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INTRODUCTION

Geminos, a Greek scientific writer of wide-ranging interests, has been assigned dates ranging from the first century B.C. to the first century A.D., with, we believe, the first century B.C. the more likely. We know nothing of the circumstances of his life. Of three works he is believed to have written, only one, the *Introduction to the Phenomena*, has come down to us. (This work is also frequently referred to as the *Isagoge*, from the first word of its Greek title, *Eisagōgē eis ta phainomena*.) The translation of his *Introduction to the Phenomena* here presented is the first complete English version ever published.

For the modern reader, Geminos provides a vivid impression of an educated Greek's view of the cosmos and of astronomy around the beginning of our era. Moreover, he is frequently a graceful and charming writer, constantly aware of his audience, and his book remains quite readable today. Indeed, it is one of a very small number of works of ancient astronomy that can be read right through with appreciation and understanding by a nonspecialist. Because Geminos covers most of the central topics of ancient Greek astronomy, his text provides an excellent general survey of those parts of that astronomy not dependent on sophisticated mathematical models. An English translation of the *Introduction to the Phenomena* should thus be useful not only to historians of astronomy but also to historians of science more generally, to those interested in classical civilization, and to astronomers who would like to know more about the history of their discipline.

We have furnished our translation with a commentary, printed at the foot of the page and signaled in the text by superscript numerals. The purpose of the commentary is not to summarize all that is known on the topics at hand, but to open up Geminos's text, to make it more comprehensible, and to reveal its connections with other ancient sources—philosophical and literary, as well as scientific. It should serve, as well, to direct readers to the specialized scholarly literature. Textual notes, signaled in Geminos's text by superscript roman letters, are grouped together in appendix 1.

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1. Significance of Geminos's *Introduction to the Phenomena*

Geminos's *Introduction to the Phenomena*, a competent and engaging introduction to astronomy, was probably written in conjunction with teaching. Geminos discusses all of the important branches of Greek astronomy, except planetary theory. This he promises to take up "elsewhere." Perhaps he did discuss planetary theory in another work, but if so, it has not survived. Topics covered in Geminos's *Introduction* include the zodiac, solar theory, the constellations, the theory of the celestial sphere, the variation in the length of the day, lunisolar cycles, phases of the Moon, eclipses, heliacal risings and settings of the fixed stars, terrestrial zones, and an introduction to Babylonian lunar theory. Because the work was written for beginners, it does not often get into technical detail—except in the discussion of lunisolar cycles, where Geminos does indulge in a bit of arithmetic.

Geminos's book is important to the task of filling gaps in the history of Greek astronomy in several ways. In general terms, Geminos provides an overview of most of astronomy in the period between Hipparchos (second century B.C.) and Ptolemy (second century A.D.), and thereby provides a good deal of insight into what was current and common knowledge in Geminos's own day. One of the more charming aspects of his work, frequently in evidence, is his desire to set straight common misconceptions about astronomical matters. In this way, he offers us valuable information about the beliefs of his own audience.

More specifically, Geminos provides detailed discussions of several topics not very well treated by other ancient sources. (1) His discussion of Babylonian lunar theory is an important piece of the story of the adaptation of Babylonian methods by Greek astronomers. (2) His discussion of the 8- and 19-year lunisolar cycles is the most detailed by any extant Greek source. (3) His discussion of Hipparchos's rendering of the constellations provides information not found in other sources. (4) His refutation of the then-common view that changes in the weather are caused by the heliacal risings and settings of the stars is the most patient and detailed such argument that has come down to us.

In the extant manuscripts, Geminos's book concludes with a *parapēgma* (star calendar) that permits one to know the time of year by observation of the stars. Many scholars believe that this compilation is older than Geminos by a century or more. Whether by Geminos or not, this *parapēgma* is one of our most important sources for the early history of the genre. The Geminos *parapēgma* was based substantially upon three earlier *parapēgmata*—those by Euktēmōn (fifth century B.C.), Eudoxos (early fourth century B.C.), and Kallippos (late fourth century B.C.). Because the Geminos *parapēgma* scrupulously cites its sources, it

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permits us to trace the stages in the evolution of the *parapēgma* between the time of Euktēmōn and the time of Kallippos. Our book includes a translation of the Geminos *parapēgma*, as well as a synoptic table of its contents (appendix 2), which should be useful in the study of this important historical document.

Although ancient and medieval Greek readers would have recognized Geminos's book as belonging to a class of "phenomena" literature (see sections 3 and 4 below), we cannot be sure that *Introduction to the Phenomena* is the title that Geminos himself gave it. This is a common difficulty with ancient scientific texts, the conventional titles of which are not always authorial. The Greek manuscripts of Geminos's text do provide good evidence for the commonly accepted title, although there are several variants. Indeed, the three best and oldest Greek manuscripts present a bit of a puzzle: one gives as its title *Geminos's Introduction to the Phenomena*; another gives *Geminos's Introduction to the Things on High* (*meteōra*); and still another gives neither title nor author's name, since the copyist never filled in this information. Some later Greek manuscripts simply have *"The Phenomena" of Geminos*.[1] As we shall see below (sec. 14), the Latin and Hebrew translations made in the twelfth and thirteenth centuries (from an Arabic intermediary) also show that there was considerable confusion about the title and author of the text. For the sake of simplicity, we shall always refer to Geminos's book by the title commonly used today, and best supported by the Greek manuscripts, *Introduction to the Phenomena*.

2. Geminos's Other Works

Geminos was the author of two other works that have not come down to us. One was a mathematical work of considerable length that discussed, among other things, the philosophical foundations of geometry. Fortunately, a large number of passages from this work (whether in quotation or in paraphrase) are preserved by Proklos[2] in his *Commentary on the First Book of Euclid's Elements*. The exact title of Geminos's book is uncertain, but in one passage Proklos remarks, "so much have I selected from the *Philokalia* of Geminos."[3] (*Philokalia* means "Love of the Beautiful.") In one passage of considerable interest, Geminos discussed the

[1] For the Greek titles, see the first textual note (appendix 1).

[2] Proklos (c. A.D. 410–485) was a prolific Neoplatonist philosopher, best known for his *Platonic Theology* and his commentaries on Plato. His extant scientific works include a *Commentary on the First Book of Euclid's Elements* and a *Sketch of Astronomical Hypotheses*.

[3] Friedlein 1873, 177; Morrow 1970, 139. The title of Geminos's mathematical work has been disputed. See the introduction to fragment 1 for a discussion of this issue.

