An '*Almagest*' Before Ptolemy's?

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Among the remains of astronomy found in Greco-Roman period papyri from Egypt, truly theoretical writings are far outnumbered by tables and instructional texts.[1] On the basis of the subject matter so far as it can be determined in each fragment, I would identify the following papyri as clearly belonging under the heading of theory:

(1) *P. Aberd.* 12, a description of constellations, 2nd/3rd century A.D. (Parts of 10 lines of text.)

(2) *P. Iand.* V 84, spherical astronomy, 2nd century A.D. (Parts of 10 lines from the bottom of a column of text.)

(3) *P. Oslo* III 73, on measuring the apparent diameter of the Sun's disk, 1st/2nd century A.D. (27 lines from the top of a column of text.)

(4) *P. Oxy.* II 303, anomalistic motion of Moon with reference to a kinematic model, 1st century A.D. (Parts of 9 lines.)

(5) *P. Oxy.* LXI 4133 [Jones, *APO*, 1.69-80 and 2.2-5], analysis of dated observations of Jupiter, 2nd century A.D. (22 lines from the top of a column of text, and the left edge of the subsequent column.)

(6) *P. Oxy.* LXI 4138a [Jones, *APO*, 1.95-7 and 2.20-21], on eclipse intervals, 2nd century A.D. (Parts of 23 lines, the tops of two consecutive columns.)

(7) *P. Oxy.* LXI 4139 [Jones, *APO*, 1.97-9 and 2.22-3], on periods of lunar anomaly, 2nd century A.D. (Ends of eleven lines.)

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[1] Most of the roughly two hundred published astronomical papyri are either included in Jones, *APO* or listed with bibliographical references on vol. 1, pp. 301–307 of that work.

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(8) *P. Oxy.* LXI 4144 [Jones, *APO*, 1.108-109 and 2.40-41], discussion of kinematic model, 2nd/3rd century A.D. (Parts of 14 lines and part of a geometrical diagram.)

(9) *P. Par.* 1 [Blass, 1887], the 'Eudoxus Papyrus', 2nd century B.C. (Substantially complete manuscript, with 37 columns of text.)

(10) *PSI* XV 1490 [Manfredi, 1966], construction of tables for solar longitude with reference to a kinematic model, 1st/2nd century A.D. (Parts of 46 lines from a column of text, extending from the top margin to the bottom.)

Out of this list, items (1), (2), (4), and (8) are too poorly preserved to contribute significant historical information, while the Hellenistic papyrus (9) does not pertain to the kind of astronomy represented by the Roman period texts. Other fragments, not listed here, containing 'procedure text' material such as worked examples of computations may of course turn out to be from theoretical writings.

To reduce the census of this small body of texts by one will perhaps not appear to be a task meriting gratitude. In the present instance, however, nothing is lost and much is gained. We will see that two of the papyri listed above are parts of the same manuscript, a fact that one would scarcely have guessed from their contents, and that forces us to reconsider the character of the treatise to which they belonged.

Ptolemy's *Almagest* is the sole example from Greco-Roman antiquity of a book devoted to the exposition of advanced astronomical theory that the medieval manuscript has preserved for us. Its choice of subject matter and plan were emulated in a number of later Islamic and early modern European astronomical treatises. Whether there existed books comparable to the *Almagest* before Ptolemy is less easy to establish. Ptolemy himself makes reference to several books by Hipparchus concerning topics dealt with in the *Almagest*. From Ptolemy's reports it appears that several of Hipparchus' works shared characteristics with the *Almagest*, in particular the attempt to apply rigorous argument, mathematical deduction, and specific observational evidence (including dated observations) to the establishment of quantitative kinematic models for the heavenly bodies. On the other hand, Hipparchus' work along these lines was limited, so far as Ptolemy knew, to models for the Sun and Moon, and even the various elements of these models were determined, sometimes more than once and with varying results, in a series of separate publications. The large-scale deductive structure of the *Almagest*, in which the solar model provides an indispensable foundation for the lunar model, which in turn must be worked out before the theory of precession and the star catalogue, upon which finally the planetary models depend, can have had no counterpart in Hipparchus' works.

As for the contributions of the astronomers who lived during the three centuries between Hipparchus and himself, Ptolemy makes only a brief and disparaging comment (*Almagest* 9.2) about unnamed authors who attempted to exhibit the behaviour of kinematic planetary models by means of 'Eternal Tables'. Their performances, he writes, were faulty and 'lacked proofs', which seems to mean that their determination of the models was not founded upon a logically cogent analysis of phenomena and observations.[2] That observations were made and recorded is, however, shown by the presence of three records of observations from the first century A.D. (by Menelaus and Agrippa) in *Almagest* 7.3.[3] But Ptolemy gives us no clue how these observations were applied in their original context.

