1941 on Figulus' astrological prediction of what was to befall Rome at the outbreak of the Civil War.

23. The recognition that astronomy relies on both dialectical and perceptual arguments goes back to Aristotle: see Bolton 2008.

thesis held by Geminus' contemporaries such as Strabo (*Geog.* 2.5.2 and 4). Moreover, it is consistent *prima facie* with the account of this thesis reported by Simplicius (Kidd 1988–1999, F18).[24] So let us turn to Simplicius' report and consider carefully how it fits with Geminus' remarks in the *Introductio.*

24. It is also consistent with a classification of the mathematical sciences that Proclus relates in *In Euc.* prol. 1 (Friedlein 1873, 38.1–42.8: see Mueller 2004, 76–82 for a useful outline), specifically, with

> Finally, [there is] astronomy (ἀστρολογία) which grapples with the cosmic motions, the sizes and shapes of the celestial bodies, their illuminations, as well as their distances from the Earth, and all things like this, by taking much advantage of sense-perception and also sharing much with physical theory (φυσικὴ θεωρία). Therefore, of this [division of mathematical science], gnomonics is in fact a part in that it busies itself with the measurement of the hours by means of the placement of gnomons; and meteoroscopics in that it discovers the differences of the elevations [of the celestial pole] and the distances of the celestial bodies [from one another], and informs [us] of many other, diverse astronomical observational data (θεωρήματα: cf. Cicero, *De fato* 6.11); as well as dioptrics in that it observes by means of these sorts of instruments the positions of the Sun, the Moon, and the other celestial bodies. (Friedlein 1873, 41.19–42.6: with ἐποχάς ("positions") instead of ε̅ ἀποχάς ("five distances") at 42.4 following Tannery 1887, 41n2)

It is customary to ascribe this taxonomy to Geminus (cf., e.g., Evans and Berggren 2006, 243–245), but this is wishful thinking: there is no good support for it in Proclus' text. Tannery's argument (1887, 42) for the ascription is very weak. The basic claim is that, though Proclus (Friedlein 1873, 38.1–4) mentions Geminus as one among others who distinguish the sciences differently than the Pythagoreans, Proclus would "undoubtedly" have given the name of any one earlier than Geminus. From this it is inferred that the "others" must be later than Geminus; and that if they shared the same taxonomy as Geminus, then Geminus must be the source of this taxonomy (except for passages like those where Plato is cited). The reader is thus invited to ignore two possibilities. First is that Proclus is referring to anonymous literature in addition to what Geminus may have written. Second is that *if* this literature is later than Geminus and *if* it is dependent on him, we distort history by attributing to Geminus Proclus' distillation of the historical development of these diverse but still coherent views about how to classify the mathematical sciences. After all, though this development may have begun with Geminus, it may well have gone beyond what he wrote. Note that in his edition of Damianus' *Optica* Schöne (1897, ix, 22–28) entitles a summary account of optics and its sub-divisions, "Selections from Geminus," *"ohne damit behaupten zu wollen, dass sie aus diesem direct geflossen seien,"* even though there is plainly a substantial connection between what Damianus writes and Proclus' reports. Recently, Bernard Vitrac (2005), though he still ascribes to Geminus the classification that Proclus reports (cf. Mueller 2004, 76), has argued convincingly that this classification has its roots in the early Academy and Aristotle. In sum, if the first of the two classifications that Proclus reports is not really Pythagorean, as Vitrac also argues, and if the second is not really Geminus', perhaps we should just talk of "the two classifications that Proclus reports" and avoid the pitfalls of specious particularity, specifically, the inference that Geminus allowed that optics gives causal explanations (cf. *In Euc.* 40.12–22 and note 36 below).

Simplicius' Report

This report comes in the course of Simplicius' commentary on Aristotle's brief remarks addressed in *Physics* 2.2 to the question of whether astronomy is different from physical theory or part of it. It opens with a sharp distinction between physical theory (φυσικὴ θεωρία) and astronomy (ἀστρολογία):[25]

> It is for physical theory to inquire into the substance of the heavens and of the celestial bodies, into their power and quality, and into their coming into existence and destruction. Through these [investigations],[26] it can certainly offer demonstrations concerning size, shape, and ordering. Astronomy, on the other hand, does not attempt to speak about anything of that sort. Instead, it demonstrates the order of the celestial bodies after declaring that the heavens really are a cosmos, and speaks about the shapes, sizes, and distances of the Earth, the Sun, and the Moon, about the eclipses and conjunctions of celestial bodies, and about quality and quantity in their movements. It follows that since astronomy deals with the theory of quantity, duration, and type of shape, it is reasonable for it to need arithmetic and geometry for this. And concerning these matters, which are the only ones about which it undertakes to supply an account, it has the authority to make inferences through arithmetic and geometry. (Kidd 1988–1999, F18.5–18)

This distinction between physical theory and astronomy is made initially by way of their subject matters. Physical theory focuses on the essential nature and qualitative aspects of the heavens and the bodies in them; whereas astronomy focuses on their quantitative aspects, which is why it accordingly relies heavily on arithmetical and geometrical argument. The report continues by elaborating a point already indicated—that astronomy and physical theory often treat the same topics, e.g., the shape, size, and order of the celestial bodies[27]—and by drawing attention to the differences in their procedures.

> Now astronomers and physical theorists[28] will in many cases propose to demonstrate essentially the same [thesis] (e.g., that the Sun is large, that the Earth is spherical), yet they will not follow the

25. See also Bowen and Todd 2004, 193–204; Todd and Bowen 2007.

26. Kidd 1988–1999, F18.7: reading νὴ διὰ τούτων.

27. For this same point, see Aristotle, *Phys.* 193b25–30.

28. Kidd 1988–1999, F18.19 ὅ τε ἀστρολόγος καὶ ὁ φυσικός. The definite article here is generic in sense (that is, it refers to any member of the class, or to the class collectively) and should be translated consistently in the plural form. See note 33 below.

same procedures (ὁδοί). For whereas [physical theorists] will make each of their demonstrations on the basis of substance, or power, or "that it is better that it be thus," or [the processes] of coming into existence and change,[29] astronomers [will do so] on the basis of the [properties] incidental to shapes or to sizes, or on the basis of the quantity of motion and of the time interval appropriate to it.[30] And physical theorists will in many cases deal with the cause by focusing on the causative power (ποιητικὴ δύναμις); whereas astronomers, since they make their demonstrations on the basis of extrinsic properties,[31] are not adequate observers of the cause in explaining (ἀποδίδωσιν) that the Earth or the celestial bodies are spherical, for example. Sometimes they do not even aim to comprehend the cause, as when they discourse on an eclipse.[32] At other times [astronomers][33] make determinations in accordance with a hypothesis

29. Thus, for example, given the premiss that every one of its parts moves by nature to the center of the cosmos, Aristotle (*De caelo* 297a8–b23) demonstrates that the Earth is spherical. Cf. Cleomedes' argument that the cosmos is spherical at *Cael.* 1.5.126–145 (with Bowen and Todd 2004, 72–73).

30. Aristotle (*De caelo* 297b23–298a8) argues that the Earth is spherical on the basis of such perceptual evidence as the appearance of the Moon during a lunar eclipse (see Bowen 2003a, 48n41) and the variation of the night sky as one moves north and south. Cf. Cleomedes, *Cael* 1.5.1–125 (with Bowen and Todd 2004, 63–72; Bowen 2003b, 60–62).

31. Kidd 1988–1999, F18.27 ἀπὸ τῶν ἔξωθεν συμβεβηκότων: cf. F18.23–24.

32. See Todd 1990, 2.4.95–107 (with Bowen and Todd 2004, 2.4 nn8, 19) on the Posidonian physical theory underlying eclipses. Mueller (2004, 69) claims that the mention of eclipses shows that a special notion of causation is at issue, since, as he says, "it is hard to imagine that any astronomer or physicist . . . living after, say 400, would have discussed solar or lunar eclipses without mentioning as an explanation the interposition of the moon between the sun and the earth or of the earth between the moon and sun, the latter being a well-known Aristotelian example of scientific causal explanation." Mueller suggests that Posidonius/Geminus discounts the astronomer's geometrical models as really explanatory because the alleged cause is not better known than the effect. I suspect, however, that it may be a mistake to assume that, for the author reported by Simplicius, eclipses are to be explained simply by the interposition of celestial bodies. The problem is that by the first century BC, it may have been known that eclipses are characteristically periodic phenomena (cf. Bowen and Goldstein 1996 on Geminus, *Intro. ast.* 18.1 (the *exeligmos*)). But giving a proper causal explanation of eclipses so understood would require going beyond Aristotle by accounting for the periodicity of these interpositions, and such an account would necessarily lie outside astronomy, which only quantifies celestial periods. Note that Geminus *describes* when solar and lunar eclipses occur in cc. 10–11 without using the language of causation except when drawing inferences from his description. Likewise, in c. 1.31–41, Geminus demonstrates that Sun's smooth motion along an eccentric circle has the necessary consequence that the Sun appears to traverse equal arcs of the zodiacal circle in unequal times, without saying that this eccentric solar motion is a cause.