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branches of mathematical science and their relationships to one another. This is the most detailed such discussion that has come down to us from the Greeks. Moreover, it is clear that Geminos was discussing, not merely abstract divisions of mathematics, but actual genres of mathematical writing. Because several of Geminos's branches of mathematics pertain to astronomy (e.g., *sphairopoiïa*, dioptrics, and gnomonics), his discussion sheds light on the relationship of astronomy to other mathematical endeavors. Because of its interest for the history of astronomy, we have included a translation of this passage from Geminos's *Philokalia* as fragment 1.

Geminos was also the author of a meteorological work, which was perhaps a commentary on, or an abridgement of, a now lost *Meteorology* of Poseidōnios.[4] A fragment of some length is preserved by Simplikios[5] in his *Commentary on Aristotle's Physics*. Apparently, by Simplikios's time, Geminos's meteorological book had been lost, for Simplikios makes it clear that he is quoting Geminos, not from Geminos's own work, but from some work by Alexander of Aphrodisias.[6] In the course of his citation, Simplikios says that Alexander drew these remarks from Geminos's "*Concise Exposition of the Meteorology of Poseidōnios*."[7] The fragment from Geminos preserved by Simplikios is of considerable interest, for it is devoted to the limits of astronomical knowledge. In this passage, Geminos discusses the relationship of astronomy to physics (or natural philosophy), arguing that astronomy is, of itself, unable to decide between competing hypotheses and must rely on physics for guidance about first principles. We include a translation of this passage from Geminos's lost meteorological work as fragment 2.

3. On "The Phenomena" in Greek Astronomy

Geminos's *Introduction to the Phenomena* had its roots in a well-established genre. In order to explain what the writers and readers of this genre considered to be relevant, we must say a little about what Greek

[4] Poseidōnios (c. 135 to c. 51 B.C.) was a Stoic philosopher who wrote also on history, geography, and astronomy. No complete works survive, but a large number of fragments have been collected. See Edelstein and Kidd 1989; Kidd 1999. Geminos's possible debt to Poseidōnios will be discussed below.

[5] Simplikios, a Neoplatonist of the sixth century A.D., was the author of commentaries on Aristotle's *Physics* and *On the Heavens* and was one of the philosophers who left Athens after the emperor Justinian closed the pagan schools of philosophy in 529.

[6] Alexander of Aphrodisias, who flourished around A.D. 200, was the author of commentaries on Aristotle, many of which survive.

[7] Diels 1882, 291. See fragment 2, below, for the complete passage.

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astronomical writers mean by the *phenomena*. The word "phenomena" is a participle of the passive verb *phainomai*, which carries the meanings of "to come to light, come to sight, be seen, appear." The last two are definitive for the astronomical sense of the word, which is "things that are seen/appear in the heavens."

A late source, Simplikios, quotes Sosigenēs as having attributed to Plato the statement that the task of astronomy was to show how, by a combination of uniform circular motions, one could "save (i.e., account for) the phenomena." The ascription to Plato is controversial (see sec. 10 below), but in any case the word *Phenomena* appears as the title of a work by an associate of Plato, Eudoxos of Knidos (early fourth century B.C.). Eudoxos's work has not survived, but its essence is preserved in a poem of the same name by Aratos (early third century B.C.). The poetic *Phenomena* of Aratos was the subject of a commentary by the great astronomer Hipparchos of Rhodes (second century B.C.), who was able to compare it with the text of Eudoxos and demonstrate that Aratos had indeed relied upon Eudoxos. It appears from these sources that Eudoxos's work was devoted to a detailed description of the placement of the fixed stars and the constellations, relative to some standard reference circles on the celestial sphere. The following passages give a sense of the character of Eudoxos's book, and also an idea of what sort of "phenomena" it was occupied with. We quote directly from Hipparchos's *Commentary*, and in each case Hipparchos has made it clear that he is himself directly reporting on Eudoxos's text:

> There is a certain star that remains always in the same spot; this star is the pole of the universe.[8]

> Between the Bears is the tail of the Dragon, the end-star of which is above the head of the Great Bear.[9]

> Aratos, following Eudoxos, says that it [the Dragon's head] moves on the always-visible circle, using these words: "Its head moves where the limits of rising and setting are confounded."[10]

Because Aratos includes in his poem a discussion of the principal circles of the celestial sphere (ecliptic, equator, tropics, arctic circle, as well as the Milky Way), we may surmise that the same material was treated, in more detail, by Eudoxos. So, by the early fourth century, the basic theory of the celestial sphere had been established, and a detailed descrip-

[8] Hipparchos, *Commentary on the Phenomena of Eudoxos and Aratos* i 4.1. Hipparchos denounces this as erroneous, pointing out that the place of the celestial north pole was at that time not occupied by a star.

[9] Hipparchos, *Commentary* i 2.3.

[10] Hipparchos, *Commentary*, i 4.7. Quotation from Aratos: *Phenomena* 61–62.

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tion of the constellations given. Such were the phenomena of Eudoxos.[11]

The oldest extant work named *The Phenomena* is that of Euclid (c. 300 B.C.).[12] Unlike the work of Eudoxos, Euclid's book has no place for uranography. Rather, a short (and possibly spurious) preface introduces the north celestial pole[13] and the principal circles on the celestial sphere (including the parallel circles, the ecliptic, the horizon, and the Milky Way). The author also introduces the arctic and antarctic circles relative to a given locality and the consequent division of stars into those that never rise, those that rise and set, and those that never set. Thus Eudoxos's descriptions of the constellations have been eliminated in favor of a geometrical exploration of the sphere.

After this beginning, Euclid's treatise proceeds by a series of propositions with proofs and accompanying diagrams, in the style of his more famous *Elements*. These begin with proposition 1 on the central position of the Earth in the cosmos, and then progress through three propositions on the risings and settings of stars. Propositions 8–13 deal with the risings and settings of arcs of the ecliptic, particularly the zodiacal signs, and the work concludes with five propositions on how long it takes equal arcs of the ecliptic to cross the visible and invisible hemispheres. The very format of the work illustrates what had become a commonplace among Greek thinkers, namely that celestial phenomena can be explained rationally.

Other extant early Greek texts for which the celestial phenomena form the subject matter include two works of Euclid's contemporary, Autolykos of Pitanē, both of them written in the theorem-proof style one finds in Euclid's book. In *On the Moving Sphere*, Autolykos treats some of the phenomena arising from the uniform rotation of a sphere around its axis relative to a horizon that separates the visible from the invisible portions of the sphere. It is striking that in *On the Moving Sphere*, the descriptions of all circles other than the horizon are as abstract and geometrical as possible, and there is no explicit mention of the astronomical applications of the theorems. As an example we quote proposition 8: Great circles tangent to the same [parallel circles] to which the horizon is tangent will, as the sphere rotates, fit exactly onto the horizon. The abstract character of many of these propositions illustrates how far the Greek geometrization of astronomy had been carried by the time of Euclid and Autolykos. Many of the propositions are hard to prove, but are easy to illustrate on a celestial globe.

