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Ptolemy's *Canobic Inscription* and Heliodorus' Observation Reports

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Introduction

In A.D. 146 or 147 Ptolemy erected an inscription in the Egyptian city of Canopus, near Alexandria, recording numerical parameters serving to define the kinematic models of the heavenly bodies. The original inscription has not survived, but it apparently still could be seen in the sixth century, when the Alexandrian philosopher Olympiodorus made a passing reference to it (see Appendix 1), and a transcription of it was made in late antiquity—perhaps by Olympiodorus himself—and included among various texts prefacing Ptolemy's *Almagest* in certain medieval codices. The text of the inscription was first printed by Ismael Boulliau (Bullialdus) as an appendix to his *editio princeps* of Ptolemy's *On the Criterion*.[1] Following an unsatisfactory edition by Nicholas Halma, J. L. Heiberg produced a critical text as part of his edition of Ptolemy's "minor" astronomical writings.[2]

Useful studies of the *Canobic Inscription* (henceforth *CI*) and its relation to Ptolemy's other works were made by B. L. van der Waerden and O. Neugebauer; but we owe to N. T. Hamilton the key insight into the significance of the *CI*, that it represents a version of Ptolemy's astronomical system that preceded the *Almagest*, at least in the form that that treatise has come down to us.[3] Hamilton's discovery forms the core of a fundamental 1987 paper by Hamilton, N. M. Swerdlow, and G. J. Toomer (henceforth *HST*) that supersedes practically all the older research on the *CI*. Most recently, Swerdlow has explicated the last part of the inscription, concerning the cosmic tones associated with the heavenly bodies.[4]

One outcome of the work of *HST* is that Heiberg's text no longer provides a satisfactory basis for studying the *CI*.[5] Heiberg made a good choice of manuscripts on which to base his edition, and provided accurate collations, but it is now possible to identify many passages in which Heiberg did not adopt the correct reading from among transmitted variants, or where the reading can be securely emended. It is also easier now to isolate those passages where serious doubt about the authentic reading persists. The present paper offers a text, based on fresh collations of the manuscripts consulted by Heiberg, but reconsidered in

[1] Boulliau 1663.

[2] Halma 1820; Heiberg 1907, esp. clxxv and 147–155.

[3] Van der Waerden 1959, 1818–1823; Neugebauer 1975, v. 2, 913–917. Hamilton's discovery was first reported in Toomer 1984, 205 n. 51.

[4] Swerdlow 2004.

[5] The need for a new edition was pointed out by *HST* 71 note 1.

the light of current scholarship on the *CI*. The annotation does not attempt to subsume the detailed commentary of Hamilton *et al.* and, on the musical section and the scholion appended to it, Swerdlow's commentary.

I have also included a new edition of a brief text that immediately follows the *CI* in the manuscripts, comprising a set of reports of astronomical observations by the fifth century Alexandrian Neoplatonist Heliodorus. This text was also discovered for modern scholarship by Boulliau, and published in his *Astronomia Philolaica*.[6] Heiberg inserted a critical text in the *prolegomena* of the volume of Ptolemy's minor works, but again an improved text is possible, especially as a result of the analysis of the observations by Neugebauer.[7]

The manuscripts, and editorial conventions.

The text of the *CI* is too brief to allow one to establish the relationships among the manuscripts without recourse to evidence from the other texts that they contain. Heiberg showed that two of the oldest surviving copies of the *Almagest*, the 9th century *Vat. gr.* 1594 and the 10th century *Marc. gr.* 313 were copied from a lost manuscript written in capitals, perhaps dating from the 6th century.[8] In this manuscript the *Almagest* was prefaced by (1) the anonymous *Prolegomena to the Almagest*, (2) the *CI*, and (3) the observations of Heliodorus.[9] These texts were copied in *Vat. gr.* 1594 and *Marc. gr.* 313, but subsequently a pair of quires in *Vat. gr.* 1594 (between the present ff. 8^v and 9^r) containing the end of the *Prolegomena* and the other two texts was lost. Before this loss occurred, however, two 13th century copies of the three introductory texts were made from *Vat. gr.* 1594: *Par. gr.* 2390 and *Vat. gr.* 184.[10] Two further copies, the 14th century *Laur*. 28,1 (*CI* on ff. 14^v–15^r) and the 15th century *Vat. gr.* 1058 (*CI* on ff. 497^r–499^r), apparently descend from *Par. gr.* 2390 and in any case contribute no readings of independent textual value.[11]

Our text is therefore based on the following three copies and the presumptive stemma shown in fig. 1, employing the sigla that Heiberg adopted for his text of the *CI*:

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[6] Boulliau 1645.

[7] Heiberg 1907, xxxiv–xxxvii. Neugebauer 1975 vol. 2, 1038–1041.

[8] Heiberg 1907, xxxiv. Note that Heiberg used different sigla for these manuscripts in his editions of the *Almagest* and of the *CI*.

[9] On the *Prolegomena* see Mogenet 1956 and Knorr 1989, 155–177.

[10] Since the text of the *Almagest* in *Vat. gr.* 184 does not descend from the common exemplar of *Vat. gr.* 1594 and *Marc. gr.* 313, Heiberg assumed that its text of the *CI* was also independent of that exemplar. Pingree (1994, 81), however, has pointed out that *Vat. gr.* 184 contains a transcription of the *Almagest* scholia from *Vat. gr.* 1594 on ff. 25r–80r, immediately following the *Prolegomena*, *CI*, and Heliodorus text. Pending a satisfactory study of the textual history of the *Prolegomena*, the most plausible hypothesis is that the introductory texts too were copied from *Vat. gr.* 1594. (Moreover, the text of the *Almagest* itself in *Vat. gr.*184 was evidently corrected by collation with *Vat. gr.* 1594; see Heiberg 1907, cxvii–cxx.)

[11] Heiberg 1907, xxxix–xl shows this for the text of the *Almagest* in Laur. 28,1. Unlike the other manuscripts mentioned above, *Vat. gr.* 1058 contains the *Prolegomena* but not the *Almagest* itself.

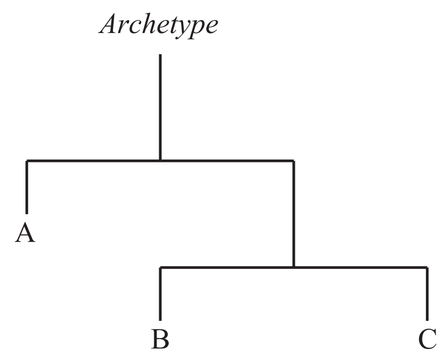

Fig. 1. Presumed stemma for the *Canobic Inscription* and Heliodorus' observations.

A *Marc. gr.* 313, ff. 28^{v}–29^{v}
B *Par. gr.* 2390, ff. 13^{v}–14^{v}
C *Vat. gr.* 184, ff. 23^{v}–24^{v}

It may thus be inferred that where A, B, and C have the same reading or where A agrees with either B or C against a variant reading in the remaining manuscript, A has the reading of the archetype. It should be noted, however, that some readings have been obscured or obliterated by erasures and corrections, especially in B where some contamination from the *Almagest* seems to have occurred.

In the apparatus I have been more sparing than Heiberg in reporting the frequent abbreviations and compendia. In particular I do not report instances in which a manuscript gives an abbreviated form of a word that has an indeterminate ending consistent with the reading adopted in the text. The manuscripts follow a convention, probably introduced in late antiquity, of marking whole numbers with a horizontal stroke above the numerals and sexagesimal fractions with accent-like superscripts; thus ιγ'''' represents 13 "fourths" (13×60^{-4}).[12] I have followed Heiberg's practice (which, as we now know, corresponds to the usual practice in astronomical papyri of Ptolemy's time) of placing a horizontal stroke above *all* numerals other than the zero sign; and rather than burden the apparatus with numerous reports of insignificant notational variants, I have normalized the accent marks when citing specific manuscript readings. For convenience of reference I have divided the text into numbered sections, which appear in brackets.

The layout of the inscription, and the diagram in *Marc. gr.* 313.

It seems probable on textual grounds that the archetype of the manuscript tradition of the *CI* was written no later than the sixth century. On the other hand the original transcription of the inscription from Ptolemy's original, like the transcript from Heliodorus' (or his elder brother Ammonius'?) notebook that comes next in the manuscripts, was likely the work of someone from the Neoplatonist circle of the Heliodorus and Ammonius, i.e. a few years

[12] On the late appearance of the accent marks see Rome 1936, 450 note 1.

later than the latest of Heliodorus' observations (A.D. 510).[13] Thus the most critical interval in the history of the *CI*'s transmission would have been very brief. The archetype can hardly have been the immediate transcript from the stone inscription (for practical reasons this is easier to imagine as having been made on loose sheets rather than as part of a codex or papyrus roll of the *Almagest*), but could plausibly have been an apograph of that transcript.

The degree, however, to which the archetype faithfully reproduced Ptolemy's inscription would have depended on other circumstances besides the mere number of copyings. Three and a half centuries of weathering could have significantly impaired the legibility of the inscription, the transcriber would likely have had difficulty understanding the meaning of some of its contents, and he may have been tempted to reformat it so that it would fit more efficiently on whatever medium he chose for the transcript.

The extant copies of the *CI* in manuscripts A, B, and C are similarly formatted. The oldest of them, A, may be taken as representative (cf. figs. 2–4). In all three copies the pages devoted to the inscription are written out in two columns, although in the immediately preceding and subsequent texts A and C use only one wide column per page. This follows naturally from the fact that much of the inscription consists of tabular lists of numerical parameters, which do not require the whole breadth of the page, so that we cannot infer that Ptolemy's original was laid out in double columns, though the tabular arrangement of the data is presumably authentic. Each section of the inscription has a heading, written in capitals in A, and a decorative line marks the divisions between the sections. In the ancient inscription, and again in the archetype, all lettering would of course have been in capitals. The dividing lines are evidently an editorial addition, since some are misplaced; thus the division comes *after* the words φάσεων ἀποστάσεις in line 89, and *before* πρώτων κύβων ἅμα καὶ τετραγώνων ὅροι in lines 98–99. Moreover line 109 is presented as a heading, though without a dividing line.

In all the manuscripts there are frequent abbreviations and symbols, representing both word endings (e.g. case terminations) and common astronomical terminology (κύκλος, κέντρος, ἀστήρ, the sun, moon, and planets). Except for the symbols for the sun and moon, none of these is attested in use in papyri or inscriptions before late antiquity, so they are probably due to one of the ancient transcribers, not Ptolemy. The fractional parts of numbers are consistently notated in the tabular parts of the inscription as sexagesimals.[14] As noted in the preceding section, the accent marks denoting the rank of the sexagesimal fractions are most probably an editorial addition.

[13] Heiberg 1907, xxxiv–xxxvii drew attention to the significance of the Heliodorus reports as evidence that the archetype of this family of *Almagest* manuscripts originated in the Alexandrian Neoplatonist school.

[14] *HST* 65 and 71 note 17 raise the possibility that the numbers in lines 22 and 61 employ conventional "Egyptian-style" fractions rather than sexagesimals. Since both numbers involve textual uncertainties and there are no certain instances of non-sexagesimal fractions elsewhere among the many securely read numerals in the tables, I think this possibility can be ruled out.

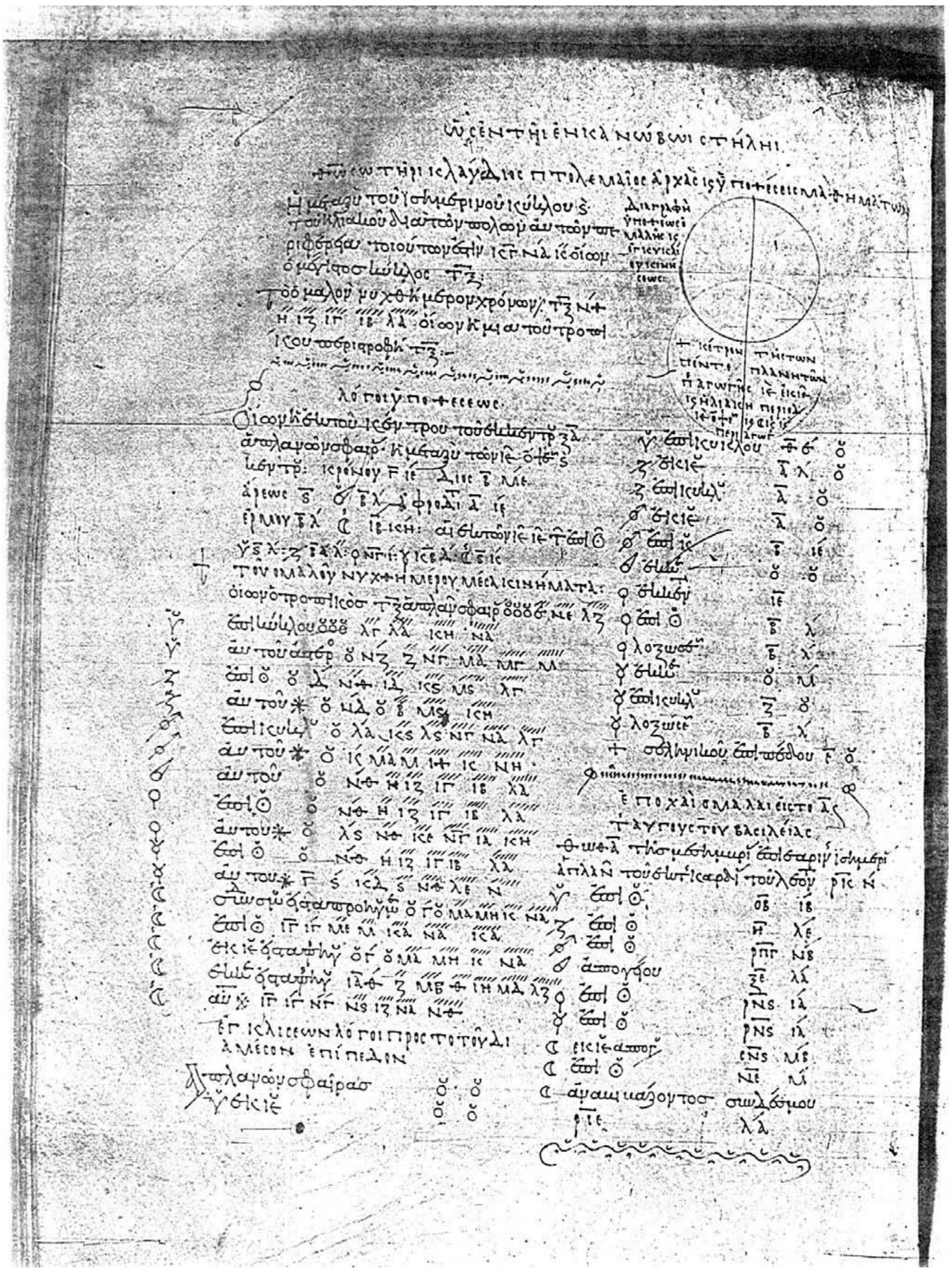

Fig. 2. *Marc. gr.* 313, f. 28v: beginning of the *Canobic Inscription*.

