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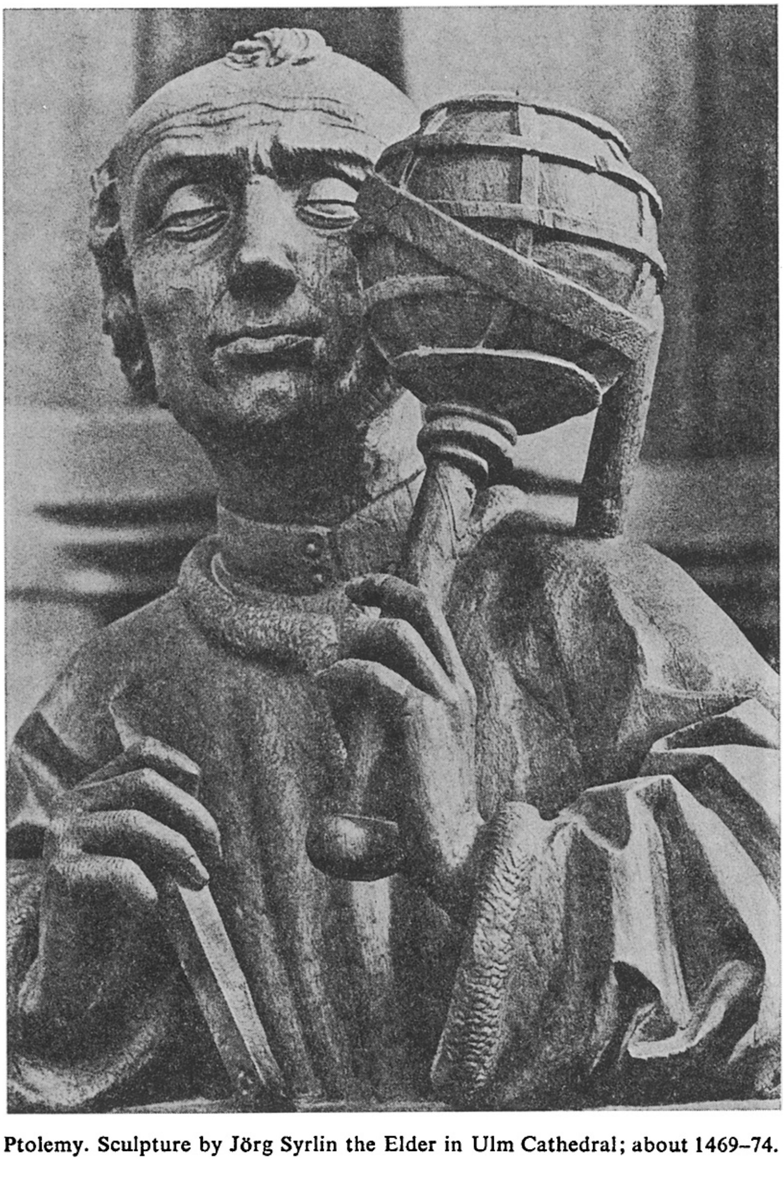

Ptolemy. Sculpture by Jörg Syrlin the Elder in Ulm Cathedral; about 1469–74.

Olaf Pedersen

A Survey of the *Almagest*

With Annotation and New Commentary

By Alexander Jones

Springer

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ISBN 978-0-387-84825-9 e-ISBN 978-0-387-84826-6
DOI 10.1007/978-0-387-84826-6
Springer New York Dordrecht Heidelberg London

Mathematics Subject Classification (2010): 85-03

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Foreword to the Revised Edition

There are many reasons why one should wish to read Ptolemy's *Almagest*. As well as being a masterpiece of scientific writing, it was the one major work on the scientific modelling of the celestial phenomena that survived from Greco-Roman civilization. It is our chief informant on Greek mathematical astronomy during the interval of its highest development (from the second century B.C. to about A.D. 150, roughly the date when the *Almagest* was published), and its influence shaped the astronomy of later antiquity, medieval Islam, and early modern Europe.

But it was never an easy read. As Ptolemy says in his preface, he wrote concisely and counted on his reader to be already rather experienced in the subject: comfortable with the deductive geometry of Euclid's *Elements*, proficient in numerical calculation involving a place-value system for fractions, and familiar with the visible phenomena of the heavenly bodies and the way they were recorded in observation reports. In Ptolemy's own day there were probably very few readers who could appreciate the treatise as much more than a collection of tables useful for astrological calculations, embedded in interminable stretches of indigestible mathematical prose. By the fourth century A.D., two hundred years after Ptolemy, the *Almagest* had been adopted as a school text for the most advanced philosophical and mathematical students in Alexandria, and its teachers Pappus and Theon felt the need to help their pupils along by composing commentaries, longer than the *Almagest* itself, that filled out Ptolemy's terse logic into a more leisurely, nay tedious, exposition. The modern student, who is more remote from Ptolemy's world and its scientific and mathematical conventions, needs help with a wider range of topics, but no longer expects to be led by the hand through each step of each of Ptolemy's mathematical arguments; and judicious use of mathematical notation helps one to grasp what Ptolemy expresses verbally in sentences that can run to several lines, and relate it to the mathematical tools we all learn in school. Where the pupils of Pappus and Theon read the *Almagest* to master its subject, we read it as a historical document representing an astronomy whose subject matter lies at the extreme margins of modern astronomy and astrophysics. We therefore have to learn the basic facts about naked-eye astronomy that today's schools no longer teach, and we look for information about the book's intellectual background and legacy.

Olaf Pedersen's *Survey of the Almagest* follows in a long tradition of introductory companions, part paraphrase and part commentary, that can be traced back through Paul Tannery (*Recherches sur l'histoire de l'astronomie ancienne*, 1893) and J. B. Delambre (the second volume of his *Histoire de l'astronomie ancienne*, 1817) to Regiomontanus' *Epitome of Ptolemy's Almagest* (printed posthumously in 1496) and indeed to Proclus' excellent *Sketch of the Astronomical Models* (mid fifth century). The eighty years since the last "survey of the *Almagest*" had seen considerable advances in our knowledge of the ancient astronomy, and of course there had also been great changes in the way students learn and what background knowledge they could be expected to have. Pedersen's *Survey* earned the universal praise of historians of early astronomy, and since 1974 it has been the first book one puts in the hands of a student approaching the *Almagest*.

Olaf Pedersen (1920–1997) was trained as a theoretical physicist before turning to the history of science in his doctoral study.[1] His earlier work centered on medieval European physics and astronomy, and his interest in Ptolemy came by way of research on medieval texts known as *Theorica* that present detailed descriptions of versions of the Ptolemaic system of celestial models. The *Survey* arose out of lectures on the *Almagest* that he gave in the Department of History of Science that he founded at the University of Aarhus, and its effectiveness as an introduction to a singularly difficult book reflects this pedagogical origin.

The English-reading student of the *Almagest* in 2010 has a substantial advantage over his or her predecessor of 1974 in being able to read Ptolemy's text in the splendid translation by G. J. Toomer (1984). It is very easy to find the passages in Toomer's translation corresponding to Pedersen's discussions, since Pedersen's references give the volume and page number in Heiberg's standard edition of the Greek text, and these also appear in Toomer's margins. Toomer's footnotes, appendix of worked examples of computations, and index are also invaluable as a supplement to Pedersen. "Book I" of O. Neugebauer's *A History of Ancient Mathematical Astronomy*, which was published one year after Pedersen's *Survey*, provides a detailed analysis of the mathematical astronomy in the *Almagest* that is often complementary to Pedersen's.

In this revised edition, Pedersen's text has been left unaltered except for the correction of typographic and other isolated errors that could be corrected in-line.[2] Where scholarship of which Pedersen was unaware or that has appeared since 1974 calls for modification or expansion of his discussion, a reference in the margin alerts the reader to a supplementary note at the end of the volume. This supplement, like the supplementary bibliography following it, is selective and does not pretend to supply a comprehensive review of the recent scholarly literature.

Alexander Jones

1) For a biography see North (1998).

2) For many of these, as well as other corrections in the supplementary notes, I am indebted to the reviews by G. J. Toomer (1977), G. Saliba (1975), and V. E. Thoren (1977).