33. Kidd 1988–1999, F18.30–32: the subject is ὁ ἀστρολόγος. By taking the article as generic and construing this subject as the class of astronomers, or "any astronomer" (see

(ὑπόθεσις)[34] by setting out some modes (τρόποι) [of accounting for the phenomena];[35] and, if these are the case, the phenomena will be saved. (Kidd 1988–1999, F18.18–32)

This section of Simplicius' report casts light on the relation of physical theory and astronomy. In F18.18–30, it effectively distinguishes two forms of explanation: the causal, demonstrative accounts offered by physical theorists and the non-causal, demonstrative accounts offered by astronomers. The former accounts are plainly assigned a higher cognitive worth. After all, the physical theorist, by arguing in terms of the intrinsic properties of some celestial object, secures knowledge of the object itself and explains *why* something is as it is. In contrast, the astronomer, by arguing in terms of the extrinsic properties of the same object, can show only *that* the thing is as it is.[36]

At F18.30–32, this report makes an important addition by affirming that even non-causal accounts offered on the basis of hypotheses, rather than on the basis of some (known) extrinsic properties of a celestial object, may still save the phenomena if the hypotheses prove to be the case (or

note 28 above), one avoids attributing to Posidonius/Geminus the claim that a given astronomer will commit to more than one hypothesis at a given time (see below).

34. At Todd 1990, 2.1.310–311 and 332–333 similar language is used in connection with premises in a calculation of the size of the Sun, though there the hypotheses are assumptions made within the larger argument rather than the kind of foundational hypothesis that concerns Posidonius/Geminus here.

35. Evans and Berggren (2006, 254) misconstrue this sentence. In addition, they neglect the fact that the term τρόπος is significant in contemporary philosophy: τρόπος, used here for one of a number of explanations, is reportedly the term used by the Sceptic Aenesidemus (first century BC) to designate a causal explanation (see Sextus, *Pyrr. hyp.* 1.181). Mueller (2004, 69) has "conditions" for τρόποι here and "method" for τρόπος at F18.37–38. The passage does, however, make sense if the occurrences of τρόπος at lines 31 and 38 are translated in the same way with an eye to the philosophical usage.

36. Cf. Aristotle, *An. post.* 76a4–13, 78b34–39: the latter passage subordinates accounts explaining *that* something is the case (the ὅτι) to those explaining *why* it is the case (the διότι).

Diogenes Laertius, in his book on the Stoic Zeno of Citium, asserts (*Vitae* 7.132–133) that both scientists (οἱ ἀπὸ τῶν μαθημάτων: see note 70, below) and physical theorists study the cosmos but differ in the particular subjects of their inquiries. After describing this difference in much the same was as Simplicius reports, he then indicates that there is a similar difference in the sorts of causal explanation (ὁ αἰτιόλογος λόγος) that they offer. It is interesting that in describing the explanations offered by the scientists, Diogenes does not cite astronomical *explananda* specifically but only vision and images in a mirror, as well as clouds, thunder, rainbows, halos, and comets; and he maintains that the explanations offered are causal. For the view that explanations in optics are not causal, a view that acknowledges its dependence on Posidonius and seems to draw on what Simplicius reports of Posidonius/Geminus, see Seneca, *Ep.* 88.26 with Bowen 2008c.

true).[37] That is, according to this report, while a hypothesis as such may be offered without knowing the relation of what is posited to the objects in question, it may still save or explain the phenomena, *if* it is in fact true. But who is concerned with the truth of such hypotheses—the astronomer, or the physical theorist, or both? The clear implication is that both are: the physical theorist, because he is concerned with the *realia* by profession; and the astronomer, because he wants to claim that a given hypothesis does indeed *save* the phenomena. Thus, while the astronomers being envisaged may collectively, or even individually, have known of a number of hypotheses by which to account for the same astronomical phenomena, the assumption in the present text appears to be that each astronomer will offer only one hypothesis in doing this, since, after all, only one of them can be actually the case.[38]

One may, of course, debate whether this realist interpretation of astronomical hypothesizing is credible, and whether it is a decent characterization of the typical practice and attitudes of astronomers of the time. Specifically, one may challenge the claim that, when an ancient astronomer says that a hypothesis saves the phenomena, he is committed to its actually being the case, though, of course, *qua* astronomer he cannot demonstrate that. This claim does have a certain plausibility *prima facie,* however. For, even if astronomers were not really interested in offering non-causal accounts *per se,* and regardless of their being troubled or untroubled by competing hypotheses in accounting for given phenomena, each did, so far as we know, settle on a single hypothesis in devising any given table quantifying these phenomena. In any event, this claim is essential to the view expressed subsequently that the astronomer must take the starting-points of his demonstrations from the physical theorist. In Simplicius' report, the

37. Note that in the conditional sentence ὧν ὑπαρχόντων, σωθήσεται τὰ φαινόμενα ("if these [modes of accounting for the phenomena] are true, the phenomena will be saved"), the antecedent of ὧν in the protasis ὧν ὑπαρχόντων, a genitive absolute, is τρόπους τινάς in F18.31. Note also that the verb of the apodosis (σωθήσεται) is a *future* indicative. It identifies not the ways in which the phenomena might be saved (ἂν σωθείη would be the Greek in that case), but the ways in which they are in fact explained and thus saved. Thus, the force of ὑπαρχόντων is that the applications of the hypothesis in the various modes of demonstrative explanation are the case, not just that they successfully account for the phenomena. That is, the modes must not only be logically valid arguments, they must be sound if they are to save the phenomena. But this is possible only if the hypothesis is true.

38. See notes 28 and 33 above. But see Lloyd 1991, 267 in which it is claimed that, for Geminus (see note 14 above), "it is his (*scil.* the astronomer's) business to say in how many ways it is possible to save the phenomena" (cf. Mueller 2004, 74–75). As I read the text (cf. Bowen and Todd 2004, 197n8), however, that astronomers produce a number of hypotheses is seen as an inevitable consequence of the fact that each astronomer tries to save the phenomena but lacks the means to demonstrate that his hypothesis is true.

dependence of astronomy on physical theory is intrinsic to astronomy itself because physical theory is knowledge of the *realia* the extrinsic properties of which are studied by astronomers, and because astronomers wish to make claims about how things are. That is, this dependence is rooted in the fact that, when astronomers assert that they can save phenomena using a given hypothesis, they mean (or must be understood to mean) that this hypothesis is the case or true.

As for the relation between making "determinations in accordance with a hypothesis" and "setting out some modes [of accounting for the phenomena]"in F18.30–32, it is apparently supposed that any given astronomer will on occasion posit a single hypothesis which is adapted to account for the same phenomena in different circumstances. Each adaptation to the different circumstances constitutes what is here called a mode, that is, a way of accounting for the phenomena (cf. λόγον ἀποδώσειν at F18.17). Thus, for example, a phenomenon common to several objects, such as the first morning appearance of an outer planet, might be accounted for on the basis of an epicyclic hypothesis that is quantified differently for Mars, Jupiter, and Saturn.

At this point Simplicius' report begins to show its curious history; and we have the first of two dislocations marking ellipses that may be the result of the way texts have been excerpted, summarized, expounded, and quoted. The reader, though initially promised an example of the preceding account of astronomical procedure, is suddenly confronted with a question that appears to have some very serious consequences.

