Geminos's *Introduction to the Phenomena*

A Translation and Study

of a Hellenistic Survey of Astronomy

James Evans and J. Lennart Berggren

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Preface

A famous mathematician of the twentieth century once lamented, "The algebraic topologist has practically ceased to communicate with the point-set topologist!" This remark is characteristic of our time and culture, in which knowledge has become fractured into thousands of specialties and subspecialties, and in which no one science can claim to hold a privileged place. It was not so in Greek Antiquity, when astronomy was the central science, with vital links to nearly every other aspect of the culture.

Astronomy had important relations with other sciences, such as physics (or philosophy of nature) and mathematics. As Aristotle pointed out, the motions of the celestial bodies were the best clues to the physics (or essential natures) of these bodies. But the methods of investigation, as well as of demonstration and application, in astronomy were so thoroughly mathematical that astronomy was often considered to be a branch of applied mathematics. It was partly for this reason that Plato included it in the quadrivium of mathematical arts recommended for the education of the guardians of his ideal state. Astronomy also had links to ancient religion, for the planets were widely held to be divine, and the celestial phenomena commanded the attention of the poets, who from the time of Hesiod had sung of the celestial signs and of the revolving year. Astronomy provided subject matter for craftsmen, who represented the heavens in the form of ingenious globes and mechanisms. And, finally, it was one of the most significant channels of intellectual exchange between ancient civilizations, most notably between the Babylonians and the Greeks. Geminos's *Introduction to the Phenomena* manifests all these cultural affiliations of ancient astronomy. This graceful manual of astronomy, written probably in the first century B.C. by a man who had had some experience of teaching, remains today an engaging introduction to the central natural science of Antiquity.

Much of ancient astronomy requires of the reader an approach over a long and difficult road. This includes Ptolemy's *Almagest* as well as the planetary theories of the Babylonian scribes. And much else is either devoted to special problems (such as Aristarchos's treatise *On the Sizes and Distances of the Sun and Moon*) or consists of repetitive material arranged in theorems and proofs that survived because it was useful for teaching (such as Autolykos's *On Risings and Settings*). Finally, there is a good deal of low-level, nontechnical material written for ancient readers

who were not willing to try very hard (such as the astronomical portions of Pliny's *Natural History*), material that cannot really give a modern reader a fair appreciation of the ancient science.

Geminos's *Introduction to the Phenomena* is one of a very small number of ancient astronomical works that can be read with appreciation and understanding by a nonspecialist, but one that offers, nevertheless, a competent and reasonably comprehensive account of its subject. The English translation of the *Introduction to the Phenomena* here presented is the first complete one ever to be published. We hope it will be of interest and use not only to historians of science, but also to students of ancient civilization, as well as to scientists who want to know more about the origins of their art.

The book that the reader now holds had a long gestation. JE encountered Geminos while completing a doctoral dissertation at the University of Washington. Working from Germaine Aujac's relatively recent edition of the Greek text (Aujac 1975), he translated most of Geminos's chapter v, on the circles of the celestial sphere, for his students to read in a course he was teaching on the history of astronomy. He was struck by Geminos's patience and clarity, and charmed by his frequent use of literary examples to illustrate a point of astronomy. Geminos was an excellent writer for students to read—the astronomy was accurate and useful, but the priorities and concerns of the ancient thinker came through loud and clear as well. A student could read Geminos with scientific as well as historical senses open. In 1983–84, JE spent a year in Paris, with the aid of a Fulbright Grant, working at the Centre Koyré under the patronage of the late René Taton, and going regularly to the history of astronomy sessions of the *Équipe Copernic* (Copernicus team) at the Paris Observatory. He spent most of the year working on eighteenth-century physics. But in his spare time, simply for pleasure and as a way of keeping up his Greek, he completed a draft translation of the whole of Geminos's *Introduction to the Phenomena*. Some time later, at the International Congress of the History of Science, held at Berkeley, he had opportunity to meet Germaine Aujac, who responded generously by lending him her microfilms of the most important Geminos manuscripts. JE used his translation of Geminos for many years in teaching a course on the history of astronomy at the University of Puget Sound. A short extract from Geminos's chapter v appeared in his *The History and Practice of Ancient Astronomy* (Evans 1998). While working on other projects, he occasionally took time out for his ongoing commentary on Geminos.

JLB and JE had known each other for a long time before beginning a collaboration on Geminos. JLB works on both medieval Arabic mathematics and ancient Greek mathematics. With R.S.D. Thomas, he had published a translation of and commentary on Euclid's *Phenomena*

(Berggren and Thomas 1996), which well equipped him for further work on Greek phenomena literature. And, with Alexander Jones, he had published an annotated translation of the theoretical chapters of Ptolemy's *Geography* (Berggren and Jones 2000). Through a happy alignment of their stars, JLB and JE had free time, at the same time, to devote to getting Geminos into final form. JLB undertook a complete review and revision of the translation. The two translators consulted regularly on issues raised by the Greek text and its translation, striving not only for accuracy and readable English but also for fidelity to Geminos's style and cadences. JLB also reviewed and corrected the draft commentary, adding to it his own insights. The two authors wrote the introduction and appendices together. Although they were able to do much of their work apart, communicating by telephone, e-mail, and fax, they retain fond memories of working together at the Evans's dining room table in Seattle, at the Berggren's house in Coquitlam, British Columbia, and their mountain retreat in Whistler, as well as in the bar of the Sylvia Hotel in Vancouver. The final push to completion of the manuscript was carried out at the Helen Riaboff Whiteley Center, in Friday Harbor, Washington.