[11] Aristotle (*On the Heavens* ii 13), who was Eudoxos's younger contemporary, also uses the word "phenomena" in its astronomical sense.

[12] For an English translation and commentary, see Berggren and Thomas, 1996.

[13] Here, as in Eudoxos's *Phenomena*, also claimed to be occupied by a star.

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Autolykos's other book, *On Risings and Settings*, is devoted to heliacal risings and settings—the annual cycle of appearances and disappearances of the fixed stars. This had been a part of Greek popular astronomy from the earliest days, as illustrated by Hesiod's use of the heliacal risings and settings of the Pleiades, Arcturus, and Sirius to tell the time of year in his poem, *Works and Days* (c. 650 B.C.). Clearly, the sidereal events in the annual cycle were a part of what the Greeks considered "phenomena." Autolykos's goal in *On Risings and Settings* is to provide a mathematical foundation, in the form of theorems, for a field that had previously been in the domain of popular lore. Geminos devotes chapter xiii of his *Introduction to the Phenomena* to the same subject. Indeed, Geminos's heading for chapter xviii is the same as the title of Autolykos's book. As we point out in our commentary on that chapter, Geminos follows Autolykos in all significant details, but eliminates the proofs.

The other major writer on the phenomena was Theodosios of Bithynia (c. 100 B.C.), whose *On Habitations* and *On Days and Nights* are the earliest extant works devoted to a discussion of how the phenomena change from one locality to another: as an observer moves north or south, the stars that are visible will become different and the lengths of the day and night may change. An example of a proposition from the first of these is:

> For those living under the north pole[14] the same hemisphere of the cosmos is always visible and the same hemisphere of the cosmos is always invisible, and none of the stars either sets or rises for them, but those in the visible hemisphere are always visible and those in the invisible [hemisphere] are always invisible.[15]

Geminos's use of Theodosios is quite clear, for the Greek heading of Geminos's chapter xvi is the same as that of Theodosios's *On Habitations*,[16] and the heading of chapter vi is only trivially different (singular nouns instead of plurals) from that of Theodosios's *On Days and Nights*.

Many of the founding works on the phenomena, such as those by Euclid, Autolykos, and Theodosios, survived because they were short enough and elementary enough for use in teaching. They became staples of the curriculum for mathematics and astronomy, and so survived through late Antiquity and into the Middle Ages, in both the Arabic and Latin worlds.

The motions of the Sun, Moon, and planets around the zodiac are also part of what the Greeks considered "phenomena." Several features of

[14] Recall that for the Greeks the north pole was a point on the celestial sphere.

[15] Berggren and Eggert-Strand, forthcoming.

[16] But in our translation we have chosen the more descriptive rendering, "On Geographical Regions," for the chapter title.

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planetary motion posed challenges for explanation: the Sun appears to move more slowly at some times of year, and more rapidly at others. The planets are even more puzzling, since they occasionally stop and reverse direction in what is known as retrograde motion. Most scholars believe that the earliest Greek effort to explain the complex motions of the planets was the book *On Speeds* by Eudoxos. It is lost, but we have two rather lengthy discussions of it, one by Aristotle, who was a contemporary of Eudoxos, and one by Simplikios, who lived 900 years later, and whose account must therefore be used with caution. Probably by the time of Apollōnios of Pergē (late third century B.C.) and certainly by the time of Hipparchos, Eudoxos's approach of modeling the planetary phenomena by the gyrations of nested, homocentric spheres had given way to eccentric circles and epicycles lying in a plane. But this was daunting material to address in an elementary work.[17]

4. The Greek Genre of Astronomical Surveys

In the Hellenistic period, there emerged a demand for popular surveys—works that would take students through the celestial phenomena without forcing them through theorems and proofs. The poetic *Phenomena* of Aratos can be considered one of the first such popularizations. The new popular surveys eschewed the austere geometrical demonstrations of Euclid, Autolykos, and Theodosios tended simply to summarize mathematical results in plain language. They also tended to include a greater variety of subjects of interest to the broad public—phases of the Moon, eclipses, and elements of astronomical geography, such as the theory of terrestrial zones. Of course, all of these topics had deep roots in the history of Greek science. What was new was the attempt to produce comprehensive astronomy textbooks written at an elementary level.

The popular surveys of astronomy could be read for their own sake, but some were clearly intended to form part of the curriculum of studies expected of a well-born student. The geographical writer Strabo (c. 64 B.C. to c. A.D. 25) mentions that students can learn in the elementary mathematics courses all the astronomy they will need for the study of geography. He mentions as an example of the standard astronomical curriculum the theory of the celestial sphere—tropics, equator, zodiac, arctic circle, and horizon.[18] The sort of elementary astronomy course that

[17] Of all the elementary writers on astronomy, only Theōn of Smyrna does a good job with planetary phenomena. Geminos (chapter i) gives only an explanation of the eccentric-circle theory of the Sun's motion, a vague reference to the *sphairopoiïa* for each planet, and a brief mention of the basic planetary phenomena.

[18] Strabo, *Geography* i 1.21.

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Strabo had in mind is well represented by Geminos's *Introduction to the Phenomena*. Diogenēs Laertios tells us that instruction in basic astronomy was part of the curriculum of Stoic teachers.[19] And, of course, astronomy had long been part of the quadrivium of mathematical studies in the Platonist school.[20] Whether for the sake of popular reading, or for liberal education, or as part of the preparation for more advanced studies, introductions to the astronomical phenomena permeated Greek culture from about 200 B.C. to the end of Antiquity.

It is quite appropriate, then, that Geminos's work is named *Introduction to the Phenomena*, for *eisagōgē* ("introduction") carries two meanings. On one hand, this is a regular word for an elementary treatise on a subject; on the other, it can denote a conduit, or channel, into a harbor. Thus an *eisagōgē* could serve either as a liberal arts survey of astronomy, complete in itself, or as the preparatory course for higher studies in the subject.