> For example (οἷον): Why do the Sun, the Moon, and the planets appear to move unsmoothly (ἀνωμάλως)? Because[39] whether we hypothesize that their circuits are eccentric, or that the celestial bodies go round along epicycles, their apparent unsmoothness [in motion) (ἀνωμαλία) will be saved.[40] And [we] will have to go

39. Kidd 1988–1999, F18.33 ὅτι: the ὅτι-clause explains why the question is being asked.

40. The eccentric and epicyclic hypotheses are treated here as independent rather than equivalent. No extant Greek or Latin writer of the first centuries BC and AD mentions this equivalence and those that do address the issue of the planetary motions choose one hypothesis or the other, not both. On the project of saving the phenomena of the planetary motions before Ptolemy, see Bowen 2001.

It is curious that Theon of Smyrna reports that Adrastus of Aphrodisias (late first or early second century AD (Martin 1849, 74–75)) was the first to show that the eccentric hypothesis follows incidentally (κατὰ συμβεβηκός) from the epicyclic hypothesis, but then claims for himself the proof that the epicyclic hypothesis follows from the eccentric hypothesis (Hiller 1878, 166.10–13). On the value of such reports when they cannot be confirmed, see Bowen 2002b.

Ptolemy suggests the possible equivalence of the two hypotheses at *Alm.* 3.3 (cf. Toomer

> through *all* the modes according to which these phenomena can be caused, so that our systematic treatment[41] of the wandering stars will look like a causal theory (αἰτιολογία) [set out] according to each possible mode [of causation] (κατὰ τὸν ἐνδεχόμενον τρόπον). (Kidd 1988–1999, F18.32–39)

This question about why the planets appear to move as they do was important in the first century BC, a time when the effort to develop or adapt different models in order to account for planetary stations and retrogradations began in earnest. Geminus, for instance, prefers an eccentric model for the Sun (*Intro. ast.* 1.31–41) and a model for the Moon that is based on a Babylonian zigzag scheme (cf. Bowen and Goldstein 1996), while Vitruvius (*De arch.* 9.1.5–14) adopts an epicyclic model for the inner planets and an eccentric model (supplemented with a causal component involving the power of the Sun) for the outer planets (see Bowen 2001, 826–829). But, as Robert Todd and I have argued elsewhere (Bowen and Todd 2004, 193–199), this question is not posed to astronomers: it is asked, instead, of the reader who is plainly one of "us" and so, presumably, a Stoic philosopher with a keen interest in physical theory, assuming that these lines ultimately come either from Posidonius or from Geminus in his summary and exposition of what Posidonius wrote.[42] In short, the question is asked of someone who is aware of various ways in which astrono-

1984, 144 n32), but does not discuss it until *Alm.* 12.1. On the strength of the latter text, some modern scholars (see, e.g., Neugebauer 1955, 1959) suppose that the proof of this equivalence goes back to Apollonius of Perga (third century BC). But this overlooks the fact that the single demonstration Ptolemy gives in *Alm.* 12.1 of the planetary stationary points is (apparently) his own, and that, according to Ptolemy, his predecessors made their cases for each hypothesis separately (see Bowen 2001, 821–822). Note also that at *Alm.* 4.11 Ptolemy claims that in *Alm.* 4.5 he has shown the equivalence of the solar eccentric and epicyclic models both numerically and in terms of the phenomena; moreover, he criticizes Hipparchus for making careless mistakes in quantifying the models and implies that Hipparchus did not understand their equivalence.

Alexander Jones has kindly pointed out to me that in papyrus PSI inv. 515 (= PSI XV 1490), which dates from the very early second century AD and may be part of a larger treatise (see Jones 2004), the author alludes to an eccentric and an epicyclic model for solar motion and uses the same maximum equation for both (cf. Jones 2000, 83–86).

41. πραγματεία: the term does not mean a "theory" (Heath 1913, 276), or "study" (Kidd 1988–1999, 2.133; 3.80), but either an actual treatise, or the kind of systematic exercise that would be embodied in one: cf., e.g., Alexander's usage (Bruns 1887, 30.24).

42. It is important to remember that such Stoics would belong to the later, Posidonian branch of Stoicism, a branch which is evident in Cleomedes' *Caelestia.* Not all Stoics were sympathetic to this kind of inquiry: see Strabo, *Geog.* 2.3.8. (On Strabo's Stoicism, see Mueller 2004, 75.) Seneca, *Ep.* 88.21–28 ignores it in making the same general point about the relation between physical theory and astronomy, and indicates why in 88.29–46.

mers account for the planetary motions, and its aim is to make him determine for himself why the planets move as they do.[43]

That this question is addressed to philosophers or physical theorists is not surprising, given, as we have noted, that the astronomers' assertion that the various hypotheses in use save the phenomena of planetary motion entails divergent claims about the underlying *realia.* But what exactly is the problem for philosophers with listing all the possible modes of explanation, that is, with listing every non-causal account of the phenomena covered by each applicable hypothesis? Recall that a hypothesis can save phenomena *only* if it is the case or true. But knowing that a hypothesis (which concerns some extrinsic feature of an object) is indeed the case requires knowing the underlying *realia;* and this in turn presupposes having a proper causal account of the phenomena. In Aristotelian terms, the problem in astronomy is that one usually cannot know *that* a hypothesis is true without knowing *why* it is true (cf. note 36 above). Thus, any philosopher lacking a proper causal account of why the planets move as they do will be much embarrassed when confronted by the various hypotheses put forth by astronomers, since he will not be able to determine which, if any, is in accord with reality. Consequently, when this philosopher is asked to account for such phenomena, he will do no better than list all the astronomical hypotheses (and their modes) available to him on the ground that, so far as he knows, each is true or saves the phenomena. And, so, to the extent that these hypotheses are divergent, he will endorse contradictions in his physical theory—clearly an undesirable outcome.

This first dislocated paragraph thus turns on its head Aenesidemus' criticism of dogmatism (*scil.* Stoicism, for instance) that it sometimes holds to a single account of phenomena when many are possible (cf. Sextus Empiricus, *Pyrr. hyp.* 1.180–182). For such sceptics, the existence of many accounts undermined the search for a single causal explanation; but for the

43. See Mueller 2004, 69–70. Evans and Berggren (2006, 254) misrepresent Kidd 1989–1999, F18.31–35. Further, their supplement in "[The astronomer would answer] that if we assume that their circles are eccentric. . . ," is a gross intrusion that goes back at least to Tannery (Heiberg and Zeuthen 1929, 256) and was rejected by Aujac (1975, 112). At the same time, it makes the implausibility of their view that the "we" are astronomers obvious. (For his part, Tannery obscures the problematic "we' by writing *"L'astronome dira qu'en supposant leurs cercles excentriques. . . ."*) For, if the subject is ὁ ἀστρολόγος, would one not expect "he" instead of "we"? And why would the author reported by Simplicius confuse his readers by abandoning his account of ὁ ἀστρολόγος and introducing the plural οἱ ἀστρολόγοι, and then having these astronomers speak in the first person rather than in the third? It is perhaps not coincidental that Evans and Berggren (2006, 53–58) conflate Posidonius and Geminus, and treat the latter solely or primarily as an astronomer. The case of Cleomedes is ample proof of the untenability of that assumption, however.

Stoic, a multiplicity of accounts demanded it (see Bowen and Todd 2004, 197).[44]

Simplicius' report continues with yet another dislocation. It initially promises a conclusion based on the preceding lines [note δῐό]; but, instead of following up on the problem posed by diverse hypotheses for given (planetary) phenomena, it introduces someone who proposes a single hypothesis about an unspecified motion of the Earth and a stationary Sun.

> That is why a certain Heraclides of Pontus even came forward to say[45] that the apparent unsmooth motion of the Sun can be saved [on the hypothesis that][46] the Earth actually moves somehow (πως), while the Sun somehow (πως) remains stationary.[47] (Kidd 1988–1999, F18.39–42)

It is difficult to discern the contextual logic of the remark about Heraclides.[48] At first glance it seems best to suppose that the process of summarizing, expounding, and quoting that constitutes the transmission of what came to Simplicius has obscured the fact that this remark actually follows on the earlier observation (F18.25–32) that astronomers often ignore causation and simply resort to hypotheses that purport to save the phenom-

44. The point of this paragraph in Simplicius' report is not that the astronomer's hypotheses are false, as Mueller (2004, 70–71) maintains, but that none is known to be true. Epicurus advances a view that falls between the Stoic and Sceptic positions. For Epicurus, it is possible to get knowledge of matters in the heavens and thus to secure tranquility and happiness. Such knowledge lies primarily in grasping that they are but the outcome of the original inclusion of aggregates of atoms in the birth of our world. It does not come from the study of risings and settings, solstices, eclipses, and so forth, because such study is not predicated on knowledge of what the heavenly bodies are or of what the most important causes are, and because we have different explanations of the same phenomena (since they are at a distance from us). Indeed, so far as such study goes, Epicurus holds that we will preserve our tranquility and happiness if we are aware of the various ways in which celestial phenomena may be explained. Cf. Epicurus, *Ep. ad Herod.* (Diogenes Laertius, *Vitae* 10.77–80) and *Ep. ad Pyth.* (*Vitae* 10.90–98: cf. 10.113–114) using the text of von der Muehll 1996.