Contents

FOR
THE MASTER AND FELLOWS
OF ST. EDMUND’S HOUSE
CAMBRIDGE

Preface

This book contains a survey of the *Almagest*. It is the outcome of a course of lectures given on several occasions, and its only aim is to help students of the history of astronomy to understand and appreciate Ptolemy's great and classical work. Therefore the emphasis is on the various astronomical theories and their structural relationships, while a critical analysis of Ptolemy's observational efforts falls outside the scope of the present study. Appendix A gives a list of all the dated observations quoted in the Almagest; it is compiled only for purposes of reference and is not based on any re-examination of Ptolemy's empirical data.

The problem of notation has been rather difficult and it has been necessary to go beyond the means that Ptolemy had at his disposal. On the one hand, many essential features of the methods and models employed by Ptolemy become both clearer and more accessible to modern readers if common mathematical expressions are introduced as condensed, formalized versions of procedures explained by Ptolemy in the form of verbal or numerical statements. On the other hand, Ptolemy's surprisingly non-technical and sometimes ambiguous terminology can be made more specific by means of concepts and terms borrowed from the vocabulary of Mediaeval Latin astronomers. I hope that these departures from the form and style of the Almagest will help to make the exposition useful to students whose principal interests are in the astronomy of the Middle Ages, or even in Copernicus and his immediate successors.

In establishing the mathematical formalism I must confess to a certain number of repetitions of equations and procedures. They are introduced in order to make it easier to study the theory of the motion of a particular kind of heavenly body, the various chapters on the motion of the Sun, the Moon, the superior, and the inferior planets being presented as more or less self-contained parts of the text.

No complete and detailed analysis of the Almagest has appeared since 1817 when Delambre published the second volume of his *Histoire de l'Astronomie Ancienne*. Since then a great number of papers and dissertations have dealt with particular problems in Ptolemaic astronomy. Most of these publications are listed in the bibliography and references to them are scattered throughout the text. Because of its limited purpose this survey does not pretend to have utilized all this material to its full extent. A few particular questions have been referred to the notes to each chapter.

A work like this cannot come to light without help and support from many different quarters. I am gratefully obliged to the Danish Council for Scientific Research which supported the studies preparatory to this book and also facilitated its publication. My sincere thanks are due to Professor Mogens Pihl for recommending another book of mine for publication in this series, and for friendly and unfailing help and advice over many years. Likewise I wish to thank Mr. Torkil Olsen of the Odense University Press, and the Cooperative Printing Company, Odense, for their excellent services in producing a most difficult book.

This study was begun and finished in the hospitable and scholarly atmosphere of St. Edmund's House, Cambridge. My most heartfelt gratitude is due to the Master and Fellows of this college for making me one of their own and providing me with excellent working facilities. In the same vein I am grateful to my wife for her constant encouragement and great patience with a husband absorbed in burning midnight oil for years on end. I am greatly indebted to my friends and colleagues Dr. Michael A. Hoskin, Cambridge, Professor Willy Hartner, Frankfurt a. M., and Professor Owen Gingerich, Harvard, for reading parts of the manuscript and recommending its publication. The proofs were read by Professor Willy Hartner, Frankfurt a. M. and by Dr. John D. North, Oxford, who both made criticisms and suggestions for which I am most grateful. I am under a special obligation to my friend Dr. A. G. Drachmann, Copenhagen, who for several years put his copy of Heiberg's editon of Ptolemy's works at my disposal. The staff of the Institute for History of Science, Aarhus University, has been most helpful. In particular I wish to thank Dr. K. P. Moesgaard for his careful examination of the complete text, and Mr. Kurt Møller Pedersen, M. Sc., for his help with many numerical calculations. Dr. G. A. Dirac, Aarhus University, took upon himself the task of revising the text from a philological point of view; I am truly grateful for his assistance without which I should not have ventured to publish this book. I thank also Mrs. Tove Asmussen for help with some of the illustrations. Last, but not least, I wish to express my profound gratitude to my secretary, Mrs. Kate Larsen, whose untiring efforts have been the *causa efficiens* of the whole work at all its different stages.

O. P.

CHAPTER 1

The Almagest through the Ages

The *Almagest* has shared the fate of many other major works in the history of science. It has been talked about by many, but studied seriously only by the few. Yet it was just as important to ancient science as Newton's *Principia* was to the 17th century, and there is no question that it was a greater scientific achievement than the *De revolutionibus* which has obliterated its fame, just as Copernicus has outshone Ptolemy as an astronomical genius. The Almagest was the culmination of Greek astronomy, and unrivalled in Antiquity as an example of how a large and important class of natural phenomena could be described in mathematical terms in such a way that their future course could be predicted with reasonable precision. It taught scientists of many ages how geometrical and kinematical models could be constructed and, by means of empirical data stemming from careful observations, made to simulate nature in a way which came to influence scientific method until the present day. It is true that the Babylonians had succeeded in developing highly sophisticated, algebraic methods to deal with the phenomena. But, as far as we know, they never tried to summarize either their methods or their results in a comprehensive work comparable with this brilliant exposition of everything achieved by Ptolemy himself and by the most remarkable of his predecessors among the Greek astronomers.

The Life and Work of Ptolemy

We know but little about the author of the Almagest. His life and personality are remarkably obscure compared with what we know of some other eminent scientists of the ancient world, but the reason is close at hand. Thus Plutarch gave us vivid biographical sketches of both Aristotle and Archimedes – but only because the former happened to be the teacher of a great warrior, and because the latter was killed by a soldier of a general in whom Plutarch was interested. Now Plutarch must be excused for not writing the life of Ptolemy who was his contemporary. But the 3rd century lexicographer Diogenes Laertius does not even mention his name, and also later tradition concerning Ptolemy is very scarce. Everything points to the conclusion that he lived and died peacefully, unnoticed by the mighty of this world and devoting himself to the composition of scientific works of a highly technical nature, unable to attract the attention of the literati of late Antiquity. What little remains from their hands has been collected by Boll (1894) and Fischer (1932), together with a few

O. Pedersen, *A Survey of the Almagest*, Sources and Studies in the History of Mathematics and Physical Sciences, DOI 10.1007/978-0-387-84826-6_1,

fragments from later Arabic authors and of a more or less legendary nature – e.g. that he was of moderate height, with a pale face, a black, pointed beard, a small mouth and a mild and pleasant voice, etc. .... This is, in fact a standard description of a Stoic philosopher, without any historical value at all. The result is that our image of Ptolemy lies hidden in his own works from which at least some biographical information can be extracted1).

Let us first consider the list of the observations recorded in the Almagest (see Appendix A). About one third of the total number are due to Ptolemy himself, the first being an observation of an eclipse of the Moon made in Alexandria in the 9th year of Hadrian's reign, or more precisely A.D. 125 April 5. The last is an observation of the maximum elongation of Mercury made in the 4th year of Antoninus Pius, i.e. A.D. 141 February 2, also in Alexandria. This shows that Ptolemy collected the observational data for his planetary theories in the period A.D. 125–141, and that the Almagest must have been finished after the later date. But there is sufficient evidence to show that Ptolemy continued his scientific activity after he completed his Almagest. Thus we know that in the 10th year of Antoninus (A.D. 147/48) he erected a stele in the town of Canopus some 15 miles East of Alexandria. It was provided with an inscription giving improved parameters of the planetary models. Still better parameters are found in the so-called *Handy-Tables*, or *Tabulae manuales* which accordingly seem to be of an even later date (Stahlmann, 1960, and v. d. Waerden, 1953, 1958). Also the work on the *Planetary Hypotheses* as well as the astrological *Tetrabiblos* are later than the Almagest, as stated explicitly in the texts. Finally it seems that Ptolemy's great treatise on *Geography* is later than the Handy Tables. If we remember that Ptolemy also left a considerable number of other works on optics, harmonics, mathematics and philosophy, we must realize that a large span of years was required to produce them. Everything considered it would seem that Ptolemy's scientific activity went on from about A.D. 125 to well into the reign of Marcus Aurelius (161–180). This agrees well with a statement in Olympiodorus that Ptolemy worked in Canopus for 40 years (v. d. Waerden, 1957, col. 1789). Probably the dates of his birth and death are about A.D. 100 and A.D. 165.