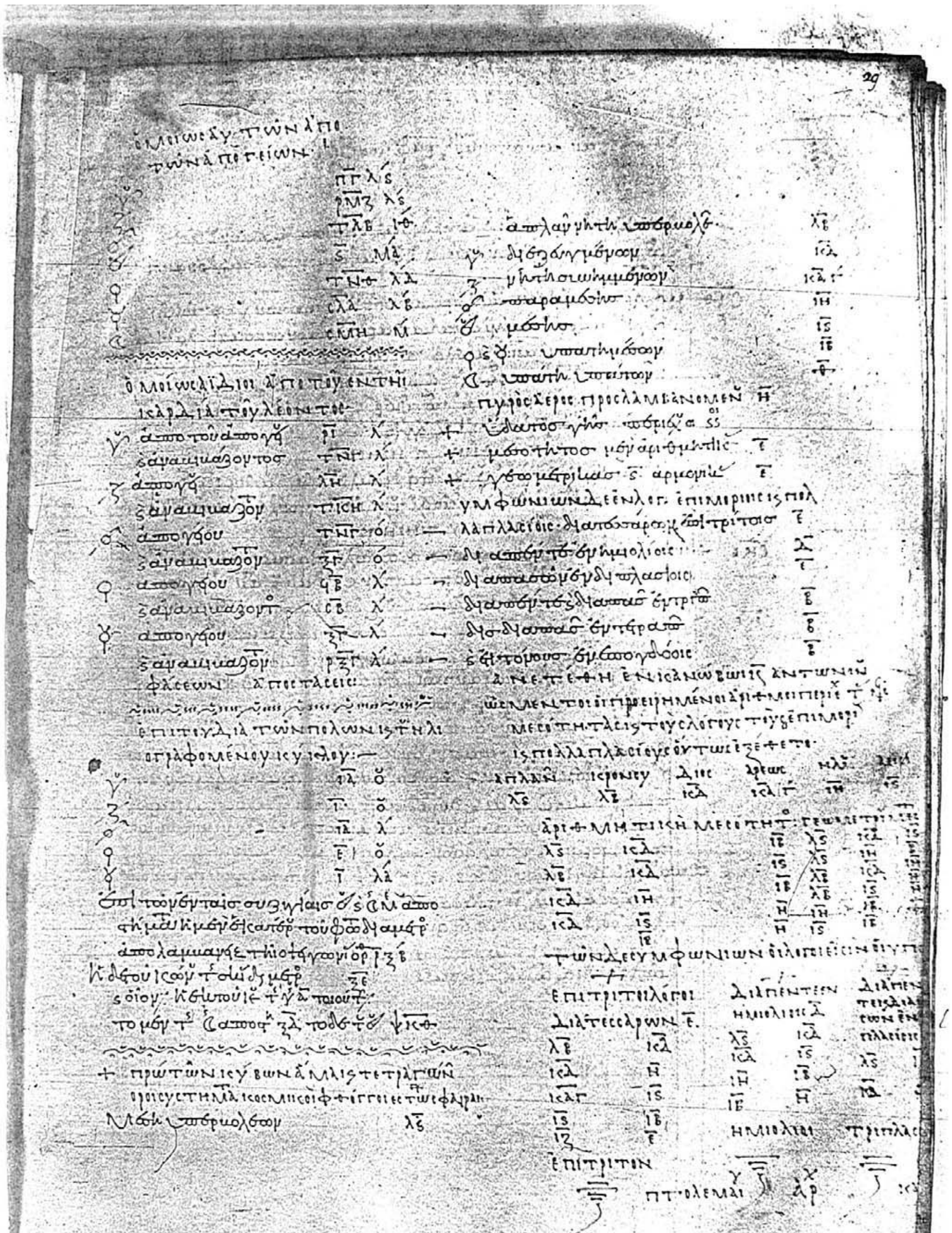

Fig. 3. *Marc. gr.* 313, f. 29r: conclusion of the *Canobic Inscription*.

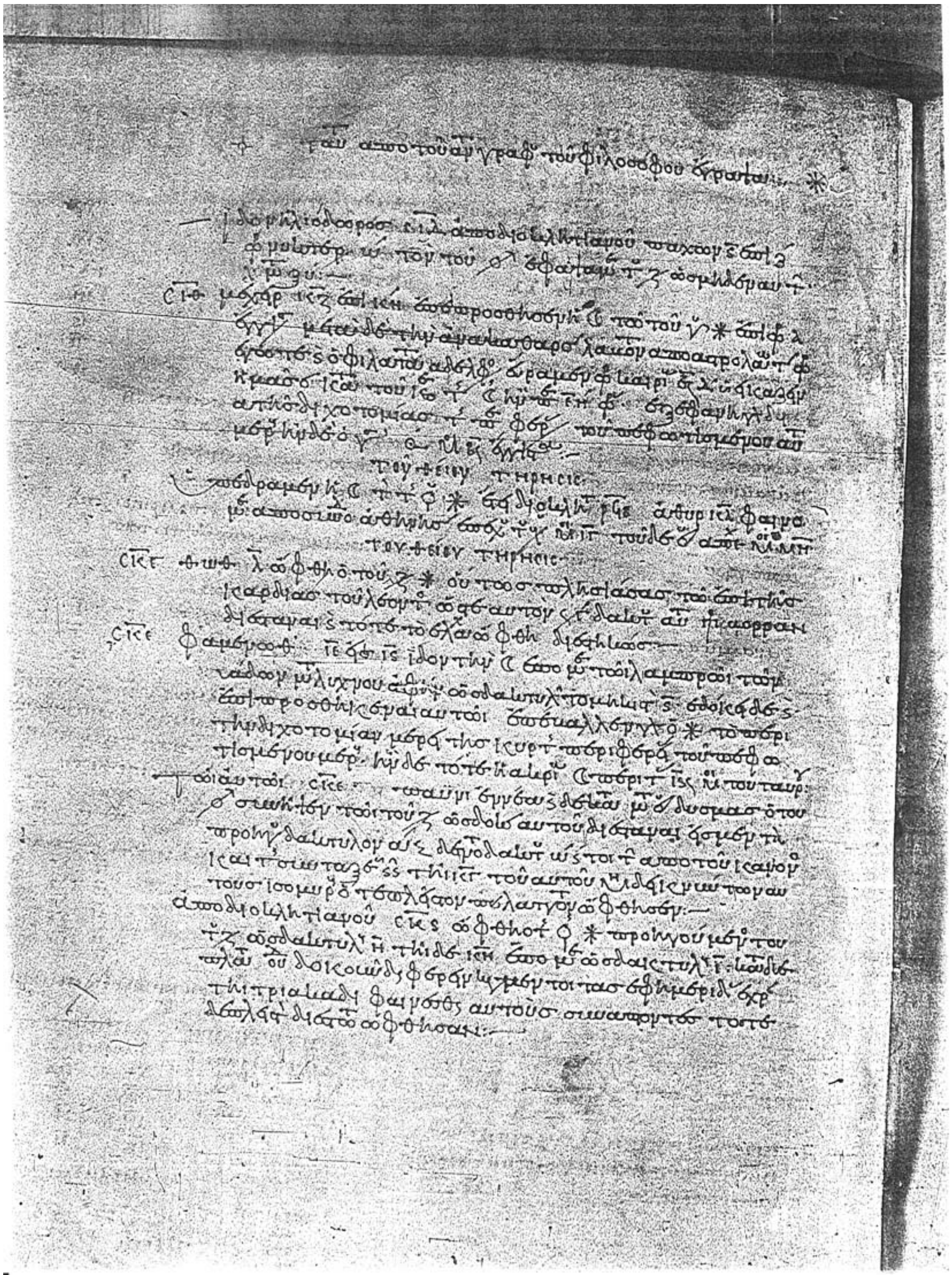

Fig. 4. *Marc. gr.* 313, f. 29^v: observations of Heliodorus.

Manuscript A alone has a diagram (cf. fig. 5), placed to the right of lines 3–6 in such a way that it appears intended to occupy a place between lines 6 and 7, i.e. one is intended to read the left column of f. 28v down to line 6, then the diagram in the right column, then continue with the remainder of the left column before the remainder of the right column. Heiberg relegates the diagram to his apparatus. It is certainly corrupt, both with respect to the drawing and to the accompanying text, but a case might be made that some sort of diagram appeared in Ptolemy's inscription at this point to illustrate the schematic placement of the various centres of circles in the kinematic models. As we have it in A, the diagram comprises two intersecting circles with their common diameter; no other points are marked. To the left of the upper, slightly smaller circle is the following text:

> διαγραφὴ ὑποθέως [*l.* ὑποθέσεως] ὁμαλῆς καὶ ἐγκυκλίου κινήσεως
> "Diagram of a model of uniform and circular motion"

Inside the lower circle is the following:

> κέτρον [*l.* κέντρον] τῆς τῶν πέντε πλανητῶν περιαγωγῆς, κέντρον ἐκκέντρ(ων?) καὶ ἡλιακὴ [*l.* ἡλιακῆς] περιόδ(ου), κέντρον ὄψεως καὶ σεληνιακῆς καὶ [? perhaps corrupted from σεληνιακοῦ ἐκκέντρου] περιαγωγῆς
> "Centre of the revolution of the five planets, centre of eccentres and solar cycle, centre of vision and of the revolution of the lunar eccentre [?]"

I would guess that the original diagram (whether Ptolemy's or an ancient annotator's)

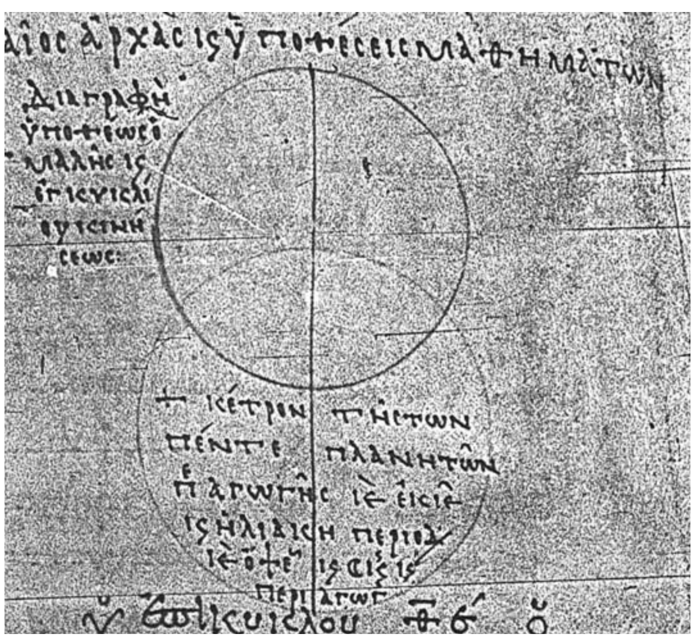

Fig. 5. Detail of *Marc. gr.* 313, f. 28v: the diagram.

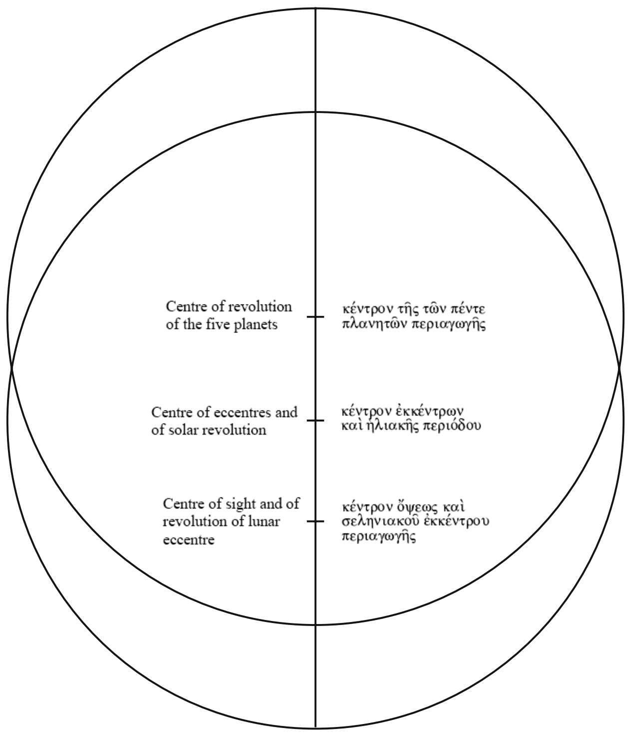

Fig. 6. Tentative restoration of the diagram.

distinguished three points along the diameter line: (1) the equant point uppermost, designated the “centre of the revolution of the five planets,” (2) the centre of the eccentric deferent (doubling as the centre of the solar eccentre), and the earth lowermost, designated the “centre of vision” (cf. end of note to section [5]).[15] It is not clear whether the garbled reference to the lunar model pertains to the same point as the “centre of vision,” considered as the centre of the circle around which the centre of the moon’s eccentre revolves (as tentatively emended and translated above), or a separately marked point for the centre of the moon’s eccentre itself (which would result if we simply deleted the troublesome καὶ). There is no suggestion that the diagram showed an epicycle. For a tentative reconstruction of the diagram see fig. 6.

Appendix 1. Olympiodorus’ reference to the Canobic Inscription.

