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Uses and Users of Astronomical Commentaries in Antiquity

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My purpose in the following pages will be to examine the role of commentaries in the Babylonian and Greek astronomical literature. Only certain kinds of primary astronomical texts appear to have inspired the production of commentaries, and these in differing ways; but there is a common thread in that commentaries seem to have been most often motivated by mathematical complexity in the commented texts.[1] We can see this tendency clearly in the so-called Procedure Texts that are the subject of the first two parts of this paper, which are associated with a tradition of mathematical predictive astronomy that originated in Mesopotamia and subsequently spread to the Greco-Roman world. In the third part, I will attempt to show that the practical intention of the Procedure Texts, to instruct the reader in the mathematical operations involved in astronomical prediction, finds its natural continuation in certain of the more formal commentaries on Ptolemy's works that were composed in late antiquity, side by side with a more academic style of commentary directed towards the reader's rational acceptance of Ptolemy's chains of reasoning about the structure of the heavens.

Babylonian Procedure Texts

Among the scribes of the Esagila temple in Babylon during the last three centuries B.C. were a group referred to as *ṭupšar Enūma Anu Enlil*, that is, 'Scribes of *Enūma Anu Enlil*', named after the great compilation of Mesopotamian astral omens. A temple document dating probably from the first century B.C. specifies among the duties of these scribes the 'observations (*naṣāru*), calculations (*tērsētu*),

1 A category of commentary that will not be considered here is the literary tradition devoted to Aratus' *Phaenomena*. Hipparchus' *Commentary on the Phaenomena of Aratus and Eudoxus* has a unique situation in relation to this tradition, as a technical polemic attacking Aratus and his interpreters as astronomically incompetent.

and measurements (*meš-ḫi*)'.[2] These three terms can with great likelihood be identified with certain categories of extant tablets that are known to modern scholarship as Diaries, Almanacs, and ACT Tables.[3] Diaries contain records of nightly observation of astronomical phenomena and weather, along with monthly summaries of planetary positions, news, commodity prices, and river levels.[4] Almanacs record astronomical phenomena of the same kind as the Diaries, but these are exclusively forecasts.[5] So far as we know, neither of these categories of text was supplemented in antiquity with auxiliary texts that we might call commentaries.

Our concern here will be primarily with the third variety of tablet produced by the Scribes of Enūma Anu Enlil the so-called ACT Tables. These documents are laid out in tabular form, in rows and columns, usually such that each row represents a single predicted astronomical phenomenon of some kind, and the columns contain elements, mostly numerical, that specify details of the phenomenon in question. As an illustration of a typical ACT table, we may take the following translated excerpt:[6]

2 G. J. P. McEwan, *Priest and Temple in Hellenistic Babylonia*, Freiburger Altorientalische Studien Bd. 4, Wiesbaden, 1981, 18-20 (CT 49, 144). Cf. R. J. van der Spek, "The Babylonian Temple during the Macedonian and Parthian Domination", in: *Bibliotheca Orientalis* 42 (1985) 547-562, esp. 551-552.

3 F. Rochberg, "The Cultural Locus of Astronomy in Late Babylonia", in: H. D. Galter (ed.), *Die Rolle der Astronomie in den Kulturen Mesopotamiens*, Grazer Morgenländische Studien Bd. 3, Graz, 1993, 31-45, esp. 40-41. The terms Diary and Almanac were introduced by A. Sachs, "A Classification of the Babylonian Astronomical Tablets of the Seleucid Period", in: *Journal of Cuneiform Studies* 2 (1948) 271-290; ACT is the acronym of O. Neugebauer, *Astronomical Cuneiform Texts*, London, 1955. ACT tablets, and a single Diary tablet, have survived from Uruk as well as Babylon.

4 Edition in progress: A. J. Sachs and H. Hunger, *Astronomical Diaries and Related Texts from Babylonia*, Österreichische Akad. der Wiss., phil.-hist. Kl., Denkschriften Bd. 195, 210, Wien, 1988–.

5 Inventoried in A. J. Sachs, *Late Babylonian Astronomical and Related Texts Copied by T. G. Pinches and J. N. Strassmaier*, Providence, 1955, xxiii-xxiv. For editions and translations of some late Almanacs, see A. J. Sachs, "The Latest Datable Cuneiform Tablets", in: B. L. Eichler et al. (edd.), *Kramer Anniversary Volume: Cuneiform Studies in Honor of Samuel Noah Kramer*, Kevelaer and Neukirchen-Vluyn, 1976, 379-398.

6 From ACT no. 611, cols. I-II, lines 21-33. The year numbers in the last two lines are partially restored.

202	Dūzu	22	18° 20'	Cancer	first appearance
203	Ābu	4	18° 20'	Leo	first appearance
204	Ulūlu	17	18° 20'	Virgo	first appearance
205	Tašrītu	29	18° 20'	Libra	first appearance
206	Araḫsamna	12	19° 30'	Scorpio	first appearance
207	Kislīmu	28	23° 15'	Sagittarius	first appearance
208	Ṭebētu	15	28° 40'	Capricorn	first appearance
209	Adaru	3	4° 40'	Pisces	first appearance
210	2nd Adaru	21	10° 40'	Aries	first appearance
212	Aiaru	9	16° 40'	Taurus	first appearance
213	Simānu	25	20° 26' 15"	Gemini	first appearance
214	Dūzu	9	22° 30'	Cancer	first appearance
215	Ābu	21	22° 30'	Leo	first appearance

Each line of this table is a description of an occurrence of the planet Jupiter's first appearance, that is, the date when it can first be seen in the eastern sky before sunrise after an interval of nights on which it could not be seen at all. Thus the first line can be interpreted, 'Year 202 of the Seleucid Era, month Dūzu, day 22, first appearance with Jupiter at 18° 20' within the zodiacal sign Cancer.' Each successive line pertains to a consecutive first appearance, roughly thirteen months after the preceding one. The ACT tables that have to do with one or another of the five planets known to the Babylonians (Mercury, Venus, Mars, Jupiter, and Saturn) seldom get much more complicated than this in structure. The planetary tables account for about half the surviving ACT tables. The other half are tables concerned with phenomena involving the moon, especially at or close to full moon and new moon; these are much more elaborate in structure, typically involving between ten and twenty columns of data.

Like the Almanacs, the ACT tables contain exclusively predicted data, not derived from observations on the dates in question, but our basis for believing this is different in the two cases. The argument for the Almanacs depends on the kind of information they contain, and the way it is expressed. In particular, they refer only to phenomena that were (for a Babylonian) strictly predictable, and include some that could not have been observed; thus weather is never mentioned in its own right or as an obstacle to observation, and times are specified for lunar eclipses even when they fall during the daylight.[7] With very few exceptions, we do not know how the predictions were made.[8] In the ACT tables, on the other hand, we know

7 Sachs, "A Classification" (see n. 3), 287-288.

8 Current speculation presumes a mixture of data derived from older Diary-style observations and from ACT tables, but this hypothesis has so far been difficult to verify. See H. Hunger,

that the data are predicted because the numbers in the rows and columns conform to strict arithmetical rules, in such a way that the contents of almost any 'cell' of the table can be calculated by a formula from the contents of cells in higher rows in the same column and of cells in other columns in the same row.

Except to the extent that they use ideograms representing calendrical months, zodiacal signs, names of phenomena, and signals such as 'additive' and 'subtractive', the ACT tables contain no prose text. Texts that discussed aspects of the tables were, however, written, sometimes on the same tablet, but more often on separate tablets. Neugebauer refers to these as *Procedure Texts*, for reasons that will become obvious presently.