Geminos occasionally employs demonstrative mathematical arguments (e.g., in his treatment of lunisolar cycles in chapter viii), and he did not write his book for those who were afraid of numbers or geometry. However, his motto seems to have been "mathematics if necessary, but not necessarily mathematics"—and in any case he makes no use of formal mathematical proofs. Nor does Geminos's work smell of the mathematics classroom. There is none of the graded progression from the easy to the complicated that one finds in, for example, Euclid's *Phenomena*. Had Geminos intended to write a textbook of mathematics he would surely have put chapters iv (the axis and the poles) and v (circles on the sphere) at the beginning, and in any case before chapter i (on the zodiac). A third feature of his work is its blending of the topics of the two earlier genres of phenomena literature (the descriptive uranography of Eudoxos and the mathematical topics of Euclid and his successors) with topics outside of these traditions, namely those he treats in chapters viii–xii, xvii, and xviii. Geminos even stretches the definition of the phenomena to include the astrological aspects of the zodiac signs, in chapter i. In summary, Geminos, in his account of the celestial phenomena, extended the tradition of topics treated to include virtually anything having to do with the fixed stars, the Sun, and the Moon. And he did so in a way that was not simply systematic or mathematical, but discursive and, in a broad sense of the word, scientific.

Geminos's *Introduction to the Phenomena* is but one of several Greek elementary textbooks of astronomy that survive from Antiquity. The two most nearly comparable examples are Theōn of Smyrna's *Mathematical*

[19] Diogenēs Laertios, *Lives and Opinions* vii 132.
[20] Plato, *Republic* vii 527d.

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Knowledge Useful for Reading Plato[21] (second century A.D.) and Kleomēdēs' *Meteōra*[22] (probably early third to mid-fourth century A.D.). These three surveys have a fair amount of overlap—for example, they all discuss the eccentric-circle theory of the motion of the Sun. But each of the three also treats subjects not covered by the other two. For example, Theōn of Smyrna gives an introduction to the deferent-and-epicycle theory of planetary motion, a subject avoided by Kleomēdēs and Geminos. Kleomēdēs, for his part, is our most detailed source for the famous measurement of the Earth by Eratosthenēs. And Geminos gives a detailed discussion of lunisolar cycles, a subject avoided by Theōn and Kleomēdēs.

These three textbooks of astronomy also differ markedly in tone. While Theōn's book is pervaded by Platonism, Kleomēdēs' book is steeped in Stoic physics and concludes with a savage attack on the Epicureans. Theōn and Kleomēdēs, then, give us nice examples of how an introduction to astronomy could be incorporated into a general course in philosophy—and we have examples in two flavors, Platonist and Stoic. By contrast, Geminos's *Introduction to the Phenomena* is remarkable for its comparative freedom from philosophy, for he is very much a straightforward astronomer. Geminos does, however, display a certain literary bent, and is fond of quoting poets, such as Aratos or Homer, in illustration of astronomical points. His *Introduction to the Phenomena* is also considerably earlier than the textbooks of Theōn and Kleomēdēs, and sheds light on the Greeks' reactions to Babylonian astronomy and astrology, which, in Geminos's day, were in the process of being absorbed and adapted.

An earlier, though shorter and much less polished, survey of astronomy is the *Celestial Teaching* (*Ouranios Didascalea*) of Leptinēs.[23] See fig. I.1. This famous papyrus, conserved in the Louvre, is the oldest existing Greek astronomical document with illustrations. It was composed in the decades before 165 B.C. by a certain Leptinēs as an introduction to astronomy for members of the Ptolemaic court. (So it seems that, despite

[21] For a French translation of Theōn of Smyrna, see Dupuis 1892.

[22] For Kleomēdēs, see Todd 1990 (text) and Bowen and Todd 2004 (translation). The original title of Kleomēdēs' work is uncertain, and a number of different titles have been used by editors and translators. On the title issue, see Goulet 1980, 35; Todd 1985; and Bowen and Todd 2002, 1n1. The dating of Kleomēdēs is also difficult. Kleomēdēs says that Antares and Aldebaran are diametrically opposite in the zodiac, the first at Scorpio 15° and the second at Taurus 15°. Using this datum, Neugebauer (1975, 960) arrived at a date for Kleomēdēs around A.D. 370. Bowen and Todd situate Kleomēdēs around A.D. 200, because his work reflects the Stoic polemics against the Peripatetics that began to fade after that period, and because works of Stoic pedagogy become rare after the second century.

[23] Earlier writers call this P. Parisinus 1, but it is now known in the Department of Egyptian Antiquities at the Louvre as N 2325. For the text, see Blass 1887. There is a French translation in Tannery 1893, 283–94. On the history of this papyrus see Thompson 1988, 252–65.

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Fig. I.1. A portion of the *Celestial Teaching* of Leptinēs on a papyrus, written shortly before 165 B.C. The left column treats the circles of the celestial sphere and the celestial poles. The right column explains that the stars are called fixed because the constellations always retain their forms and their relationships to one another. Département des Antiquités Egyptiennes, Inv. N. 2325, Musée du Louvre. Photo: Maurice and Pierre Chuzeville.

what Euclid is supposed to have said about geometry, there *was* a royal road to astronomy.) Modern writers sometimes refer to this tract as the "Art of Eudoxos," a name that comes from an acrostic poem on the verso of the papyrus, in which the initial letters of the twelve lines of

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verse spell out *Eudoxou Techne*. But the colophon on the recto clearly gives the title as the *Ouranios Didascalea of Leptinēs*. In any case, the contents of the treatise are certainly not by Eudoxos. Rather, the tract is a brief and rather choppy account of standard astronomical matters. The text includes a short *parapēgma*, an account of the progress of the Sun and Moon around the zodiac, descriptions of the circles on the celestial sphere, a discussion of eclipses, and values for the lengths of the four seasons according to various authorities. This fare overlaps considerably with the material treated more gracefully by Geminos in the next century.

Finally, numerous commentaries on Aratos's poem *Phenomena* often served as introductions to astronomy. One of the most complete is that of Achilleus (often called Achilles Tatius, probably third century A.D.), whose *Introduction to the "Phenomena" of Aratos* formed a part of his On the All (*Peri tou Pantos*).[24] In our commentary on Geminos, we shall occasionally make comparisons to these other works, which can be thought of as constituting a genre of elementary astronomy textbooks.

5. Geminos's Sources for His *Introduction*

Appendix 4 lists the writers that Geminos cites in his *Introduction to the Phenomena*. He enjoys quoting the poets Homer, Hesiod, and Aratos in illustration of scientific points. This reflects not only his own tastes but also his concession to the literary training of his students and readers. He is not, however, one to ascribe too much scientific knowledge to Homer, and feels that critics such as Kratēs have sometimes gone overboard in this regard. (The occasional use of poetry occurs in other elementary surveys as well, e.g., those of Kleomēdēs, Theōn of Smyrna, and Leptinēs.)