In addition to publishing the *editio princeps* of the *Canobic Inscription*, Boulliau was the first to draw attention to one of the very few biographical mentions of Ptolemy that we have from antiquity that appear to preserve a tradition about him independent of what can be deduced from his works.[16] This is in the commentary on Plato’s *Phaedo* by the sixth

[15] For the relevance of the diagram to the problem of Mercury’s model in the *CI*, see Appendix 2

[16] Boulliau 1663, 203–213.

century Alexandrian Neoplatonist Olympiodorus.[17] At *Phaedo* 72b8 Socrates illustrates the necessity of certain contrary processes of change by the example of falling asleep and waking: "If the process of falling asleep existed, but the process of waking was not provided in compensation as coming to be out of the state of sleep, you understand that eventually everything would deprive Endymion of his point…." Commenting on this passage, Olympiodorus rationalizes the myth by asserting that Endymion was said to be always asleep because he passed his life in isolation "doing astronomy" (ἀστρονομῶν). He continues:

> And they say this [i.e. apparently that he was "always asleep"] also about Ptolemy; for he lived for forty years in what is called the Wings of Canopus [τοῖς λεγομένοις Πτεροῖς τοῦ Κανώβου] studying astronomy, and this is why he erected an inscription on the stelae there comprising the astronomical teachings discovered by him.

Olympiodorus' report, which Boulliau took seriously as a testimonium, was one of the many casualties in Boll's severe review of the ancient and medieval biographical notices of Ptolemy.[18] Recognizing that the "inscription on the stelae" refers to the *Canobic Inscription* preserved by the manuscript tradition, and noting that in the *Almagest* Ptolemy always identifies his place of observation as Alexandria, Boll asserted that Olympiodorus concocted the claim that Ptolemy worked at Canopus to account for the presence of the inscription there; he also cast doubt on the genuineness of the forty-year duration of Ptolemy's scientific career, though he could not explain the origin of this number. In their encyclopedic articles on Ptolemy both van der Waerden and Toomer endorsed Boll's dismissive judgement.[19]

Apparently no scholar since Boulliau has commented on Olympiodorus' peculiar mention of the "Wings" of Canopus except, rarely, to echo his hypothesis that it was a feature of a temple.[20] Adducing various classical and Byzantine sources, Boulliau distinguished two uses of the term πτερὸν signifying parts of temples: an inclined triangular roof, or—the sense which he attributes to Olympiodorus—buildings adjacent to the chambers of temples or labyrinths (*aedificia cellis templorum vel Labyrinthis apposita*). Inferring from the dedicatory line of the *Canobic Inscription* that it was erected in the famous temple of Serapis at Canopus, he speculated that this temple was endowed with πτερὰ in a Greek architectural style, such as Vitruvius (3.2) describes, i.e. in the manner of a portico. Ptolemy presumably installed his observational instruments in this portico while living nearby in the dwelling of the priests of Serapis, himself very likely a priest.

But there exist two other mentions of the "Wings of Canopus," which seem not to have been noticed hitherto.[21] First, a scholion to Aelius Aristides, *Panathenaicus* 97.7, writes

[17] Text Westerink 1976, 142–143.

[18] Boll 1894, 53–66.

[19] Van der Waerden 1959, 1789; Toomer 1975, 186.

[20] E.g. Allman 1911, 619: "probably elevated terraces of the temple of Serapis at Canopus near Alexandria…."

[21] None of the ancient allusions to the Wings is in the collection of texts relating to Canopus in Bernand 1976.

that the temples of Athens had certain structures incorporated in them (συνῳκοδομημένα) "signifying how the initiate must become elevated, hence the inhabitants of Egypt speak of the Wings of Canopus."[22] Secondly, the seventh-century hagiographer Leontius of Neapolis, in his life of the saintly patriarch Johannes Eleemon (John the Almsgiver, died A.D. 619), tells of one Sabinos "living at Alexandria in what are called the Wings of Canopus," who had a vision of the saint on the day that he died in Cyprus.[23]

While the Olympiodorus passage has generally been interpreted since Boulliau as referring to a part of a temple at Canopus, H. Gelzer and A. J. Festugière, who edited and commented on Leontius' text, hypothesized that the Πτερὰ Κανώβου designated a street that bends at a right angle, specifically a street in Alexandria (in Festugière's words) "qui mène à la porte de Canope."[24] Notwithstanding Festugière's presentation of this reading of the expression as an established fact, there seems to be no direct evidence supporting it; Gelzer argued for it by combining Pliny's (5.62) description of Alexandria as having been laid out in the image of a Macedonian cloak or *chlamys*, with angular projections on its periphery, and the lexicographer Hesychius' definition (s.v., ed. Latte v. 2, 317) of θετταλικὰ πτερὰ as wing-like angular projections on a Thessalian *chlamys*.

Neither of the interpretations of the Πτερὰ Κανώβου so far offered fits all the facts. Olympiodorus clearly indicates that this was both where Ptolemy lived for forty years and where he erected the *Canobic Inscription*, and both the title (added by the ancient transcriber) and the final line of the *Canobic Inscription* unambiguously state that its site was at Canopus, not Alexandria proper; yet we can see from Leontius that one could speak of Canopus in broad terms as part of Alexandria. Secondly, both Olympiodorus and Leontius tell us that the Wings of Canopus was a place where one could dwell. Thirdly, although the Wings of Canopus was evidently an established enough name to turn up without explanation in three disparate contexts, there appear to be no instances in ancient texts of Πτερὰ "of" any other city, so that this must have been a special local name, not an instance of a common terminology of urban geography. Fourthly, the point of Olympiodorus' mentioning the specific place where Ptolemy lived and worked is evidently to liken his case to that of Endymion, who is supposed to have practiced astronomy "in isolation" (ἐπ' ἐρημίας).

Two possibilities offer themselves. If we are to take seriously the connection drawn by the scholiast to Aelius Aristides between the Wings of Canopus and some feature of temples, then it would seem that the Wings must have been some sort of outbuildings of a temple complex, presumably the temple of Serapis. But the scholiast is perhaps not to be trusted; not only is the pertinence of his remark about temples as an explanation of the commented passage in Aristides highly dubious, but the rationalization of the συνῳκοδομημένα as signifying to initiates some sort of elevation seems to point to an architectural feature or motif, for example on the roof, certainly not a potential dwelling. Hence I am inclined to

[22] Text in Dindorf 1829.

[23] Text in Festugière and Rydén 1974, 408.

[24] Gelzer 1893, 153–154; Festugière and Rydén 1974, 625 and 274. (Oddly, Leontius' allusion to the Wings of Canopus is relegated to the apparatus of Gelzer's edition.)

dismiss the alleged association of the Wings of Canopus with a temple, and suggest instead that it was an outlying and sparsely inhabited site close to Canopus.

Olympiodorus' report may of course be a fiction as Boll maintained. But the story of Sabinos in Leontius removes the principal argument for thinking so, namely that the report is inconsistent with Ptolemy's indications in the *Almagest* that he observed at Alexandria. Canopus was close enough to the great metropolis, and minor enough in relation to it, that an astronomer no less than a hagiographer might feel justified in specifying a less exact but more readily identified location for the benefit of distant readers. (Differences in time-reckoning affecting astronomical observations between Canopus and Alexandria would have been close to or below the threshold of accuracy of Ptolemy's geographical data and astronomical measurements, and he surely knew that.) The working career of forty years cannot be derived in any obvious manner from the dates of Ptolemy's observations in the *Almagest* or the date of the *Canobic Inscription*, so it may come from an independent biographical tradition. Since the span from the earliest of Ptolemy's observation reports in the *Almagest* to the *Canobic Inscription* is approximately twenty years, and Ptolemy claims in his much later *Planetary Hypotheses* that he continued to revise his models in the light of observations, forty years, taken as a round number, is not implausible, though of course it could simply be a conventional figure for a long career.

Appendix 2. The model for Mercury in the Canobic Inscription.

Ptolemy's remarks on his revisions to his models in *Almagest* 4.9 single out the moon, Saturn, and Mercury as the bodies for which he had obtained improved parameters since the earlier state of his work that we now can identify with the *CI*. Ptolemy's revisions of the lunar model seem to have been concerned entirely with the mean motion of the nodal line and the interrelated parameters for the sizes and distances of the moon, the earth's shadow, and the sun. For Saturn he apparently only modified the eccentricity. By contrast, several parameters of Mercury in the *CI* are different from the *Almagest*, and there is some question whether Ptolemy's basic model structure for this planet was the same at the time of the *CI* as the peculiar model of the *Almagest* involving a rapidly revolving eccentre.

Let us first note which parameters seem *not* to have changed from the *CI*:

1) The mean motions in longitude and anomaly
2) The epoch positions of the centre of the epicycle relative to the vernal equinoctial point and of the planet relative to the apogee of its epicycle
3) Probably the epicycle radius (though a variant is attested in the manuscripts)
4) The fact that the apsidal and nodal lines are sidereally fixed[25]

[25] *HST* 66–67 suggest that since the longitude of Mercury's apogee according to the *CI* for Augustus year 1 is the same as the longitude established in *Almagest* 9.7 for the early fourth century B.C., Ptolemy had a tropically fixed apsidal line for Mercury at the time of the *CI*. If this were so, however, it would have made no sense to list the apogee's elongation from Regulus instead of its tropical longitude, as Ptolemy does for the sun.

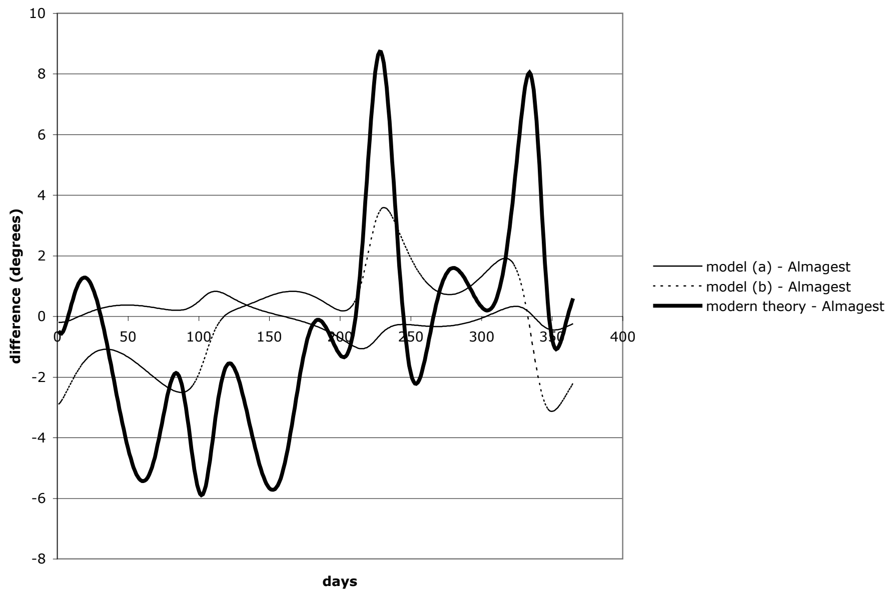

Fig. 7. Comparison of longitudes computed by models for Mercury.

On the other hand, the following parameters seem to have changed:

1) The eccentricity
2) The inclinations of the eccentre and epicycle
3) The specific elongations of the apogee and ascending node from Regulus
4) The *arcus visionis*

So far as the longitudinal motion of the planet is concerned—and excluding the possibility that Ptolemy's model at the time of the *CI* was something different from any planetary model attested in the *Almagest*—there seem to be only two prospective models worth considering: either (a) the model was exactly as in the *Almagest* (cf. fig. 11) except that the radii *TE*, *ED*, and *EC* joining the earth *T*, the equant *E*, the centre *D* of the circle carrying the eccentre's centre, and the eccentre's centre *C* were all 2 1/2 sixtieths of the eccentre's radius instead of 3 sixtieths, or (b) the model was like the *Almagest* models of the other planets (cf. fig. 10), with a sidereally fixed eccentre, the centre *C* of which bisects the line joining the earth *T* and the equant *E*.

For what it is worth, fig. 7 shows computed differences between longitudes computed by models (a) and (b) and modern theory relative to the *Almagest* model over a typical year's motion (beginning with November 15, 265 B.C.). It is hardly surprising that even model (a) diverges significantly from the *Almagest* model, although the differences are generally on the order of ±1° or less. Changing the model structure results in much larger differences, so that we can be sure that if the *CI* model was (b) its empirical justification must have been quite different from the one presented in the *Almagest*. Compared with modern theory, all three models are about equally unsatisfactory.

HST suggest that the model may have been (b) on the grounds that the inscription does not make any distinction between Mercury and the other planets, but they consider the matter to be inconclusive.[26] If the diagram in *Marc. gr.* 313, which *HST* do not discuss, is a debased copy of something that formed part of the inscription, then the argument for (b) becomes much stronger, since the text in the diagram speaks of the "centre of revolution of the five planets," evidently identifying the same point on the diagram as standing for the equant in all the models. Conversely, if other considerations were to lead us to reject model (b), then the diagram would have to be a scholiastic intrusion on the part of someone who was unaware of the special Mercury model in the *Almagest*. (My general impression, however, is that the Alexandrian Neoplatonist circle with which the preservation of the *CI* is associated was quite well informed about Ptolemy's astronomy.)

Rawlins has offered an argument that the *CI* model was (a), along the following lines:[27]

i) In *Almagest* 9.10, Ptolemy demonstrates the validity of his mean motions for Mercury through analysis of two widely-spaced observations of Mercury: the earlier one on the morning of November 14/15, 265 B.C., and the later one on the evening of May 17, A.D. 139. Ptolemy also derives his epoch position for Mercury from the earlier observation in *Almagest* 9.11. The calculations take as givens the longitudes of Mercury reduced from the observations and the parameters of the model deduced in the preceding chapters.

ii) For the 265 B.C. observation Ptolemy gives what purports to be the original report, that Mercury was one "moon" east of the straight line through the stars β and δ Sco and two "moons" north of β Sco. Using Ptolemy's coordinates for these stars for a date approximately 400 years before the epoch of the *Almagest* star catalogue, the longitude of Mercury deduced from the report should be $\lambda = 212;20° + {}^{13}/_{9}m$, where m is the assumed breadth of the moon's disk. Taking $m = 0;33°$, $\lambda = 213;8°$. Ptolemy, however, states the longitude to be 213;20°, a value that, as Neugebauer previously noted, cannot be reconciled with the report.[28]

iii) Using model (a) with the *CI* parameters, the computed longitude of Mercury for the date of the observation is approximately 213;7°, in almost exact agreement with the longitude deducible from the report.

iv) To explain this agreement, Rawlins hypothesizes that the report of the Nov. 15, 265 B.C. observation is not authentic but was concocted by Ptolemy from model (a) to yield the mean motions and epoch positions attested in the *CI* and *Almagest*, which Ptolemy had appropriated from other sources. At the time of the *CI*, Ptolemy (according to this reconstruction of events) composed an ostensible derivation of the mean motions and epoch

[26] *HST* 65.