Before looking at the Procedure Texts from the point of view of their relationship as 'commentaries' to the ACT tables, it may be useful as a control to review the principal modern commentary on the same texts, in Neugebauer's *Astronomical Cuneiform Texts* (henceforth abbreviated as *ACT*). *ACT* is ostensibly an edition of the ACT tables (as well as the relevant procedure texts), and so the heart of the work comprises transliterations of the tablets according to assyriological conventions, i.e. replacing the cuneiform with the Roman alphabet and Arabic numerals. Neugebauer supplements the editions in several ways, which I list roughly in order of increasing remoteness from the actual tablets:

1. Restorations. Text lost through damage to the tablets is restored in brackets in the edition. Often entire columns that have broken off are restored when their contents can be deduced from the surviving parts. As a rule the restored text is *translated*, i.e. names of months and zodiacal signs are given using modern symbols instead of transliterated ideograms.
2. Commentaries on the individual tablets. These usually comprise three parts: a header section briefly identifying the contents, date, format, and provenance; an apparatus signalling scribal errors; and a commentary proper. This last section is mostly concerned with individual characteristics of the table: the specific types of column that it contains, discussion of its peculiarities and errors, and references to other closely related tablets.
3. A philological introduction, dealing with general questions of provenance and chronology, the colophons, and the scribes.
4. Introductions to the planetary tablets as a whole, and to the lunar tablets as a whole. These interpret the astronomical meaning of the tables and their various columns, and present and discuss the formulas employed in the tables to determine their contents. The rules are given straightforwardly in modern notation; little is said either about how the rules were originally derived or how they were rediscovered by modern scholarship. On the other hand, from the formulas that the Babylonian scribes are presumed to have used, Neugebauer derives further formulas useful to the modern scholar for checking the arithmetic in the tables and establishing connections between tablets.
5. An introduction presenting mathematical methods that are generally pertinent to the ACT tables and their modern analysis.
6. Various lists and explanations of terminology and symbols, and a glossary of ideograms.

"Non-mathematical Astronomical Texts and their Relationships", in: N. M. Swerdlow (ed.), *Ancient Astronomy and Celestial Divination*, MIT Press, Cambridge (U.S.A.), in press.

Broadly speaking, Neugebauer's commentary has two distinguishable goals. In the first place, it attempts to make it possible for a modern student possessing some knowledge of astronomical phenomena and elementary mathematics to read the individual Babylonian tables with understanding of the basic purpose and methods of the table and each of its components. But at the same time it treats each single tablet as a particular instance of a general *theory* of the behaviour of one of the heavenly bodies, which can be expressed compendiously in the formulas set out in the general introductions. By using the word 'theory' Neugebauer implies that his purpose in presenting us with the formulas is not so that we can generate ACT tables ourselves (although the possibility of doing this becomes part of his equipment as an editor), but so that we can subsequently analyse the formulas in the hope of learning about the nature and history of a more abstract level of astronomical thought among the Babylonians that was not explicitly recorded in the documents that we possess. This further, historiographical stage was not part of Neugebauer's scope within *ACT*, although it was implied by its structure; as he remarks in his preface,

> This edition of Astronomical Cuneiform Texts is intended to furnish the basis for a chapter on Babylonian Astronomy in a larger History of Ancient Astronomy. In the present work, however, no attempt has been made to arrive at general historical conclusions, though the introductions to volumes I and II provide the reader with the necessary background of Babylonian lunar and planetary theory.[9]

The commentaries in *ACT* obviously do not aspire to saying the last word on the ACT tablets, but their structure is complex and designed to help the reader in more than one way. The Babylonian Procedure Texts are considerably simpler. Their

9 Neugebauer, *ACT* vol. 1, xi. The promise was eventually fulfilled in Book II of Neugebauer's *History of Ancient Mathematical Astronomy*, Berlin etc., 1975.

general character may be inferred from the following example of a complete, though fairly short, tablet:[10]

[*Section 1*] Jupiter. From 9° Cancer to 9° Scorpio add 30°. Surplus beyond 9° Scorpio multiply by 1,7,30. From 9° Scorpio to 2° Capricorn add 33° 45'. Surplus beyond 2° Capricorn multiply by 1,4. From 2° Capricorn to 17° Taurus add 36°. Surplus beyond 17° Taurus multiply by 56,15. From 17° Taurus to 9° Cancer add 33° 45'. Surplus beyond 9° Cancer multiply by 53,20.

[*Section 2*] From 9° Cancer to 9° Scorpio: slow. From 9° Scorpio to 2° Capricorn: medium. From 2° Capricorn to 17° Taurus: fast. From 17° Taurus to 9° Cancer: medium.

[*Section 3*] In the slow. With the sun, from 9° Cancer to 9° Scorpio, each day 12' 30" it moves. After it appears, 30 days, each day 12' 30" it moves. 3 months, each day 6' 40" it moves, it stands still. 4 months, each day 4' 10" it moves backward, it stands still. 3 months, each day 6' 23" 20"' it moves. 30 days before it disappears, each day 12' 30" it moves, it disappears.

[*Section 4*] In the medium. With the sun, from 9° Scorpio to 2° Capricorn, each day 14' 3" 45"' it moves. After it appears, 30 days, each day 14' 3" 45"' it moves. 3 months, each day 7' 30" it moves, it stands still. 4 months, each day 4' 41" 15"' it moves backward, it stands still. 3 months, each day 7' 11" 15"' it moves. 30 days before it disappears, each day 14' 3" 45"' it moves, it disappears.

[*Section 5*] In the fast. With the sun, from 2° Capricorn to 17° Taurus, each day 16' 52" 30"' it moves. After it appears, 30 days, each day 9' it moves. 3 months, each day 5' 37" 30"' it moves, it stands still. 4 months, each day 8' 37" 30"' it moves backward, it stands still. 3 months, each day 16' 52" 30"' it moves. 30 days before it disappears, each day 16' 52" 30"' it moves, it disappears.

[*Section 6*] In the medium. With the sun, from 17° Taurus to 9° Cancer, each day 14' 3" 45"' it moves. After it appears, 30 days, each day 14' 3" 45"' it moves. 3 months, each day 7' 30" it moves, it stands still. 4 months, each day 4' 41" 15"' it moves backward, it stands still. 3 months, each day 7' 11" 15"' it moves, which is 10° 46' 52" 30"' motion. 30 days before it disappears, each day 14' 3" 45"' it moves, it disappears.

10 ACT no. 810. The translation given here is more mechanically literal than Neugebauer's, but the restorations (all certain) are not indicated as such, and signs for degrees, minutes, seconds, and thirds have been added for clarity. The section numbers are Neugebauer's.

As its first word indicates, this text is concerned entirely with Jupiter. The first two sections, in fact, concern an ACT table such as the one translated above, listing dates and positions for consecutive occurrences of a phenomenon such as first appearance. Section 1 states the rule for deriving the zodiacal position in any line from the position written one line higher. For example, the position recorded in the first line of the table is Cancer 18° 20'. According to the rule, for a position between Cancer 9° and Scorpio 9° one adds 30° (i.e. exactly one zodiacal sign). This rule has been followed down to the fourth line. In that line, the position, Libra 18° 20', is still short of Scorpio 9°, but adding 30° takes us 9° 20' past it. The continuation of the rule tells us to multiply this surplus by 1,7,30 (which is sexagesimal notation for 9/8). The result, 10° 30', is still to be understood as "surplus beyond" Scorpio 9°, so that the new position for the fifth line is Scorpio 19° 30'. For the next line, we will be using the next part of the rule in Section 1, and so forth for the remainder of the table.

Section 2 merely designates the four zones of the zodiac used in Section 1 as 'slow', 'medium', and 'fast', in accordance with the number of degrees added from line to line of the table within each zone. The remaining sections tell us how Jupiter will move from day to day while it is in each zone, by specifying time intervals and rates of daily progress for the intervals between the main stages of Jupiter's motion: its first appearance, the two stationary points delimiting its retrogradation, and its last visibility. We can designate this kind of pattern as a 'velocity scheme'. Unlike Section 1, these are descriptions rather than prescriptions: they do not tell the reader what to do, but assert that Jupiter acts in a certain way.

The nature of the Procedure Texts can be explained to a great extent by the fact that they were documents written for, and apparently by, the same scribes who produced the ACT tables themselves. In the first place, the subject matter seems much more limited than in Neugebauer's commentary. Many questions that preoccupy a modern historian were implicitly understood by the scribe, or of no interest to him, or have arisen only because of the loss of information inherent in a transmission by means of broken documents in a dead language. He did not need to have a written explanation of the purpose for which he was computing the tables, and it is quite likely that he did not care much about the empirical and theoretical basis of the formulas.

The scribes evidently also did not require philological aids when working with ACT tables, probably because the tradition was of comparatively recent origin — no trace of it has been found before the middle of the fifth century B.C. The situation may be contrasted with that of the omen literature, in which many standard texts were relics of the second millenium B.C. that called for an extensive interpretative apparatus already by the seventh century.