Where Ptolemy was born is not known. His real name Claudios is Greek, whereas his second name Ptolemaios could be an indication that he came from one of the various Egyptian towns named after the Ptolemaic kings, perhaps Ptolemaïs Hermeiu in Middle Egypt. Purely legendary is the Mediaeval tradition that he was of the old royal stock. Certain is only the fact that he performed his observations at Alexandria as stated in several places in the Almagest. Accordingly the new instruments he invented and constructed must have been placed there in some kind of observatory. But the undoubted tradition that he erected his stele at the neighbouring Canopus shows a certain connection with this locality. Perhaps he had his home in this smaller town, which offered better possibilities for a quiet life of study than the noisy capital of the Hellenistic world.

1) Cf. to the following B. L. van der Waerden (1957). This brilliant survey has superseded earlier expositions by Bunbury et al. (1926), Sarton (1927), and others.

Since the reign of king Ptolemy I Soter (d. 282 BC) Alexandria had been famous for its school where e.g. Euclid had been a scholar, Archimedes a student, and Eratosthenes a librarian. Its libraries were unsurpassed in the Ancient world and contained several hundred thousand writings of both Greek and Oriental provenance, together with catalogues of a considerable part of the collections (Parsons, 1952). The list of observations referred to above shows that Ptolemy often searched them for records of earlier observations. Here he had access not only to the results of Hipparchus, Aristarchus, and the first Alexandrian astronomer Timocharis, but also to 5th century observations made in Athens by Meton and Euctemon, and even to very ancient Babylonian records enabling him to make use of a Lunar eclipse observed in Babylon as early as 721 B.C. There is only one reference to a contemporary scientist, Theon of Smyrna, who gave some of his observations from A.D. 127–132 to Ptolemy, who may have been his friend or pupil [X, 1; Hei 2, 296]. It was Ptolemy's personal merit that he was more careful than most other Hellenistic authors in quoting his sources and acknowledging his predecessors; but it was the great Alexandrian library which enabled him to do so.

The richness of the library is part of the explanation of a characteristic feature of Alexandrian learning. Critical scholarship and bibliography were born here, and from the beginning there was a marked predilection among scholars for large and comprehensive expositions. The famous *Elements* of Euclid are a good example of a handbook containing most of the achievements of previous Greek mathematicians, arranged in a logical order and therefore easy to use in further research. Now Ptolemy is remembered chiefly as an astronomer; but a look at the titles of his many extant or lost works reveals him as a scientist of much more catholic interests. It is almost as if he had intended to compile a huge "Encyclopedia of Applied Mathematics" as a counterpart to already existing comprehensive expositions of pure mathematics.

It has to be admitted that Ptolemy succeeded in carrying this project out. Nevertheless, it would be wrong to regard him as a mere compiler of the results of others. Because he always acknowledged his debts to earlier scientists his own results stand out clearly, and all his works contain important personal contributions. His scientific spirit and love of research appear clearly from the fact that he did not rest upon what he had already achieved: once the Almagest was finished, by a rare and remarkable intellectual effort Ptolemy immediately began to improve both the theories of latitude and the parameters of the Lunar model, as shown by the Canopus-inscription and the Handy Tables. But that such restless urges to better his own results are most clearly seen in his astronomy is, perhaps, a testimony that with all his widespread interests Ptolemy was in his heart an astronomer, as tradition maintained.

The Spread of Ptolemaic Astronomy

For more than a century after Ptolemy's death Hellenistic scientists were silent about his work; but there is every reason to suppose that it was held in high esteem in the Alexandrian School where the mathematician Pappus (about A.D. 300) wrote the first of the many commentaries to the Almagest. Only Book 5 and 6 have survived (ed. Rome, 1931). In the second half of the 4th century A.D. a new commentary was published by another Alexandrian mathematician named Theon; most of this work is extant. According to tradition also Theon's famous daughter Hypatia wrote about Ptolemy, before she was murdered by a mob of Christian fanatics in A.D. 415 in foreboding of the approaching downfall of the Alexandrian School (Sarton, 1927, p. 386). But even after that date the Byzantine mathematician and neo-Platonic philosopher Proclus (410–485) was able to study astronomy at Alexandria. Later he became head of the old Platonic Academy at Athens, where he wrote his *Hypotyposis* or introduction to the astronomy of Hipparchus and Ptolemy (ed. Manitius, 1909). This was the last Greek work on Ptolemaic astronomy before the closing of Plato's Academy in A.D. 529 marked the end of the culture of the ancient world.

Already before Hellenistic civilization had reached its final stage Greek science had begun to penetrate the cultures of the East. From the troubled schools of Alexandria, Antiochia and Athens Greek scholars emigrated to Mesopotamia and Persia, and even in India the impact of Greek astronomy was felt in the great Sanskrit *Siddhantas* from about A.D. 500 onwards (Neugebauer, 1956, cf. Sen, 1971). These astronomical manuals are based on planetary theories of Greek origin, containing both pre-Ptolemaic and Ptolemaic features. The details of this transmission are not completely known and the spread of Greek astronomy among Oriental people is largely a matter of future research. But up to now we have no evidence that either the Persians, or the Indians, ever possessed the Almagest in their own languages.

The Almagest among the Arabs

On the other hand it is probable that there existed an Almagest translation in the Syriac language, through which the Arabs acquired much of their first knowledge of Ancient culture when they began to cultivate science and philosophy in Baghdad under the great Khalif al-Manṣur (754–775). But it is certain that their first knowledge of astronomy was derived from one of the Indian Siddhantas translated into Arabic about A.D. 773 (Brockelmann, I, 248). The result was that the first important astronomical works of the Muslim world were strongly influenced by Hindu astronomy. That was the case with e.g. the large *zīj*, or collection of astronomical tables with rules for their use, written by the Persian scientist al-Khwārizmī (d. ca. A.D. 850) (ed. Suter, 1914, transl. Neugebauer, 1962). Where specific Indian concepts and methods occasionally turn up in later Western astronomy (Neugebauer and Schmidt, 1952) they can usually be traced back to a Latin translation by Adelard of Bath (about A.D. 1126) of an Arabic version of this work.

It is a curious fact that Ptolemy became known to the Arabs as an astrologer before they learned about his astronomical achievements. Actually, already before or about A.D. 800 there was an Arabic translation of the Tetrabiblos made by the physician al-Baṭrīq (Suter, 1900, p. 4), while the Almagest had to wait until a later date before becoming accessible to Muslim scholars. Unfortunately the literary history of the Arabic Almagest is rather obscure and we do not know for certain when and by whom the first translation was made. One possible candidate is the Jewish Rabbi Sahl al-Ṭabarī who probably flourished about the beginning of the 9th century (Suter, 1900, p. 14). However, most scholars are inclined to doubt the existence of a translation of that early date. Another possibility is an anonymous scholar at the Bagdhad court who in A.D. 827 made a translation based on the Greek text. An Arabic MS of this version is still preserved in the University Library at Leiden.

About the same time another translation was made in Baghdad by al-Ḥajjāj ibn Yusuf, whose version appeared in 829–30 and is said to have been based on a Syriac text (Suter, 1900, p. 208). It was this translation which happened to give the work its current title. It was called *Kitāb al-mijisti, kitāb* meaning 'book' and *al-mijisti* being the Arabic term which later was rendered into Latin as Almagest. There is no certain explanation of the origin of this term. The original Greek title of the work was Μαθηματικῆς Συντάξεως βιβλια ιγ̄ or *The 13 Books of Mathematical Collections*. Later it may have been called Μεγάλη σύνταξις or *The Great Collection*. Now the superlative of μεγάλη is μεγίστη, and it may well be that the Arabs simply provided the latter term with the article *al*, thus creating the mixed form *al-megiste*, from which the Latin *Almagest* emerged (Brockelmann, Suppl. I, 363).

What became the final and most widely used Arabic version of the Almagest was a translation from the Greek made by Ishāq ibn Ḥunain (Brockelmann, I, 227; Sarton, 1927, pp. 600 and 611) who died in Baghdad 910/11 and was the son and collaborator of one of the most gifted, critical and prolific of the Baghdad translators, a Nestorian named Ḥunain ibn Ishāq (810–877). Ishāq lacked specialized knowledge of astronomy, but his translation was revised by the astronomer Thābit ibn Qurra (827–901) who was a famous translator in his own right (Suter 1900, p. 34).