Of the astronomical writers, Geminos names Euktēmōn, Kallippos, Philippos, Eratosthenēs, and Hipparchos, though he may not have known the works of all these people firsthand. Geminos was quite well-informed about lunisolar cycles, but we cannot tell from his remarks on those matters whose works he really had access to. He seems to have used some work of Hipparchos on the constellations that was different from Hipparchos's *Commentary on The Phenomena of Eudoxos and Aratos*. For, in chapter iii, he mentions three decisions of Hipparchos regarding the constellations that have no counterpart in the *Commentary*.

[24] See Maass 1898, 25–85 for what remains of Achilleus's *Commentary* on Aratos. On Achilleus, see Mansfield and Runia 1997, 299–305. Hipparchos's extant *Commentary on the Phenomena of Eudoxos and Aratos* is not a part of this genre, since it is highly technical and numerical in its content.

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The clearest and most significant of these is the attribution of the constellation Equuleus (*Protomē hippou*) to Hipparchos. Geminos's is the first mention of this constellation in the Greek tradition. Perhaps it comes from Hipparchos's star catalogue. In any case, Ptolemy adopted this constellation name in the *Almagest*. Among writers on such geographical questions as mountain heights, the extent of Ocean, and the arrangement and habitability of the zones, Geminos cites Dikaiarchos, Pytheas, Kleanthēs, and Polybios.

Geminos was clearly influenced by the Stoic Poseidōnios in his philosophical musings and in his work on meteorology. (See fragment 2.) In sec. 7 we address the controversial question of whether Geminos, in writing the *Introduction to the Phenomena*, might have used a lost textbook of Stoic astronomy and physics written by Poseidōnios. Here, it suffices to point out that he does not mention Poseidōnios a single time in the *Introduction to the Phenomena*. The material of Geminos's *Introduction* consists largely of notions that were the common property of all astronomers. His contribution was in the selection and shaping of material, in his graceful prose, and in the tasteful incorporation of literary examples.[25] He would have needed no help from Poseidōnios for this.

But Geminos does leave some of his most important sources unnamed. For as we have seen, and though he does not cite them by name, Geminos clearly knows the material in Euclid's *Phenomena*, Autolykos's *On the Moving Sphere* and *On Risings and Settings*, and Theodosios's *On Habitations* and *On Days and Nights*. We shall see below that he probably knew also Hypsiklēs of Alexandria's *Anaphorikos*. Geminos's merit as a teacher is to absorb all this rather dry mathematical material and transform it into graceful prose—though often at the expense of the original mathematical rigor.

Highly significant are Geminos's citations of the "Chaldeans," by which he means Babylonian astronomers. We should say a few words about this term. The Chaldeans were a group of tribes who moved into southern Mesopotamia by about 1000 B.C. They assumed a growing importance, and in the eighth century succeeded in putting a king on the throne of Babylonia. Within a few decades, the Chaldean kings lost control to the Assyrian kings, who intervened repeatedly in Babylonian affairs. But under Nabopolassar a new Chaldean dynasty was established, which ruled Babylonia from 625 B.C. until the Persian conquest in 539.[26] Ancient Greek writers often used the term "Chaldeans" (*Chaldaioi*) simply to mean Babylonians. But because Babylon had a reputation for arcane knowledge, "Chaldean" also came to mean *an astronomer or*

[25] Compare Aujac 1975, lxxxviii, n1.
[26] On the Chaldeans, see Oates (1986), 111–14.

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astrologer of Babylon. Here are a few examples that span the range of meanings from "Babylonian" to "astronomer of Babylon" to "astrologer or magus": In the *Almagest*, Ptolemy refers to the "Chaldean" (i.e., Babylonian) calendar. Vitruvius says that Berossus came from the "Chaldean city or nation" to spread the learning of this people. Theōn of Smyrna says that the Chaldeans save the phenomena by using arithmetic procedures. For Herodotos, the Chaldeans are priests of Bel (i.e., Marduk). This is quite reasonable, since astronomy and astrology were concentrated in the temples, and many of the practitioners were priestly scribes. In *Daniel* 2.2–4, the Chaldeans are interpreters of dreams and are associated with magicians and sorcerers. For Sextus Empiricus, Chaldeans are astrologers.[27]

By about 300 B.C. the Babylonians had developed very successful theories for the motions of the planets, Sun, and Moon. These theories were based upon arithmetic rules, rather than on the geometrical models that characterized the Greek approach. When the Greeks began to deal quantitatively with planetary theory, they were able to base their geometrical models on numerical parameters borrowed from the Babylonians. This process was well under way in the second century B.C. In the *Almagest* (second century A.D.), Ptolemy begins with planetary periods that he ascribes to Hipparchos (second century B.C).[28] But in fact these parameters were of Babylonian origin and turn up on cuneiform tablets. In his discussion of the Moon's mean motions, Ptolemy again starts with Hipparchos's values, but in this case says explicitly that Hipparchos had made use of Chaldean observations.[29] Hipparchos's works on lunar and planetary theory have not come down to us, so we do not know exactly how he came into contact with the Babylonian parameters.

In the period between Hipparchos and Ptolemy, the Greek geometrical planetary theories had not yet reached maturity, and were not capable of yielding accurate numerical values for planet positions. But the rise of astrology (which entered the Greek world from Babylonia in the second or first century B.C.) imposed a need for quick, reliable methods of calculating planetary phenomena. Greek astronomers and astrologers adopted the Babylonian planetary theories with enthusiasm. Astronomical papyri from Egypt show Greeks of the first century A.D. using Babylonian planetary theories with complete facility. Ptolemy's publication of his planetary theories and tables in the *Almagest* and the *Handy Tables*

[27] Ptolemy, *Almagest* ix 7 and xi 7. Vitruvius, *On Architecture* ix 2.1. Theōn of Smyrna, *Mathematical Knowledge Useful for Reading Plato* iii 30. Herodotos, *Histories* i 181–84. Sextus Empiricus, *Against the Professors* v 2–3.

[28] Ptolemy, *Almagest* ix 3. For a discussion, see Neugebauer 1975, 150–52.

[29] Ptolemy, *Almagest* iv 2. See Neugebauer 1975, 69–71, 309–10.

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produced a major change in the way practical astronomy was done. But calculating methods based on Babylonian procedures still existed side by side with methods based on Ptolemy's tables in the fourth century A.D.