What the procedure texts do supply in abundance is, firstly, instructions for generating ACT tables, and secondly, instructions and theory pertaining to the immediate application of data in the tables. Even in this domain the procedure texts leave out much that a scribe would certainly need to know. Consider once more the procedure text translated above. We know from actual ACT tables that the rules in Section 1 were used to generate tables of dates and positions for five phenomena of Jupiter: its first and last appearances, first and second stationary points, and acronychal rising (i.e. rising at sunset); in some tablets all these phenomena are tabulated in a series of five pairs of columns, so that one can read across the table to get a complete cycle of consecutive phenomena, the rightmost of which is followed by the leftmost in the next line down. Yet all that the procedure text says to identify the phenomena to which the rules apply is the one word 'Jupiter'.

Secondly, the generating rules in Section 1 presume that the scribe already has 'line 1' of the table. In fact no procedure text explains how one is to get the initial values without which no ACT table can be produced. In many cases the scribes would simply have taken over the final line from a previous table; but every sequence must have started somewhere, and the frequency with which surviving ACT tables of nearby date fail to 'connect' numerically shows that the scribes possessed some way of finding initial values for all the functions in a table independent of the rules in the procedure texts, perhaps making use of contemporary observations.

Thirdly, the rules themselves are expressed elliptically. 'From 9° Cancer to 9° Scorpio add 30°', for example, means 'If the previous position falls in the interval of the zodiac from 9° in Cancer to 9° in Scorpio, add 30° to obtain the next position.' Again, 'Surplus beyond 9° Scorpio multiply by 1,7,30' means 'If the sum obtained in the last step goes beyond 9° in Scorpio, take the surplus and multiply it by 9/8, and the product is the amount by which the next position is beyond 9° in Scorpio.' By way of compensation for their terseness, the rules provide the key bits of information (conditions and operations) in a very practical order for putting them to repeated use; hence the ease with which they translate into algorithms and computer language has been remarked.[11]

Fourthly, the procedure text does not give rules for finding the dates of the predicted phenomena. In this instance the omission is specific to the tablet in question; other procedure texts do provide the needed information.[12] But it may be remarked of the Procedure Texts in general that they do not present a complete and self-sufficient set of instructions for generating a complete table. Sections of a procedure text may appear in an illogical order, and one tablet may even have sections pertaining to different planets or, without so much as saying so, to variant methods of calculating the same phenomena for the same planet, or even mathematical problems unrelated to astronomy.

Fifthly, Sections 3-6, which go beyond the process of generation of an ACT table for Jupiter, tell us certain properties of the planet's motion between one phenomenon and the next, but not how this information can be used. For this reason I would describe these sections as 'theoretical', although the theory in question is not far removed from practical applications. It would be easy for a scribe to use Section 3, for instance, to find the position of Jupiter an arbitrary number of days after one of its first appearances as tabulated in an ACT table, or to determine the date following a first appearance when Jupiter will cross from one zodiacal sign to the next.

Lastly, one is not given practical illustrations of the computations. This is the more surprising, because the habit of stating complex sequences of arithmetical operations as a general verbal formula had little precedent in the much older tradition of mathematical texts in Mesopotamia. Babylonian mathematical problems, even in tablets contemporary with the procedure texts and written by the very same scribes, always address a specific hypothetical situation with given numbers.[13] Because the Procedure Texts express their rules in terms of variables, each text is not associated with a specific ACT tablet, but with an indefinitely expandable corpus of tables sharing a common structure.

To sum up, the Procedure Texts cannot have been intended as a complete description of the methods underlying the ACT tables. I believe that their role is best understood in relation to the milieu in which the scribes performed their duties, and learned to perform them: a self-contained temple hierarchy maintaining specialized scribal traditions by direct instruction from generation to generation. Most of the routine of nightly observation, prediction, and record-keeping must have been taught orally and by demonstration, and memorized through years of training. But because the mathematical predictive schemes of the ACT tables involved many more fixed numerical parameters than it would have been convenient to commit to memory, scribes and scribes-in-training wrote down the rules for this department alone of their profession, as an *aide-mémoire* rather than a primary means of instruction.

Among the reasons that might suggest that the scribes needed Procedure Texts especially towards the beginning of their careers and while they were still undergoing schooling, we might cite the inclusion of geometrical problems in two tablets,

11 A. Aaboe and J. A. Henderson, "The Babylonian Theory of Lunar Latitude and Eclipses according to System A", in: *Archives Internationales d'Histoire des Sciences* 25 (1975) 181-222, esp. 183.

12 E.g. ACT no. 812, Section 2.

13 There are some rare exceptions in a few Old Babylonian mathematical tablets, where a rule is expressed without providing specific numbers. These texts have no historical connection with the astronomical texts of the Seleucid period, but they do demonstrate that there is no need to hypothesize foreign (e.g. Greek) influence to account for the generality of the Procedure Texts.

and the occurrence of undetected errors in some texts. The Procedure Text for Jupiter quoted above illustrates this point. Section 3 sets out a pattern of daily progress of the planet applicable to the 'slow' zone of the four zones of the zodiac mentioned in Sections 1-2. We know from other similar texts that the patterns prescribed for the other zones ought to involve speeds in the same ratios to the corresponding speeds in the slow zone as the ratios of the line-to-line advances associated with the zones in section 1, that is, in the present instance, 33° 45'/30° for the two 'medium' zones and 36°/30° for the 'fast' zone. The former ratio has been correctly applied in sections 4 and 6 for the medium zones. The speeds for the fast zone in Section 5, however, are spoiled by two separate mistakes: first, the scribe has applied the necessary ratio to the speeds in Section 4 instead of Section 3, thereby obtaining excessively large speeds, and then he has put each speed one stage too early in the cycle of Jupiter's phenomena. These errors would surely have been caught as soon as someone attempted to apply the rule to practical computation. But it is also noteworthy that this part of the text was clearly generated by the scribe himself, not copied from an exemplar.

Above I have characterized the contents of Procedure Texts as dividing into (a) instructions for the generation of ACT tables and (b) theoretical information directed towards the application of ACT tables. A browse through the extant Procedure Texts will show that most of the contents of texts concerning the moon come under heading (a), while the planetary texts are more evenly distributed between (a) and (b). Perhaps we should include under heading (a) various rules that seem to be meant to help the scribe in checking his work. For example, ACT nos. 813 (Section 1) and 814 (Section 1) tell us what should be the difference between computed positions of Jupiter separated by 12 and 71 years. Again, ACT no. 200, a Procedure Text related to the lunar tables, has a rule (Section 10) for finding one of the defining parameters in the formula that generates a column from an arbitrary pair of numbers recorded in the column; since the scribe would surely know the formula already, the likely application of this rule was to allow him to check whether the column was correctly computed. It is an interesting fact that such 'checking rules' also constitute a prominent part of the editorial tools that Neugebauer deduces in the introductions to *ACT*.

Procedure Texts in Greek Papyri

Until only a few decades ago, almost the only evidence for astronomical tables in the Greek world was to be found in the extant tables in Ptolemy's *Almagest* (Σύνταξις Μαθηματική) and *Handy Tables* (Πρόχειροι Κανόνες), and it was generally taken for granted that these represented the culmination of a tradition of so-called 'kinematic' tables extending at least as far back as Hipparchus in the second century B.C., in which the numbers were derived from geometrical models of planetary motion. Recent and extensive discoveries of astronomical papyri from Roman Egypt show that the evolution of table-making in Greek astronomy was not so straightforward.[14] In particular, where it was formerly believed that the extent of Greek familiarity with Babylonian mathematical astronomy was limited to a few parameters, especially periodicities, associated with the ACT tables, we now know that ACT tables themselves, of both the planetary and lunar variety, were being produced in Egypt during the first through the fourth centuries of our era.[15] This fact, along with the comparatively small number of kinematic tables unrelated to Ptolemy's that have so far turned up on papyrus, raises the possibility that it was through contact with ACT tables that Greek astronomers were first exposed to the possibility of prediction by means of numerical tables.