45. Kidd 1988–1999, F18.39 διὸ καὶ παρελθών τίς φησιν Ἡρακλείδης ὁ Ποντικός.

46. The genitive absolute describing the Earth and the Sun at 18.40–41 is obviously the protasis of a conditional sentence; and in the present context the protasis is a hypothesis, as defined just above.

47. Given the Sun's immobility, one might suppose that the Earth moves around it on an eccentric circle that is oblique to the celestial equator. But this may be too specific. That the Sun is said to remain stationary πως suggests that this particle is intentionally indefinite and that it should not be construed to mean "in a certain way" or taken to imply some real theory as Eastwood 1993, 238 or Evans and Berggren 2006, 254 suppose.

48. Cf. Todd and Bowen 2007.

ena. At least, this would seem to be how Ptolemy (*Alm.* 1.7) understands the sort of proposal that Heraclides supposedly made: for, as he writes,

> There are in fact some who, in their view, assent rather plausibly to the preceding [arguments for the immobility of the Earth] because they have nothing to say against them, yet believe that there is nothing to counter-witness them if they suppose for the sake of argument (λόγου χάριν) that the heavens are unmoved while the Earth performs approximately one rotation around the same axis [as the heavens] from west to east during each day—or they could even move both [the Earth and the heavens] any amount whatever,[49] just as long as it is around the same axis (as we just said) and in a manner suitable for their overtaking one another. But it has escaped them that, regarding the phenomena involving the celestial bodies, while nothing might perhaps prevent this from being the case, at least at a rather simple level of awareness, yet this sort of thing should be seen as completely ridiculous on the basis of occurrences around us alone[50] as well as those in the air.[51] (Heiberg 1898–1907, 1.1.24.5–18)

Ptolemy, whom Simplicius apparently follows in speaking of Heraclides,[52] does not accuse its unnamed proponents of ignoring orthodox theory; he simply notes that they offered an alternative "for the sake of argument", and then castigates this alternative as absurd because it naïvely ignores what we know from experience.

Of course, one might suppose instead that the remark about Heraclides does indeed follow from the question posed to (Stoic) philosophers and the elaboration of the consequences of not being able to answer it (F18.32–39). This would involve conjecturing that, at some time in the evolution of the material prior to Simplicius' reporting it, the mention of Heraclides and his single hypothesis about the Sun and Earth was but one of a number of examples, others of which introduced hypotheses about eccentric and epicyclic motions.[53]

49. Cf. Aristotle, *De caelo* 289b1–4 for an analogous proposal about the celestial bodies and the celestial spheres.

50. *scil.* terrestrial events.

51. For one of his arguments, see Heiberg 1894, 542.2–7 and Heiberg 1898–1907, 1.1.25.4–14.

52. Cf. Heiberg 1894, 444.31–445.3, 519.9–11, 541.28–29.

53. See Todd and Bowen 2007 on whether this is an authentic report about Heraclides and, if so, whether the reference to the Earth's moving and the Sun's being at rest "somehow" is, say, a rhetorical flourish (Gottschalk 1980, 168), or a proposal with a serious, technical force (cf. Eastwood 1992, 238; Evans and Berggren 2006, 254), or just a travesty of a

Finally, Simplicius' report draws to a close with a general claim that brings us back to Geminus' citation of the Pythagoreans and the requirement that the astronomers' accounts of the planetary motions start from the hypothesis that the celestial bodies all move smoothly on circles.

> For, in general, it is not for astronomers to know what is by nature at rest and what sorts of things are moved. Instead, by introducing hypotheses of some things being stationary, others in motion, they investigate from which hypotheses the phenomena in the heavens will follow. But astronomers should take as first principles (ἀρχαί) from physical theorists that the motions of the celestial bodies are simple, smooth, and orderly, and through these [principles] they will demonstrate that the choral dance[54] of all [those bodies] is circular, with some revolving in parallel circles, others in oblique circles.[55] (Kidd 1988–1999, F18.42–49)

Both Simplicius' report and Geminus' citation (*Intro. ast.* 1.19–22) of the Pythagoreans agree in requiring that the astronomers begin their accounts of the planetary motions from certain propositions about the celestial motions. But they also differ in some interesting ways. In the first place, Geminus calls such propositions "hypotheses" (ὑποθέσεις) in the *Introductio,* whereas in Simplicius' report they are called "first principles" (ἀρχαί). The distinction is not merely verbal: in the report itself, the reference to first principles highlights the difference between what the astronomer receives from the physical theorist and any hypothesis that he devises on his own. Next, in the *Introductio* the fundamental proposition in astronomy is that all the celestial motions are smooth and circular. In Simplicius' report, however, the fundamental proposition is that the celestial motions are simple, smooth, and orderly; and it is on this basis that astronomers are to demonstrate that they are circular.

Hypotheses and First Principles

Let us begin with the remark that astronomers should receive their first principles from physical theorists. When in Simplicius' report it is said

view the Stoics regarded as demonstrably wrong (cf. Cleomedes, *Cael* 1.5–6 with Bowen and Todd 2004, 77n14).

54. χορεία: for this metaphor, see Plato, *Tim.* 40c3–d5 (cf. Bowen 2001, 814–816).

55. It is difficult to decide whether astronomers are to demonstrate (and so to account for) the phenomenon of circularity by way of direct argument (cf. F18.8, 19, 23, 27) or to display or make it known in demonstrating other phenomena (cf. F18.9). Cf. Liddell, Scott, and Jones 1968, *s.v.* ἀποδείκνυμι.

that astronomers should take as a first principle the fundamental proposition that the celestial motions are simple, smooth, and orderly, the implication is that this proposition, which has been demonstrated in physical theory, is a proper starting-point for an astronomical explanation of the celestial motions that not only purports to account for the phenomena but actually does save them because it is the case. That is, when an astronomical account starts from a proper physical explanation of the planetary motions and proceeds in that context by limiting itself to the extrinsic features of the bodies and motions mentioned in the physical explanation, it will inevitably be in accord with reality and thus epistemically different from accounts that are not so grounded. This account will, in fact, be *un*hypothetical, at least in the sense that the word ὑπόθεσις has been used thus far to designate a starting-point for argument that is offered as true but is not known to be so.[56] Moreover, given that the alternative is to base astronomy on hypotheses devised (by astronomers) in the mere hope or faith that they are the case, it will be superior. Indeed, it will constitute real knowledge, albeit knowledge that is still not causal.[57]

Thus, the question just posed to philosophers about the planetary motions was not asked solely with a view to deciding which of the number of current astronomical hypotheses is correct, since none may actually be the case. Rather, the point of the question was to secure a single causal, demonstrative account in physical theory that will warrant and ground a single astronomical account which is thus unhypothetical in the limited sense that its starting-points (i.e., first principles) are known to be true by philosophers.[58] This is, I think, how Simplicius saw the challenge. As he says,

> In this way, then, Aristotle has given his solution of the problem, after conceding to it and granting that the planets perform motions

56. If these starting-points or first principles are still to be called hypotheses, it is by an equivocation. That is, for example, one might persist in calling them hypotheses because they are accepted, but not known, as true by astronomers *qua* astronomers (cf. Plato, *Resp.* 510b2–511d2); or because they are statements affirming one limb of a contradiction (cf. Aristotle, *An. post.* 72a20–24).

57. Thus, I disagree when Mueller (2004, 71) says that "In any case, it is clear that they [*scil.* Posidonius/Geminus, Seneca] are denying that astronomy gives causal explanations, and that, at least for Posidonius/Geminus, this is because it relies on hypotheses which have no physical justification." For even when such justification is provided, it still remains true that astronomical demonstrations concern only the properties incidental to the shapes and magnitudes of the underlying *realia* (cf. Kidd 1988–1999, F18.23–25).