The authors are grateful to friends and colleagues who helped in many different ways in the course of this project. Our greatest scholarly debt is to Germaine Aujac, whose Greek text provided the basis for our translation. Alexander Jones, Liba Taub, and Noel Swerdlow read considerable portions of the manuscript and were generous with comments and suggestions, many of which resulted in improvements or saved us from errors. Marinus Taisbak helped with several translations from the Latin, and Tasoula Berggren proofread the Greek of the glossary and typed the index. JE remains grateful to the late Will Humphreys for a day-long discussion of Proklos's citations of Geminos in the *Commentary on the First Book of Euclid's Elements*. Daryn Lehoux generously lent us his own translation of the Geminos *parapēgma* in advance of the publication of his book on *parapēgmata*. Other scholars took the trouble to respond to questions, among whom we particularly thank Lawrence Bliquez, David Lupher, and A. Mark Smith. We alone, of course, are responsible for any errors or shortcomings in the final product.

Ernst Künzl and Rudolph Schmidt helped obtain photographs for use as illustrations, and Ross Mulhausen aided with photographic work and image processing. The University of Puget Sound provided sabbatical leave that enabled Professor Evans to concentrate on the project, as Simon Fraser University did for Professor Berggren. Both institutions also provided financial support for the payment of fees for the reproduction of some of the images appearing in the book. The Helen Riaboff Whiteley Center, at Friday Harbor on San Juan Island, generously welcomed us

for a stay while we were completing the final version of the book. It has also been a privilege and a pleasure to work with the capable staff of Princeton University Press, including Ingrid Gnerlich, editor; Jill Harris, production editor; and Bill Carver, copy editor. We are grateful to the following institutions and their helpful staffs for supplying photographs and for permission to use them in this book: Musée du Louvre, Museo Archeologico Nazionale di Napoli, Museo Archeologico Nazionale di Aquileia, Bibliotheca Nazionale Marciana (Venice), Bibliotheca Apostolica Vaticana, Römisch-Germanisches Zentralmuseum Mainz, Antikensammlung (Berlin), University of Washington Libraries, The British Museum, Trinity College Dublin, and the Musée National d'Histoire et d'Art Luxembourg.

It remains only to say that we owe our deepest thanks to Sharon Evans and Tasoula Berggren for their understanding and support during the years it took us to complete this work.

J.E.
J.L.B.
January 2006

Introduction

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.

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

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.

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., *sphairopoïia*, 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.

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.

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.

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.

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 *sphairopoïia* for each planet, and a brief mention of the basic planetary phenomena.

[18] Strabo, *Geography* i 1.21.

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.

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.

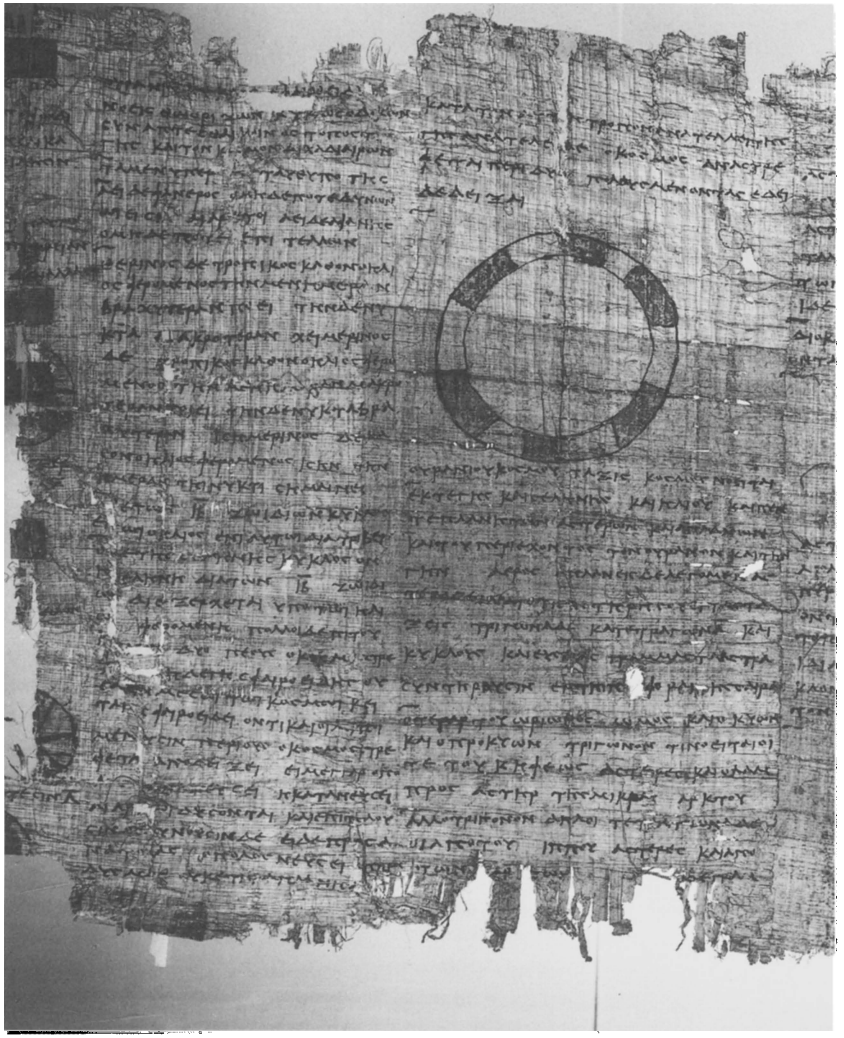

Fig. I.1. A portion of the *Celestial Teaching* of Leptinēs on a papyrus, written shortly before 165 B.C. The left column treats the circles of the celestial sphere and the celestial poles. The right column explains that the stars are called fixed because the constellations always retain their forms 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

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.

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.

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.