Naturally we would expect to find Procedure Texts alongside ACT tables among the papyri, and in fact we do. Nevertheless there were certain differences in the conditions under which predictive astronomy was carried out in Seleucid and Arsacid Babylonia and in Roman Egypt, which could have had an effect on the kinds of supplementary text that the practitioners wanted. The cuneiform tablets originated in a small, well-organized, and reasonably self-contained hieratic community associated with two temples in Babylon and Uruk. We now know that in some Egyptian temples during the Roman period astrology — and hence predictive astronomy — formed part of the activity of the priests.[16] But most of the papyri relating to astrology and predictive astronomy, including the very rich remains from Oxyrhynchus, have no evident connection with temples, and the typical situation for a Greco-Roman astrologer was as an independent professional.

A direct consequence was that one no longer had access to certain resources that the temple could provide. Such an archive of observational records as the Diary texts at Babylon was neither portable nor easily reproduced; and so the predictive component of astronomy was largely cut off from its observational component. Thus the astronomical papyri are predominantly the counterparts (in purpose if not

14 A. Jones, *Astronomical Papyri from Oxyrhynchus*, Memoirs of the American Philosophical Society, Philadelphia (forthcoming) presents 123 new fragments of astronomical texts and tables; Appendix B is an inventory of 71 previously published astronomical papyri. For further discussion, see A. Jones, "A Classification of Astronomical Tables on Papyrus", in: N. M. Swerdlow (ed.), *Ancient Astronomy and Celestial Divination*, MIT Press, Cambridge (U.S.A.), in press, and "Models and Tables in Greek Astronomy", in: *ANRW* II 37.6 (forthcoming).

15 The spread of ACT astronomy from Mesopotamia to Egypt, with the concomitant translation from Akkadian to Greek (and to some extent Egyptian), took place before the end of the first century B.C., but it is difficult to say how long before, because the earlier papyrus record is scanty.

16 D. Baccani, "Appunti per oroscopi negli ostraca di Medinet Madi", in: *Analecta Papyrologica* 1 (1989) 67-77; A. Jones, "The Place of Astronomy in Roman Egypt", in: T. D. Barnes (ed.), *The Sciences in Greco-Roman Society*, Apeiron 27.4, Edmonton, 1994, 25-51, esp. 39-46.

always in mathematical methods) of the ACT tables and of those parts of the Almanacs that could be derived from ACT tables. The shift in emphasis seems to parallel the growth in relative importance of personal horoscopic astrology as an application of astronomy. Secondly, as the methods of Babylonian mathematical astronomy were diffused, the conditions for training people in its technicalities must have become less favourable, with less opportunity for sustained oral instruction, supervision, and examination. To make up for this loss, one could arrange things so that each user did not need to know how to produce his own tables, or augment the role of written commentaries. Hence we would anticipate finding proportionally more almanac-like tables of pre-computed planetary positions, which could be 'published' and used by astrologers who had not mastered the mathematical predictive schemes, and Procedure Texts in smaller numbers but covering a wider range of topics in a more lucid style.

These *a priori* expectations are to some extent confirmed by the papyri known at present. Almanacs are definitely much more common than ACT tables, and it seems highly unlikely that each almanac was independently computed by the scribe who used it. The Procedure Texts, on the other hand, are not very numerous, and this has the unfortunate consequence that there is only a handful of texts that are well enough preserved so that we can understand their contents.

An example of a text that does the same sort of thing as the Babylonian Procedure Texts is *P. Oxy.* LXI 4135.[17] It describes a pattern of motion of Venus covering a cycle beginning with the date of the planet's first appearance as evening star, in a manner very similar to that of the Procedure Text for Jupiter discussed above, e.g.:

> In 60 days it will move 74°, each day 1° 14'; and in 60 days, 73°, each day 1° 13'; then in 60 days, 72°, each day 1° 12'; then in another 40 days, 30°, each day 0° 45'; and then in 20 days, 10°, each day 0° 30'; then in 3 days, 0° 18', each day 0° 6'; and it will be at evening station. Total 243 days, 259° 18'.

This is so similar in expression to the Babylonian velocity schemes that one might take it for a translation of one, although the rules in question are not attested in any Babylonian text. Another papyrus contains descriptions of several columns of one of the varieties of ACT lunar table, again using expressions that can be paralleled in cuneiform texts.[18]

17 Published in Jones, *Astron. Papyri* (see n. 14). The translation given here tacitly incorporates restorations.

18 *PSI* XV 1491 (as yet unpublished). The interpretation of the text in Neugebauer, *Hist. Anc. Math. Astron.* (see n. 9) 946 is incorrect.

Given the small number of well preserved Procedure Texts, it is likely a mere accident that none deals with the usual concern of the Babylonian Procedure Texts, namely the generating rules for an ACT table. A papyrus written perhaps a generation before Ptolemy does contain generating rules, however, for a set of kinematic tables, in which one table contained the so-called 'mean motions' (the uniform circular motions hypothesized in a geometrical model), and the other contained the 'anomalies' (conversion of the mean motions into an apparent position relative to a terrestrial observer).[19] The text is very fragmentary, so that it is not easy to see how the instructions for making the tables worked. But the mere existence of such a Procedure Text is interesting, because we tend to think of kinematic tables such as Ptolemy's as fixed authorial texts that would be reproduced by copying rather than by rederivation from a formula.

Further insights into the character of the Greek Procedure Texts can be obtained from two examples concerned with the 'Standard Lunar Scheme', a set of tables for calculating lunar positions that is of Greek origin although derived from a variety of Babylonian ACT table.[20] The Standard Scheme required two tables: an ACT-style table (or 'epoch table') of dated positions of the moon at fixed intervals, and an auxiliary table (or 'template') setting out the pattern of motion between the dates in the epoch table. The template serves a similar purpose to the velocity schemes in procedure texts, but the tabular format simultaneously allows for a more complex mathematical description of changing speeds, and simplifies the use of the tables. Several examples of both tables survive in papyrus copies.

P. Ryl. I 27 gives instructions for determining an epoch date and corresponding lunar position in a given year. The style of the instructions is somewhat more 'filled out' than in the cuneiform texts but still elliptical, for example:

> All the years from Commodus. Add 92. Divide by 25. Then the remainder by 365, and the cycles of 25 by 32. After adding to make one number, divide if you can by 3031, and the remainder by 248, and in this way the remainder will be the number falling short of 298. Count these from Thoth 1.

Here the user is expected to understand that "all the years from Commodus" means the number of the year in question, counted inclusively from the first regnal year of

19 To be published as *PSI* XV 1490. Provisional edition (as P.S.I. inv. 515): M. Manfredi, "Presentazione di un testo astronomico ed discussione di un documento di Antinoe", in: *Atti dell' XI Congresso Internazionale di Papirologia, Milano 2-8 Settembre 1965,* Milano, 1966, 237-243.

20 For details, see A. Jones, "Studies in the Astronomy of the Roman Period I: The Standard Lunar Scheme", in: *Centaurus* 39 (1997) 1-36. Textual revisions and a translation of *P. Ryl.* I 27 appear in Appendix 2 to that article; the translation here tacitly incorporates restorations and corrections. *P. Oxy.* LXI 4136 is published in Jones, *Astron. Papyri* (see n. 14).

Commodus, and that the "number" obtained in the last step is the number of the day in the unreformed Egyptian calendar, counted inclusively from the first day of the year (Thoth 1). But what is most interesting about this text, from our present point of view, is that the rules do not tell us how to construct the rest of an epoch table given the contents of the first line, as is the usual task in Babylonian Procedure Texts, but how to find the first line itself.

The other Standard Scheme Procedure Text, *P. Oxy.* LXI 4136, gives instructions (roughly comparable in style to *P. Ryl.* I 27) for finding partial totals of numbers in the template table, at intervals of 27 and 28 lines corresponding to dates of the moon's slowest progress. This is presumably intended as a 'checking rule'. But the situation is peculiar: unlike the epoch table, the Standard Scheme template was essentially identical for all users at all dates, so that it is not easy to see the practical sense of providing elaborate general rules for deriving a series of perhaps 11 subtotals that could simply have been listed in a fraction of the space. I can only account for this by supposing that the author of the text was stimulated by the intrinsic interest of the mathematical properties of the template, and therefore chose to devise a set of instructions that partially reflect the method of solution of his problem rather than merely stating the answers.