58. This astronomical account will at the same time be hypothetical in the sense that its first principles ultimately derive from undemonstrated first principles in physical theory.

that are many in kind not only because of their apparent direct motions,[59] but also [because of] their [apparent] retrogradations, stations, [their] different phases, advances, followings, and [their] various kinds of unsmoothness. For, those who hypothesize eccentric [circles] and epicycles as well as those who hypothesize homocentric [spheres] (the ones called turning [spheres])[60] admit more than one motion for each [planet] in order that these [apparent motions] be saved. The true account (ὁ ἀληθὴς λόγος), of course, which accepts neither the stations [of the planets] or their retrogradations nor the additions and subtractions of the numbers in their motions (even if they are observed moving in this way), does not admit the hypotheses as being the case.[61] Rather, by drawing inferences from the substance [of the planets] it demonstrates that the celestial motions are simple, circular, smooth, and orderly. But, since [people] were not able to grasp precisely how the [characteristic] features of the established [planetary motions] are appearance (φαντασία) only and not reality (ἀλήθεια), they desired to discover on what hypotheses it would be possible to save, by means of smooth, orderly, and circular motions, the phenomena of the motions of the [stars] that are said to wander.[62] Indeed, as Eudemus recorded in the second book of his *Astronomical History,*[63] and as Sosigenes[64] who got it from Eudemus [also recorded], Eudoxus of Cnidus was the first of the Greeks said to lay hold of hypotheses of this kind, after Plato, as Sosigenes states, had proposed to those who are serious about these matters the following question: By hypothesizing which smooth and or-

59. Heiberg 1894, 488.5 προποδισμοί: this term is not found in an astronomical context before Proclus (cf., e.g., *Hyp. ast.* 7.4). Direct motions are eastward, that is, in the direction opposite to the apparent daily rotation of the celestial sphere.

60. Heiberg 1894, 488.9: Simplicius uses ἀνελίττουσαι, Aristotle's term for the unwinding spheres in *Meta.* Λ 8, more generally of homocentric spheres whether winding or unwinding. I have, therefore, translated the term as Simplicius uses it by "turning" to avoid confusion: cf. Aujac 1979, 138n1.

61. It is important to notice here that Simplicius does not say explicitly here that the various astronomical hypotheses used to account for planetary stations are false. He says only that the true account does not admit these hypotheses as true, which means that it will not use them as its starting-points.

62. Cf. Heiberg 1894, 492.25–31 for a recapitulation of this passage, where Simplicius says that the hypothesis of "turning spheres" has no necessity, since "other [thinkers] saved the phenomena through other hypotheses." He adds that "it would be appropriate for our accounts of the heavens and the celestial bodies to discuss briefly too those hypotheses which, after being hypothesized, each [of these thinkers] insisted saved the phenomena."

63. On this book, see Bowen 2002a.

64. Sosigenes (second century AD), a Peripatetic philosopher and teacher of Alexander of Aphrodisias (cf. Hayduck 1899, 143.12–14; Bowen 2008b).

> derly motions, may the phenomena of the motions of the wandering {stars} be saved? (Heiberg 1894, 488.7–24)

For his part, however, Simplicius does think that the homocentric hypothesis is false in that it fails to address certain phenomena (cf. Heiberg 1894, 504.16–505.21); and he does suspect that the other hypotheses *may* be false as well. Still, he declines to say that they are all false: the most he says is that they are not proven to be true.[65] In this way he acknowledges the great difficulty in coming up with a proper physical account—it was, after all, a *desideratum* until the time of Kepler and Newton—and so seems more tolerant of the diversity of astronomical hypotheses and the effort to come up with them than Posidonius/Geminus.[66]

Given this explanation of the difference in calling the fundamental propositions of astronomy hypotheses or first principles, is Geminus' talk of the way the Pythagoreans set the agenda for astronomical research consistent with the report's account of the subservience of astronomy to philosophy? Indeed, it is; and Geminus himself would, I think, have endorsed calling the fundamental proposition that the celestial motions are all smooth and circular a Pythagorean hypothesis *and* a first principle.

The key is that the *Introductio* is explicitly addressed to novices wishing to learn astronomy, whereas the report shows every sign of being addressed to Stoic philosophers concerned to understand the place of astronomy in their conceptual world.[67]

65. Cf. Heiberg 1894, 488.25–27: "Then, if the motions (which are more numerous in each case than the quite numerous wandering bodies) are hypotheses, if they are not proven to be so in truth—as the fact that one hypothesizes them in one way and another in another makes clear. . . ."

66. Cf. Heiberg 1894, 32.22–32:

> The Hipparchans, {his predecessor} if there is one, and subsequently Ptolemy, hypothesized eccentric spheres and epicycles, thereby overlooking the fact that all the celestial bodies move around the centre of the universe, while supplying in accordance with these hypotheses (ὑποθέσεις) the causes that had been neglected by those {astronomers: *scil.* Eudoxus and Callippus} who were mentioned earlier. Now Aristotle says nothing about these matters here, and in those passages in which he does mention them, he appears to follow the hypotheses of his predecessors. And it is clear that differing about these hypotheses is not a ground for complaint (ἔγκλημα). For the {question} proposed is, Given what hypothesis can the phenomena be saved? So it is not surprising if different people tried to save the phenomena on the basis of different hypotheses.

Simplicius' tolerance of hypotheses, however, does not extend to Heraclides, because, like Ptolemy whom he cites, Simplicius thinks that Heraclides' hypothesis, far from saving the phenomena, is in conflict with them: cf. Heiberg 1894, 541.13–542.7. See also Cleomedes, *Cael* 1.6.

67. The report and Cleomedes' *Caelestia* are in fact addressed similarly, the main differ-

Thus, in his *Introductio,* Geminus typically presents the field of astronomy without explicit regard for any relation which it may have to other disciplines such as philosophy or physical theory. The main exception, however, comes in the first chapter when Geminus raises the question of the planets and their motion—a question which gains importance by its coming so early in the sequence of chapters[68]—introduces the Pythagorean hypothesis that the celestial motions are smooth and circular, and then supplies philosophical arguments for its truth. So why does Geminus persist in treating the proposition that the celestial motions are smooth and circular as a hypothesis? Obviously, one good reason is that it must be so for his novice astronomers. But this raises the question of Geminus' own view of the arguments offered in support of the hypothesis. If he accepted them and regarded the proposition as true and, hence, as a first principle, then his continuing to call it a hypothesis would have to rest on an equivocation (See notes 56 and 58 above). But, if he rejected these particular arguments—as well might a Stoic who posited cycles of cosmic destruction and rebirth—then, in the context of the *Introductio,* this proposition remains a hypothesis which is epistemically the same as the proposition that the Sun moves on an eccentric circle. Only in adept philosophical hands could it become a proper first principle, but this would be a task for another occasion.

However one sorts this out, Geminus' usage in the *Introductio* is consistent with his holding that the ultimate goal of planetary theory is an account that is not hypothetical at all but ontologically valid because it starts from first principles demonstrated in the higher discipline of physical theory and proceeds in accordance with the explanations of these principles that have been given by physical theorists. Indeed, one would expect this, given Geminus' role in the history of what Simplicius reports and the fact that there is no real trace of any disagreement on his part in the *Introductio.*[69]

What is Demonstrated in Astronomy

Next, we come to the claim in Simplicius' report that astronomers will demonstrate (ἀποδεικνύναι) that the celestial motions are circular on the basis of first principles, specifically, the proposition that these motions are

ence being that Cleomedes' treatise is part of a curriculum of lectures to students of Stoic philosophy.

68. Geminus returns to planetary theory at *Intro. ast.* cc. 9–12 and 18.

69. On the connections between Seneca, *Ep.* 88 and this view of astronomy and its dependence on physical theory or philosophy, see Toulouse 2005, esp. 164–170 and Bowen 2008c.

simple, smooth, and orderly, which they receive from philosophers or physical theorists. What is unclear is how astronomers are to demonstrate that the apparent choral dance of the celestial bodies is circular. One possibility is that the astronomer is not to deduce their circular motion so much as he is to display it or make it known in accounting for celestial phenomena (cf. note 55 above). The problem with this is that it would be very hard to display circularity in this way without assuming it; and so one would have to suppose that the hypothesis of circularity, although not mentioned by Simplicius, was included with the others in his source (cf. Geminus, *Intro. ast.* 1.19–21, which posits circularity). Another possibility is that astronomers are to argue dialectically that the simple, smooth, orderly motion of such bodies is circular.