[27] Rawlins 1987, 236–237 and 239 notes 23–24.

[28] Neugebauer 1975 v. 1, 166–167; cf. Toomer 1984, 464 note 99.

positions in which the report was accurately reduced to a longitude according to Ptolemy's star coordinates. Then, after revising the model's parameters, Ptolemy would have had to use a *different* longitude, 213;20°, to extract the same preconceived mean motions and epoch positions, but he did not trouble to change the report to bring it into agreement with this new longitude.

Rawlins's hypothesis would carry more weight if the report was an inaccurate representation of what would really have been observed on the date in question, since model (a), like the *Almagest* model for Mercury, yields longitudes that are typically in error by a degree or more, even when corrected for the systematic error in Ptolemy's tropical frame of reference. But the report is actually rather good by ancient naked-eye standards. At 3:30 UT, Mercury was approximately 1;29° north of β Sco and 0;48° east of the line through β and δ Sco, and we know from other ancient reports that observers tended to overestimate the "moon's breadth" as a unit of distance by about 50%.[29] Moreover, Ptolemy goes on to state that a report from four days later, i.e. the morning of November 19, situated Mercury one and a half "moons" east of the same line through the two stars, which is again consistent with the elongation according to modern theory (1;21°) and a similarly inflated "moon's breadth" unit; but this time the longitude implied by the report according to Ptolemy's star coordinates, approximately 213;24°, does not agree so closely with the longitude of 213;37° that would be computed from model (a).[30]

A more plausible explanation of the agreement between the Nov. 15 report and model (a) would be that the report was genuine, and Ptolemy really used it together with model (a) to derive the mean motions and epoch position that he published in the *CI*. Later, when he wrote the chapters of the *Almagest* setting out the revised model for Mercury, he wished for some reason to leave both the mean motions and the epoch unchanged; and so he pretended that the report implied the longitude that he needed to get the old results from the new model. The possibility remains, however, that the coincidence between the November 15 report and model (a) is accidental, so that we cannot be absolutely sure that the *CI* model was indeed (a) rather than (b) or an unknown model structure.

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I am grateful to Dennis Duke and to a reader for this journal for their suggestions and corrections.

[29] See for example the observation report from A.D. 104/105 in *P. Oxy. astron.* 4133, discussed in Jones 1999a v. 1, 69–71.

[30] Rawlins 1997, 29 states that the longitude derivable from the November 19 report and Ptolemy's coordinates is 213.6° (i.e. 213;36°), which would be in very close agreement with model (a) and an apparent confirmation that model (a) was somehow behind both reports. But the only way to get 213.6° seems to be to add half a moon's breadth to Ptolemy's *incorrectly* reduced longitude for the November 15 observation, which by Rawlins's hypothesis Ptolemy introduced only after abandoning the *CI* model.

Edition and translation of the texts.

[Canobic Inscription]

[1] ὡς ἐν τῇ ἐν Κανώβῳ στήλῃ.

[2] Θεῷ Σωτῆρι Κλαύδιος Πτολεμαῖος ἀρχὰς καὶ ὑποθέσεις μαθημάτων.

[3] ἡ μεταξὺ τοῦ ἰσημερινοῦ κύκλου καὶ τοῦ ἡλιακοῦ διὰ τῶν πόλων αὐτῶν περιφέρεια τοιούτων ἐστὶν κ̅γ̅ ν̅α̅ κ̅ οἵων ὁ μέγιστος κύκλος τ̅ξ̅. τὸ ὁμαλὸν νυχθήμερον χρόνων ἐστὶ τ̅ξ̅ ν̅θ̅ η̅ ι̅ζ̅ ι̅γ̅ ι̅β̅ λ̅α̅ οἵων ἡ μία τοῦ κόσμου περιστροφὴ τ̅ξ̅.

[4] λόγοι ὑποθέσεων.

[5] οἵων ἡ ἐκ τοῦ κέντρου τοῦ ἐκκέντρου ξ̿, [ἀπλανῶν σφαίρας] ἡ μεταξὺ τῶν κέντρων [ὄψεως καὶ κέντρου]

Κρόνου	γ̅ ι̅ε̅
Διὸς	β̅ μ̅ε̅
Ἄρεως	ς̅
ἡλίου	β̅ λ̅
Ἀφροδίτης	α̅ ι̅ε̅
Ἑρμοῦ	β̅ λ̅
σελήνης	ι̅β̅ κ̅η̅

[6] αἱ ἐκ τῶν κέντρων τῶν ἐπικύκλων

Κρόνου	ς̅ λ̅
Διὸς	ι̅α̅ λ̅
Ἄρεως	λ̅θ̅ λ̅
Ἀφροδίτης	μ̅γ̅ ι̅
Ἑρμοῦ	κ̅β̅ λ̅
σελήνης	ς̅ κ̅

| 1 ὡς—στήλῃ om. B | 2 θ̅ω̅ ABC | 3 post διὰ add. τὴν B | 4 περιφέρια C | τοιοῦτον C, B? | ἐστὶ C | (ν̅)α̅ corr. e κ? C | οἵων: οἱον C^1, corr. C^2 | ὁ om. C | τ̅ξ̅ in ras. C | 5 η̅: κ̅ C om. B | κόσμου scripsi τροπικοῦ ABC | τ̅ξ̅: λ̅ς̅ C | 6 λόγοι ὑποθέσεων Bullialdus λόγοι ὑποθέσεως AB om. C | 7 ξ̿ Heiberg ξ̅α̅ ABC | ἀπλανῶν σφαίρας deleui, post ὄψεως καὶ κέντρου transp. Bullialdus, ante ὄψεως transp. Heiberg | 8 ὄψεως καὶ κέντρου (scil. ἐκκέντρου) deleui ὄψεως καὶ κέντρων C | 9 ante Κρόνου add. °̅ °̅ Bullialdus | γ̅ κ̅ε̅ Bullialdus | 12 β̅ δ′ C | 13 δ̅ ιε′ C | 16 ἐκ: ἐν C | τοῦ ἐπικύκλου B | 18 ι̅α̅ λ: ι̅α̅ /// λ′ in ras. B β̅ α′ λ″ AC | 19 Ἄρεως λ̅θ̅ λ̅ om. A Ἄρεως λ̅ θ′ λ″ C, B^1 corr. B^2 in ras. | 20 ν̅γ̅ ι′ AC, B^1 ut uidetur, corr. B^2 | 21 κ̅β̅ δ′ A κ̅δ̅ δ′ C (κ̅)β̅ λ′ in ras. B

[Canobic Inscription]

[1] As in the inscription at Canopus.

[2] To the Saviour God, Claudius Ptolemy [dedicates] the first principles and models of astronomy.

[3] The arc between the equatorial circle and the solar [circle] through their poles is 23;51,20 of such units as the great circle is 360. A mean nychthemeron is 360;59,8,17,13,12,31 of such time-units as one revolution of the cosmos is 360.

[4] Parameters of models.

[5] Of such units as the radius of the eccentre is 60, the [straight line] between the centres is:

Saturn	3;15
Jupiter	2;45
Mars	6
Sun	2;30
Venus	1;15
Mercury	2;30
Moon	12;28

[6] The radii of the epicycles are:

Saturn	6;30
Jupiter	11;30
Mars	39;30
Venus	43;10
Mercury	22;30
Moon	6;20

[7] τοῦ ὁμαλου νυχθημέρου μέσα κινήματα.
οἵων ὁ κύκλος τ̅ξ̅

ἀπλανῶν σφαίρας	ō ō ō ε̅ ν̅ε̅ δ̅ ζ̅
Κρόνου ἐπικύκλου	ō β̅ ō λ̅γ̅ λ̅α̅ κ̅η̅ ν̅α̅
Κρόνου αὐτοῦ ἀστέρος	ō ν̅ζ̅ ζ̅ μ̅γ̅ μ̅α̅ μ̅γ̅ μ̅
Διὸς ἐπικύκλου	ō δ̅ ν̅θ̅ ι̅δ̅ κ̅ς̅ μ̅ς̅ λ̅α̅
Διὸς αὐτοῦ ἀστέρος	ō ν̅δ̅ θ̅ β̅ μ̅ς̅ κ̅ς̅
Ἄρεως ἐπικύκλου	ō λ̅α̅ κ̅ς̅ λ̅ς̅ ν̅γ̅ ν̅α̅ λ̅γ̅
Ἄρεως αὐτοῦ ἀστέρος	ō κ̅ζ̅ μ̅α̅ μ̅ ι̅θ̅ κ̅ ν̅η̅
ἡλίου αὐτοῦ	ō ν̅θ̅ η̅ ι̅ζ̅ ι̅γ̅ ι̅β̅ λ̅α̅
Ἀφροδίτης ἐπικύκλου	ō ν̅θ̅ η̅ ι̅ζ̅ ι̅γ̅ ι̅β̅ λ̅α̅
Ἀφροδίτης αὐτοῦ ἀστέρος	ō λ̅ς̅ ν̅θ̅ κ̅ε̅ ν̅γ̅ ι̅α̅ κ̅η̅
Ἑρμοῦ ἐπικύκλου	ō ν̅θ̅ η̅ ι̅ζ̅ ι̅γ̅ ι̅β̅ λ̅α̅
Ἑρμοῦ αὐτοῦ ἀστέρος	γ̅ ς̅ κ̅δ̅ ς̅ ν̅θ̅ λ̅ε̅ ν̅
σελήνης συνδέσμου εἰς τὰ προηγούμενα	ō γ̅ ι̅ μ̅α̅ μ̅η̅ κ̅ ν̅α̅
σελήνης ἐπικύκλου	ι̅γ̅ ι̅γ̅ μ̅ε̅ μ̅ κ̅α̅ ν̅α̅ κ̅α̅
σελήνης ἐκκέντρου εἰς τὰ προηγούμενα	ι̅α̅ θ̅ ζ̅ μ̅β̅ [θ̅] ι̅η̅ μ̅δ̅ λ̅ζ̅
σελήνης αὐτοῦ ἀστέρος	ι̅γ̅ γ̅ ν̅γ̅ ν̅ς̅ ι̅ζ̅ ν̅α̅ ν̅θ̅

[8] ἐγκλίσεων λόγοι πρὸς τὸ τοῦ διὰ μέσων ἐπίπεδον

ἀπλανῶν σφαίρας	ō ō
Κρόνου ἐκκέντρου	†ō ō†
Κρόνου ἐπικύκλου	†θ̅ ε̅ ō†
Διὸς ἐκκέντρου	α̅ λ̅ [ō]
Διὸς ἐπικύκλου	α̅ ō
Ἄρεως ἐκκέντρου	α̅ ō

| 24 κύκλος scripsi τροπικὸς ABC | 25 ἀπλανοῦς C | ō ō ō ε̅ ν̅ε̅ δ̅ ζ̅ Heiberg ō ō′ ō″ ε‴ νε⁗ λ̅ζ̅′′′′′ AC ō ō′ ō″ ε‴ ν⁗ λζ′′′′′ B ō ō′ ō″ ε‴ νε⁗ δ′′′′′ ς′′′′′′ Bullialdus | 26 ō β̅ ō λ̅γ̅ λ̅α̅ κ̅η̅ ν̅α̅ Bullialdus ō ō′ ō″ λγ‴ λα⁗ κη′′′′′ να′′′′′′ ABC | 27 ō ν̅ζ̅ ζ̅ μ̅γ̅ μ̅α̅ μ̅γ̅ μ̅ Bullialdus ō νζ′ ζ″ νγ‴ μα⁗ μγ′′′′′ μ′′′′′′ ABC | 28 ō δ̅ ν̅θ̅ ι̅δ̅ κ̅ς̅ μ̅ς̅ λ̅α̅ Neugebauer ō δ′ νθ″ ιδ‴ κς⁗ μς′′′′′ λγ′′′′′′ ABC | 29 ō ν̅δ̅ θ̅ β̅ μ̅ς̅ κ̅ς̅ Heiberg ō ν̅δ̅ θ̅ β̅ μ̅ς̅ κ̅ς̅ ō Bullialdus ō νδ′ ō″ β‴ μς⁗ (-ς e corr. C) κη′′′′′ ABC | 30 ō λα′ κς″ λς‴ νγ⁗ να′′′′′ λγ′′′′′′ in ras. C ō λδ′ κς″ λς‴ νγ⁗ να′′′′′ λγ′′′′′′ B | 31 ō κ̅ζ̅ μ̅α̅ μ̅ ι̅θ̅ κ̅ ν̅η̅ Bullialdus ō κ′ μα″ μ‴ ιθ⁗ κ′′′′′ νη′′′′′′ ABC | 32 (ō νθ′) η″ (ιζ‴ ιγ⁗ ιβ′′′′′ λα′′′′′′): κ″ B, A^1 corr. A^2 | 33 ō νθ′ η″ ιζ‴ ιγ⁗ βδ′′′′′ λα′′′′′′ C | 34 ō λς′ νθ″ κε‴ νγ⁗ ιδ′′′′′ κη′′′′′′ (κη′′′′′′ in ras.) C | 37 ō γ̅ ι̅ μ̅α̅ μ̅η̅ κ̅ ν̅α̅ Neugebauer ō γ′ ō″ μα‴ μη⁗ κ′′′′′ να′′′′′′ ABC | 39 ante σελήνης ἐκκέντρου add. σελήνης ἐκκέντρου εἰς τὰ προηγούμενα ō γ′ ō″ μα‴ μη⁗ (-η in ras. C) κ′′′′′ να′′′′′′ ABC | ι̅α̅ θ′ ζ″ μα‴ θ⁗ ιη′′′′′ μα′′′′′′ λζ C | θ̅ del. Neugebauer | 40 ι̅γ̅ γ̅ ν̅γ̅ ν̅ς̅ ι̅ζ̅ ν̅α̅ ν̅θ̅ Neugebauer ι̅γ̅ ιγ′ νγ″ νς‴ ιζ⁗ να′′′′′ νθ′′′′′′ A ι̅γ̅ ιγ′ νγ″ νβ‴ ιζ⁗ να′′′′′ νθ′′′′′′ B ι̅γ̅ ιγ′ νγ″ νς‴ ιζ⁗ να′′′′′ ηθ′′′′′′ C | 41 μέσον A | 44 θ̅? ε′ ō″ e corr. B | 45 ō″ deleui | 46 δ̅ ō′ C | 47 δ̅ ō′ C