In chapter ii of the *Introduction to the Phenomena*, Geminos shows that he is familiar with some features of Chaldean astrology, though he mentions only a few doctrines in passing, and does not seem intensely interested in the subject. In any case, nothing about the level of his familiarity with Chaldean astrology is surprising for a writer of his time. Far more detailed and more historically significant is Geminos's discussion of the Babylonian lunar theory in chapter xviii. His discussion there is important because his is the oldest extant classical text to display familiarity with the technical details of a Babylonian planetary theory based on an arithmetic progression. In particular, Geminos explains a scheme for the motion of the Moon, according to which the daily displacement increases by equal intervals from day to day, until it reaches a maximum, then falls by equal increments from one day to the next. The numerical parameters of Geminos's theory are in exact agreement with cuneiform sources. Geminos's treatment of the Babylonian lunar theory is discussed below in sec. 13, below, where we also address the question of the form that his source for the Babylonian lunar theory might have taken. In chapter xi, Geminos mentions that eclipses of the Moon take place in an eclipse zone (*ekleiptikon*) that is 2 degrees wide. Though he does not mention the Chaldeans in this passage, the 2-degree eclipse zone also comes from Babylonian astronomy. In total, Geminos's remarks provide important information about the adoption and adaptation of Babylonian knowledge by the Greeks of his time. By contrast, Geminos cites the "Egyptians" simply for the general structure of the Egyptian calendar and the circumstances of a festival of Isis.

6. Geminos's Country and Date

Modern scholars sometimes refer to our astronomer as "Geminos of Rhodes,"[30] but there is no ancient mention of his native land or city. The few ancient writers who cite him refer to him simply as Geminos, or as "Geminos the mathematician." The evidence for placing him in Rhodes is suggestive, but not conclusive. In several passages in the *Introduction to the Phenomena*, Geminos uses Rhodes as an example in making some astronomical point—involving the length of the longest day, or the portion of the summer tropic cut off above the horizon, or the meridian alti-

[30] For example, Sarton 1970, vol. 2, 305; Bowen and Todd 2004, 194n2.

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tude of the star Canopus, or the date of the morning rising of the Dog Star.[31] But although he does use Rhodes most frequently for such examples, he also gives examples for Alexandria, Greece, Rome, and the Propontis.[32] Does his proclivity for using Rhodes suggest a fondness for his native city, or merely reflect Rhodes's usefulness in astronomical examples, owing to its roughly central location in the Greek world? Geminos remarks (xiv 12) that celestial globes and armillary spheres were commonly constructed for this *klima*, or band of latitude. And it is noteworthy that in the second century A.D., Ptolemy, who lived at Alexandria, still found it natural to construct examples for the parallel through Rhodes, "where the elevation of the pole is 36 degrees and the longest day 14½ hours."[33] Or perhaps, as Dicks suggests,[34] Geminos's use of the *klima* of Rhodes reflects examples he found in his sources, which may have included the geographical or astronomical works of Hipparchos. Blass makes an interesting point about Geminos's use of two geographical examples. Geminos (xvii 3) refers to Mt. Kyllēnē, and immediately specifies that it is "the highest mountain in the Peloponnesos"; but in the very next sentence he refers to Mt. Atabyrion without making any similar specification that it is on the island of Rhodes.[35] Does this suggest that he expected his readers to be familiar with Rhodian geography?

Finally, we know that Geminos wrote some sort of abridgment of, or commentary on, the *Meteorology* of Poseidōnios, whose native land was Rhodes. And a likely dating of Geminos's *Introduction to the Phenomena* would make Geminos a younger contemporary of Poseidōnios, and thus potentially his student. (Geminos's possible debts to Poseidōnios will be discussed below.) Near the end of her own discussion of this issue, Aujac concludes, "Let us allow, then, since no other better hypothesis presents itself, that Geminos was born at Rhodes and that he there received his first instruction."[36] This is not an unreasonable position to take, since no convincing evidence exists for placing him elsewhere.[37]

[31] *Introduction to the Phenomena* i 10, 12; iii 15; v 25; vi 8; xvii 40.

[32] *Introduction to the Phenomena* iii 15; v 23; vi 8.

[33] Ptolemy, *Almagest* ii 2, trans. Toomer 1984, 76. Ptolemy's example continues, using the same latitude, in ii 3.

[34] Dicks 1972.

[35] Blass 1883, 5. The mss. actually call the mountain *Satabyrion*, which was corrected by Petau (followed by Aujac). See also Dicks 1960, 30n3.

[36] Aujac 1975, xv.

[37] However, Schmidt (1884b) argues that Geminos wrote the *Introduction to the Phenomena* at Rome for a Roman audience. Against this, Tannery (1887, 37) points out that Geminos is not mentioned by Pliny, who would certainly have included him in his long list of authorities, if he had ever heard of him. Manitius (1898, 247) believes that Geminos wrote at Rhodes, but that the work we have is due to a much later excerptor, who lived in the *klima* of 15^h, and most likely at Constantinople.

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But we simply do not know. In any case, as Tannery has pointed out,[38] all the writers who cited Geminos were associated with Alexandria or with Athens, which suggests that his works circulated mainly in the Greek world of the eastern Mediterranean.

Whether *Geminos* is a Greek name or a Hellenization of a Latin name (Geminus) has been the subject of dispute. As Aujac remarks, "Petau made it a Latin name, Manitius a Greek name, Tittel again a Latin name (!)"[39] A crucial point in the argument is the length of the central vowel—a long vowel favoring the Greek. Whatever the origin of his name, Geminos was thoroughly Greek in education, intellectual interests, and manner of expression.

But when did Geminos write? There are two ways to narrow the possibilities. Appendix 4 lists the writers that Geminos mentions. The latest datable writers cited in the *Introduction to the Phenomena* are Hipparchos, Polybios, and Kratēs of Mallos, who all flourished in the middle of the second century B.C. Conversely, Geminos was quoted by Alexander of Aphrodisias, the Aristotelian commentator, who flourished at the end of the second century A.D. Thus we may place Geminos between 150 B.C. and A.D. 200.

It appears possible to date Geminos more closely by his remark (viii 20–22) concerning the wandering year of the Egyptians:

> . . . most of the Greeks suppose the winter solstice according to Eudoxos to be at the same time as the feasts of Isis [reckoned] according to the Egyptians, which is completely false. For the feasts of Isis miss the winter solstice by an entire month. . . . 120 years ago the feasts of Isis happened to be celebrated at the winter solstice itself. But in 4 years a shift of one day arose; this of course did not involve a perceptible difference with respect to the seasons of the year. . . . But now, when the difference is a month in 120 years, those who take the winter solstice according to Eudoxos to be during the feasts of Isis [reckoned] according to the Egyptians are not lacking an excess of ignorance.

The feasts of Isis (*ta Isia*) were celebrated at a fixed date in the Egyptian year. But as the Egyptian year consists of 365 days (with no leap day), the feast days shift with respect to the solstice by 1 day every 4 years. Because the Egyptian year is too short, the feast days gradually fall earlier and earlier in the natural, or solar, year. If we knew the Egyptian calendar date on which this Isis festival was observed, it would be easy

[38] Tannery 1887, 37.