Ptolemy's Demarcation of Astronomy and Physical Theory

When Ptolemy addresses the question of the relation of physical theory and astronomy in *Alm.* 1.1, which is in effect a preface to this treatise, he begins by distinguishing philosophy (φιλοσοφία) into its practical and theoretical parts, and by affirming that he thought it fitting to devote himself for the most part to intellectual pursuits (σχολή) in order to teach theoretical studies (θεωρήματα) which are numerous and beautiful, especially, those that are specifically termed "scientific" (Heiberg 1898–1907, 1.1.4.7–5.7).[70] Next, he divides theoretical philosophy into three parts: the physical, the scientific, and the theological (Heiberg 1898–1907, 1.1.5.7–10). Though Ptolemy cites Aristotle as an authority for this tripartition, it quickly becomes clear that Ptolemy is neither responding to nor following Aristotle specifically. Indeed, he is using the Philosopher, Aristotle, as a means to distance himself from the conception of astronomy

70. It is customary to translate the adjective μαθηματικός -ή -όν by "mathematical" in this passage. The problem is that both what *we* mean by "mathematics' and what Ptolemy understands as arithmetic and geometry are but a part of what he calls the τὸ μαθηματικὸν γένος or εἶδος of theoretical philosophy: see note 73 and note 74 *ad* Heiberg 1898–1907, 1.64–6, as well as note 85. It was, of course, common by Ptolemy's time to use the adjective μαθηματικός -ή -όν to mean "astronomical"; but this too will not work in the present context. More promising is that there was also precedent for treating arithmetic, geometry, and astronomy as μαθήματα (things learned, bodies of knowledge, sciences, mathematical sciences): the related verb is μανθάνειν (to perceive, learn). Accordingly, I will translate μαθηματικός -ή -όν by "scientific" (cf. Bowen 2008a), and trust that the reader can bear in mind that the sciences in question are all mathematical because their argumentation occurs through or draws on arithmetic and geometry (cf. Heiberg 1898–1907, 1.6.19–21) and that they include subjects which we would call mathematics as well as ones we would not. One advantage gained by this is a sharper presentation of Ptolemy's denial that physical theory constitutes knowledge (cf. Heiberg 1898–1907, 1.6.11–7.4).

held by philosophers of his day, the Stoics (cf. Wolff 1988, 498–502 (esp. 499n31), 543–544). As he explains this tripartite division,

> All things that exist have their being from matter, form, and motion; and each of these cannot be observed but only thought of separately (that is, without the others) in a subject. In consequence of this, if one should take the primary cause of the primary motion of the universe[71] without qualification, one would consider it an invisible and unmovable god (θεός), and the kind (εἶδος) {of theoretical philosophy} which can inquire into this {primary cause} as theological (θεολογικόν), because such an actuality can only be thought of as up somewhere around the highest parts of the cosmos and because it is absolutely separate from perceptible beings. The kind {of theoretical philosophy} which can investigate material and ever changing quality (ποιότης) and which engages with the white, the hot, the sweet, the soft, and things like this, one would call physical because such being abides among things that can for the most part cease to exist (that is, it abides below the lunar sphere). But one would define as scientific the kind {of theoretical philosophy} which can make statements about quality in respect of shapes (εἴδη)[72] and in respect of motions from place to place (μεταβατικαὶ κινήσεις), because it can inquire into shape, quantity, size, and, further, into place, time, and the like. Such being falls, as it were, between those {other} two not only because it can be thought of through sense-perception[73] and apart from sense-perception,[74] but also because {such being} is a property of absolutely all things that are both mortal and immortal. {And this is the case} because it alters (συμμεταβάλλεσθαι) along with those things that are ever altering (μεταβάλλειν) with respect of their inseparable form,[75] whereas for things that are eternal (that is, of an ether-like nature) it preserves unchanged (ἀκίνητον) the {aspect} of their form that cannot be altered (ἀμετάβλητον).[76] (Heiberg 1898–1907, 1.1.5.10–6.11)

71. *scil.* the daily rotation.

72. Cf. Aujac 1993, 200.

73. *scil.* as it is in astronomy, for example.

74. *scil.* as it is in arithmetic and geometry.

75. Heiberg 1898–1907, 1.1.8–9 κατὰ τὸ εἶδος τὸ ἀχώριστον: thus, for instance, Socrates, whose inseparable form is his being a man, is always changing in shape, configuration, and position. Aujac's *"vu qu'elle {scil. la science} en est inséparable"* (1993, 201) misconstrues both the subject of the phrase and the syntax.

76. Cf. Aristotle, *De an.* 1.2–4.

Ptolemy has elaborated his tripartition of philosophy, and cast the scientific and physical branches as coordinate with theoretical philosophy. Next, using Stoic ideas and language, he argues that scientific philosophy alone constitutes real knowledge.

> We reasoned from this that one should describe the other two kinds (γένη) of the theoretical {division of philosophy} more as conjecture (εἰκασία) rather than as apprehension which can yield knowledge (κατάληψις ἐπιστημονική)—the theological because of its utterly non-evident and ungraspable {character}, and the physical because of matter's unstable and unclear {character} (with the result that, for this reason, philosophers can never expect to agree about them). {We also reasoned} that, if one approaches it rigorously, only the scientific {kind of theoretical philosophy} can provide knowledge that is sure and incontrovertible (εἴδησις βεβαῖα καὶ ἀμετάπιστος) to its practitioners because its demonstration must be through indisputable procedures (ὁδοί), namely, arithmetic and geometry. In consequence of this, we were persuaded to cultivate in the first place all theory like this in accordance with our ability, and especially the {theory} which understands divine (that is, celestial) things. For this {theory} alone busies itself with the investigation of things that are always in the same state; and, for this reason, in respect of its own apprehension it can itself also be always in the same state (which is neither unclear nor disordered)—this is a characteristic feature of knowledge[77]—and it can contribute to the other {kinds of theoretical philosophy} no less than they themselves.[78] Indeed, this {theory} in particular paves the way for the theological kind {of theoretical philosophy} in that it alone can in fact make proper inferences about the unmovable and separate actuality on the basis of its nearness to the properties of perceptible beings that are, on one hand, both causes of motion and moved, and, on the other, eternal and impas-

77. Heiberg 1898–1907, 1.1.7.1–2 περὶ τὴν οἰκείαν κατάληψιν: the point is that one apprehends what is eternally the same when one apprehends either the subject matter of this special scientific theory or the theory itself—a typical instance in which the study of a subject matter is said to take on the character of its subject matter. The point is not that this scientific theory is eternally the same "in its own domain": cf. Toomer 1984, 36; Aujac 1993, 202.

78. Heiberg 1898–1907, 1.7.4 τὰς ἄλλας οὐχ ἧττον αὐτῶν ἐκείνων συνεργεῖν. Though by itself this line might suggest that τὸ μαθηματικόν contributes as much to τὸ φυσικόν and τὸ θεολογικόν and as they do to τὸ μαθηματικόν, the next lines (Heiberg 1898–1907, 1.7.5–17) indicate that Ptolemy's point here is that τὸ μαθηματικόν contributes as much (or as significantly) to the development of the other branches of theoretical philosophy as they do to their *own* development.

sive (that is, in respect of their locomotions and the arrangements of their motions). And to physical theory it can make a significant contribution. For the universal characteristic of material being is more or less made known from the distinctive manner of its motion from place to place. So, the perishable itself and the imperishable [are made known] from motion in a straight line and circular motion, and the heavy and the light (or the passive and the active) from motion to the center and motion from the center.[79] (Heiberg 1898–1907, 1.1.6.11–7.17)

The force of this argument is telling. Ptolemy effectively uses ideas in Stoic epistemology to propose that astronomy, that part of scientific philosophy which studies the visible, eternal motions that are ever the same, is a surer guide to reality than what the Stoics call physical theory or, in his terms, theological and physical philosophy.[80] To press the point home, Ptolemy then explains how scientific philosophy, in addition to being master of its own domain, contributes significantly to the other divisions of theoretical philosophy; and, after that, he adds the argument first made known in Plato's *Republic* and *Timaeus* that it also contributes to practical philosophy (Heiberg 1898–1907, 1.1.7.17–24).