[7] Mean motions in a mean nychthemeron.
Of such units as a circle is 360:

Sphere of the fixed stars	0;0,0,5,55,4,7
Saturn's epicycle	0;2,0,33,31,28,51
Saturn, the planet itself	0;57,7,43,41,43,40
Jupiter's epicycle	0;4,59,14,26,46,31
Jupiter, the planet itself	0;54,9,2,46,26
Mars' epicycle	0;31,26,36,53,51,33
Mars, the planet itself	0;27,41,40,19,20,58
The Sun itself	0;59,8,17,13,12,31
Venus' epicycle	0;59,8,17,13,12,31
Venus, the planet itself	0;36,59,25,53,11,28
Mercury's epicycle	0;59,8,17,13,12,31
Mercury, the planet itself	3;6,24,6,59,35,50
The Moon's node, westwards	0;3,10,41,48,20,51
The Moon's epicycle	13;13,45,40,21,51,21
The Moon's eccentre, westwards	11;9,7,42,18,44,37
The Moon, the planet itself	13;3,53,56,17,51,59

[8] Parameters of inclination with respect to the plane of the ecliptic:

Sphere of the fixed stars	0;0
Saturn's eccentre	0;0 [!]
Saturn's epicycle	9;5,0 [!]
Jupiter's eccentre	1;30
Jupiter's epicycle	1;0
Mars' eccentre	1;0

Ἄρεως ἐπικύκλου	β ιε
ἡλίου ἐκκέντρου	ō ō
Ἀφροδίτης ἐκκέντρου	⟨ō⟩ ιε
Ἀφροδίτης ἐπικύκλου	β λ
Ἀφροδίτης λοξώσεως	β λ
Ἑρμοῦ ἐκκέντρου	ō μ
Ἑρμοῦ ἐπικύκλου	ζ ō
Ἑρμοῦ λοξώσεως	β λ
σεληνιακοῦ ἐπιπέδου	ε ō

[9] ἐποχαὶ ὁμαλαὶ εἰς τὸ α′ ἔτος τῆς Αὐγούστου βασιλείας Θῶθ α′ τῆς μεσημβρίας.

ἀπὸ ἐαρινῆς ἰσημερίας·

ἀπλανῶν τοῦ ἐπὶ τῆς καρδίας τοῦ Λέοντος	ρκ ν
Κρόνου ἐπικύκλου	οβ ιβ
Διὸς ἐπικύκλου	η λε
Ἄρεως ἐπικύκλου	ρπγ νβ
ἡλίου ἀπογείου	ξε λ
Ἀφροδίτης ἐπικύκλου	ρνς ια
Ἑρμοῦ ἐπικύκλου	ρνς ια
σελήνης ἐκκεντρου ἀπογείου	σνς μβ
σελήνης ἐπικύκλου	νε μ
σελήνης ἀναβιβάζοντος συνδέσμου	ριε λα

[10] ὁμοίως αὐτῶν ἀπὸ τῶν ἀπογείων

Κρόνου	πγ λς
Διὸς	ρμζ λς
Ἄρεως	τλβ ιθ
ἡλίου	ϙ μα
Ἀφροδίτης	τνθ λδ
Ἑρμοῦ	σλδ λβ
σελήνης	σμη μ

| 50 ō add. Hamilton et al. | 53 ō λα′ C | 56 ἐπίπεδον C | 57 ποχαὶ B | α′[1]: δ′ C | α′ τῆς[2]: δ′ τῆς C ἀπὸ B | 59 ἀπὸ scripsi ἐπὶ ABC | 60 ἐπὶ: ἐκ A | τῆς om. B | τοῦ om. B | ρκ η′ BC | 64 ξε λ Hamilton et al. ξε λα′ ABC | 66 ρης ια′ C | 67 σνς λαβ′ C | 68 νε λβ′ C | 70 αὐτῶν A (errat Heiberg), C om. B τῶν Heiberg | 74 ϙ μα Hamilton et al. ς μα′ AB, C in ras. | 75 τηθ λδ′ C | 76 σλα λβ′ A | 77 σμη λα′ C

Mars' epicycle	2;15
The Sun's eccentre	0;0
Venus' eccentre	0;15
Venus' epicycle	2;30
Venus' slant	2;30
Mercury's eccentre	0;40
Mercury's epicycle	7;0
Mercury's slant	2;30
Lunar plane	5;0

[9] Mean positions on Augustus year 1, Thoth 1, noon.

From the vernal equinoctial point:

Fixed stars, the one on the heart of Leo	120;50
Saturn's epicycle	72;12
Jupiter's epicycle	8;35
Mars' epicycle	183;52
The Sun's apogee	65;30
Venus' epicycle	156;11
Mercury's epicycle	156;11
The apogee of the Moon's eccentre	256;42
The Moon's epicycle	55;40
The Moon's ascending node	115;31

[10] Similarly, from their apogees:

Saturn	83;36
Jupiter	147;36
Mars	332;19
The Sun	90;41
Venus	359;34
Mercury	234;32
The Moon	248;40

[11] ὁμοίως ἀίδιοι ἀπὸ τοῦ ἐν τῇ καρδίᾳ τοῦ Λέοντος

Κρόνου ἀπὸ τοῦ ἀπογείου	ρ̅ι̅ λ̅
καὶ ἀναβιβάζοντος	†τ̅ν̅γ̅† λ̅
Διὸς ἀπογείου	λ̅η̅ λ̅
καὶ ἀναβιβάζοντος	τ̅κ̅η̅ λ̅
Ἄρεως ἀπογείου	τ̅ν̅γ̅ 𐅷
καὶ ἀναβιβάζοντος	σ̅ξ̅γ̅ 𐅷
Ἀφροδίτης ἀπογείου	σ̅ϙ̅β̅ λ̅
καὶ ἀναβιβάζοντος	σ̅β̅ λ̅
Ἑρμοῦ ἀπογείου	ξ̅γ̅ λ̅
καὶ ἀναβιβάζοντος	ρ̅ξ̅γ̅ λ̅

[12] φάσεων ἀποστάσεις, ἐπὶ τοῦ διὰ τῶν πόλων καὶ τοῦ ἡλίου γραφομένου κύκλου

Κρόνου	ι̅α̅ 𐅷
Διὸς	ι̅ 𐅷
Ἄρεως	ι̅α̅ λ̅
Ἀφροδίτης	ε̅ 𐅷
Ἑρμοῦ	ι̅ λ̅

[13] ἐπὶ τῶν ἐν ταῖς συζυγίαις ἡλίου καὶ σελήνης μέσων ἀποστημάτων ἡ μὲν ἑκατέρου τοῦ φωτὸς διάμετρος ἀπολαμβάνει πρὸς τῇ ὄψει γωνίας ὀρθῆς ρξβʹ, ἡ δὲ τοῦ κώνου τῆς σκιᾶς διάμετρος ξεʹ, καὶ οἵων ἐστὶν ἡ ἐκ τοῦ κέντρου τῆς γῆς α̅ τοιούτων ἐστὶ τὸ μὲν τῆς σελήνης ἀπόστημα ξ̅δ̅, τὸ δὲ τοῦ ἡλίου ψ̅κ̅θ̅, πρώτων κύβων ἅμα καὶ τετραγώνων ὅροι.

[14] συστήματος κοσμικοῦ φθόγγοι ἑστῶτες

ἀπλανῶν σφαίρας	†μέση ὑπερβολαίων†	λ̅ς̅
Κρόνου	νήτη ὑπερβολαίων	λ̅β̅
Διὸς	⟨νήτη⟩ διεζευγμένων	κ̅δ̅
Ἄρεως	νήτη συνημμένων	κ̅α̅ γʹ

| 78 ἀίδιοι ABC αἱ διαστάσεις Bullialdus | 80 τ̅η̅γ̅ λʹ C | 83 τ̅η̅γ̅ 𐅷ʹ C | 84 σ̅ξ̅γ̅ 𐅷 Hamilton et al. ξ̅γ̅ 𐅷ʹ ABC | 85 σ̅ϙ̅β̅ λ̅ Hamilton et al. ϙ̅β̅ λʹ AB ρ̅β̅ λʹ C | 88 ρ̅ν̅γ̅ λ̅ Hamilton et al. | 89 φάσεων ἀποστάσεις om. BC | ἡλίου γραφομένου Heiberg ἡλιογραφομένου ABC | 95 ι̅ λ̅ Bullialdus ι̅ λαʹ AC ι̅ λδʹ B | 97 ὀρθας C | 98 οἷον A ἐστὶ C | 99 ἀπὸ τη C | ρώτων B | 101 συστήματος Heiberg συστήματ() A συστήματα BC | κοσμικοῦ scripsi κοσμικοὶ ABC | 102-110 ἀπλανῶν, Κρόνου, Διὸς, Ἄρεως, ἡλίου, Ἀφροδίτης καὶ Ἑρμοῦ, σελήνης, πυρὸς ἄερος, ὕδατος γῆς initio seqq. ll. posita ABC corr. Heiberg (sed ἀπλανῶν post σφαίρας transp.) | 102 σφαιραι AC | μέση: μετὰ Swerdlow monente Vincent | ὑπερβολεων A, C^1? corr. C^2 in ras. | 103 ὑπερβολεων AB, C^1? corr. C^2 in ras. | 104 νήτη add. Swerdlow

[11] Similarly, everlasting [? positions] from the [star] on the heart of Leo:

Saturn’s apogee	110;30
and ascending node	353;30 [?]
Jupiter’s apogee	38;30
and ascending node	328;30
Mars’ apogee	353;0
and ascending node	263;0
Venus’ apogee	292;30
and ascending node	202;30
Mercury’s apogee	63;30
and ascending node	163;30

[12] Intervals for phases, on the circle described through the poles and through the sun:

Saturn	11;0
Jupiter	10;0
Mars	11;30
Venus	5;0
Mercury	10;30

[13] At the mean distances of the Sun and Moon at syzygies, the diameter of either luminary subtends at the sight $^{1}/_{162}$ of a right angle, and the diameter of the cone of the shadow is $^{1}/_{65}$ [of a right angle], and of such units as the radius of the earth is 1, the distance of the Moon is 64 and that of the Sun is 729, terms simultaneously of the first cubes and squares.

[14] Fixed pitches of the cosmic tuning:

Sphere of the fixed stars	mese hyperbolaion [?]	36
Saturn	nete hyperbolaion	32
Jupiter	nete diezeugmenon	24
Mars	nete synnemenon	21 $^{1}/_{3}$

ἡλίου	παραμέση	ιη
Ἀφροδίτης καὶ Ἑρμοῦ	μέση	ις
σελήνης	ὑπάτη μέσων	ιβ
πυρὸς, ἄερος	ὑπάτη ὑπατῶν	θ
ὕδατος, γῆς	προσλαμβανόμενος	η

[15] περιέχουσιν οἱ ἀριθμοὶ

μεσότητας μὲν ἀριθμητικὰς	ε
γεωμετρικὰς	ς
ἁρμονικὰς	ε

[16] συμφωνιῶν δὲ ἐν λόγοις ἐπιμορίοις καὶ πολλαπλασίοις

διὰ τεσσάρων ⟨ἐν⟩ ἐπιτρίτοις	ε
διὰ πέντε ἐν ἡμιολίοις	δ
διὰ πασῶν ἐν διπλασίοις	ε
διὰ πέντε καὶ διὰ πασῶν ἐν τριπλασίοις	β
δὶς διὰ πασῶν ἐν τετραπλασίοις	β
καὶ ἔτι τόνους ἐν ἐπογδόοις	β

[17] ἀνετέθη ἐν Κανώβῳ ι′ ἔτει Ἀντωνίνου.

[Scholion]

[18] ὡς μέντοι οἱ προειρημένοι ἀριθμοὶ περιέχουσι τὰς εἰρημένας μεσότητας καὶ τοὺς λόγους τοὺς ἐπιμορίους καὶ πολλαπλασίους οὕτως ἐξέθετο.

[19]

ἀπλανῶν	Κρόνου	Διός	Ἄρεως	Ἡλίου	†αεισι†	Σελήνης
λς	λβ	κδ	κα γ′	ιη	ις	ιβ

| 106 παραμεσης A παρὰ μέσης C | 107 μέση Heiberg μέσης ABC | 109 υρος λερος B | 110 προσλαμβανομένου A προσλαμβανομένη C | 111 περιεχου A | 112 μεσότητος A | μὲν om. C | 115 υμφωνιων A | 116 ἐν add. C^2, Bullialdus | 122 ἀντωνίνω C| 123 περιέχει C | εἰρημένας Heiberg μεσημβρινὰς ABC | 125 ἄρεος C | αεισι A αμσι B δεισι C Ἀ. καὶ Ἑ. Heiberg | Σελήνης recisum A | 126 ιβ Heiberg ιε BC recisum A

The Sun	paramese	18
Venus and Mercury	mese	16
The Moon	hypate meson	12
Fire and Air	hypate hypaton	9
Water and Earth	proslambanomenos	8

[15] The numbers contain:

Arithmetic means	5
Geometric [means]	6
Harmonic [means]	5

[16] Concords in epimoric and multiple ratios:

Fourths, in 4 : 3 ratios	5
Fifths, in 3 : 2 ratios	4
Octaves, in 2 : 1 ratios	5
Fifths plus octaves, in 3 : 1 ratios	2
Double octaves, in 4 : 1 ratios	2
And lastly tones, in 9 : 8 ratios	2

[17] Erected at Canopus in the 10th year of Antoninus.

[Scholion]

[18] That, however, the aforesaid numbers contain the stated [numbers of] means and the epimoric and multiple ratios is set out as follows.

