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The Almagest, like Euclid's Elements of four-and-a-half centuries earlier, was a work of such thoroughness that it had the effect, undesirable to the historian, of rendering superfluous all earlier writings on its subject. This was true, not only of the mathematical astronomy treated in the Almagest, but also of Ptolemy's treatises on optics, harmonics, and cartography. The disappearance of all but a few earlier works within these disciplines may be attributed to Ptolemy's evidently successful project of compiling what Professor Pedersen aptly calls an "Encyclopedia of Applied Mathematics." In the case of astronomy the eradication of earlier writings was so severe that even those that would have provided the technical background preparatory to studying the Almagest fell into disuse (the handful of surviving examples of pre-Ptolemaic Greek astronomy are too disparate and, in some cases, of too poor quality to have formed any sensible course of pedagogy), and thus from at least the fourth century, when Pappus and Theon wrote their commentaries, it was evident that the Almagest required explanation in order to be understood by readers lacking the competence that Ptolemy had taken for granted. It must be understood that Ptolemy's treatise was written on an advanced level. While his object was certainly to be comprehensive, he was not so much writing a textbook for the student as a systematic exposition of subjects already at least partially known to his reader.

Until the remarkable discoveries of the early seventeenth century made it an object of historical rather than current scientific study, the Almagest remained the fundamental exposition of mathematical astronomy. Through the original Greek as well as later Arabic and Latin translations, it guided the theory and practice of every astronomer worthy of the name for nearly 1500 years, a record of durability surpassed only by Euclid. A number of Latin printings were made in the first half of the sixteenth century and the Greek text was printed in 1538, but throughout the seventeenth and eighteenth centuries there was not one edition of the Almagest printed in any language. Following some preliminary investigations carried out largely in France at the end of the eighteenth century, the beginning of the modern historical study of the Almagest is marked by M. Halma's edition and translation (Paris, 1813-16) and J. B. J. Delambre's detailed analysis in his Histoire de l'astronomie ancienne (Paris, 1817). Since Delambre there has appeared the analysis by N. Herz (Geschichte der Bahnbestimmung von Planeten
und Cometen I, Leipzig, 1887), the critical edition by J. L. Heiberg (Leipzig, 1898-1903), the new standard translation by K. Manitius (Leipzig, 1912-13), and an extensive literature on specific subjects both astronomical and historical. Even so, beyond a handful of specialists Ptolemy's work is but imperfectly known. This could well be changed by the book under review.

Professor Pedersen's *A Survey of the Almagest* grew out of a series of lectures, and its purpose, as modestly described by the author, is "to help students of the history of astronomy to understand and appreciate Ptolemy's great and classic work." He has accomplished this task admirably. The prior knowledge of mathematics and astronomy that Ptolemy took for granted is clearly and simply explained, giving any student the requisite background to study the *Almagest* with full understanding. But far more than an introduction, the *Survey* is the most extensive and thorough study of the *Almagest* since Delambre's. Considering both the additional research of the last 150 years and the peculiarities of Delambre's attitude toward Ptolemy, Professor Pedersen has given us the most clear, correct, and useful analysis of the *Almagest* yet written. Because of its clarity and because nothing beyond elementary mathematics is assumed beforehand, even the beginning student will be able to read the book from cover to cover and achieve a really thorough knowledge of Ptolemaic mathematical astronomy. Because of its thoroughness and penetration, it will be a constant reference for the scholar studying either the *Almagest* or later sources derivative of it, which means, of course, nearly 1500 years of mathematical astronomy. Further, the book is so well written and contains such a wealth of original and careful observations that every historian who takes the time will read it through with interest and pleasure.