Up to the present no fragments of ancient manuscripts of the *Almagest* have come to light. If one did, it would probably be no more extensive than the scraps and pieces listed above, and the text written on it would represent only one of the several 'textures' of the *Almagest*. An instructive exercise is to open Heiberg's edition of the *Almagest* at random, and imagine what we might conjecture about the nature of the whole work if all that we had was a half page, as it might be of historical review, mathematical argument, analysis of observations, or de-

[2] The 'Eternal Tables' are mentioned also by Vettius Valens (6.2, ed. Pingree, p. 232) and in the horoscope *P. Lond*, I 130 (= Neugebauer & Van Hoesen, *GH*, no. 81, lines 1–26) cast by Titus Pitenius for a person born in A.D. 81. Both indicate that these tables yielded precise numerical positions in degrees and minutes.

[3] Ptolemy also cites a few observations by Theon 'the mathematician' in *Almagest* 9.9, 10.1, and 10.2; but this Theon seems to have communicated the observations to Ptolemy directly.

scription of the layout of a table. As it happens, these four textures of prose are recognizable respectively in papyri (7), (2), (5), and (11) in the list above. That does not necessarily mean that the works to which these fragments belonged were all proto-*Almagests*, of course. What it does show is that the kinds of thing that Ptolemy does in the *Almagest* were not exclusive to Hipparchus and Ptolemy, but typical of the astronomical literature of Ptolemy's time.

Continuing our experiment of randomly dipping in Heiberg's edition, we might try what could be guessed from the top halves of *two* pages, with their page numbers intact. If the pages are close, we likely will learn little more about the broad scope of the work than from either single fragment. A bit further apart, and we will observe more than one variety of argument concerning the same heavenly body—say, the discussion of early astronomers' period relations for the Moon, and the instructions for use of the Moon's anomaly table. Still further apart, and we discover that the treatise dealt with more than one of the heavenly bodies.

In the Spring of 2000, through the kindness of Guido Bastianini (Istituto Papirologico G. Vitelli, Florence) and Rosario Pintaudi (Biblioteca Medicea-Laurenziana), I obtained photographs of several astronomical and astrological papyri destined for publication in the long-delayed fifteenth volume of the *Papiri della Societé Italiana (PSI)* series. I was astonished to recognize in *PSI* XV 1490, item (10) in our list, the same distinctive hand that wrote both *P. Oxy.* LXI 4133, item (5) in our list, and *P. Oxy.* LXI 4134. Further examination showed that the Florence papyrus, like *P. Oxy.* LXI 4133, has a column number above the text in the upper margin, and that the margins of both papyri contain jottings—apparently nothing to do with astronomy—in the same hand, which is different from the hand that wrote the text. It is practically certain that *PSI* XV 1490 and *P. Oxy.* LXI 4133 belonged to one and the same papyrus roll, and almost as certain that their contents are parts of a single treatise. (It is conceivable, but I think improbable, that a single roll contained the end of one text and the beginning of an unrelated one; if this was the case, then the inferences in the remainder of this article are false.)

The texts of *P. Oxy.* LXI 4133 and *PSI* XV 1490 have been published (in the latter case in a professedly provisional, but accurate, transcription), and I have discussed both papyri in other articles in ignorance of their common provenance (Jones, 1999 and 2000). A summary will therefore suffice here.

P. Oxy. LXI 4133 begins with the tail end—actually just the last half on the final word—of a report of an observation of Jupiter near opposition on December 30/31, 241 B.C. The author reduces to an ecliptic frame of reference Jupiter's reported position relative to one or more nearby stars. Then he states the time interval—344 Egyptian years plus 87 days—from this observation to one of Jupiter near opposition that the author made himself on December 31, A.D. 104/January 1, A.D. 105. Again the reported position relative to nearby stars is reduced to the ecliptic. From this point the text becomes very broken, about twenty-four lines are lost, and then we have bits of the beginnings of a series of lines that evidently included citation and discussion of further observations.