[19]

Fixed stars	Saturn	Jupiter	Mars	Sun	[corrupt]	Moon
36	32	24	21 $^{1}/_{3}$	18	16	12

[20]

ἀριθμητικὴ μεσότης

$\overline{\lambda\varsigma}$	$\overline{\kappa\delta}$	$\overline{\iota\beta}$
$\overline{\lambda\beta}$	$\overline{\kappa\delta}$	$\overline{\iota\varsigma}$
$\overline{\kappa\delta}$	$\overline{\iota\eta}$	$\overline{\iota\beta}$
$\overline{\kappa\delta}$	$\overline{\iota\varsigma}$	$\overline{\eta}$
$\overline{\iota\varsigma}$	$\overline{\iota\beta}$	$\overline{\eta}$

γεωμετρικὴ μεσότης

$\overline{\lambda\varsigma}$	$\overline{\kappa\delta}$	$\overline{\iota\varsigma}$
$\overline{\lambda\varsigma}$	$\overline{\iota\eta}$	$\overline{\theta}$
$\overline{\lambda\beta}$	$\overline{\kappa\delta}$	$\overline{\iota\eta}$
$\overline{\lambda\beta}$	$\overline{\iota\varsigma}$	$\overline{\eta}$
$\overline{\iota\eta}$	$\overline{\iota\beta}$	$\overline{\eta}$
$\overline{\iota\varsigma}$	$\overline{\iota\beta}$	$\overline{\theta}$

ἁρμονικὴ μεσότης

$\overline{\lambda\varsigma}$	$\overline{\kappa\delta}$	$\overline{\iota\eta}$
$\overline{\lambda\beta}$	$\overline{\kappa\alpha}$ γʹ	$\overline{\iota\varsigma}$
$\overline{\kappa\delta}$	$\overline{\iota\varsigma}$	$\overline{\iota\beta}$
$\overline{\kappa\delta}$	$\overline{\iota\beta}$	$\overline{\eta}$
$\overline{\iota\eta}$	$\overline{\iota\beta}$	$\overline{\theta}$

[21]

τῶν δὲ συμφωνιῶν οἱ λόγοι εἰσὶν οἱ ὑποκείμενοι·

[22]

ἐπίτριτοι λόγοι διὰ τεσσάρων $\overline{\varepsilon}$

$\overline{\lambda\beta}$	$\overline{\kappa\delta}$
$\overline{\kappa\delta}$	⟨$\overline{\iota}$⟩$\overline{\eta}$
$\overline{\kappa\alpha}$ γʹ	$\overline{\iota\varsigma}$
$\overline{\iota\varsigma}$	$\overline{\iota\beta}$
$\overline{\iota\beta}$	$\overline{\theta}$

ἐπίτριτοι

| 127 μεσότητος A | 130 $\overline{\kappa\delta}$ om. BC | 132 $\overline{\iota\varsigma}$ Heiberg $\overline{\kappa\delta}$ B $\overline{\delta}$ C om. A | 134 ($\overline{\kappa}$)$\overline{\delta}$ e corr. C | 135 $\overline{\theta}$ Heiberg $\overline{\beta}$ ABC | 140-145 recisum A | 141 $\overline{\iota\eta}$: $\overline{\kappa\eta}$ C | 142 $\overline{\kappa\alpha}$ γʹ Heiberg $\overline{\kappa\gamma}$ BC | 146 τῶν δὲ συμφωνιῶν οἱ λόγοι εἰσὶν οἱ ὑποκείμενοι om. B | (ὑπο)κείμενοι recisum A | 149 $\overline{\kappa\delta}$: $\overline{\kappa\eta}$ B | 150 $\overline{\kappa\alpha}$ γʹ: $\overline{\kappa\delta}$ γʹ BC | 152 $\overline{\iota\beta}$ Heiberg $\overline{\iota\zeta}$ ABC | $\overline{\theta}$ Heiberg $\overline{\varepsilon}$ ABC | 153 ἐπίτριτοι: ἐπίτριτον A om. B

[20]

Arithmetic mean

36	24	12
32	24	16
24	18	12
24	16	8
16	12	8

Geometric mean

36	24	16
36	18	9
32	24	18
32	16	8
18	12	8
16	12	9

Harmonic mean

36	24	18
32	$21\,^{1}/_{3}$	16
24	16	12
24	12	8
18	12	9

[21]

The ratios of the concords are as below:

[22]

4 : 3 ratios, [i.e.] fourths: 5

32	24
24	18
$21\,^{1}/_{3}$	16
16	12
12	9

4 : 3 [ratios]

διὰ πέντε ἐν ἡμιολίοις δ̅

λ̅ς̅	κ̅δ̅
κ̅δ̅	ι̅ς̅
ι̅η̅	ι̅β̅
ι̅β̅	η̅

ἡμιόλιοι

διὰ πέντε καὶ διὰ πασῶν ἐν τριπλασίοις β̅

λ̅ς̅	ι̅β̅
κ̅δ̅	η̅

τριπλάσιοι

δὶς διὰ πασῶν ἐν τετραπλασίοις β̅

λ̅ς̅	θ̅
λ̅β̅	η̅

τετραπλάσιοι

τόνοι ἐν ἐπογδόοις β̅

λ̅ς̅	λ̅β̅
ι̅η̅	ι̅ς̅
θ̅	η̅

ἐπόγδοοι

[23] Πτολεμαίου ἀρχαὶ καὶ ὑποθέσεις.

[Observations of Heliodorus]

[1] ταῦτα ἀπὸ τοῦ ἀντιγράφου τοῦ φιλοσόφου ἔγραψα.

[2] εἶδον Ἡλιόδωρος σ̅ι̅δ̅ ἀπὸ Διοκλητιανοῦ Παχὼν ς̅ ἐπὶ ζ̅ ὥρᾳ νυκτερινῇ β̅ τὸν τοῦ Ἄρεως ἐφαψάμενον τοῦ Διὸς ὡς μηδὲν αὐτῶν εἶναι μεταξύ.

[3] σ̅ι̅θ̅ Μεχὶρ κ̅ζ̅ ἐπὶ κ̅η̅ ἐπεπρόσθησεν ἡ Σελήνη τῷ τοῦ Κρόνου ἀστέρι ἐπὶ ὥραν δ̅ ἔγγιστα, μετὰ δὲ τὴν ἀνακάθαρσιν λαβόντες ἀπὸ ἀστρολάβου τὴν ὥραν ἐγώ τε καὶ ὁ φίλτατος ἀδελφὸς εὕραμεν ὥρας καιρικὰς ε̅ ∟ δʹ ὡς εἰκάζειν ἡμᾶς ὅτι κατὰ

| 159 ἡμιόλιοι om. B | 160 (π)α(σῶν ἐν) τρι(πλασίοις) recisum A | 161 (ι̅)β̅ recisum A | 162 η̅ A | 163 τριπλάσιοι om. B | (τριπλάσ)ιοι recisum A | 164-172 recisum A | 165 λ̅ς̅: λ̅ C | 167 τετραπλάσιοι om. B | 168 τόνοι Heiberg τ() B τοὺς C | 172 ἐπόγδοοι om. B | 173 (κα)ὶ ὑποθέσεις recisum A | 2 ἴδον AC | 4 μεχὶ ρ̅ C | τῷ: τῶν C | 5 δ̅: α̅ A | 6 φιλατατος AB

Fifths in 3 : 2 [ratios]: 4

36	24
24	16
18	12
12	8

3 : 2 [ratios]

Fifths and octaves in 3 : 1 [ratios]: 2

36	12
24	8

3 : 1 [ratios]

Double octaves in 4 : 1 [ratios]: 2

36	9
32	8

4 : 1 [ratios]

Tones in 9 : 8 [ratios]: 2

36	32
18	16
9	8

9 : 8 [ratios]

[23] First principles and models of Ptolemy.

[Observations of Heliodorus]

[1] I have written the following from the philosopher's copy.

[2] I, Heliodorus, saw in Diocletian year 214, Pachon 6/7, 2nd hour of night, Mars in contact with Jupiter such that there was nothing between them.

[3] Year 219, Mechir 27/28, the moon occulted Saturn at approximately the 4th hour. After the clearing, I and my dearest brother, getting the time from the astrolabe, found 5 $^{1}/_{2}$ $^{1}/_{4}$ seasonal hours, so that we estimated that it was at the centre of the

τοῦ κέντρου τῆς Σελήνης ἦν περὶ ε̅ η´ ὥραν. ἐξεφάνη γὰρ διὰ τῆς διχοτομίας τῆς περιφερείας τοῦ πεφωτισμένου αὐτῆς μέρους. ἦν δὲ ὁ Κρόνος Καρκίνου μοίραις β̅ ∟ ἔγγιστα.

[4] τοῦ θείου τήρησις.
[5] ὑπέδραμεν ἡ Σελήνη τὸν τῆς Ἀφροδίτης ἀστέρα ἔτει Διοκλητιανοῦ ρ̅ϙ̅β̅ Ἀθὺρ κ̅α̅ φαινομένη ἀπὸ συνόδου Ἀθήνησιν ἐπέχουσα τοῦ Αἰγόκερω μοίρας ι̅γ̅, τοῦ δὲ Ἡλίου ἀπέχουσα μοίρας μ̅η̅.
[6] τοῦ θείου τήρησις.

[7] σ̅κ̅ε̅ Θὼθ λ̅ ὤφθη ὁ τοῦ Διὸς ἀστὴρ οὕτως πλησιάσας τῷ ἐπὶ τῆς καρδίας τοῦ Λέοντος ὥστε αὐτὸν ἔλασσον γ̅ δακτύλων αὐτοῦ πρὸς βορρᾶν διεστάναι, καὶ τότε τὸ ἐλάχιστον ὤφθη διεστηκώς.

[8] σ̅κ̅ε̅ Φαμενὼθ ι̅ε̅ εἰς ι̅ς̅ εἶδον τὴν Σελήνην ἑπομένην τῷ λαμπρῷ τῶν Ὑάδων μετὰ λύχνου ἁφὴν ὡς δακτύλους τὸ μήκιστον ς̅. ἐδόκει δὲ καὶ ἐπιπροσθηκέναι αὐτῷ. ἐπέβαλλεν γὰρ ὁ ἀστὴρ τῷ περὶ τὴν διχοτομίαν μέρει τῆς κύρτης περιφερείας τοῦ πεφωτισμένου μέρους. ἦν δὲ τότε ἡ ἀκριβὴς Σελήνη περὶ τὰς ι̅ς̅ ∟ μοίρας τοῦ Ταύρου.

[9] τῷ αὐτῷ σ̅κ̅ε̅ Παῦνι ἐννεακαιδεκάτῃ μετὰ Ἡλίου δυσμὰς ὁ τοῦ Ἄρεως συνῆψε τῷ τοῦ Διὸς ὡς δοκεῖν αὐτοῦ διεστάναι εἰς μὲν τὰ προηγούμενα δάκτυλον α̅, πρὸς δὲ νότον δακτύλους β̅, καίτοι τῶν ἀπὸ τοῦ Κανόνος καὶ τῆς Συντάξεως ἀριθμῶν τῇ κ̅γ̅ τοῦ αὐτοῦ μηνὸς δεικνύντων αὐτοὺς ἰσομοίρους ὅτε πλεῖστον παραλάττοντες ὤφθησαν.

[10] ἀπὸ Διοκλητιανοῦ σ̅κ̅ς̅ ⟨Μεσωρὴ κ̅ζ̅⟩ ὤφθη ὁ τῆς Ἀφροδίτης ἀστὴρ προηγούμενος τοῦ τοῦ Διὸς ὡς δακτύλους η̅, τῇ δὲ κ̅η̅ ἑπόμενος ὡς δακτύλους ι̅, κατὰ δὲ πλάτος οὐδὲν δοκοῦν διαφέρειν, κατὰ μέντοι τὰς ἐφημεριδὰς ἐχρῆν τῇ τριακάδι φαίνεσθαι αὐτοὺς συνάπτοντας. τότε δὲ πλειστὸν διεστῶτες ὤφθησαν.

| 7 περὶ: παρὰ B | ὥρας B | 8 αὐτῆς: αὐτοῦ B | Κρόνος Καρκίνου: (Κρόνος) (κύκλος) A γ̊ (κύκλος) BC | 12 ἐπέχουσαν B | 15 τῷ: τῶν C | 16 ἔλασσον γ̅: χγ B χ̅γ̅ C | 17 ἐλάχιστον: ἔλασσον C | 18 ἴδον AC | τῶν λαμπρῶν C τὴν τῷ λαμπρῷ B | 19 δακτύλων A | αὐτῶν C | 20 τῷ περὶ: τὸ περὶ A τῷ παρὰ B τῶν παρὰ C | 21 περὶ: παρὰ C | 23 ἐννεακαιδεκάτῃ: θ̅ι̅ BC | συνῆψεν A | 24 τῷ: τῶν C | δάκτυλον α̅: δάκτυλ() δ̅ C | 25 ἀριθμοῦ C | 26 μηνὸς: μοι() B | αὐτοὺς: αὐτῶν BC | ἰσομυρους A | παραλάττοντας B | 27 ὤφθησεν A | 28 Μεσωρὴ κζ´ addidi monente Bullialdus | 29 δακτύλων (bis) B | πλάτος om. C | 31 συναπτοντες A | δὲ om. C

moon about 5 $^{1}/_{8}$ hours. For it appeared through the midpoint of the periphery of [the moon's] illuminated part. Saturn was approximately at Cancer 2 $^{1}/_{2}$ degrees.

[4] Observation of our uncle.
[5] The moon passed beneath Venus in Diocletian year 192, Hathyr 21, having made its appearance after conjunction at Athens occupying Capricorn 13°, and being 48° away from the sun.
[6] Observation of our uncle.

[7] Year 225, Thoth 30, Jupiter was seen approaching the [star] on the heart of Leo in such a way so that it stood less than 3 fingers from it to the north, and at that time it was seen as being least distant.

[8] Year 225, Phamenoth 15/16, I saw the moon trailing the bright [star] of the Hyades after lamp-lighting by at most 6 fingers. It also seemed to have occulted it. For the star was against the part about the midpoint of the convex periphery of [the moon's] illuminated part. At that time the true moon was at about Taurus 16 $^{1}/_{2}$ degrees.

[9] In the same year 225, Payni 19, after sunset, Mars came into conjunction with Jupiter such that it seemed to stand 1 finger ahead of it and 2 fingers to the south, although the numbers from the Handy Tables and the Almagest showed them as being at an equal number of degrees on the 23rd of the same month, when they were seen as being very far apart.

[10] Diocletian year 226, <Mesore 27>, Venus was seen ahead of Jupiter about 8 fingers, and on the 28th [it was seen] trailing about 10 fingers, seeming to have no difference in latitude, although according to the ephemerides they ought to have been seen in conjunction on the 30th; but at that time they were seen to be very far apart.

Notes.

Canobic Inscription and scholion.

[1] The heading was presumably provided by the transcriber in late antiquity.