In the course of the 9th century the Almagest was thus rescued from oblivion by Arabic speaking scholars. The result was that Muslim astronomy soon turned away from the earlier Hindu influence and acquired a definite Ptolemaic character. This appears both from elementary introductions, such as brief compilations made by al-Farghānī in the middle of the 9th century[2]), and from great scientific expositions, like the famous zīj of al-Battānī (ca. 850–929) upon which so much of our knowledge of Arabic astronomy is founded (ed. Nallino 1899–1907). The Almagest itself gave rise to a large number of more or less revised versions (Steinschneider, 1892) among which one of the most important was a long paraphrase by the Moorish astronomer Jābir ibn Afflaḥ, named Geber by the Latins (Vernet, 1963). It dates from about A.D. 1140 and was rendered into Latin by Gerard of Cremona[3]). It is fundamentally

2) In a Latin version by Johannes Hispalensis (12th century) this little manual was much used by Western astronomers. There is a printed edition *Brevis ac perutilis Compilatio Alfragani astronomorum peritissimi, quod ad rudimenta Astronomica est opportunum*, Norimbergæ 1537. It was also known as *Liber 30 differentiarum*.

3) This version was printed with the title *Gebri Filii Affla Hispalensis De astronomia libri IX, in quibus Ptolemæum, alioqui doctissimum, emendauit* as an appendix to the *Instrumentum primi mobilis* by Petrus Apianus, Norimbergæ 1534.

Ptolemaic, but very critical of Ptolemy on a number of technical points of small astronomical importance.

Ptolemy in the Latin Middle Ages

We must now turn our attention to the Latin Middle Ages, where the 12th century marks the great divide in the history of astronomy. Before that time Ptolemy was known by name only among authors whose astronomy was ultimately derived from Pliny and other compilers, but not from the original Hellenistic tradition. In the famous encyclopedia by St. Isidore of Seville, about A.D. 631, he is even mentioned as *Ptolemaeus rex Alexandriae* and thus confused with the Ptolemaic kings of Egypt (*Lib. Etym.* iii, 26). Accordingly Mediaeval MSS often depict him with a royal crown, an iconographical tradition persisting well into the era of printed books[4]) although the legend had been exploded long before[5]). Not until the 12th century was the real Ptolemy made known to Latin astronomers through a long series of translations of his works (Carmody, 1956). Also here astrology preceded astronomy, one of the first translations being a Latin version of the Tetrabiblos made in A.D. 1138 by Plato of Tivoli. In A.D. 1143 followed the Planisphaerium in a translation by Herman of Carinthia (H. Dalmata) and in 1154 the Optics was translated by Eugenius of Sicily. All these versions were based on previous Arabic translations. What we know of the Latin Almagest is due mainly to the researches of Haskins (1924), who has established the existence of several little known and not widely used translations. Actually at least four different versions were made, either from the Greek or the Arabic.

1) A translation made about A.D. 1160 in Sicily directly from the Greek, by an anonymous translator. It was discovered in 1909 by Lockwood and Bjørnbo independently and is the earliest known Latin version of the Almagest. Four MSS are known, of which only Vat. Lat. 2056 is complete. It has a preface by the translator with the incipit: *Eam pingendi Gratias antiqui feruntur habuisse consuetudinem*, whereas the incipit of the Ptolemaic text itself is: *Valde bene qui proprie philosophati sunt, o Sire*. The small number of MSS shows that this version was but little used. Actually, it was soon superseded by

2) a translation made in A.D. 1175 from the Arabic by the most industrious of

4) See e.g. Wm. Cunningham: *The Cosmographicall Glasse*, London, 1559, as reproduced in R. T. Gunther: *Early Science in Cambridge*, Oxford, 1937, p. 150.

5) This was done by an 11th-century Moorish astronomer Alī ibn Ridwan, called Haly Abenrudian by the Latins (see Suter, 1900, p. 103 and Sarton, 1927, p. 729), who in the preface to his Arabic translation of the *Tetrabiblos* showed that the stellar positions in the Almagest referred to an epoch in Imperial times, the longitudes of the fixed stars quoted being much too large to correspond to the times of the Ptolemies (because of precession). This fine example of historical criticism based on astronomy was known to Nicole Oresme who in the 14th century translated Haly's book into French, cfr. the MS Paris Bibl. Nat. F. Franç. 1348, 2vb–3ra: *Et trouuons que cetay ptholomee, qui composa le livre de almagesti, nomme les lieux des estoilles selon la rectification delles et selon ce que il doivent estre mises ou temps emperieres des romains et fust moult grant apres les temps des roys de alexandrie. Pour quoy nous entendon que cest ptholomee ci le ludian ne fu pas un des roys de alexandrie.* – But this late insight had no effect on Mediaeval history of astronomy in general.

all 12th century translators, Gerard of Gremona, who lived and worked at Toledo. It has the incipit (of Book I): *Bonum scire fuit quod sapientibus non deviantibus.* This became the standard version of the Almagest during the following three or four centuries. Carmody (1956) notes the existence of at least 32 extant MSS, without saying whether they are all of them complete.

3) A third translation with the incipit: *Bonum quidem fecerunt illi qui perscruti sunt scientiam philosophie* is extant only in fragments. According to Haskins (1924 p. 106) it was made from the Arabic, probably in Spain sometime during the 13th century.

4) Finally, there exists a fourth version of the first four books of the Almagest with the incipit *Preclare fecerunt qui corrigentes scienciam philosophie, O Syre.* Only one copy is known and the text can have had no wide circulation. The translator is anonymous; he worked before A.D. 1300 but we do not know where.

It is probable that other complete or partial translations were made, but in the present state of Mediaeval studies it is impossible to arrive at even an approximate survey of the whole field. Not even a check list of the extant MSS has been published. Peters and Knobel (1915) list 21 Greek, 8 Latin, and 4 Arabic MSS. Zinner (1925) has 24 MSS from what he calls the "German Cultural Domain" including Italy, Belgium, Poland, and Czekoslovakia, besides Germany and Austria, but gives only very little bibliographical information without distinguishing between the various translations.

Accordingly we must acknowledge that the literary tradition of the Almagest during the Middle Ages is very much a matter of future research, of equal importance to our understanding of both Mediaeval and Renaissance astronomy. Here we can venture only upon a few tentative conclusions.

First, the number of MSS and their distribution over the various translations shows that Gerard of Cremona's version was the most widely used. This is confirmed by the astronomical bibliographies of the Middle Ages, among which the most comprehensive is the famous 13th-century *Speculum Astronomie*, probably written by St. Albert the Great[6]). It first mentions a book with the incipit *Sphaera celi* ascribed to a certain Nembroth gigas[7]), but only to discard it as of too little use and erroneous (*paruum proficui et falsitates nonnullæ*). According to the Speculum a good introduction to astronomy is the Almagest: *Sed quod de hac scientia utilius inuenitur, est liber Ptolemæi Pheludensis, qui dicitur Græce megasti, Arabice almagesti, Latine minor perfectus, qui sic incipit: Bonum fuit scire, etc. quod tamen in eo diligentiæ causa dictum est prolixe ....* The incipit quoted here reveals that the reference is to Gerard's translation.

Second, we can conclude that in spite of the high esteem in which the Almagest was

6) *B. Alberti Magni* [...] *Opera*, Tom. V, Lugduni, 1651, pp. 656 ff. For the problem of the authorship, see Thorndike, 1923, vol. 2, pp. 692–717, and Nallino, 1948, p. 317.
7) The mythical astronomer Nembroth (or Nimrod) appears in Latin astronomy already in a 9th-century treatise *De forma celi* to which Haskins (1924 p. 336 ff.) has drawn attention, with the further remark that "Astronomical tables under his name are known to have been current in Arabic" (p. 338). However, this statement is not borne out in E. S. Kennedy (1956) in which the name does not occur.

held by Mediaeval astronomers it was but rarely studied from cover to cover. The small number of extant manuscripts points to the conclusion that the majority of astronomers never possessed a copy nor even had access to one in a library. The reason is not difficult to guess. The Almagest is a highly technical work which still to-day presents many difficulties and obscurities for a modern reader. It must have been much more difficult to a Mediaeval scholar equipped with less astronomical and mathematical knowledge. We have to remember that e.g. the *Elements* of Euclid were translated only a short time before the Almagest, and that it must have been an enormous task to assimilate such long and demanding treatises.