The Commentaries on Ptolemy

Only two of Ptolemy's several writings on astronomy seem to have provoked commentaries in antiquity: one wrote either on the *Almagest* or on the *Handy Tables*, or occasionally on the relationship between the two works. One man, Theon of Alexandria, produced commentaries of all three varieties. Each was a response to a different set of problems, and so there is less uniformity among them than one might at first expect. In the following pages I propose to consider each of these kinds of Ptolemaic commentary in turn, with the main emphasis on Theon's commentaries for the necessary reason that they are the only ones before the Byzantine period that are substantially extant. First, however, we will recall to mind the nature of Ptolemy's two publications.

The *Almagest* is a fundamentally theoretical work of science. Ptolemy's plan is to put forward certain hypothetical geometrical models of planetary motion, to show how all the components of these models can be measured empirically using observations, and lastly to demonstrate that the recognized phenomena of the heavenly bodies can be deduced logically and mathematically from the models. Ptolemy's philosophical preface makes it clear that this demonstration is an end in itself, and his intended reader is the philosopher and the mathematician.

Predictive tables appear at various points in the course of the *Almagest*. Ptolemy devotes entire chapters to the mathematical construction of the tables and to instructions for their use, passages that if taken in isolation are essentially Procedure Texts. The tables and Procedure Texts are integral parts of Ptolemy's plan, serving two purposes. Firstly, tables generated in one part of the *Almagest* are often put to use in subsequent deductions; for example, the tables for solar motion presented in Book III are required in Book IV to establish the sun's (and hence the moon's) precise location on the occasion of certain eclipses for which the date and time had been observed. Secondly, the tables form part of Ptolemy's demonstration that the phenomena are consequences of the hypothetical models; thus tables for predicting eclipses and planetary visibilities and stationary points lead to general results that are in accord with empirical expectation.

Ptolemy was of course perfectly aware that his tables had practical applications, especially in astrology. He says nothing about this in the text of the *Almagest*, but it is surely not an accident that the tables make up a dossier containing the wherewithal for practically the entire range of astronomical prediction that the astrology of his time required. But their original placement, appearing here and there in the *Almagest* wherever the theoretical discussion reaches the appropriate point, was utterly impractical — one need merely observe that a single horoscope would have required seven tables appearing in the midst of six papyrus rolls.

Ptolemy therefore published a revised version of the *Almagest* tables separately as the *Handy Tables*. The revisions are of several kinds. First, Ptolemy added a few tables, such as a list of geographical coordinates of cities in the known part of the world, that were not included in the *Almagest*. Secondly, he altered the contents of a few tables in the light of theoretical improvements to his models. Thirdly, he modified the structure of many tables, sometimes to make them easier to use, sometimes to save space, and in general to fit the tables to a manuscript of different dimensions from the *Almagest* rolls, probably in codex form.[21] The *Handy Tables* were popular as early as the third century, at least among the astrologers of Egypt, as we know from a large number of fragments among the papyri.[22]

That Ptolemy had no illusions about the degree to which the users of the *Handy Tables* would care to understand its theoretical foundation can be seen from his *Arrangement and Calculation of the Handy Tables*, which is the only accompanying text that he is known to have published in conjunction with the tables. This work, which Ptolemy addressed to the same Syrus who was the dedicatee of the *Almagest* and several of Ptolemy's other writings, is nothing more than a catalogue of the tables making up the collection and a set of Procedure Texts giving instructions for using the tables. All that Ptolemy sees fit to explain about the derivation of the tables is expressed in the first sentence:

21 All but one of the currently known papyri containing parts of the *Handy Tables* were codices, and Theon mentions tables comprising several 'leaves' (πλειόνων πτυχίων) in his *Little Commentary*: A. Tihon, *Le "Petit Commentaire" de Théon d'Alexandrie aux Tables Faciles de Ptolémée*, Studi e testi 282, Città del Vaticano, 1978, 201.

22 Jones, "A Classification" (see n. 14), section IV 3.

> The structure of the *Handy Tables* [προχείρου κανονοποιίας] directed to the positions of the planets, Syrus, was made by us in a certain manner in accordance with their uniform circular models, so that one can exhibit their apparent positions in longitude with respect to the zodiacal circle by means also of eccentres and epicycles drawn in the plane in the ratios demonstrated in the *Syntaxis* such that they will be in agreement with the positions obtained by calculation ...

What this means is that someone with a copy of the *Almagest* at hand could easily perform approximate calculations of planetary positions by making drawings of the models of the *Almagest* in their instantaneous situations for a given time, using the mean motion tables of the *Handy Tables* to find the various angles. This is true, since the changes that Ptolemy made in his models between the *Almagest* and the *Handy Tables* only affect their latitudinal motion, which could not be displayed in such drawings anyway. But Ptolemy does not draw the slightest attention to the revised latitudinal models, or to the extension of the *Almagest*'s theory of planetary visibilities, that were incorporated in the *Handy Tables*.

The instructions that make up the great part of the *Arrangement and Calculation*, although they mention practically every step involved in the use of the single tables, are so terse that they would have been very difficult for a beginner to understand; and Ptolemy provides his reader with no worked examples. It is not clear that he intended that the text should form part of the same manuscript as the tables themselves. A few of the medieval copies of the *Handy Tables* include the text, but for the most part the traditions of the text and tables appear to have been independent. There is of course a practical advantage in having the instructions in a separate manuscript from the tables, so that one can consult both simultaneously.

Whether because Ptolemy's own instructions were scarce, or because they were difficult to follow, other hands undertook the task of writing practical manuals for the *Handy Tables*. Fragments of two such works survive on papyrus. One of these (*P. Oxy.* LXI 4142) was copied out in the fourth century on the back of a documentary roll. The preserved portion deals in a very elementary and long-winded manner with the various time-conversions needed to translate a given local time in seasonal hours into the Alexandria mean time of Ptolemy's tables. Each section is followed by a worked example. One of these illustrates the conversion from local time at Rome to local time at Alexandria; this need not imply that the author was writing at Rome, since this particular choice of meridians turns up in examples of astronomical computations in other *Handy Tables* manuals as well as in Heron's *Dioptra*. The other papyrus, *P. Oxy.* LXI 4143, is part of a codex page containing instructions for Ptolemy's tables for planetary latitudes, with a worked example for September 22, A.D. 352. As in other comparable texts, the date of the example is likely to be close to that of the work's composition, so that we have here an unknown commentator active only a decade before Theon.

Theon of Alexandria's so-called *Little Commentary* on the *Handy Tables* seems at first glance to have been the last of his three Ptolemaic commentaries to be conceived, since its preface, addressed to the same pupil (τέκνον) Epiphanius who is the dedicatee of the *Almagest* commentary and the fourth book of the *Greater Commentary* on the *Handy Tables*, refers back to the *Greater Commentary*, as that work's preface refers back to the *Almagest* commentary. As we shall see, however, the chronology of the three commentaries in their extant form is caught in a tangle of cross-references and revisions. The *Little Commentary* illustrates several of its earlier chapters with worked examples for a date in A.D. 360 (ed. Tihon, 205, 209, 213, 224, 232). The choice of date was arbitrary, and probably reflects when Theon composed these chapters. An example worked out for a date in A.D. 377 would then be a subsequent insertion (ed. Tihon, 262).

Theon writes in his preface that 'most of those who approach us for instruction in this subject [i.e. the *Handy Tables*], besides not being able to follow multiplications and divisions of numbers satisfactorily, prove also to be wholly uninitiated in geometrical proofs,' and it is for these people that he wrote the *Little Commentary*. Like the earlier commentaries discussed above, the *Little Commentary* is devoted to the practical task of explaining how to use the *Handy Tables* for the full range of predictions required by an astrologer. It accomplishes this goal very efficiently and lucidly, and it was no doubt because of its comparative excellence that the *Little Commentary* was copied extensively in the Middle Ages (more than 50 manuscripts exist). One relative shortcoming is in the examples, which Theon seems originally to have provided only for the basic operations of time-conversion and the computation of the ascendant, the midheaven, and the longitudes of the heavenly bodies, that is, just those computations that one would need to cast a horoscope. More difficult, or less often demanded, calculations such as eclipses and planetary latitudes and visibilities are described without examples, although in one or two cases the defect was subsequently supplied, it is not clear whether by Theon himself.[23]

Theon's *Little Commentary* was the source or model for subsequent commentaries of similar scope, in particular the *Preceptum Canonis Ptolomei* compiled in Latin in the sixth century, and the seventh-century manual to the *Handy Tables* attributed to the emperor Heraclius (though usually ascribed in modern discussions

23 Besides the example already mentioned of the computation of a conjunction for September 17, A.D. 377, a few manuscripts of the *Little Commentary* incorporate a long computation of the solar eclipse of June 16, A.D. 364, adapted from Theon's *Almagest* commentary; cf. A. Tihon, "Le calcul de l'éclipse de Soleil du 16 juin 364 p.C. et le «Petit Commentaire» de Théon", in: *Bulletin de l'Institut historique belge de Rome*, 46/47 (1976-1977) 35-79.

to Stephanus of Alexandria).[24] On the present occasion, however, we will neither pursue this trail beyond Theon, nor bring into consideration the various collections of scholia to the *Handy Tables*, but turn instead to the tradition of commentaries on the *Almagest*.