[2] Since Boulliau it has been assumed, plausibly enough, that the "Saviour God" was Serapis, whose temple was the principal one at Canopus. The formula Θεῷ Σωτῆρι is not especially common in inscriptions, and in most instances where the "god" can be identified, refers to a deified emperor or patron or to the healer Asclepius.

The distinction that Ptolemy intends to draw by the expression ἀρχὰς καὶ ὑποθέσεις is not entirely clear, but probably ὑποθέσεις in the context of the inscription means the permanent parameters defining a model, such as the eccentricity and epicycle radius, whereas ἀρχαὶ are the epoch positions.

[3] The "solar" circle is the ecliptic, usually designated "the circle through the middle of the zodiacal signs" in the *Almagest*. In *Almagest* 1.12 Ptolemy expresses his value for obliquity of the ecliptic only by the statement that the ratio of the arc between the solstices to the entire meridian circle is 11 to 83, whereas here (as in the table of declinations, *Almagest* 1.15) he gives it as 23;51,20°, which is the nearest approximation to $180\times(^{11}/_{83})$ to two sexagesimal places.

Ptolemy's definition here of the "time-degree" (χρόνος) makes it equal to the time in which 1° of the celestial equator, *relative to the equinoctial points*, crosses the meridian, so that this unit is slightly smaller than the conventional astronomical χρόνος, ultimately derived from the Babylonian UŠ, that is $^{1}/_{360}$ of a mean *nychthemeron* (day and night). In such time-degrees the mean *nychthemeron* is 360 plus the sun's mean daily motion in

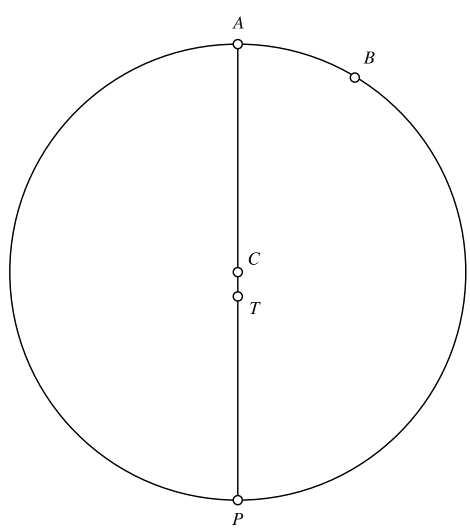

Fig. 8. The *Almagest* model for the sun.

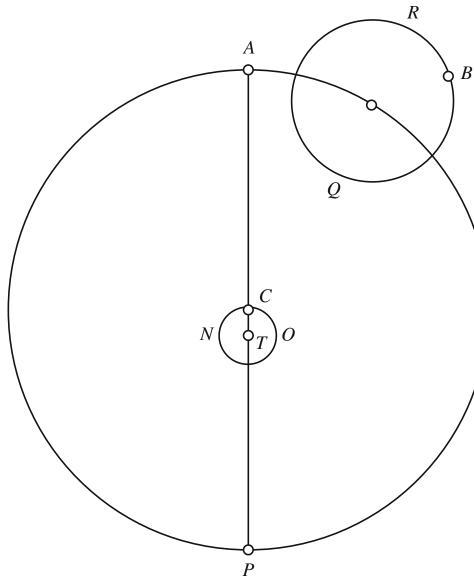

Fig. 9. The *Almagest* model for the moon.

tropical longitude, 0;59,8,17,13,12,31° according to *Almagest* 3.1 (derived from a tropical year of 365;14,48 *nychthemera*); hence the *CI* parameter agrees with the *Almagest*.

The text as transmitted by the manuscripts twice refers to the "tropic" (τροπικὸς), here and in [7]. Both are surely corruptions. In the present context τροπικὸς would have to designate one of the solstitial *points*, which of course revolve with the same daily cosmic revolution around the earth (κόσμου περιστροφή) as the celestial equator, but in [7] a circle, not a point, is evidently meant. Yet in neither context would a reference to one of the tropic *circles* be appropriate. A misreading of κόσμου as τροπικοῦ in [3] is paleographically plausible, and the idiom is sufficiently well established to justify emendation. In [7] the circle with respect to which degrees are defined should either be specifically the ecliptic (normally for Ptolemy ὁ διὰ μέσων, "the circle through the middle of the signs") or just an arbitrary circle, ὁ κύκλος, as assumed in the present edition.

[4] λόγοι here means not "ratios" but "parameters," as is clear from section 8.

[5] Ptolemy here lists a single quantity for the model of each of the seven heavenly bodies. For convenience we will designate this quantity the "*CI* eccentricity." The meaning of this parameter is different for each of the various model types.

In Ptolemy's solar model (Fig. 8), the Sun *B* travels uniformly on an eccentre *AP* centred on a tropically fixed point *C*. In *Almagest* 3.4 (Heiberg 1.238) Ptolemy expresses the ratio of the distance between the centre of the cosmos *T* and *C* to the eccentre's radius *CA* as 2;30 : 60, in agreement with the *CI* eccentricity. (The variant reading 2 1/4, or 2;4, in C is obviously a scribal lambda-delta error.)

In the *Almagest* lunar model (Fig. 9), the Moon *B* travels uniformly on an epicycle *QR* that revolves uniformly around an eccentre *AP*. The centre of *AP* in turn revolves on a circle *NO*, the centre of which is the centre of the cosmos *T*. In *Almagest* 5.4 (Heiberg 1.366) Ptolemy gives the ratio of *TN* to *NP* as 10;19 : 49;41 (i.e. scaled such that *TN* + *NP* = 60). This ratio is equivalent to 12;27,32,… : 60, in approximate agreement with the *CI* eccentricity.

In the models for Venus, Mars, Jupiter, and Saturn (Fig. 10), the planet *B* travels uniformly on an epicycle *QR* that revolves around an eccentre *AP*, the centre of which, *C*, is sidereally fixed. The revolution of the epicycle's centre is uniform as seen from an equant point *E* situated on *TP* such that *TC* = *CE*. In the *Almagest* the distance *TC* is either explicitly given (such that *CP* = 60) or trivially obtainable as half the given distance *TE*:

Venus	1;15	10.3 (Heiberg 2.306)
Mars	6	10.7 (Heiberg 2.340)
Jupiter	2;45	11.1 (Heiberg 2.375)
Saturn	3;25	11.5 (Heiberg 3.406)

Except for Saturn, these agree exactly with the *CI* eccentricities.

In the *Almagest* model for Mercury (Fig. 11), the planet *B* travels uniformly on an epicycle *QR* that revolves around an eccentre *AP*, the centre of which, *C*, revolves uniformly on a circle *CE*, the centre of which, *D*, is sidereally fixed. The revolution of the epicycle's centre is uniform as seen from the sidereally fixed equant point *E* that bisects *TD*; hence *TE* = *ED* = *DC*. *Almagest* 9.9 (Heiberg 2.279) gives *TE* as 3;0 such that *CP* = 60. The *CI* eccentricity is thus in disagreement with the *Almagest* model. *HST* suggest that the model to which the *CI* refers may have had the same structure as the models for the other planets, rather than employing the *Almagest*'s rapidly revolving eccentre and nonstandard placement of the equant point. Rawlins, on the other hand, has argued that the *CI* model must have been

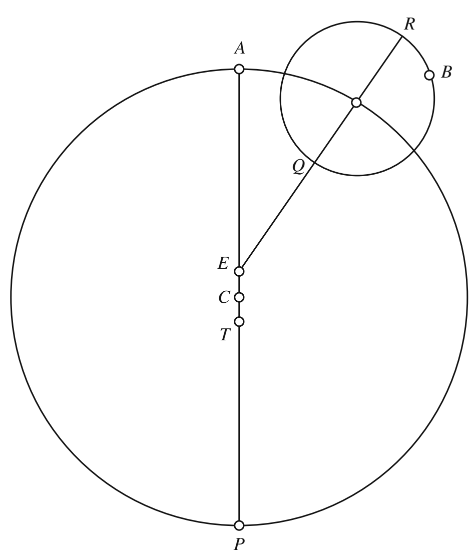

Fig. 10. The *Almagest* model for the planets (excepting Mercury).

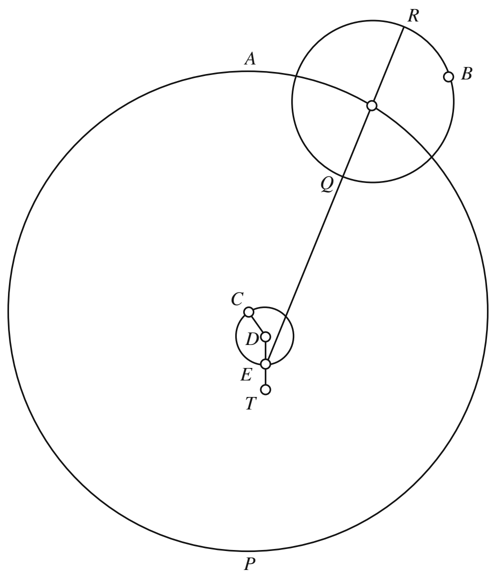

Fig. 11. The *Almagest* model for Mercury.

structurally identical to the *Almagest* model. (For discussion, see Appendix 2.) *HST* also point out that in the *Planetary Hypotheses* the model for Mercury is structurally the same as in the *Almagest* but with *DC* reduced to 2;30 units while *TE* and *ED* remain 3 units.

It has often been remarked that the distance of Venus' equant in the *Almagest* is exactly the Sun's eccentricity; in the *CI* it is also the case that Mercury's eccentricity—whatever that may mean in terms of the model—is equal to the Sun's. A less obvious relationship, again lost in the revisions that took place between the *CI* and the *Almagest*, is that the sum of the eccentricies of Saturn and Jupiter is equal to that of Mars. Such kinships among the models' parameters may have seemed significant to Ptolemy at this stage in his work; whether the shared eccentricities of the Sun, Mercury, and Venus reflect influence of pre-Ptolemy heliocentric models for the inferior planets is a moot question.

The heading of this section in the manuscripts contains two phrases that appear to be erroneous glosses. The words ὄψεως καὶ κέντρου, almost certainly a corruption of ὄψεως καὶ ἐκκέντρου ("of sight and eccentre"), are evidently an attempt to identify which centres Ptolemy means. "Centre of vision" would thus mean the centre of the cosmos, effects of parallax being disregarded; the expression is used in *Almagest* 3.3 (Heiberg v. 1 p. 219) for the observer's position in relation to an eccentre. But the distances that Ptolemy lists for the planetary models are *not* those between the centre of the cosmos and the centre of the eccentre. Again, the words ἀπλανῶν σφαίρας, "of the sphere of the fixed stars," were assumed by Bullialdus and Heiberg to be the remnant of a line giving the eccentricity of the sphere of fixed stars as zero, preceding the line for Saturn. It is improbable that Ptolemy would have included such an entry, or written of an "eccentre" that is not eccentric. I assume that ἀπλανῶν σφαίρας is another attempt at identifying one of Ptolemy's centres.

[6] The following are the epicycle radii given in the *Almagest*, in the case of the Moon scaled such that the eccentre's radius is 60 rather than 49;41 as in the *Almagest*:

Saturn	6;30	11.6 (Heiberg 2.419)
Jupiter	11;30	11.2 (Heiberg 2.386)
Mars	39;30	10.8 (Heiberg 2.351)
Venus	43;10	10.2 (Heiberg 2.302)
Mercury	22;30	9.9 (Heiberg 2.279)
Moon	6;20,24,…	4.9 (Heiberg 1.335)

Except for Saturn and the Moon, the manuscript tradition of the *CI* does not consistently agree with the *Almagest* radii, but in all instances but one the discrepancies can be ascribed to miscopying of numbers that originally agreed with the *Almagest* (in B the variants are obscured by corrections that seem to derive from collation with the *Almagest*).

The possible exception is the epicycle radius for Mercury. In A this is given as 22 $^1/_4$ (the alternative interpretation of the numerals as 22;4 is improbable); in C it is 24 $^1/_4$; and B probably had the same reading as C before it was corrected. The fraction is easily dispensed with: except in sections [13] and [14] Ptolemy consistently uses sexagesimals for fractions in the *CI*, so we are dealing again with delta-lambda misreading. Whether, however, the *CI* originally gave 22;30 or 24;30 is not so easy to settle. The "conservative" reading is adopted here, without conviction.

[7] The mean daily motions of the five planets and the sun are exactly the numbers prescribed for motion in longitude ("epicycle") and anomaly ("planet itself") in *Almagest* 9.3, although minor corruptions have affected the transmission of some numerals in the manuscript tradition. The agreement for Saturn and Mercury is surprising since the derivations of the precise mean motions in the *Almagest* are ostensibly dependent on the other parameters of the model, including the eccentricities for which the *CI* has different values. The mean daily motion of the fixed stars is not explicitly given in the *Almagest*, but can be derived from the precessional rate of 1° per hundred Egyptian years since $^{1°}/_{36500 \text{ days}}$ equals 0;0,0,5,55,4,6,34,…°/day.

The *CI* expresses the mean motions of the moon in terms of the uniform motions of each separate component of the *Almagest* model rather than in terms of longitudinal, anomalistic, dracontic, and synodic periods as in *Almagest* 4.4. Thus the first motion listed ("Moon's node") is the longitudinal motion of the nodes, equivalent to the difference between the *Almagest*'s "increment in latitude" and "increment in longitude"; the second motion ("Moon's epicycle") is the revolution of the epicycle's centre relative to the nodal line, equivalent to the *Almagest*'s "increment in latitude" or to the difference between the *Almagest*'s "increment in longitude" and the (negative) longitudinal motion of the nodes; the third motion ("Moon's eccentre") is that of the centre of the moon's eccentre on its circle (*NO* in Fig. 7), equivalent to the difference between the second motion and twice the "increment in elongation"; and the fourth motion is that of the moon on its epicycle, identical to the *Almagest*'s "increment in anomaly." Minor corruptions in the manuscript tradition can be corrected from internal consistency.

Except for the last motion listed, the lunar mean motions in the *CI* differ significantly from those obtainable from the *Almagest* parameters. The differences all stem from Ptolemy's preliminary derivation of the moon's mean motion in latitude, the method of which was outlined and repudiated in *Almagest* 4.9, and reconstructed in detail by *HST*.