Now astronomy was one of the seven liberal arts, which all through the Middle Ages formed the basic framework of higher education, both in the schools of the 12th and the universities of the 13th and later centuries. This means that any Mediaeval student had to follow a course of astronomy as a preparation for his degree of Master of Arts, before he was allowed to go on to more specialized studies of law, medicine, or theology. At this introductory level it was clearly impossible to make use of the Almagest as a student's textbook. It remained a technical work for the advanced and competent scholar, while the ordinary student had to be provided with some more easily digestible manual. From the literary point of view the history of Mediaeval astronomy is the history of how Ptolemaic astronomy was assimilated, taught and moulded in its particular Latin form without direct use of the Almagest itself.

We shall not here follow this process in any detail, but only indicate a few of the main roads along which it proceeded. At a high level it was possible to use an abbreviated version or a paraphrase of the Almagest. Of this genre we have already mentioned the *De astronomia* by Jābir ibn Afflaḥ, which gave a summary of the whole work. A widely used manual wrongly ascribed to the same author was the *Almagestum parvum* or the *Almagesti minoris libri VI.* It was accessible in a Latin translation by Gerard of Cremona (Incipit: *Omnium recte philosophantium*) and gave an introduction to the more mathematical sections of the Almagest.

Even works of this kind were too difficult for students who had just learned their spherical astronomy from a very elementary manual like the widely used *Tractatus de sphera* by Johannes de Sacrobosco (ed. Thorndike, 1949). This extremely popular work contained about a page and a half of planetary theory, and had to be supplemented by an introduction to planetary theory at about the same level. Several such introductions are known, but the most popular was a certain *Theorica planetarum.* This work has been ascribed to Gerard of Cremona as well as to the 13th century astrologer Gerard of Sabbioneta, but seems to be the work of an unknown author from the latter half of the 13th century (Pedersen, 1962). The text was not free from errors, the most fatal being a wrong determination of the stationary points. But it had the advantage of being brief, with clear definitions of the main concepts of the various planetary models of the Almagest, illustrating them with a number of good diagrams. These obvious qualities ensured its success as the standard university textbook of planetary astronomy during almost 300 years. In the 14th and 15th centuries almost every student must have known it. There are still more than 200 MSS left, besides a great number of variant editions and commentaries.

The Almagest among the Humanists and the Printers

Until well into the 15th century the Almagest appears to have been neglected by the great majority of scholars. Though they knew it by name, they cultivated astronomy by means of secondary texts. That Ptolemy's work was rescued from oblivion is the merit of a small group of scientists influenced by the new Humanism and its predilection for everything Greek, including the Greek sources of natural science. The central figure in this new development was a young Austrian scholar, George Peurbach (1423–1461) who spent most of his academic life at the university of Vienna[8]). Here the Humanistic movement had been inaugurated by the famous Italian scholar Aeneas Silvius Piccolomini (later Pope Pius II), who was Papal Legate in Austria 1443–1455 and, at least on one occasion, lectured at the university, where the masters gave lectures on classical subjects as early as 1451. Peurbach's humanistic proclivities appear from the fact that in the year 1454 he lectured both upon the Aeneid of Virgil, and on planetary theory. The latter lectures were made public in the form of a new manual called *Theoricae nouae planetarum*. This book was clearly intended to replace the old Theorica planetarum as a standard textbook. It is interesting to note that Copernicus presumably learned his first astronomy from Peurbach's book in 1491–96, when he was a student at Cracow, where Albert of Brudzewo had lectured upon it[9]). In the course of time it came to enjoy an immense popularity. Zinner (1938) mentions no less than 56 printings of the Latin text up to 1653, besides translations into French, Italian, and Hebrew. From the linguistic point of view the book would not seem to stem from a Humanistic pen, written as it is in the usual Latin idiom of Mediaeval astronomers. It also follows the old Theorica in the arrangement of the subject matter, and the general impression is that of a very careful exposition along traditional lines. Ptolemy is quoted in a few places towards the end of the book, but nothing indicates that Peurbach had made the Almagest the subject of any detailed study when he prepared his lectures. Despite his interest in classical literature he is not yet a Renaissance scholar in astronomy.

The following years saw a radical change in this situation, caused by the activities of two of the very greatest among the Byzantine scholars who had sought refuge in the West in the troubled years before Constantinople fell to the Turks in 1453. One of these was the Cretan philosopher George of Trebizond (1395–1484) who lived in Italy from about 1430 and became secretary to the Pope. For Nicholas V he produced a great number of translations from the Greek, among which was a complete Latin

8) There is still no satisfactory work on Peurbach. Most of what we know about him has been assembled by E. Zinner (1938).

9) Albert's lectures have been published by L. Birkenmajer: *Commentariolum super theoricas novas planetarum Georgii Purbachii . . . per Mag. Albertum de Brudzewo*, ed. L. A. Birkenmajer, Cracow, 1900.

version of the Almagest published in 1451 (Incipit: *Peroptime mihi videtur, O Syre*). This was the first time Ptolemy's main work appeared in a translation from the original, if we disregard the less influential Sicilian version mentioned above.

But George of Trebizunt's translations were often too hastily made, and open to criticism by other scholars. Moreover, he was a militant Aristotelian who often offended against the prevalent Platonic sympathies of other Renaissance humanists. Finally, it is doubtful whether he possessed the necessary astronomical qualifications for producing a Latin Almagest. It would have fared better with a philologically competent astronomer as translator. That such a person could be found in Vienna was discovered in A.D. 1460 when the city was visited by another eminent humanist and papal legate, this time the famous cardinal Johannes Bessarion (1403–1472) who was at the very centre of the Humanistic movement in Rome; it was his private collection of Greek MSS which later became the kernel of the San Marco Library at Venice. Bessarion's antagonism to George of Trebizond was well known and resulted in 1469 in a treatise called *In calumniatorem Platonis*. But already during his stay at Vienna he tried to remedy the defects of the Almagest translation by persuading Peurbach to make a new translation from the Greek. Peurbach went to work with great eagerness and succeeded in finishing a draft translation or paraphrase of the first six books before his premature death in 1461. The unfinished MS was taken over by his pupil Johannes Müller, or Regiomontanus (1436–1476), who the same year followed Bessarion to Rome; later he travelled with the Cardinal to various places in Italy before in 1465 he became professor at the new university of Pressburg. There he stayed until 1471, when he finally settled down at Nuremberg.

Here at Nuremberg Regiomontanus created something which Latin Europe had never seen before – a scientific research institution outside the universities and independent of them. It was given generous support by a rich citizen called Bernard Walther (1436–1508) and comprised an observatory, a workshop for astronomical instruments, and last but not least a printing press for publishing scientific literature.

With this undertaking begins the history of the printed editions of the Almagest. An advertising sheet (Zinner, 1938, Pl. 26) published by Regiomontanus about A.D. 1474 announced that he had for sale the planetary theory of Peurbach, which thus became the first printed book on theoretical astronomy[10]). But the sheet also announced that Regiomontanus intended to publish a new translation of the Almagest: *Magna compositio Ptolemaei*; *quam uulgo uocant Almagestum noua traductione*. There is no doubt that Regiomontanus had the translation by Peurbach in mind from which we may conclude that he himself had the intention of finishing it. However, again an untimely death intervened, and the project came to nothing. Not until 1496 did a German printer at Venice publish the part of the work completed by Regiomontanus[11]).

10) *Theoricae nouae planetarum Georgii Purbachii astronomi celebratissimi*: *cum figurationibus oportunis*; 20 leaves in-fol., Nuremberg, ca. 1473: Ex officina Joannis de Regiomonte habitantis in Nuremberga oppido Germaniae celebratissimo.

11) *Epytoma Joannis de Monte regio in Almagestum ptolemei*, Venetiis (Hamman) 1496. – Other editions are Basle, 1543, and Nuremberg, 1550.

Thus the first attempt at making the fundamental work of astronomy accessible in a Latin printed version had produced nothing but a torso – an incomplete, free, paraphrase. At a time when the cry for printed editions of almost any classical author was heard all over Europe this was a serious situation, particularly since Ptolemy's other main work, the Geography, had already been on the market for many years, printed as early as A.D. 1475 by Hermann Lichtenstein at Vicenza, and later in 1482 (Ulm), 1486 (Ulm), and 1490 (Rome). Also the astrological Tetrabiblos had appeared in Latin as the *Liber quadripartitus*, printed in 1484 and 1493 (Venice), thus confirming the general rule that in Ptolemy's case the astrologer was always made known before the astronomer.