Parts of two *Almagest* commentaries (in the strict sense of that word) are extant in something like their original form: Pappus of Alexandria's on Books V and VI, and Theon's on all thirteen books except Books V and XI; much of Theon's fifth book has recently been rediscovered disguised as scholia in the margins of a manuscript of the *Almagest*, *Vat. gr.* 198.[25] In addition to these coherent and continuous expositions, there is a great wealth of similar material to be found among the scholia, which fall outside our present scope.[26]

Pappus seems to have written his commentary about the 320s, to judge by the sole dated example in the extant books, which is for A.D. 320. Theon's can be dated roughly by its inclusion of a computation of the circumstances of two eclipses in A.D. 364, which the author observed. Elsewhere Theon has inserted examples of computations of the longitudes of the sun and moon for January 5, A.D. 323, which look as if they have been 'cannibalized' from an independent opuscule (by Pappus? or Theon's own horoscope?).[27] It is unfortunate that the beginning of Pappus's commentary, where he presumably explained what he was up to, has not come down to us; but the resemblances in character between his commentary and Theon's are so numerous that we may be confident that they originate in the same circumstances.

Theon writes (ed. Rome, 317) that he undertook to write his commentary (ὑπομνηματισμός) because he had been 'continually urged by pupils [τῶν ἀκροατῶν] to give advice about the things in Ptolemy's *Mathematical Syntaxis* that

24 D. Pingree, "The Preceptum Canonis Ptolomei", in: *Rencontres de cultures dans la philosophie médiévale: Traductions et traducteurs de l'antiquité tardive au xive siècle*, Louvain-la-Neuve/Cassino, 1990, 355-375; A. Tihon, "L'astronomie byzantine (du v^e au xv^e siècle)", in: *Byzantion* 51 (1981) 603-624, esp. 607-609.

25 A. Tihon, "Le livre V retrouvé du *Commentaire à l'Almageste* de Théon d'Alexandrie", in: *L'Antiquité Classique* 56 (1987) 201-218.

26 The entire range is surveyed by D. Pingree, "The Teaching of the *Almagest* in Late Antiquity", in: T. D. Barnes (ed.), *The Sciences in Greco-Roman Society*, (Apeiron 27.4), Edmonton, 1994, 75-98, and A. Tihon, "Propos sur l'édition de textes astronomiques grecs des iv^e et v^e siècles de notre ère", in: *Les problèmes posés par l'édition critique des textes anciens et médiévaux*, Louvain-la-Neuve, 1992, 113-137.

27 The example of the solar longitude in Book III (ed. Rome, 907-911) is introduced — incongruously for the context — with an announcement that the positions of sun, moon, and the five planets will be computed. The second installment is delivered only in Book V (Tihon, 'Le livre V retrouvé', 208-217), while the remainder ought to have been in the lost Book XI. The computation of the lunar longitude is carried out according to both the *Almagest* and the *Handy Tables*, a comparison that has little motivation in the *Almagest* commentary.

appeared difficult to each.' Rome (note *ad loc.*) infers that the work is 'la rédaction d'un cours', though from Theon's wording the situation seems to have been, not a formal class or lectures, but the importuning of students reading the *Almagest* by their own lights. The ambitions of the pupils were mixed, for Theon speaks of his concern for 'the training of astronomers and the incitement of students of mathematics [τῆς τε τῶν ἀστρονομούντων ἀσκήσεως καὶ τῆς τῶν στοιχειουμένων προτροπῆς]'. I take the latter, who are literally described as 'those who are instructed in elements', to be students who had worked through Euclid's *Elements* and were progressing to the *Almagest* as a work of more advanced mathematical reasoning, and the former to be astrologers. The latter, at least, Theon does not expect to take a great interest in philosophy, for before embarking on a careful explanation of Ptolemy's introductory philosophical chapter (ed. Rome, 319), he reassures the reader that it will not be the business of the professed astronomer (τὸν ἀστρονομεῖν ἐπαγγελλόμενον) to bring in the 'lengthy arguments [μακρολογίας]' of philosophy. He even suggests, most implausibly though with some humour, that Ptolemy himself was writing for youthful pupils whom he did not wish to see 'dragged into the profound inquiries [βαθέα ζητήματα] of the philosophers.'

In practice both Pappus and Theon give the most attention to Ptolemy's mathematical reasoning at the small scale, that is, the individual geometrical and numerical demonstrations. Page after page is devoted to quotation, paraphrase, and filling out of Ptolemy's argument where the commentator judged it to be too elliptical for the student to grasp. Pappus and Theon are doing for the *Almagest* much the same thing that Pappus does in *Collection* Book VII for the geometrical treatises of Apollonius and Euclid that composed the so-called *Treasury of Analysis*, supplying supplementary demonstrations of steps that the authors considered obvious, treatments of multiple cases where the author provided only one, and alternative proofs.

On the other hand neither Pappus nor Theon shows much interest in or understanding of the large-scale plan of the *Almagest*. It seems to have been enough if the student could justify to himself each step of reasoning along the way, without bothering himself much about where he was ultimately headed and why. Hence Theon does little more than paraphrase the contents of such chapters as *Almagest* IX 2 that discuss fundamental problems of scientific methodology. Only very occasionally will Pappus or Theon incorporate information derived from authors before Ptolemy, and then only to clarify or justify Ptolemy's statements; thus when Ptolemy (*Almagest* I 3) states that the circle is the figure with the greatest area for a given perimeter, Theon inserts the proof of this by the Hellenistic geometer Zenodorus, and Pappus provides more details of Hipparchus' treatise *On Sizes and Distances* to explain Ptolemy's criticism of it at *Almagest* V 11. Neither commentator shows any deeper interest in the historical background of the *Almagest*, or in the extension or refinement of Ptolemy's researches through new observations, although this is a possibility that Ptolemy himself raises in the opening and closing chapters of the treatise. Hence whether or not ἀστρονομεῖν means for Theon 'to do astrology' as I have suggested, it certainly does not mean 'to do astronomy' in the sense that Hipparchus and Ptolemy were astronomers.

The third category of commentary on Ptolemy, which concerns both the *Almagest* and *Handy Tables* and their relationship to one another, is represented by Theon's so-called *Great Commentary* on the *Handy Tables*. Theon asserts in his preface (ed. Mogenet-Tihon, 94) that he had seen no comparable work by his predecessors, but we are fortunate to possess a fragment of such a dual commentary that dates from the first half of the third century (it contains a worked example for A.D. 213).[28] The anonymous text discusses aspects of Ptolemy's lunar model and the lunar tables in the *Handy Tables* in a strangely incoherent and sloppy manner, but with interesting allusions to matter that seems to be of purely historical interest, such as the Babylonian origin of a certain periodicity that Ptolemy ascribes to Hipparchus, and an early charge by an otherwise unknown Artemidorus that Ptolemy was inconsistent in his revisions to Hipparchus's lunar theory. At the same time our commentator attempts to guide the reader through the arrangement of the lunar tables as they appear in varying form and with different headings in manuscript copies. One has the impression of a writer who intended to produce a practical introduction to the *Handy Tables* but kept getting sidetracked.

By way of contrast, Theon has a clear idea of what his *Great Commentary* is supposed to do. He writes (ed. Mogenet-Tihon, 93) that he undertook this treatise in five books (of which the first three and the first part of the fourth are extant) in response to the demands of his addressees, Eulalius and Origenes, for a 'reasoned introduction' to the *Handy Tables*. He sees his work as a contribution to theoretical science (μαθηματικῇ θεωρίᾳ) but one with a practical application as well: for while Theon's exposition of the models underlying the *Handy Tables* will be of purely intellectual interest, his discussion of the numerical derivation of the tables will also allow the reader to check and correct his own copy.