[8] *HST* observe of this section that "the inclinations of the planes of the eccentrics and epicycles appear so garbled in the text that it is difficult to decide what is and is not a significant difference from the *Alm*[*agest*]" (67–68). This much at least seems certain, that the model structures for the planetary latitudes are essentially the same as in the *Almagest* (13.3) but with the sole exception of Mars the actual angles of inclination of the components of the models are different (cf. *Almagest* 13.4). The *CI* thus marks the first documented stage of Ptolemy's long struggles with planetary latitude. A description of the *Almagest* models would be out of place here, so I refer the reader to Swerdlow 2005, which describes them and their subsequent revisions in the *Handy Tables* and *Planetary Hypotheses*.

Fixed stars. This refers to the precessional motion of the stars, which in Ptolemy's *Almagest* theory takes place uniformly around the poles of the ecliptic, hence zero inclination.

Saturn. Both numbers are surely corrupt: an inclination of zero for the eccentre is out of the question, while the transmitted inclination of the epicycle is about twice what it should be, and bears a surely spurious second fractional place. The *Almagest* parameters are respectively 2;30° and 4;30°. Perhaps the original *CI* value for the inclination of the epicycle was 5;0°, with the preceding theta being an intrusion.

Jupiter. The *CI* inclination of the eccentre is in agreement with the *Almagest*'s 1;30°, though the zero following the minutes is surely spurious. The inclination of the epicycle is notably different from the *Almagest*'s 2;30°. While corruption cannot of course be ruled out, one might expect some instability in this parameter, since Jupiter's epicycle is small relative to its eccentre so that small changes in the empirical data would result in large changes in the derived inclination.

Mars. The two inclinations agree exactly with the *Almagest*. This incidentally confirms that the *CI* lists the planetary latitudinal inclinations in the same form as in *Almagest* 13.4, i.e. inclination of the eccentre relative to the ecliptic and of the epicycle relative to the eccentre.

Sun. The solar model of course lies entirely in the plane of the ecliptic.

Venus. *HST* suggest that a zero has dropped out before the 15 of Venus' eccentre's inclination, i.e. that one should read 0;15°. With this correction, the *CI* parameters are plausible as a predecessor of the *Almagest*'s parameters, respectively 0;10°, 2;30°, and 3;30°.

Mercury. Again there is no strong *prima facie* reason to presume that the *CI* parameters for Mercury's inclinations are corrupt, especially given the unsatisfactory character of Ptolemy's Mercury model in general. The *Almagest* inclinations are respectively 0;45°, 6;15°, and 7;0°.

Moon. The inclination of 5° for the entire model is in exact agreement with the *Almagest*.

[9] The epoch positions of the components of the models are grouped as follows: in section [9] those that are naturally expressed as directions relative to the vernal equinoctial point; in section [10] those that are naturally expressed as directions relative to the apogee of an eccentre or epicycle; in section [11] those that are naturally expressed relative to a sidereally fixed direction, for which the longitude of Regulus is chosen as in the *Handy Tables*. With the exception of the longitude of the sun's apogee in line 64, all the directions in sections [9] and [10] are properly epoch positions valid only for the chosen epoch date. Those in section [11] are constants, and if the word ἀΐδιοι in line 78 is not a corruption, that is what Ptolemy must mean by it.

HST observe that, once the obvious textual errors have been emended, the *CI*'s epoch positions are consistent with the parameters of the *Almagest*, rounded to the nearest minute for the chosen epoch date, with the following exceptions:[1]

Saturn. Since the *CI* model for Saturn had a different eccentricity from the *Almagest*'s, one would expect some discrepancy in the epoch positions, and in fact from the *Almagest* parameters, the mean longitude of the centre of the epicycle is 73;3,30°, and the mean epicyclic anomaly is 83;7,44° so that the *CI* disagrees with both numbers. At least one of the *CI* values is corrupt, however, since their sum should be equal to the sun's mean longitude (156;11°). Since a coincidental corruption of both parameters for Saturn is comparatively improbable, we should presumably read either 72;35° for the mean longitude of the epicycle's centre or 83;59° for the mean epicyclic anomaly. Unfortunately in neither case is there an obvious paleographical explanation of the corruption. From the *Almagest* parameters one would find the ascending node at 330;30° from Regulus. *HST* take the *CI*'s reading, 353;30°, as a probably authentic difference from the *Almagest* theory, though they note that this would make the elongation of the node from the apogee not a round multiple of 10°, contrary to Ptolemy's consistent practice elsewhere. I presume the number is corrupt, at least with respect to the units place.

Mercury. The surprising thing here is that Mercury's epoch positions for the epicycle's centre and epicyclic anomaly are exactly consistent with the *Almagest* parameters, notwithstanding the differences in the assumed model. On the other hand, the *Almagest* parameters would place the apogee at 67;30° and the ascending node at 157;30° from Regulus. *HST* defend the *CI* reading for the apogee's location, while offering to emend the number for the node to 153;30° to maintain consistency with the *Almagest*'s value of 90° for the elongation of the node from the apogee.

Moon. For the moon's mean motions the equation of time is significant; we therefore calculate the epoch positions from the *Almagest* for 0;19,14 equinoctial hours before mean noon, Alexandria. The following table compares recomputation from the *Almagest* parameters with the *CI* values:

[1] *HST* 66–67. We disregard discrepancies of 1 in the rounded minutes.

	Almagest	*CI*
apogee of eccentre	256;40,14°	256;42°
centre of epicycle	55;40,40°	55;40°
ascending node	115;35,18°	115;31°
moon on epicycle	248;42,1°	248;40°

As *HST* (61) point out, the significant discrepancy in the longitude of the ascending node (which is relatively insensitive to small changes in the assumed epoch time) is to be expected since the epoch position would have been derived from the same analysis of eclipses that yielded the *CI*'s non-*Almagest* mean motion in latitude. The discrepancies in the remaining numbers are probably attributable to rounding errors or to inaccuracy in the assumed equation of time.

[12] As *HST* remark (68), the *CI* values for the *arcus visionis* of the planets agree with the *Almagest* except in the case of Mercury, where the *Almagest* has 10°. The *CI* value of Mercury's *arcus visionis* is in doubt since the manuscripts give implausible readings of 10;31° or 10;34°. Following Boulliau, I assume that only the units place of the minutes is an intrusion.

[13] The *CI* values for the apparent sizes and distances of the sun and moon differ from those of the *Almagest*. See *HST* 1987, 68–70 for a full discussion of this section.

[14]–[16] For these concluding sections on cosmic tones associated with the heavenly bodies and the four elements of the sublunary world, I have no remarks to add to the excellent commentary in Swerdlow 2004, 165–178.

[18–22] This scholion accounts (with the omission of the octaves) for the total numbers of means and specific ratios among the cosmic tones listed in [15] and [16]; see Swerdlow 2004, 167–168.

Heliodorus.

[1] It is uncertain whether the "philosopher" is Heliodorus himself or his brother Ammonius, whose claim to this epithet was perhaps stronger as the occupant of the Neoplatonist "chair" at Alexandria until his death c. A.D. 520.

[2] This is the only report that explicitly identifies the observer as Heliodorus. Diocletian year 214, Pachon 6 was A.D. 498, May 1. According to modern theory for an observer at Alexandria we have:[2]

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[2] I have used the software Starry Night (version 4.0). Because of the uncertainty of ΔT (on the order of perhaps ±15 minutes for dates around A.D. 500) all times may be consistently in error by a fraction of an hour. For

sunset, May 1	16:36 UT
sunrise, May 2	3:13 UT
middle of 2nd hour of night	18:49 UT
longitude of Mars at 18:49 UT	150;38°
latitude of Mars	+1;34°
longitude of Jupiter	150;40°
latitude of Jupiter	+1;37°

It is not surprising that such a small interval between the two planets would have been seen as actual contact between their apparent disks.

[3] This observation is reported as having been made by the writer together with his brother, i.e. presumably Heliodorus and Ammonius. Diocletian year 219, Mechir 27 (Alexandrian calendar) was A.D. 503, February 21. According to modern theory for an observer at Alexandria we have:

sunset February 21	15:53 UT
sunrise February 22	4:36 UT
beginning of occultation	21:00 UT (4.8 seasonal h. past sunset)
end of occultation	21:50 UT (5.6 seasonal h. past sunset)
longitude of Saturn at 21:00 UT	95;42°
latitude of Saturn	+0;2°
latitude of Moon	–0;6°

According to the *Almagest* theory, the longitude of Saturn at 12 equinoctial hours past noon was 92;35°, so that the reported longitude in the text is probably computed from Ptolemy's tables, not observed. The reported time of the beginning of the observation is very rough, whereas the time of clearing, determined by means of an "astrolabe" (presumably a plane astrolabe, not an armillary) is fairly accurate. For the purpose of estimating the time of mid occultation, Heliodorus takes the time of the beginning to be 4 $^{1}/_{2}$ seasonal hours past sunset. Saturn would have been observed as entering and leaving the moon's disk towards its northern limb, so that Heliodorus' specification of where the planet reappeared seems to be inaccurate if I have interpreted his meaning correctly.

[5] Apparently both the preceding heading [4] and the following [6] identify the observer of this report, which is more than 22 years before the earliest of the remaining reports and uniquely specifies Athens as the place of observation. Rather than meaning "the divine

computations from the *Almagest* theory I have used the JavaScript software by R. van Gent, currently accessible at http://www.phys.uu.nl/~vgent/astro/almagestephemeris.htm.

one," and referring as Tannery proposed to Proclus, Westerink 1971, 20 n. 27 is surely correct in interpreting ὁ θεῖος as "our uncle," i.e. Gregorius, the brother of Heliodorus' father Hermeias.[3]

The date is A.D. 475, November 18. According to modern theory, the occultation began about 15:10 UT, practically coinciding with sunset, and ended about 16:30 UT. According to the *Almagest* theory, Venus' longitude at 6 equinoctial hours past noon, meridian of Alexandria, was 283;6°, so that the reported longitude was probably computed, not observed. The sun's longitude according to the *Almagest* was 235;33°, agreeing reasonably well with the reported elongation of 48°. Conjunction had occurred on the evening of November 14.

[7] No observer is specified. Diocletian year 225, Thoth 30 was A.D. 508, September 27; however, since the observation must have been made after midnight, there is some ambiguity about whether the actual date intended is September 27 or September 28. From modern theory we have:

	Sept. 27, 1:00 UT	Sept. 28, 1:00 UT
longitude of Jupiter	129;3°	129;13°
latitude of Jupiter	+0;44°	+0;44°
longitude of α Leo	129;10°	129;10°
latitude of α Leo	+0;24°	+0;24°

The "finger" is an originally Babylonian astrometric unit, equivalent to 1/24 of a "cubit" (πῆχυς); Greek writers assumed that 1 cubit was equal to 2°, so that 1 finger would be 0;5° (Jones 2004, 520). Jupiter was thus approximately 4 fingers north of the star.

[8] The report is in the first person, thus presumably Heliodorus was the observer. The date is A.D. 509, March 11. Sunset occurred at 16:06 UT. According to modern theory we have for an observer at Alexandria:

sunset, March 11	16:06 UT
longitude of moon	49;35°
latitude of moon	–5;9°
radius of moon's disk	0;15°
longitude of α Tau	49;1°
latitude of α Tau	–5;34°

Thus at sunset the western limb of the moon was "trailing" (east of) α Tau by approximately 4 fingers. As Neugebauer (1975 v. 2, 1041) remarks, no occultation had actually taken place.

[3] By error named "Georgius" by Neugebauer 1975 v. 2, 1039.

According to the *Almagest* tables the true longitude of the moon (i.e. uncorrected for parallax) at 6 equinoctial hours past noon was 46;45°, while, as Neugebauer computes, the *Handy Tables* give 46;31°, the discrepancy being due to the equation of time corresponding to the difference between the *Almagest* and *Handy Tables* epochs. Heliodorus probably used the *Handy Tables*.

[9] The observer is not identified. The date is A.D. 509, June 13. From modern theory we have:

sunset, June 13	17:44 UT
longitude of Mars	132;2°
latitude of Mars	+1;13°
longitude of Jupiter	132;9°
latitude of Jupiter	+1;1°

Thus Mars was roughly 1 finger "ahead" (i.e. west) and 2 cubits *north* of Jupiter. The incorrect latitudinal direction in the report may be an authorial rather than a scribal error.

According to the *Almagest* the longitude of Mars at 6 equinoctial hours past noon, Alexandria on June 17 was 131;8° and that of Jupiter was 131;5°, confirming Heliodorus' statement. Computation using the *Handy Tables* would result in the same longitudes (± 0;2° because of rounding approximations).[4] In fact Mars was more than a degree and a half east of Jupiter on June 17.

[10] Again the observer is not specified. The date is defective in the manuscripts, but Boulliau established that the observations must have been made on the evenings of August 20 and 21, A.D. 510. From modern theory we have:

	August 21, 17:00 UT	August 22, 17:00 UT
longitude of Venus	169;13°	170;27°
latitude of Venus	+1;6°	+1;4°
longitude of Jupiter	169;30°	169;43°
latitude of Jupiter	+1;11°	+1;11°

Thus Venus was approximately 3 fingers "ahead" (i.e. west) of Jupiter on the 21st, and approximately 9 fingers "trailing" (i.e. east of) Jupiter on the 22nd. The discrepancy with the reported 8 fingers for the earlier date seems rather large (a textual error cannot be ruled out).

[4] Neugebauer 1975 v. 2, 1040 obtained different longitudes for this and the next observation report using the *Handy Tables*; his calculations were apparently thrown off by the same systematic sign error in his formula for calculating planetary longitudes from the *Handy Tables* (v. 2, 1003 equation 4, where "$k_7 \geq 0$" should be corrected to "$k_7 \leq 0$") that I have pointed out (Jones 1999b, 85) in his analysis of the horoscope of Proclus.

By "ephemerides" Heliodorus is referring to tables listing computed longitudes of the sun, moon, and planets at intervals of one day, such as are well attested among Greco-Egyptian papyri; the several specimens that we have from the fifth century—none are currently known from after A.D. 489—were all calculated using Ptolemy's *Almagest* or *Handy Tables*.[5] According to the *Almagest* theory, the longitude of Venus on August 23, 6 equinoctial hours past noon, Alexandria, was 168;13°, and that of Jupiter was 168;19°, confirming Heliodorus' statement that the ephemerides predicted a conjunction on that day. Venus was actually almost 3° east of Jupiter on the 23rd.

[5] Jones 1999a v. 1, 40–42 and 175–176.

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