The honour of having published the first complete translation of the Almagest fell to the printer Petrus Lichtenstein, who in 1515 printed the old translation by Gerard of Cremona[12]). Thus the printed Almagest entered the world of the Renaissance in a Latin translation made from an Arabic version of the Greek original. In other words, it was the Almagest of the Mediaeval astronomers, and therefore apt to awaken the suspicion of any scholar of Humanistic inspiration. A translation directly from the Greek was much to be preferred, and in 1528 the famous Giunti printing house at Venice thought it proper to publish the unreliable Latin version made in 1451 by George of Trebizond[13]).

These two diverging versions made it imperative to have a printed edition of the original Greek text. It was prepared by Simon Gryneus and Joachim Camerarius from a (now lost) MS at Nuremberg formerly in the possession of Regiomontanus, and said to have been valued higher than a province by Bessarion. The edition appeared at Basle in 1538[14]). Thus, at long last, the original Almagest had been resurrected. But the two unsatifactory Latin versions remained the only translations for centuries to come.

The new editions made it possible to study the more technical aspects of the Almagest better than before at a time when the general level of mathematical knowledge was enhanced, partly due to a first rate textbook[15]) of plane and spherical trigonometry by Regiomontanus, published in 1533 long after his death. In a way the great work of Copernicus may be regarded as one of the principal results of this renewed interest in theoretical astronomy as a mathematical discipline, and for still a century to come Ptolemy kept his position as the greatest of all astronomers. On the isle of Hven Tycho Brahe had Ptolemy's portrait painted, and gave it an honourable place in his house above a Latin epigram of his own composition. As late as 1651 the Bolognese astronomer Giov. Batt. Riccioli (1598–1671) gave the title of *Almagestum*

12) *Almagesti Cl. Ptolemei Pheludiensis Alexandrini, astronomorum principis, opus ingens ac nobile, omnes cælorum motus continens*, Venetiis, 1515, in officina Petri Liechtenstein.
13) *Almagestum seu magnae constructionis mathematicae opus plane divinum Latina donatum lingua ab Georgio Trapezuntio.* In urbe Veneta, (Junta), 1528.
14) *Claudii Ptolemaei Magnae Constructionis, id est Perfectae coelestium motuum pertractationis, Libri XIII*, Basileae, (Joh. Walder), 1538.
15) *Doctissimi Viri* [...] *Joannis de Regio Monte de Triangulis omnimodis libri quinque*, Norimbergæ, (Petreius), 1533. – Facsimile edition with English translation: *Regiomontanus on Triangles*, by B. Hughes, Madison, Wisc. 1967.

novum to his immense handbook of astronomy – one of the most comprehensive ever written – and hailed Ptolemy as the Prince of Astronomers, Geographers, and Astrologers.

The Declining Fame of Ptolemy

But about this time, after a reign of almost 1500 years, Ptolemy's star began to fade. Copernicus had shown the mathematical possibility of a heliocentric theory of the Solar system, and even though the new theory used the same mathematical technique as the Almagest, many found it preferable. This was not only for philosophical reasons, but also because it explained the order of the planets which in the old astronomy had been arbitrary. Kepler had provoked a much more fundamental theoretical revolution by deducing his laws for the motion of the planets from Tycho's observations, and Galileo had finally, by means of the telescope, proved the impossibility of upholding the traditional physical notions of the nature of the heavenly bodies. These notions were mainly Aristotelian, but had become deeply connected with Ptolemy's name. But even a militant Copernican like Galileo held Ptolemy in high esteem, maintaining that both he and Aristotle would have been Copernicans if they had known the observations and other reasons which had moved Copernicus to change the system of the world (*Opere*, vii, p. 562, 1933).

Others were less judicious, and at last it became clear that the new astronomy not only meant the ruin of Ptolemaic planetary theory, but also pulled down his own scientific reputation. In the 18th century only a few had sufficient historical sense to realize that even if Ptolemy's astronomy had to be discarded, he himself had been a better scientist than most of those who now talked haughtily of his mistakes (that he was no Copernican) or his dogmatism (that he believed in natural circular motions). This degradation set in with the great French astronomers, among whom was Jerome le Français Lalande (1732–1807) who tried to rob him of any original significance: *One is convinced that Ptolemy was no observer, and that he took everything which is good in his work from Hipparchus and his other predecessors*, says Lalande in the sketch of the history of astronomy which he included in his *Astronomie* (Lalande, 1792, p. 119). From now on the myth of Ptolemy as a mere imitator of Hipparchus is commonplace in almost any account of the history of astronomy with the notable exception of Laplace (1796 p. 235). To Lalande, Ptolemy is important only because he has preserved some valuable observations of the ancients, and because the Almagest kept astronomy alive during the dark ages until the time when Copernicus revitalized it. But though it was thus impossible to rob Ptolemy of all astronomical importance, Lalande found it quite unforgivable that he should have tainted his memory with astrology: *One ascribes to Ptolemy a book on astrological predictions called Liber quadripartitus. However most critics find this to be unworthy of the learning and reputation of the author, the more so since in his Almagest there is nothing similar to that kind of phantasy* (Lalande, 1972 p. 119). This unsuccessful attempt to save Ptolemy from his own personal belief in astrology reveals the curious lack of historical sense which was one of the characteristics of the Enlightenment. Lalande's evaluation of Ptolemy is clearly based, not upon any deep understanding of the role played by astronomy and astrology in Hellenistic society, but upon enlightened 18th century opinion of what an astronomer ought to do.

An even worse fate befell Ptolemy when Jean-Baptiste-Joseph Delambre (1749–1822) picked up the thread from Lalande. Delambre was not only a highly competent astronomer and one of the fathers of the metric system, but also one of the best informed among the historians of astronomy of all times. His *Histoire de l'Astronomie Ancienne* (1817) is still a mine of information on ancient astronomy. Nevertheless, Delambre seems to have been singularly blind when he had to evaluate Ptolemy himself. Thus he is angry with Ptolemy for his somewhat cavalier description of astronomical instruments: *In the first chapter of Book 5* ⟨of the Almagest⟩ *he assures us that he has observed the Moon with an astrolabe which he describes giving neither its radius nor the division in degrees. This is hardly the manner in which an astronomer describes an instrument which he has been using* (Delambre, 1817, p. xxvii). In the same way Delambre is dissatisfied with Ptolemy's description of his observations, particularly the measurement of the circumference of the Earth mentioned in Chapter 3 of the first Book of the Geography: *Is it thus one tells of new and important procedures – if they are real* (ibid., p. xxv)? The latter insinuation is no slip from the pen – Delambre makes it explicit in words allowing no ambiguity at all: *We can admit that Ptolemy has really seen these eclipses, but we cannot conclude that he was an observing astronomer. They give him a value of the eccentricity of the Moon so close to that which he deduces from the three Babylonian eclipses, that one is tempted to believe that his* ⟨own⟩ *three eclipses are computations made by means of tables* (ibid., p. xxvii). Or elsewhere: *Did Ptolemy observe? Are the observations which he claims to have made not calculations by means of tables, and examples intended for a better understanding of his theories* (ibid., p. xxv)?

This is without doubt the most serious accusation against Ptolemy ever made. Now he is no longer a rather insignificant follower of Hipparchus – he is no less than a scientific cheat, swindling with the very method of science and betraying the empirical character of astronomy, setting forth results computed from theory disguised as empirical data in support of this same theory. After that it is only small comfort that Delambre condescends to admit that Ptolemy had the sole merit of being a forerunner of Kepler, because he in his Lunar theory twisted one of the circles into an oval shape resembling a Kepler orbit: *One is permitted to believe that this hypothesis of Ptolemy has guided Kepler towards the ellipse* [. . .]. *Thus Ptolemy would have the honour of having prepared the way for Kepler, who again prepared it for Newton. This reflection, which so far as I know has not been made by any astronomer, will show that even if it seems that we would at times take some of his glory from Ptolemy and render it to Hipparchus, on the other hand we give him his due measure of justice, our only purpose being to write an exact history of astronomy* (Delambre, 1817, vol. ii, p. 381 f.).

Ptolemy Re-evaluated

One might think that Ptolemy's star would now have set never to rise again. Lalande and Delambre were authorities, and their attack was supported by an intimate study of Ptolemaic astronomy as a theoretical system. Yet their position suffered from one weakness which in the long run should undermine their conclusions. They wore the spectacles of their own century and were willing to condone the errors of Ptolemy only in so far as he could be regarded as a forerunner of one or another of the great pioneers of the astronomy of their own day. Therefore their judgment could not be final; it lasted only until historical research made it possible to see the Almagest and its author in their proper historical setting.