Appealing to the date close to the beginning of the second century A.D., the manner of the observation, and the use of the Roman calendar, I conjectured in my original publication of *P. Oxy.* LXI 4133 that the author was the mathematician and astronomer Menelaus of Alexandria, who was active in Rome about A.D. 100. The new insights on the text offered below do not, I believe, significantly strengthen or weaken the case for this tentative attribution. However, it is enough to know that this is a treatise written less than half a century before the *Almagest.*

There are two plausible explanations of what the author is doing with the observations in *P. Oxy.* LXI 4133. Either he is trying to establish a period relation for Jupiter's anomalies, or he is investigating the long-term behaviour of some aspect of Jupiter's motion for which observations at opposition are useful. The specific technique of comparing pairs of widely separated observations of a heavenly body at the same phase and as nearly as possible the same longitude plays no part in Ptolemy's planetary theory, although analogous methods turn up in both Hipparchus' and Ptolemy's treatment of solar and lunar theory.

PSI XV 1490 preserves a longer stretch of text, but in a more broken condition so that almost every line has a gap that cannot be securely restored. The first lines prescribe how to lay out a table in which the rows represent days in a calendrical scheme that groups days in thirties and also involves a four-year cycle—pretty clearly the Alexandrian (reformed Egyptian) calendar. We are given numbers representing mean motions in longitude, 'depth' (anomaly), and latitude to record in the second line (meaning the first line below the headings). Apparently rules are then set out for filling the remainder of the table, presumably through the repeated addition of constant increments for daily progress. The heavenly body to which these mean motions belongs is not named in the preserved parts of these lines. The text's editor, Manfredi, suggested the Moon; I believe that it is the Sun, according to a model in which the Sun has a latitudinal deviation from the ecliptic and a shifting apsidal line.

Now the text turns to the topic of solar anomaly, asserting that according to either an eccentric or an epicyclic model the Sun 'increases and decreases its motion by' (i.e. has a maximum equation of) 2;24=B0. The author refers us here to a discussion in a previous section on the Sun's anomaly. The rest of the preserved text appears to describe how to construct an anomaly table for the Sun, it is not clear on what mathematical basis.

And now we may raise the question: what kind of book would contain both the kind of discussion found in *P. Oxy.* LXI 4133 and the kind found in *PSI* XV 1490? It dealt with more than one heavenly body: Jupiter as well as the Sun. And once we have gone beyond one, the most likely remaining hypothesis is that all the planets as well as the Sun and Moon were the subjects of the complete work. It was about the motions of the heavenly bodies, explained by means of kinematic models of the epicyclic and eccentric varieties. Dated observation reports fully comparable to those cited in Ptolemy's *Almagest* were adduced, and the components of the models were assigned numerical values. Tables based on the principle of analysis of motion into mean motions and corrections for anomaly were derived from the quantitative models.

So far, the resemblances to the *Almagest* are obvious. But there are important contrasts too: the reliance on planetary observations separated by a periodic restitution; the very unptolemaic solar model with its three independent mean motions; the cumbersome-sounding calendrically structured mean motion table. There are also differences in plan and scale. *P. Oxy.* LXI 4133 contains the fourteenth (and traces of the fifteenth) column of the papyrus roll; the damaged numeral in the upper margin of *PSI* XV 1490 seems to be 51, and is definitely a number in the fifties. Unless the fragments come from different rolls (which is improbable because of the marginal scrawls), the construction of the solar tables came *after* the analysis of observations of Jupiter. Perhaps this means that all the theoretical work was carried out in the first part of the treatise, and the tables reserved for the end.

One column of text would have contained a little more than an average page of Heiberg's *Almagest* edition: about two hundred forty words compared to about two hundred. Hence *P. Oxy.* LXI 4133 was the equivalent of about eleven or twelve Heiberg pages from the beginning of the roll, and *PSI* XV 1490 was about thirty Heiberg pages further along. Obviously there was not space for treatment of most of the other heavenly bodies in the thirteen lost columns of the beginning of the roll, so we must assume that this was a treatise in more than one 'book'. Even so, the scale of treatment has to have been much smaller than in the *Almagest*, each book of which averages nearly a hundred pages. The comparative concision is in fact apparent in the extant fragments, especially in *PSI* XV 1490, where the author turns from mean motion to anomaly table with a briskness unimaginable in Ptolemy.

What makes the *Almagest* so long is primarily the space it devotes to mathematical analyses. Our hypothetical treatise must have had much less of these; and we may recall Ptolemy's complaint that the presentations of his more immediate predecessors 'lacked proofs'. I have argued in [Jones, 1999] that Ptolemy probably saw this treatise, and plundered it for observation reports. From the point of view of methodology he would probably have professed to find little to learn from it.

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