The result is a very unusual kind of commentary. In a sense Theon is attempting to reconstruct the *Almagest* as it would have been written if the tables in it had been the *Handy Tables*. But of course Theon's situation is not parallel to Ptolemy's: where Ptolemy was deriving new tables from models that he was himself testing and calibrating through observations, Theon must show how a preexistent set of tables can be derived from the *Almagest* models. On the one hand Theon does not need to justify the models themselves empirically, but on the other he has to reconstruct, seemingly without any documentary evidence at all, the lost steps leading either from an *Almagest* table to its *Handy Tables* counterpart or from the *Almagest* model directly to the pertinent table in the *Handy Tables*. This is really a problem of historical analysis of scientific texts, exact analogues of which can be found in modern scholarship. It is a pity that we no longer possess the sections concerning the planetary tables, in which Ptolemy incorporated significant alterations to his models — not because one would expect Theon to have had more direct knowledge of these theoretical modifications than can be deduced from the tables themselves, so much as because Theon displays enough acumen in the extant parts of the commentary to make us curious about how he would have handled these more difficult problems.

Theon's commentaries thus turn out to be three quite divergent compositions addressed primarily to different kinds of user of Ptolemy's works. The intended reader of the *Little Commentary* is the easiest for us to visualize. He was just the sort of man who was responsible for many of the astronomical papyri: the astrologer who was not content to rely on published almanacs for the data in his horoscopes, and who had learned that the arithmetical methods of prediction that had once been the tools of the trade were being supplanted by Ptolemy's more difficult, but more accurate tables. He could perform the basic operations of arithmetic with the astronomers' base-sixty numerals, but he had neither the inclination nor the necessary education to follow Ptolemy's deductive arguments.

Notwithstanding the immense labour that must have gone into Pappus' and Theon's *Almagest* commentaries, I find it hard to believe that even in Alexandria they found as many readers as the instruction manuals for the *Handy Tables*. Aside from the occasional astrologer with more intellectual pretensions than the norm, Pappus and Theon were writing for pupils studying mathematics (mostly Euclidean geometry), sometimes as an end in itself, perhaps more often as part of a broad liberal education. In the polemical piece that has come down to us as the third book of his *Collection*, Pappus gives us a glimpse of this milieu, as he describes his encounters with a series of not very adept students who had come to study geometry with him after a first training in the subject under another teacher who was, interestingly, a woman. The Hermodorus who was the recipient of Books VII and VIII of Pappus' *Collection* and Theon's dedicatee Epiphanius, both of whom are addressed as τέκνον, were probably outstanding pupils.

And as for the *Great Commentary*, I wonder whether it ever found an ancient reader who took as much pleasure in mastering it as Theon must have had in writing it. In spite of Theon's best efforts to make it useful as an editorial tool, a sort of Procedure Text for checking the text of the *Handy Tables*, it survived through the Middle Ages by way of only a single copy. Of Theon's commentaries this is the one for which we have the most defective text, both in completeness and in accuracy.

The relation of Theon's commentaries to the Procedure texts discussed in the first part of this paper is a reflection of two shifts that occurred in Greek astronomy, largely in response to Ptolemy. From its Mesopotamian beginnings predictive

28 A. Jones, *Ptolemy's First Commentator*, Transactions of the American Philosophical Society 80.7, Philadelphia, 1990.

astronomy had involved tables that the user constructed for himself according to rules that could be committed to memory or expressed in Procedure Texts. This tendency to regard tables as products rather than as transmitted texts persisted even after Greek astronomers began to use tables based on kinematic geometrical models, and indeed its continuation can be seen in Indian astronomy. Ptolemy too explained in the *Almagest* how his tables were generated. But this was for the sake of convincing his reader of the tables' dependence on his models, not in the serious expectation that anyone would try to reconstruct them anew from the text; most of them were far too complex for that. In either of their published forms, Ptolemy's tables were a received text. Hence the Procedure Texts with their generating rules were displaced by instruction manuals like Theon's *Little Commentary*.

At the same time the *Almagest* seems to mark a change in the sort of book in which topics in theoretical astronomy were presented. In place of the specialized monographs of the kind that Hipparchus wrote, Ptolemy presented an entire system of planetary models as a unified and cumulative chain of deductions, which apparently assumed a role in academic education analogous to that of Euclid's *Elements* in pure mathematics.[29] Instead of showing the way towards more refined researches into the celestial motions, such as Ptolemy seems to have anticipated, the *Almagest* was by the fourth century ossified as a 'Great Book', something that an intelligent youth could read for intellectual profit with the guidance of Pappus' or Theon's commentary.

Appendix. Theon as reviser and editor

This excursus deals with two interrelated topics that specifically concern Theon's activity as a commentator: the significance of the evidence for authorial revisions, and the question of whether the commentaries were made in conjunction with editions of the commented texts.

All three commentaries evidently contain material that did not form part of the original composition. In the *Little Commentary*, as we have already noted, Theon appears originally to have included worked examples only for the more common varieties of astronomical computation, and these consistently use a date in A.D. 360, which is therefore likely to be the year in which Theon wrote the book. The example of a computation of a syzygy, using a date in A.D. 377, is therefore probably a later insertion, but probably by Theon himself. Now Theon addresses the preface of the *Little Commentary* to Epiphanius, and says there (without further remark) that he had previously written a more 'reasoned' commentary in five

29 It may not be accidental that the *Almagest* is divided into the same number of books (thirteen) as the *Elements*.

books, obviously meaning our *Great Commentary*. If we could be sure that the preface as we have it was present in the original text of 360, it would follow that the *Great Commentary* was written before that year.

The *Great Commentary* itself, however, shows that Theon was capable of reissuing a work with a change of addressee. Like the *Almagest* (after which it is loosely modelled), the *Great Commentary* marks something of a half-way point after the completion of the lunar theory and with the introduction of the fixed stars and planets; and when this happens, at the beginning of Book IV, Theon marks a new beginning by addressing his dedicatee again in the preface. But in Book I the dedicatees were Theon's ἑταῖροι Eulalius and Origines, whereas in Book IV the dedicatee is Epiphanius. Now if an ancient author issued a work in installments, it was possible for the original recipient to die before its completion; this occurred for example with Apollonius' *Conics*. But an *unexplained* change of dedicatee within a single composition is an anomaly. In Pappus' *Collection* four of the surviving books are addressed to three different people, but this is almost certainly to be explained by the fact that the *Collection* is merely a bringing together of several separately issued monographs on unrelated topics.[30] In the case of Theon's *Great Commentary* I think the only plausible explanation of the discrepancy is that Theon either released the work on a second occasion, or intended to do so. Our text could have been assembled from rolls belonging to the two issues, or it might descend from a manuscript that Theon was in the course of revising, so that one part bore the new preface, and the other still had the old one.

What is certain is that the present text of the *Great Commentary* has been reworked by Theon in several places, the usual symptom being the awkward intrusion of parenthetic sentences. Two references to the *Little Commentary* (ed. Mogenet-Tihon, 123 and 134) would have to have been later insertions if the present preface of the *Little Commentary* is the original; and the first of these references is indeed within one of the more suspect parentheses.[31] The *Great Commentary* and Book III of the *Almagest* commentary contain mutual cross-references, at least one of which must be a revision. It seems to me that there can be no certainty concerning the order in which Theon *began* to write his three commentaries. His practice seems to have been to maintain a personal copy of each of them, which he augmented from time to time with new examples, cross-references, and other material; and our manuscript traditions descend from these copies rather than from the first issue.

30 A. Jones, *Pappus of Alexandria: Book VII of the Collection*, Berlin etc., 1986, v. 1, 15-18.
31 I do not see the need, however, for the further dissection of this passage into four distinctly bracketed interpolations as suggested by the editors.

In modern scholarship Theon has often been identified as the author, or at least the reviser, of the *Handy Tables* as we find them in medieval manuscripts.[32] Tihon has, however, shown on the basis of a careful examination of the *Great Commentary* that Theon certainly did not have enough understanding of the principles behind certain of those tables that are most different from the *Almagest* versions to have been capable of producing them; and in fact Theon never mentions any modifications made by himself in the structure or content of any table.[33] The *Great Commentary* does show, of course, that Theon was interested in finding means of correcting the received text of the *Handy Tables*, but there is no evidence that he ever designated some particular corrected manuscript as an ἔκδοσις or 'edition'.