[39] Aujac 1975, xiv, n2. See Manitius 1898, 251; and Tittel 1910, col. 1027. Heath (1921, vol. 2, 222) provides a summary of the debate up to his time. Dicks (1972) makes the name Latin, but stresses that Geminos's "works and manner are patently Greek."

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to calculate the year in which the festival coincided with the winter solstice. We would then place Geminos 120 years after that year.

Most writers on the subject have tried to date Geminos by the use of a remark by Plutarch (late first to early second century A.D.):

> . . . they say that the disappearance of Osiris occurred in the month of Athyr. . . . Then, among the gloomy rites which the priests perform, they shroud the gilded image of a cow with a black linen vestment, and display her as a sign of mourning for the goddess, inasmuch as they regard both the cow and the Earth as the image of Isis; and this is kept up for four days consecutively, beginning with the seventeenth of the month.[40]

Denis Petau, in his *Uranologion* of 1630,[41] used Plutarch's remark to date Geminos's composition, with the following result:

> year 4537 of the Julian period,
> fourth year of Olympiad 175,
> year 677 after the founding of Rome,

or, as we would say, 77 B.C. Petau was followed by most later writers on the subject, with only minor adjustments. Thus, most writers who have accepted this evidence put Geminos's composition of the *Introduction to the Phenomena* in the 60s or 70s B.C.[42] But as we shall see, the margin of error should be taken quite a bit wider.

The reasoning is straightforward. Let us work with 19 Athyr, the 3rd day of the 4-day festival. Athyr is the 3rd month of the Egyptian calendar, so 19 Athyr is the 79th day of the Egyptian year.[43] In Table I.1, the first column lists years of the Julian calendar. In the second column, we have written the date of 1 Thoth, the 1st day of the Egyptian year that began in the course of the given Julian calendar year.[44] Thus, in –200, a new Egyptian year began on 12 October.[45] To obtain column 3, we add 78 days to the dates in column 2. In this way, we move from the 1st day of the Egyptian year (1 Thoth) to the 79th day (19 Athyr). Thus, in the Julian year –200, the 19th of Athyr fell on 29 December. The 4th column

[40] Plutarch, *Isis and Osiris* 39, 366D–E, F.C. Babbitt, trans.

[41] Petavius 1630, 410–11.

[42] For summaries of multiple dating attempts by various writers, see Manitius 1898, 238, and Jones 1999a, 256n2.

[43] For an introduction to the Egyptian calendar, see Evans 1998.

[44] For Julian calendar equivalents of 1Thoth over the centuries, see Bickerman 1980, 110–11.

[45] We use "astronomical reckoning." The years A.D. are written as positive numbers. The B.C. years are shifted by one, in order to introduce a year zero, and written as negative numbers. Thus, +1 = A.D. 1, 0 = 1 B.C., –1 = 2 B.C., etc.

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Table I.1
Comparing 19 Athyr and Winter Solstice

Year	*1 Thoth*	*19 Athyr*	*Winter solstice*
–250	25 Oct	11 Jan	25 Dec
–200	12 Oct	29 Dec	24 Dec
–150	30 Sep	17 Dec	24 Dec
–100	17 Sep	4 Dec	23 Dec
–50	5 Sep	22 Nov	23 Dec
0	23 Aug	9 Nov	22 Dec
+50	11 Aug	28 Oct	22 Dec

gives the date of the winter solstice[46] for each of the given Julian calendar years. Comparing the 3rd and 4th columns, we see that the winter solstice fell on 19 Athyr sometime between –200 and –150. Interpolation gives –179. Geminos wrote 120 years later, or around the year –59.

An error of 3 days in the date of the solstice could shift the date by ±12 years.[47] Again, Geminos speaks in rough fashion of a whole month, as the difference by which the Isis festival missed the solstice in his own day. He might have spoken in this same way if the actual difference were, say, as small as 28 days or as great as 32, which introduces another ±8 years of uncertainty. Finally, the festival itself stretched over a period of 4 days, which gives us 4 more years of uncertainty after 60 B.C. and 8 more years before. Putting all this together, we find the period 88–36 B.C. as the most likely for the composition of the *Introduction to the Phenomena*, or, to speak in round numbers, 90–35 B.C.

In 1975, Otto Neugebauer proposed a date for Geminos about a century later, around A.D. 50.[48] Although Neugebauer's dating was influential for a while, we shall see that it can no longer be sustained. The argument that follows will be somewhat intricate. But at the end we shall not abandon the dating of 90–35 B.C. that we have just explained. Thus, readers with little enthusiasm for details of ancient chronology should feel no guilt in skipping ahead to the next section.

The key question that Neugebauer posed is whether Petau's argument, based on Plutarch's remark, involved a confusion between the Egyptian

[46] The dates of the winter solstices have been calculated from the solar tables in Newcomb 1898. The reason why the date of the solstice slowly shifts is the incorrect length of the Julian calendar year (by approximately 3 days every 400 years), which was corrected by the Gregorian reform of 1582.

[47] Three days is not too large an error. Geminos refers to the winter solstice "according to Eudoxos." In the Geminos *parapēgma*, the winter solstice "according to Eudoxos" is separated by 3 days from the winter solstice "according to Euktēmōn."

[48] Neugebauer 1975, 579–81.

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and the Alexandrian calendars. After Egypt became a province of the Roman empire, Augustus reformed the Egyptian calendar by introducing a leap day once every four years, the first such day being inserted at the end of the Egyptian year 23/22 B.C. In the reformed calendar, now usually called "Alexandrian" to distinguish it from the original Egyptian calendar, three years of 365 days were followed by a year of 366 days. The reformed calendar thus was very similar to the Julian calendar, which had been used at Rome since 45 B.C. Of course, the Alexandrian calendar continued to use the old Egyptian months of 30 days each, as well as the original Egyptian month names. For dates near 23 B.C., a given day has nearly the same date in both the Egyptian and the Alexandrian calendars. But gradually, at the rate of 1 day in 4 years, the calendars diverge. Moreover, the two calendars continued to be used side by side. For example, Ptolemy, in the *Almagest*, used the old calendar for astronomical calculation, because of its simpler structure, nearly two centuries after it had been abandoned for civil use. In his *parapēgma*, however, Ptolemy adopted the Alexandrian calendar, because the heliacal risings and settings of a given star have more nearly fixed dates in this calendar. When an ancient writer, writing after Augustus's reform, says "the 17th of Athyr," it is not immediately clear whether he is expressing the date in terms of the Egyptian calendar or the Alexandrian calendar. One must examine the context carefully.