Ptolemy's elevation of scientific philosophy, specifically, astronomy, in cognitive status entails that the scientist's arguments for key propositions previously taken as belonging to physical theory will by themselves be sufficient to establish the truth of these propositions and that they will in fact be the best kind of argument possible. These arguments as they are found in the typically involve recourse to phenomena. Thus, for example, in *Alm.* 1.6 Ptolemy argues that the Earth has the ratio of a point to the distance of the celestial sphere on the basis of three considerations (τεκμήρια, σημεῖα):

- the fact that the sizes and distance of the fixed stars are observably the same no matter where on Earth the observer is located
- the fact that the gnomons of sundials and the centers of armillary spheres set up anywhere on Earth appear to function as though they were at the center of the Earth, and
- the fact that the horizon for any observer on Earth seems to bisect the celestial sphere.

79. Cf. Wolff 1988, 499n31.

80. In his *Intro. ast.,* Geminus uses ἀστρολογία/ἀστρολόγος for "astronomy"/"astronomer": the range of this science is indicated largely (but not entirely) by the topics covered in the treatise. Since he uses μαθηματικός and related forms much less frequently, it is difficult to say exactly what these terms mean for him, though I have argued that "scientific" is preferable to the usual alternatives (Bowen 2008a).

Moreover, in *Alm.* 1.7, which is devoted to the proposition that the Earth does not move away from the center of the celestial sphere, he recalls the arguments in *Alm.* 1.5 that the Earth is located at the center of the celestial sphere—arguments to the effect that only if it were at the center would the phenomena be preserved—and affirms the thesis of 1.7 on the basis of the arguments given in 1.5. Then, he adds that

> Consequently, for my part, I think it superfluous for someone to inquire into the causes of the motion to the center, at least once the fact that the Earth occupies the center of the cosmos and that all heavy bodies move towards [the Earth] is so very evident from the phenomena themselves. (Heiberg 1898–1907, 1.1.21.14–19)

In sum, the scientific division is sufficient to establish its own starting-points.[81] That is, for Ptolemy, the Stoic search for a physical theory of the celestial motions is misguided, if one expects such a theory to constitute knowledge be it superior to, or independent of, astronomy. Scientific philosophy, that is, astronomy, is capable on its own of yielding cognitive apprehension or knowledge of the heavens.[82]

For Ptolemy, the governing principles of astronomical theory are reached by reflection on the phenomena, not by reflection on the physical nature or substance of the underlying objects. The theory itself advances by way of what the Stoics called cognitive sense-presentation (φαντασία καταληπτική)—this is what underlies Ptolemy's unique concern with instruments, their construction, and the certification of other observers (see Goldstein and Bowen 1999)—where these sense-presentations or observations are used to quantify geometrical models numerically, models which once properly adapted permit one to account for the phenomena in breathtaking detail since they enable one to determine the configurations of the heavens at any time for any observer.[83] From the Stoic standpoint, this Ptolemaic response to the introduction of Babylonian horoscopic astrology and to the fuller understanding of the phenomena of planetary motion that came with it, exacts a high price. Gone is the

81. In his *De iud. fac.,* Ptolemy lays out his view of the contributions and sense and intellect to knowledge. The key idea for understanding the nature of scientific philosophy is that, though intellect depends on the senses for its primary input, both must work together if there is to be knowledge (see Long 1989, 151–154). Cf. Long 1989, 172n1 on the authenticity of this treatise.

82. It is important to keep in mind Geoffrey Lloyd's point (1991, 269–270) that Ptolemy does not accept hypotheses solely on the ground that they save the phenomena: cf. Wolff 1988, 499n31.

83. A similar epistemological strategy underlies Ptolemy's *Harmonica:* see Bowen 1999, 304–311 on *Harm.* 1.1–2.

idea that such causal knowledge (if any) that we may have of why the celestial bodies move as they do is superior to, prior to, or even relevant to what is known in astronomy. All one can know, according to Ptolemy (*Tetr.* 1.1–2), are the positions of the celestial bodies at any time for any observer, and this knowledge is attained through observation and mathematical demonstration (cf. Heiberg 1898–1907, 1.1.6.17–21). The generalizations governing the significance of these configurations for creatures on Earth and the related predictions, though dependent on this knowledge and still part of astronomy (ἀστρονομία), are less certain because they involve material qualities.[84]

Thus, when confronted with the Babylonian celestial science and the efforts of his predecessors to deny or assimilate it, Ptolemy focuses on the question of what can be known of the heavens and how. In so doing, he completely changed the intellectual landscape. How extensive this change was may be glimpsed in the opening lines of the *Hypotheses planetarum,* Ptolemy's cosmological treatise:[85]

> Syrus, we have treated the hypotheses (ὑποθέσεις) of the celestial motions in the books of our *Mathematical Syntaxis*[86] by demonstrating through arguments for each [hypothesis] what is reasonable and wholly consistent with the phenomena in order to indicate (πρὸς ἔνδειξιν) the smooth, circular motion that must belong to [bodies] which share eternal, orderly motion and which can in no way admit the more and the less. (Heiberg 1898–1907, 2.70.1–11)

For, what he here calls a hypothesis is not a proposition but a quantified geometrical model which is used mathematically to yield results that are consistent with observations. Moreover, such use of this model has the purpose of indicating the truth of what was earlier called a hypothesis, namely, that celestial bodies, which are of necessity eternal and orderly, move smoothly in circles. And so the question that emerges is, How are

84. Note that Ptolemy does not tend to present these configurations as visible signs by which the gods communicate with men, but rather as significant geometrical arrangements of the ethereal celestial bodies that determine the quality of the power or δύναμις emanating from them: but see Hübner 1998, 1.208–216, 1.233–240, 1.259–266.

Geminus does not isolate horoscopic astrology as a subdivision of astronomy. He does, however, propose that a *parapegma* in which the significations (correlations between sign and signified) were based on processes of natural causation would be superior to the current *parapegmata* which rely on empirical generalizations to correlate the risings and setting of stars and constellations with changes in the weather (*Intro. ast.* c17: cf. Bowen 2008a).

85. The cosmology that Ptolemy develops in this treatise belongs to the scientific division of theoretical philosophy: cf. Heiberg 1898–1907.1.7.5–10; Kidd 1988–1999, F18.8–14.

86. *scil. Almagest.*

these new hypotheses known to be true or the case, given that they are to be derived somehow from the phenomena (which they save) and not from reflection on the nature of things? At issue is a very new conception of science itself.

Conclusion

There are two contrasting ways of demarcating physical theory and astronomy in the Hellenistic texts we have studied. For Geminus and for the author reported by Simplicius, astronomy is a dependent science that must rely on physical theory for its success and epistemic authority. For Ptolemy, astronomy is a self-sufficient science of much greater authority than physical theory. This contrast belies profound differences in the very idea of what astronomy is about, that is, in the idea of its phenomena, of how to access these phenomena, and of the goals in analyzing them. To understand these differences and their genesis, and thereby to gain real insight into the Hellenistic reception of Babylonian astrology and into Ptolemy's intellectual context, one must bring to light all the ways indicated in the documents surviving from *ca* 100 BC to *ca* AD 200 in which physical theory and astronomy are marked off as well as the numerous ways in which astronomy was at the same time articulated into subfields.

References

Aujac, G. 1975. *Géminos: Introduction aux phénomènes.* Paris.

——— 1993. *Claude Ptolémée astronome, astrologue, géographe: Connaissance et réprésentation du monde habité.* Paris.

——— 1979. edd. *Autolycos de Pitane: La sphère en mouvement, Levers et couchers héliaques, Testimonia.* Paris.

Bolton, R. 2008. "Two Standards for Inquiry in Aristotle's *De caelo.*" In C. Wildberg and A. C. Bowen edd. *New Essays on Aristotle's* De caelo. Leiden (in press).

Bowen, A. C. 1999. "The Exact Sciences in Hellenistic Times: Texts and Issues." Pp. 287–319 in D. J. Furley ed. *Routledge History of Philosophy: II. From Aristotle to Augustine.* London/New York.

——— 2001. *"La scienza del cielo nel periodo pretolemaico."* Pp. 806–839 in S. Petruccioli ed. *Storia della scienza: I. La scienza greco-romana.* Rome.