Alan Cameron's recent argument that the *Almagest* commentary was accompanied by a recension of Ptolemy's treatise calls for more detailed consideration.[34] The case rests on the interpretation of inscriptions that appear in manuscripts, three of them at the head of Books I-III of Theon's *Almagest* commentary, the remaining three at the foot of Eutocius' commentaries on Archimedes' *Sphere and Cylinder* Books I and II and on his *Measurement of the Circle*. The inscriptions are worded as follows:

> Θέωνος Ἀλεξανδρέως τῆς παρ' αὐτοῦ γεγενημένης ἐκδόσεως εἰς τὸ πρῶτον τῆς Συντάξεως Πτολεμαίου ὑπόμνημα. (sim. for Book II)
> Theon of Alexandria, in the edition made by him, commentary on the first (book) of Ptolemy's *Syntaxis*.
>
> Θέωνος Ἀλεξανδρέως εἰς τὸ τρίτον τῆς Μαθηματικῆς Πτολεμαίου Συντάξεως ὑπόμνημα, ἐκδόσεως παραναγνωσθείσης τῇ φιλοσόφῳ θυγατρί μου Ὑπατίᾳ.
> Theon of Alexandria, commentary on the third (book) of Ptolemy's *Mathematical Syntaxis*, the edition having been proofread by the philosopher, my daughter, Hypatia.
>
> Εὐτοκίου Ἀσκαλωνίτου ὑπόμνημα εἰς τὸ πρῶτον τῶν Ἀρχιμήδους Περὶ Σφαίρας καὶ Κυλίνδρου, ἐκδόσεως παραναγνωσθείσης τῷ Μιλησίῳ μηχανικῷ Ἰσιδώρῳ ἡμετέρῳ διδασκάλῳ. (sim. for the other Eutocius commentaries)
> Eutocius of Ascalon, commentary on the first (book) of Archimedes' *On the Sphere and Cylinder*, the edition having been proofread by the Milesian engineer Isidorus, our teacher.

The translations I have given reflect one point that Cameron has established securely, that the verb παραναγιγνώσκειν means 'to check a manuscript copy', usually by comparison with its exemplar.[35] The word had previously been interpreted as 'revise' in a much broader sense. Hence these inscriptions are attestations of the accuracy of manuscript copies, not accreditations of editors.

Cameron's contention, however, is that the inscriptions do refer to editions, but not editions of the commentaries to which they are attached. Rather, they assert that the commentary was composed in conjunction with an edition of the commented text made by the person named.[36] That is, Theon's commentaries to *Almagest* I and II went with his own edition of those books, and his commentary to *Almagest* III with an edition of that book by Hypatia; and again, Eutocius' commentaries accompanied editions of Archimedes' writings by his teacher Isidorus.

In order for this reading to be viable, Cameron has to refute the long accepted proposal of Tannery's that the inscriptions to the Eutocian commentaries, along with a fourth reference therein to 'the Milesian engineer Isidoros, our teacher', were not written by Eutocius but instead by an unknown pupil of Isidorus of Miletus, the well-known collaborator of Anthemius in the design of Justinian's Hagia Sophia. Cameron's treatment of Tannery's hypothesis is to some extent *ad hominem*, but he does demonstrate that, contrary to Tannery's belief, it is narrowly possible chronologically for Eutocius to have been the architect Isidorus' pupil at Constantinople before he migrated to Alexandria, where he came under the tutelage of the philosopher Ammonius.[37] Nevertheless it would have been a strange career, and it is even

32 Hence for example in Neugebauer's *History of Ancient Mathematical Astronomy* (see n. 9) the *Handy Tables* are discussed in the context of Theon's works rather than Ptolemy's.

33 A. Tihon, "Théon d'Alexandrie et les *Tables Faciles* de Ptolémée", in: *Archives Internationales d'Histoire des Sciences* 35 (1985) 106-123.

34 A. Cameron, "Isidore of Miletus and Hypatia: On the Editing of Mathematical Texts", in: *Greek, Roman, and Byzantine Studies* 31 (1990) 103-127.

35 I had already asserted this in a review of the Mogenet-Tihon edition of the *Great Commentary*, in: *Centaurus* 29 (1986) 243-245. Unfortunately Cameron makes use of his definition of παραναγιγνώσκειν (which he establishes, oddly enough, only at the end of his article, pp. 123-126) only in combating other scholars. Since his own conjecture of what Hypatia and Isidorus did involves a more intrusive sort of editing, he is forced to claim (p.126) that the verb *in these inscriptions only* has come to mean 'constitute a text'.

36 Cameron maintains (p. 107) that 'with four examples, we may surely conclude that this was a stock formula, of which we would have more examples if we had modern editions of more of the technical writings of late antiquity.' The second half of this statement implies a rather exaggerated number of inadequately edited texts. In any case, since three of the four examples come from the same pen, it seems just as plausible that this writer had seen and was consciously imitating Theon's practice.

37 Cameron, "Isidore" (see n. 34), 103-106. By the way, I think that the horoscope for someone born in A.D. 497 that is attributed to Eutocius in some manuscripts should not be used as evidence that Eutocius was born in that year. Since the text does not identify the person concerned, any argument depending on a hypothetical identification of him with the author is circular.

stranger that Eutocius should have continually alluded to 'our teacher' in a commentary addressed — as pupil to teacher — to Ammonius. Moreover, the author of the so-called Book XV of Euclid's *Elements* also makes fulsome reference to 'Isidorus our great teacher' (ed. Heiberg, v. 5, 50); and so unless we are to make the implausible assumption that Isidorus had two pupils who habitually invoked his name in this manner, we are forced to identify the bumbling geometer who wrote *Elements* XV with the mathematically adept Eutocius.

I suspect that Tannery correctly identified the references to Isidorus in the commentaries of Eutocius as later supplements, although he presumed an exaggerated editorial role for Isidorus. But whether he was right or not, the inscriptions must be understood as guarantees that the copy before one had been checked and corrected by a competent eye, an assurance of great importance for mathematical texts with their particular susceptibility to graphical errors. When Theon issued an authorized copy (which would be called an ἔκδοσις), he would either do this himself or pass the work on to his daughter; likewise Isidorus personally proofread copies of Eutocius' commentaries, for which his pupil may have been the primary scribe. There is no warrant for supposing that the proofreader would have interfered with the text in any other way; in particular I concur with Cameron that attempts to detect Hypatia's hand in Theon's Book III are a vain labour.[38]

Theon's activity as an editor of scientific texts has in fact been considerably overrated in modern scholarship. Aside from his rather conservative ἐκδόσεις of Euclid's *Elements* and *Data* (which are attested in the colophons of extant manuscripts), it is not clear that he was responsible for any of the editions that are conventionally attributed to him. Two others of Euclid's works, the *Optics* and the *Phaenomena*, have come down to us in two widely divergent recensions, but the often repeated hypothesis that one version of each was produced by Theon rests on negligible evidence.[39] The presumption that he edited Ptolemy's writings has fared no better. Regrettably, claims for any one of these putative editions have repeatedly been buttressed by appeal to the others as established facts.

38 The same argument, however, applies to Cameron's effort (pp. 113-115) to identify Theonine or Hypatian interventions in the text of the *Almagest*.

39 J. L. Heiberg, *Litterargeschichtliche Studien über Euklid*, Leipzig, 1882, 90-153; H. Menge in vol. 8 of the Teubner ed. of Euclid, xxiv. On the versions of the *Optics* see now A. Jones, "Peripatetic and Euclidean Concepts of the Visual Ray", in: *Physis* 31 (1994) 47-76, esp. 49-51; and on the *Phaenomena*, J. L. Berggren and R. S. D. Thomas, *Euclid's Phaenomena: A Translation and Study of a Hellenistic Treatise in Spherical Astronomy*, New York, 1996, 13-18. Cameron's remarks on the *Optics* (p. 113) are misleading: the unique manuscript of this work that mentions Theon is late and almost certainly unauthoritative, and in any event only ascribes the anonymous preface to him.