The main prerequisites for a better understanding of Ptolemy and his work were better editions than the old 16th century printings which Lalande and Delambre had to use. The first step in this direction was taken by a French scholar, the abbé Nicolas Halma (1756–1828), who at the beginning of the 19th century conceived a great plan of publishing a new Greek edition of the complete works of Ptolemy accompanied by a translation into a language with which every scholar in Europe was familiar, i.e. into French. This project was never completed, but it resulted in a new version and French translation of the Almagest[16]), and later of the important commentary to the same work by Theon of Alexandria[17]), besides the Geography and some minor works. Halma's preface to the Almagest is a curious but important document. His many excuses for undertaking this work are a testimony to the low ebb of Ptolemy's reputation at the time. Nevertheless, Halma succeeded in persuading Delambre to provide the new edition with a series of notes and explanations. Moreover, the preface contains the first serious study of the Almagest tradition based upon an intimate knowledge of all printed editions and a great number of manuscripts. In this respect it has preserved its value until to-day.

In a way Halma's text came both too late and too early; it was too late in so far as Lalande and Delambre had given their final judgment before having access to a good text. But it was too early because classical philological scholarship had not yet learned to deal with old texts and to make critical editions from a survey of all the manuscripts in the manner which emerged during the latter half of the 19th century. The need for such an edition was felt more and more as time went on, and towards the end of the century Johan Ludvig Heiberg (1854–1928) was commissioned to make a new, critical, and complete edition of Ptolemy to be published by Teubner in Leipzig. This project was not finished. In 1898–1903 Heiberg published the Almagest in Greek in a text which is now considered authoritative, and continued with a volume of *Opera minora* (1907), when his death intervened. The result is that we still have neither

16) *Composition Mathématique de Claude Ptolémée, trad. pour la première fois du grec en français sur les manuscrits originaux de la Bibliothèque Impériale de Paris*, par Halma, et suivie des notes de Delambre, I–II, Paris, 1813–1816.
17) *Commentaire du Théon d'Alexandrie sur le livre premier de la composition mathématique de Ptolémée*, traduit pour la première fois du grec en français par Halma, I–II, Paris, 1822–1825. Cf. the critical edition of Books I–IV by A. Rome.

a complete version of Ptolemy's works in the original Greek, nor a complete translation into a modern language.

Translations of the Almagest itself are also scarce. In French we are still left with Halma's old translation. In German there is a very useful and exact translation made from Heiberg's text by K. Manitius (1912–13) who also wrote a number of notes of great importance for the understanding of the astronomical contents of the text. A reprint of this translation with a number of corrections by O. Neugebauer was published in 1963 with a curious advertisement from the publishers, stressing the importance of Ptolemy in the times of space research ...[18]). The first English translation (by Taliaferro) appeared in 1952.

The modern preoccupation with the Almagest in a reliable text and a good translation is the background of the re-evaluation which is now taking place. Ptolemy is no longer considered a mere compiler of earlier results in astronomy, but as a highly competent and original astronomer responsible for some of the most impressive features of planetary theory as set forth in the Almagest. One important branch of research is therefore concerned with the problem of separating his original contribution from that of Hipparchus and others. Another investigates the question of to what extent Ptolemy was influenced by Babylonian astronomers whose observations he certainly knew and made extensive use of, although inside an entirely different theoretical framework (Neugebauer, 1951, p. 161).

On the other hand the problem of the nature and authenticity of Ptolemy's observations has found no definite solution despite a considerable amount of work. But everything considered there is no doubt that today Ptolemy appears in a better light than in the days of Delambre. For B. L. van der Waerden (1954, p. 200) he marks the culmination of Greek astronomy. Similar voices have been raised by Sundman (1923), Okulicz (1933), and Rome (1938). There have even been attempts to show that he was one of the principal exponents in Antiquity of what can be somewhat summarily described as the scientific method (Kattsoff, 1947). And quite regardless of how Ptolemy's sincerity and integrity is evaluated there is no doubt whatever that he remains forever one of the most prominent figures in the history of astronomy, and that – in the words of O. Neugebauer (1951, p. 3) – *One cannot read a single chapter in Copernicus or Kepler without a thorough knowledge of the Almagest.*

18) »Die Zahl der Interessenten an dem Werk ist nicht zuletzt auch durch die Entwicklung der Weltraumforschung ständig gestiegen«.

CHAPTER 2

Physics and Philosophy in the Almagest

The Almagest begins with a preface [I, 1; Hei 1, 4][1]) in which the whole work is dedicated to a certain Syrus, about whom we know nothing. He must have been rather closely connected with Ptolemy, who dedicated other works to him also, thus the Planetary Hypotheses, the Handy Tables, and the Tetrabiblos, i.e. the main body of his astronomical and astrological writings.

This introductory chapter is of considerable importance from a philosophical point of view. In general, the Almagest is a highly technical and closely reasoned account of mathematical astronomy, written in a style which but rarely reveals anything about the personality of its author and his more philosophical opinions. The subject matter is everything and the author stands back all the time to let it appear in as objective a light as possible. In fact, the preface is one of the very few sections of the work in which we get more than a glimpse of Ptolemy's ideas on such general questions as epistemology, the classification of the sciences, the human value of scientific research, and the ethical implication of the study of astronomy.

The Classification of Knowledge

Let us first consider the Ptolemaic classification of the various kinds of knowledge. It can be illustrated by the following scheme:

philosophy	practical		
	theoretical	theology	
		mathematics	arithmetic
			geometry
			astronomy
		physics	

Here the first major division is between practical and theoretical knowledge. Ptolemy shows that this distinction is essential by means of an example: A man may have great insight in moral questions, and even extend it through his everyday experience of life, without any specialized education in ethics; but it is impossible to acquire any knowledge of the universe without theoretical studies in astronomy. How important this distinction was to Ptolemy appears from the fact that the Preface opens with a

1) This means Book I, Chapter 1, Heiberg's edition vol. 1, page 4. All references to the *Almagest* will be given in a similar way.

O. Pedersen, *A Survey of the Almagest*, Sources and Studies in the History of Mathematics and Physical Sciences, DOI 10.1007/978-0-387-84826-6_2,

praise of the 'genuine philosophers' who first noted it. These philosophers are not mentioned by name, but the distinction between practical knowledge resulting in human skill in arts and crafts, and theoretical knowledge leading to intellectual understanding is a commonplace among all philosophers of the Peripatetic School both in Antiquity and the Middle Ages. Therefore, the commentator Theon of Alexandria (ed. Rome, p. 321) has no difficulty in tracing it back to Aristotle himself, who adverts to it in many of his works (e.g. *Metaph.* vi, 1, 1025 b ff.). However, it is worth noticing that Ptolemy does not include the third Aristotelian category – poetic knowledge – in his scheme, although he was deeply impressed by the universal truth, the aesthetic function, and the emotional value of astronomy.

Since Ptolemy had a marked predilection for theoretical knowledge, we must now consider his division of this branch into theology, mathematics, and physics. Here again he followed Aristotle, who deduced these categories by his theory of abstraction. At the bottom of the scale we find 'physics', or natural science, which was defined by Ptolemy as the study of the ever changing material world. For Ptolemy physics was concerned with questions like e.g. whether a material substance is hot, or cold, or sweet, etc. Most of its objects belong to the corruptible part of the universe inside the sphere of the Moon. This is, roughly speaking, in agreement with Aristotle, who defined physics as the study of 'nature', and nature as the principle of 'motion' or change (*Phys.* ii, 1, 192 b, cf. *Metaph.* vi, 1, 1025 b). This implies both that physical objects are material, and that most of them (all apart from the heavenly bodies) are subject to generation and corruption. What Ptolemy omits to mention – but certainly maintains – is that in physics such objects are studied with particular regard to their materiality.

At a more abstract degree of knowledge we find the science of mathematics, which to Ptolemy is an investigation into the nature of the forms and motions of material bodies, implying notions like figure or shape, quantity, magnitude, space, and time. Again this is in agreement with the Aristotelian doctrine (*Phys.* ii, 2, 193 b) of mathematics as an abstract science of the physical world, studying the same bodies as one does in physics, but without regard to their constituent matter and concentrating on their 'mathematical' properties.