Professor Pedersen begins with a brief history of the knowledge and use of the *Almagest* from its composition until our own time, and then proceeds through the book in order. First is a summary and discussion of Ptolemy's introductory chapters, the only ones in which philosophy or physics enter the work to any degree. Following is a chapter on the mathematics used by Ptolemy, largely devoted to the derivation of the table of chords and to plane and spherical trigonometry. This is accompanied by a digression on the mathematics implicit in Ptolemy's procedures, principally his methods of tabulation and interpolation in handling functions of one, two, and three independent variables. Then follows a selective exposition of spherical astronomy which is generally sound, although two problems may be mentioned. The first is that all formulas and derivations are given in modern trigonometric functions rather than in chords as Ptolemy himself does. While this certainly is far clearer—the formulas in chords can be very cumbersome—the reader of the *Almagest* will have to re-convert the modern
notation into chords himself in order to follow Ptolemy's own exposition. Nevertheless, since clarity is probably to be valued above all, I believe Professor Pedersen has made the correct choice, and this applies of course to the use of modern trigonometric functions throughout the book. However, while the notation is modernized and clarified, the spherical diagrams are drawn in their archaic forms, that is, great circles are merely shown as arcs across a circle rather than properly projected as ellipses. In some cases this makes little difference, but occasional diagrams showing arcs extending off the sphere or showing a complete great circle as two arcs meeting at a point look strangely primitive. There are some omissions or modernizations that are curious. For example, the method of finding oblique ascensions is given only in the form of two exceedingly cumbersome equations rather than in the far simpler (and clearer) method of ascensional differences actually used by Ptolemy.

(Here it is well to remember that Delambre's inordinate love of extended trigonometric formulas does nothing to improve the clarity of his exposition.)

Chapter 5, on the solar theory, begins with an explanation of the calendars and epochs used in the Almagest, and goes on to discuss the length of the year found by Hipparchus and Ptolemy, kinematic models in general, the derivation of the parameters of the solar model (and their well-known errors), computation from the model, and the equation of time. Chapter 6 takes up the lunar theory on a similar scale, dividing Ptolemy's exposition into three rather than the usual two distinct models. While this is didactically helpful in describing the prosneusis of the lunar epicycle, I am not certain that it is historically correct. Nor does it completely explain Ptolemy's motivation in developing this correction in its admittedly peculiar form. In chapter 7 parallaxes and eclipse theory are treated, the former very thoroughly, the latter somewhat briefly considering the great elegance of Ptolemy's methods. Precession and the star catalogue are taken up in chapter 8. The discussion of errors and of the independence of Ptolemy's catalogue from Hipparchus's is especially notable.

Chapters 9-12 are devoted to the planets in the order, superior planets, inferior planets, retrogradations and maximum elongations, and latitude theory. In explaining the longitude theory of the superior planets, Saturn is used as the specimen for showing the derivation of parameters, an unusual choice since Ptolemy gives his most detailed presentation for Mars. The exposition is full, yet the inclusion of a worked example of one iteration of the procedure for finding the eccentricity and apsidal direction would have been helpful. There is a tentative discussion of Ptolemy's motivation in bisecting the eccentricity that is somewhat elaborated in the chapter on the inferior planets where Ptolemy actually derives the bisection
for Venus. Professor Pedersen suggests a number of possibilities, but does not follow up at sufficient length Ptolemy's explicit remark in X, 6 that the eccentricity producing the maximum equation of center was found in general to be twice as great as the eccentricity producing the proper retrograde arcs at apogee and perigee. This would indicate that Ptolemy had a method, not reported in the *Almagest* but probably reconstructable, of finding an eccentricity from the maximum and minimum retrograde arcs which could then be compared with an eccentricity found from three oppositions by the first iteration of the reported method. The former turning out to be approximately half the latter could then be a sound motivation for the bisection (although the proper location of the apsidal line would still remain a problem until the complete iterative method was applied).

Leaving aside these suggestions, Professor Pedersen's exposition will nevertheless give the reader a thorough control of Ptolemy's planetary theory. Continuing into the two following chapters, the proof of Apollonius's theorem on the location of stationary points is well presented, and the treatment of latitude theory is remarkably clear and complete. Throughout all the chapters on the sun, moon, and planets Professor Pedersen gives the pertinent observations, and all the observations are listed chronologically in an appendix. Likewise the computation and use of all tables are carefully explained. A final chapter deals briefly with Ptolemy's lesser astronomical writings, that is, the distance theory and physical models in the *Planetary Hypotheses*, the revised latitude theory of the *Handy Tables*, some astrology from the *Tetrabiblos*, and the principal projections from the *Analemma* and *Planisphaerium*.

The volume is well-produced, although occasional typographical errors in mathematical formulas could be confusing to a reader unfamiliar with the material. The reader who is familiar with the material will notice a few errors of fact, e.g., there is no reason to identify the Theon who observed Venus during the reign of Hadrian with Theon of Smyrna, the *Almagesti minoris libri VII* must be an original Latin work rather than a translation from the Arabic since its author's knowledge of Arabic astronomy is limited to writings translated into Latin. But none of this is to detract from a very important and well-executed study that should be required reading for every historian of the exact sciences.