——— 2002a. "Eudemus' History of Early Greek Astronomy: Two Hypotheses." Pp. 307–322 in I. Bodnár and W. W. Fortenbaugh edd. *Eudemus of Rhodes.* New Brunswick/London.

——— 2002b. "Simplicius and the Early History of Greek Planetary Theory." *Perspectives on Science* 10:155–167.

——— 2003a. "Simplicius' Commentary on Aristotle, *De caelo* 2.10–12: An Annotated Translation (Part 1)." *SCIAMVS* 4:23–58.

——— 2003b. "Cleomedes and the Measurement of the Earth: A Question of Procedures." *Centaurus* 45:59–68.

——— 2006. "Geminus and the Length of the Month: The Authenticity of *Intro. ast.* 8.43–45." *Journal for the History of Astronomy* 37:193–202.

——— 2008a. "The Definition of Astronomy: Geminus on Signs and Signification." (forthcoming).

——— 2008b. "Sosigenes 2." In P. T. Keyser and G. L. Irby-Massie edd. *Encyclopedia of Ancient Natural Scientists.* London (in press).

——— 2008c."Seneca's Demarcation of the Study of Music and Philosophy." In D. Restani ed. *Il sapere musicale come cultura: da Teofrasto a Plutarco.* Ravenna (in press).

Bowen, A. C. and B. R. Goldstein. 1996. "Geminus and the Concept of Mean Motion in Greco-Latin Astronomy." *Archive for History of Exact Sciences* 50:157–185.

Bowen, A. C. and R. B. Todd. 2004. *Cleomedes' Lectures on Astronomy: A Translation of* The Heavens. Berkeley/Los Angeles/London.

Bruns, I. 1887. *Alexandri Aphrodisiensis praeter commentaria scripta minora.* Berlin.

Diels, H. 1882. ed. *Simplicii in physicorum libros quattuor priores commentaria.* Berlin.

Eastwood, B. S. 1992. "Heraclides and Heliocentrism: Texts, Diagrams, and Interpretations." *Journal for the History of Astronomy* 23:233–260.

Evans, J. and J. L. Berggren. 2006. *Geminos's "Introduction to the Phaenomena": A Translation and Study of a Hellenistic Survey of Astronomy.* Princeton/Oxford.

Friedlein, G. 1873. ed. *Procli Diadochi in primum Euclidis elementorum librum commentarii.* Leipzig.

Getty, R. J. 1941. "The Astrology of P. Nigidius Figulus (Lucan I, 649–65)." *Classical Quarterly* 35:17–22.

Goldstein, B. R. and A. C. Bowen. 1999. "The Role of Observation in Ptolemy's Lunar Theories." Pp. 341–356 in N. M. Swerdlow ed. *Ancient Astronomy and Celestial Divination.* Cambridge, MA/London.

Gottschalk, H. 1980. *Heraclides of Pontus.* Oxford.

Hayduck, M. 1899. ed. *Alexandri Aphrodisiensis in Aristotelis meteorologicorum libros commentaria.* Berlin.

Heath, T. L. 1913. *Aristarchus of Samos: The Ancient Copernicus.* Oxford.

Heiberg, J. L. 1894. ed. *Simplicii in Aristotelis de caelo commentaria.* Berlin.

——— 1898–1907. ed. *Claudii Ptolemaei opera quae exstant omnia.* vols. 1–2. Leipzig.

Heiberg, J. L. and H. G. Zeuthen. 1929. *Paul Tannery: Mémoires scientifiques.* vol. 9. Paris.

Hiller, E. 1878. ed. *Theonis Smyrnaei philosophi platonici expositio rerum mathematicarum ad legendum Platonem utilium.* Leipzig.

Hornblower, S. and A. Spawforth. 1996. edd. *The Oxford Classical Dictionary.* Oxford/New York.

Hübner, W. 1998. ed. *Claudii Ptolemaei opera quae exstant omnia.* vol. 3. Stuttgart/Leipzig.

Jones, A. 1996. "On Babylonian Astronomy and Its Greek Metamorphoses." Pp. 139–155 in F. J. Ragep, S. P. Ragep, and S. Livesay edd. *Tradition, Transmission, Transformation: Proceedings of Two Conferences on Pre-Modern Science Held at the University of Oklahoma.* Leiden/NewYork/Köln.

——— 1999. "Geminus and the Isia." *Harvard Studies in Classical Philology* 99:255–267.

——— 2000. "Studies in the Astronomy of the Roman Period: 4. Solar Tables Based on a Non-Hipparchian Model." *Centaurus* 42:77–88.

——— 2004. "An *Almagest* before Ptolemy's?" Pp. 129–136 in C. Burnett, J. P. Hogendijk, K. Plofker, and M. Yano edd. *Studies in the History of the Exact Sciences in Honour of David Pingree.* Leiden/NewYork/Köln.

Kahn, C. H. 2001. *Pythagoras and the Pythagoreans: A Brief History.* Indianapolis/Cambridge, MA.

Kidd, I. G. 1988–1999. ed. and trans. *Posidonius.* 3 vols/4 tomes. Cambridge. Volume 1 was edited with L. Edelstein.

Liddell, H. G.; R. Scott; and H. S. Jones. 1968. edd. *A Greek-English Lexicon with Supplement.* Oxford.

Lloyd, G. E. R. 1991. *Methods and Problems in Ancient Science.* Cambridge.

Long, A. A. 1989. "Ptolemy on the Criterion: An Epistemology for a Practising Scientist." Pp. 151–178 in P. Huby and G. Neal edd. *The Criterion of Truth: Essays Written in Honour of George Kerferd Together with a Text and Translation (with Annotations) of Ptolemy's* On the Kriterion and Hegemonikon. Liverpool.

Manitius, C. 1898. ed. *Gemini elementa astronomiae.* Stuttgart.

Martin, T. H. 1849. *Theonis Smyrnaei platonici liber de astronomia.* Paris.

Mueller, I. 2004. "Remarks on Physics and Mathematical Astronomy and Optics in Epicurus, Sextus Empiricus, and Some Stoics." Pp. 57–87 in P. Lang ed. *Re-Inventions: Essays on Hellenistic and Early Roman Science. Apeiron* 37.4. Kelowna, BC.

Neugebauer, O. 1955. "Apollonius' Planetary Theory." *Communications on Pure and Applied Mathematics* 8:641–648.

——— 1959. "The Equivalence of Eccentric and Epicyclic Motion according to Apollonius." *Scripta Mathematica* 24:5–21.

——— 1975. *A History of Ancient Mathematical Astronomy.* Berlin/Heidelberg/ New York.

Rochberg, F. 1998. *Babylonian Horoscopes.* Transactions of the American Philosophical Society 88.1. Philadelphia.

Schöne, R. 1897. ed. *Damianos Schrift über Optik.* Berlin.

Tannery, P. 1887. *La géométrie grecque: Comment son histoire nous est parvenue et ce que nous en savons.* Paris.

Todd, R. B. 1990. ed. *Cleomedis caelestia.* Leipzig.

Todd, R. B. and A. C. Bowen. 2007. "The Reception of Heraclides' Theory of the Rotation of the Earth from Posidonius to Simplicius: Texts, Contexts, and Continuities." In E. Schutrümpf, W. W. Fortenbaugh edd. *Heraclides of Pontus.* New Brunswick/London (in press).

Toomer, G. J. 1984. *Ptolemy's Almagest.* New York/Berlin/Heidelberg.

Toulouse, S. 2005. *"Les sciences et l'âme chez Posidonius: Remarques sur une définition de l'âme conservée dans Plutarque et sur le statut de l'astronomie et des mathématiques dans la philosophie."* Pp. 153–172 in G. Romeyer-Dherbey and J. B. Gourinat edd. *Les Stoïciens.* Paris.

van der Waerden, B. L. 1988. "The Motion of Venus, Mercury and the Sun in Early Greek Astronomy." *Archive for History of Exact Sciences* 26:99–113.

Vitrac, B. 2005. *"Les classifications des sciences mathématiques en Grèce ancienne." Archives de philosophie* 68:269–301.

von der Muehll, P. 1996. ed. *Epicurus: Epistulae tres et ratae sententiae.* Stutgardt/Leipzig.

Wolff, M. 1988. "Hipparchus and the Stoic Theory of Motion." Pp. 471–545 in J. Barnes *et alii* edd. *Matter and Metaphysics.* Naples.