It is one of the main tenets of Aristotelian epistemology that it is possible to carry the process of abstraction even further and to study the world under still more general points of view in terms of being, existence, cause, effect, and similar 'metaphysical' concepts. The science resulting from this most general kind of inquiry is called theology both in Aristotle (*Metaph.* vi, 1, 1026 a) and in Ptolemy. In the former it is crowned with a proof of the existence of a Supreme Being called God and conceived as the 'Prime Mover' of the whole universe. In another place it is defined more directly as the knowledge of the invisible, immaterial, and unchanging God (*Metaph.* iv, 8, 1012 b, cf. xii, 7, 1072 b). Ptolemy also infers the existence of God in this philosophical sense from a metaphysical argument: The senses are incapable of analyzing the phenomena of the material world into their constituent matter, forms, and motions. This can be accomplished only by reason, with the result that reason not only shows us motion as something different from matter and form, but also reveals an ultimate cause of all motion, i.e. God.

On Certainty in the Various Fields of Knowledge

The three main branches of theoretical knowledge have not the same epistemological status. In his Preface Ptolemy is concerned primarily with the degree of certainty which they provide. Here he finds characteristic differences which to him are sufficient motivation for his personal preference for mathematics as the most perfect discipline. Like Plato, Ptolemy is deeply impressed by the perfect character of mathematical truth. Theology has no similar certainty, because its object is absolutely invisible and incomprehensible. Physics, too, is unable to attain absolute truth because of the corruptibility and obscurity of matter. This is why there is no hope that philosophers will ever agree, or arrive at a common opinion on these two branches of knowledge.

It is obvious that here Ptolemy is more agnostic than Aristotle. To the latter theology was the same as metaphysics, and he would surely have maintained that metaphysics is able to analyze the whole realm of existence in terms of metaphysical relations of an absolutely true character. But to Ptolemy theology is defined by means of the concept of God as a transcendent being beyond human comprehension, – with the corollary that theological statements are less certain than those of mathematics. Moreover, the reference to the disagreement between philosophers reveals that Ptolemy belongs to a later age than Aristotle. In fact, they were separated by a period of five hundred years in which one conflicting school had succeeded another and many different opinions on the nature of God had been ventured. This explains Ptolemy's reticence towards theology. He is certainly no unbeliever, as both the preface and several other places in the Almagest show. But he cannot ascribe to theological statements the same epistemological quality as to mathematical theorems. As we are going to see, this view entails the consequence that Ptolemy warns us against too much anthropomorphism in science. Before entering upon the very complicated theory of latitudes in Book XIII (see page 355) he tries to refute the opinion of those philosophers who maintain that astronomers ought to construct simple theories only, since the simplicity of the Supreme Being should be reflected in the description of His works. Ptolemy reminds us, first, that philosophers are not agreed upon what 'simple' means, and second, that what is simple to God may appear far from simple to man. Simplicity in God does not entail 'simplicity' in the description of nature.

In the same way physics has to be put in a more humble position for the reason that its subject matter – the material world – is both obscure and corruptible. The obscurity of matter is a commonplace in all Greek philosophy and it is no wonder that Ptolemy subscribes to this idea. It is a little more curious that he refers also to the corruptibility of matter as an obstacle making absolute truths about the physical world impossible.

Ptolemy's Conception of Mathematics

It would seem that the reason for this opinion is a conception of science slightly different from that of Aristotle to whom a true scientific statement has the character of being invariably true at all times and under all circumstances. Thus the statement that heavy bodies have a natural tendency to move towards the centre of the world is always true regardless of all the contingent vicissitudes of actual heavy bodies. So the existence of change and corruptibility in the physical world does not exclude the possibility that there may be invariable relations among its ever changing things, expressed in eternally true statements. Here Ptolemy seems to disagree when stating in the preface that *astronomy alone is concerned with the investigation of a world remaining the same throughout all eternity* [...] *which is a characteristic property of science* [I, 1; Hei 1, 6]. In other words, to Ptolemy, eternally true statements can only be about eternally unchanging objects.

We must now examine Ptolemy's conception of mathematics a little closer. First, mathematics is a very general science. It can be grasped through the senses or without them, just as there is a mathematical aspect of any kind of material being – corruptible as well as incorruptible. Perishable substances change with their changing forms and are thus objects of mathematical study, just as well as the unchanging forms of eternal beings of an ethereal nature, i.e. the heavenly bodies.

Next, mathematics leads to absolutely certain truths which, once established, can never be subjected to doubt. This is because mathematical truth is acquired by means of logical proofs, regardless of whether they are concerned with arithmetic or geometry. It is this logical character which conveys a certainty never to be attained through the testimony of the senses, and which is foreign to physics. Ptolemy confesses that we here have his own deepest personal motive for becoming a mathematician.

Mathematics, Astronomy, and Astrology

One could think that this might have disposed him to become a 'pure' mathematician. He did, in fact, a small amount of theoretical research in this field (see page 47) but the preface does not conceal that astronomy was his main interest, at any rate when he wrote the Almagest: *This is the reason which has moved us to devote ourselves – to the best of our abilities – to this pre-eminent science in general* [i.e. mathematics], *but particularly to that branch of it which is concerned with the knowledge of the Divine and Celestial Bodies*, after which follow the words quoted above on the unchanging nature of the heavens and the ensuing timelessness of astronomical truths.

At this point there arises a difficulty: How could Ptolemy become an astronomer if only mathematics was able to satisfy his longing for eternal truth? This question seems to be connected with an apparent ambiguity in Aristotle's opinion on where astronomy should be placed in the hierarchy of knowledge. In the *Physics* (ii, 2, 194 a) he calls astronomy *rather physical than mathematical* and compares it with optics and harmonics (i.e. the theory of music). But in the *Metaphysics* (xii, 8, 1073 b) astronomy appears as *one of the mathematical sciences nearest to philosophy*. In Ptolemy so much is clear that astronomy is not tainted with the obscurity and uncertainty ascribed to physics, notwithstanding the fact that it is concerned with the heavenly bodies. These bodies have a material character both to Aristotle and Ptolemy, although their matter is of a particular, ethereal nature. Nevertheless, this does not prevent astronomy from being of a loftier status than the other natural sciences.

The solution of this puzzle seems to be that Ptolemy drew a different boundary between mathematics and physics from Aristotle's. It is not said in so many words, but it is as if he thinks as follows: If one studies the changing and corruptible material world the resulting science belongs to physics, even if it has a mathematical form. On the other hand, a study of the unchanging and eternal heavens of a similar mathematical form belongs to the science of mathematics.

If this is the correct interpretation, it is clear that Ptolemy's classification of science rests upon a different foundation from that of Aristotle. The latter had defined the limits of physics, mathematics, and metaphysics (or theology) by means of the formal objects only of these sciences; and since physics studies natural objects in their material form he was compelled to include any natural science in physics, even if its statements were expressed by means of mathematics. Ptolemy goes a step beyond Aristotle in using the material object of science also as a basis for classification. It is the different properties of celestial and terrestrial matter which enable him to lift astronomy out of the realm of physics into the domain of mathematics.

It should be noticed that at this particular point he had no great following among ancient philosophers of science, who in general kept to the more logical and unambiguous Aristotelian principle of regarding the formal object only. Later, in the Middle Ages, the difficulty was felt anew and gave rise to the doctrine of *scientiae mediae*. These are sciences which, like astronomy, optics, harmonics, and mechanics, are concerned with a mathematical description of the material world. Accordingly they have something in common with both physics and mathematics without being totally subsumed under either of these headings[2]).

The status of astronomy as a part of mathematics is also, perhaps, the explanation of the very remarkable fact that the Almagest is completely free of astrology. This is not because Ptolemy did not believe in the possibility of making predictions from the stars. On the contrary, his Tetrabiblos is one of the most comprehensive manuals of judicial astrology ever written (see page 400). But astrology is concerned with the influence of the celestial world upon the terrestrial, and the influence of the stars is very closely connected with their physical nature. This means that in astrology one cannot abstract from the material qualities of the stars; for that reason astrology must be classified as a part of physics, and not treated on a par with mathematical

2) Thus St. Thomas Aquinas maintains that *some of the sciences applying mathematics to natural phenomena are placed in between, for instance music and astronomy. However, they are more related to mathematics because what interests the physicist in them is rather the material aspect, but what interests the mathematician is more the formal aspect. – In Libr. Boethii de Trinitate* q. 5, a 3, ad 6^{m}.