Neugebauer was troubled by a second reference in Plutarch to what was apparently the same Isis festival:

> . . . then Osiris got into [the chest] and lay down, and those who were in the plot ran to it and slammed down the lid, which they fastened by nails from the outside and also by using molten lead. They say also that the date on which this deed was done was the seventeenth of Athyr, when the Sun passes through Scorpio. . . . [49]

We have again the date Athyr 17, but now with the added information that the Sun passes through Scorpio during the month of Athyr. As Neugebauer pointed out, this was true in the Alexandrian, but not in the Egyptian calendar, for Plutarch's time. The Alexandrian month of Athyr runs from 28 October to 26 November (Julian), which corresponds rather closely to the sign of Scorpio. In Plutarch's time, say A.D. 118, the Egyptian and Alexandrian calendars were out of phase by 35 days: 1 Athyr (Egyptian) then fell on September 23 (Julian), corresponding to the Sun's entry into Libra, not Scorpio. Neugebauer concluded that Plutarch was using the Alexandrian, and not the Egyptian, calendar. Moreover, he surmised that Plutarch (or his source) took the original

[49] Plutarch, *Isis and Osiris* 13 356C, F.C. Babbitt, trans.

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date of the Isis festival, as expressed in the Egyptian calendar, and converted it to an Alexandrian equivalent. The Alexandrian calendar was, after all, the one in official use, and the one more likely to be understood by Plutarch's readers in the wider Roman world.

Neugebauer found the Egyptian date for what he took to be the same festival in a hieroglyphic text in the East Osiris Chapel on the roof of the Temple of Hathor in Dendera.[50] The text describes the rituals of an Osiris festival that lasted from 12 to 30 Choiak. The text is not later than 30 B.C. and thus predates the reform of the calendar. Moreover, as Neugebauer also pointed out, the papyrus Hibeh 27 (c. 300 B.C.) mentions an Osiris festival on 26 Choiak.[51] Now in Plutarch's time (A.D. 118), the date 26 Choiak (Egyptian) = 21 Athyr (Alexandrian), which appeared to confirm Plutarch's use of the Alexandrian calendar when he placed the rites on 17–20 Athyr. Neugebauer then computed the year when the winter solstice fell on 15 Choiak (Egyptian). (This date is within the span of rituals mentioned by the text in the East Osiris Chapel.) The answer is the year −70; Geminos wrote 120 years later, or around A.D. 50, according to Neugebauer. The new dating by Neugebauer, pushing Geminos forward into the first century A.D., was gradually adopted by historians of ancient astronomy.

Alexander Jones reexamined the question in 1999.[52] As Jones points out, Neugebauer deserved credit for being the first to use papyrological evidence for the date of the Isis festival. The advantage of such evidence is that it comes from a time when the Isis festival was a living custom, that it comes directly from Egypt without having passed through the hands of other writers, and that some of it comes from a date before the reform of the Egyptian calendar, thus removing any possibility of confusion between the calendars. But there was much more such evidence (in both the Greek and Egyptian languages) available than Neugebauer had realized.

Jones adduces a good deal of evidence showing that Neugebauer had wrongly taken the Osiris festival of 12 to 30 Choiak (Egyptian) to be the same festival as the *Isia* that Plutarch mentions. Jones also points out that Geminos refers to the festival simply as *ta Isia*, without any further specification. This implies that the festival was so well known that Geminos had no fear that it would be confused by his readers with other festivals associated with Isis or Osiris. Now, as Jones points out, there are at least nineteen references in Greek papyri to a festival called the *Isia* (also spelled *Iseia* or *Isieia*). Only a few of these provide calendrical information. But enough do that it is possible to confirm Plutarch's dates of

[50] For a bibliography pertaining to this text, see Porter and Moss 1927, vol. 6, 97.
[51] Grenfell and Hunt 1906, 144, 148.
[52] Jones 1999a.

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17–20 Athyr, and to be sure that these dates indeed apply to the old (Egyptian) calendar. For example, several papyri from before the calendar reform are private letters or records, with dates in Athyr, concerned with ordering or issuing supplies (logs and lamp oil) for the *Isia*. One papyrus gives the dates of the *Isia* in terms of the Macedonian calendar. These dates can be converted to the Egyptian calendar (with an uncertainty of 1 day) and indeed correspond to 17–20 Athyr. Slightly altering the chronological assumptions and broadening the error bars, Jones concludes that it is very probable that Geminos wrote his *Introduction to the Phenomena* "between 90 and 25 B.C., and definitely not during the first century of our era."[53] There is an irony in the fact, confirmed by the papyri, that after the calendar reform, the *Isia* continued to be celebrated on days called 17–20 Athyr, *but in the new calendar*. Thus, Plutarch's dates turn out to refer to the reformed calendar after all! (But they should not be converted back into the old calendar to obtain the dates that Geminos would have been familiar with.)

One minor problem with dating Geminos to the first century B.C. involves his mention of Hero of Alexandria in fragment 1. The dating of Hero has been controversial, with suggested dates from the middle of the second century B.C. to the middle of the third century A.D.[54] In *Dioptra* 35, however, Hero mentions a lunar eclipse observed simultaneously in Alexandria and Rome. Although Hero does not mention the year of the eclipse, he is detailed about its other circumstances: 10 days before the vernal equinox, 5th seasonal hour of the night at Alexandria. Neugebauer[55] has shown that these circumstances were satisfied by only one lunar eclipse between about –200 and +300, namely that of March 13, A.D. 62. If Hero used an eclipse of recent memory, we must place him in the second half of the first century A.D. Thus, if the dating of Geminos to the first century B.C. is correct, we must suppose that Proklos or a later copyist interpolated the name of Hero in fragment 1.

Finally, we note that Geminos writes about Babylonian astronomy and astrology as if they were still new to his Greek readers. This well suits a dating to the first century B.C., when this material was still being absorbed and adapted by the Greeks.[56]

[53] Jones 1999a, 266.

[54] For a summary of the older estimates, see Heath 1921, vol. 2, 298–307.

[55] Neugebauer 1938; with results summarized in Neugebauer 1975, 846.

[56] Some scholars have attempted to identify the author of the *Introduction to the Phenomena* with other men named Geminos. Aujac (1975, xxii) suggests a certain Cnaeios Pompeios Geminos, active around A.D. 15. Reinhardt (1921, 178–83) prefers to identify the author of the *Introduction* with an earlier Geminos; Tannery (1887, 37) with a later one. Aujac (1975, xx–xxii) is one of the few who discount the usual dating argument based on the feasts of Isis, and seeks to explain this paragraph (viii 20–22) in a completely different way.

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