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Dai Papiri della Società Italiana: Two Astronomical Tables from Oxyrhynchus Based on Babylonian Planetary Theory

Among the unpublished papyri of the PSI kept at the Istituto Papirologico «G. Vitelli» the very first two inventory numbers belong to fragments of two astronomical tables that were excavated at Bahnasa (Oxyrhynchus) in 1910[1]. The fragments, which derive from distinct manuscripts, contain numerals, names of signs of the zodiac, and names of Egyptian months in a tabular grid. Their layout suggests that these were a variety of table called "epoch tables", which list in successive rows dates and longitudes (degrees within zodiacal signs) of recurring events in the movement of a heavenly body, i.e. the sun, the moon, or one of the five planets known in antiquity. Epoch tables were one of several varieties of table used by astronomers and astrologers to calculate the positions in the zodiac of the heavenly bodies on arbitrary dates, for example in computing a horoscope[2].

Until recently, the only known epoch table on a papyrus was P.Lund 35a, a table for the moon of unknown provenance dating from the early second century of our era[3]. Numerous epoch tables, for all seven heavenly bodies, have now come to light among the astronomical papyri from Grenfell and Hunt's excavations at Oxyrhynchus (P.Oxy. astron. 4152-4161)[4]. One feature of these tables that has particular interest for the history of Greco-Roman astronomy is the circumstance that the dates and zodiacal positions in almost all the epoch tables for the planets can be shown to have been calculated using mathematical rules or theories that were invented in Babylonia during or before the Hellenistic period[5]. This proves also to be true of our two new fragments.

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[1] Their provenance is indicated by labels on the glass frames in which they were mounted, which read «Oxyrhynchos», «Bahnasa», and «Scavi all'Araba (Soc. 1910)».

[2] Jones 1999a, I, pp. 35-37 and Jones 1999b, pp. 305-310.

[3] Knudtzon - Neugebauer 1947.

[4] Texts published in Jones 1999a.

[5] Jones 1998. For the algorithms in their Babylonian and Greek forms, see respectively Neugebauer 1955, II, pp. 279-315 and Jones 1999a, I, pp. 17-33.

1.

PSI inv. 1 Tav. I.a

Oxyrhynchus cm 5,6 x 3,6 late I or early II[p]

The fragment, broken on all sides, is written in a literary hand in black ink in a red tabular framework; the back is blank except for a trace of ink at one edge. Three columns are preserved, containing:

(i) names of Egyptian months, sometimes abbreviated;
(ii) pairs of numerals;
(iii) names of zodiacal signs, perhaps also abbreviated.

Line 5 is slightly further below the red ruling than line 3, and there are no ink traces on the extant papyrus surface below col. iii line 5, where one would expect the next line; perhaps this was the last line of the table.

	i	ii	iii
	[μεϲο]	[ιβ] ιδ	λε[ο
	αθυρ	κζ κδ	ϲκο[
	φαμε	κγ λδ	ιχθ[
	επειφ	κε μδ	καρ̣[
4a		ι´	
5	[αθ]υρ̣	[̣] νδ	ϲκ[ο

ii 5: possibly a *kappa* crossed out.

Following the example of other known epoch tables, we can interpret the first of each pair of numerals of column ii as indicating the day number of the event within the month named in column i. To the left of this column there would have been a column for the year (regnal year number and, at the beginning of a new reign, the emperor's name). The second numeral in column ii was employed in the calculation of the dates, and can be interpreted as sixtieths of a day counted, probably, from the sunset preceding the day in question. Column iii gives the zodiacal sign occupied by the heavenly body, and a lost column to its right would have given the degrees and minutes of the position within the zodiacal sign. Hence, omitting restorations which we will justify later, we can translate the table as follows[6]:

[*month?*]	[xx];14	Leo
Hathyr	27;24	Scorpio
Phamenoth	23;34	Pisces
Epeiph	25;44	Cancer
Hathyr	10;54	Scorpio

The intervals of time from each line to the next are in the neighbourhood of three or four months, and the progress in longitude is three or four zodiacal signs per line. Such intervals are characteristic of the phenomena of only one planet, Mercury.

Several epoch tables for Mercury have previously been identified among the Oxyrhynchus papyri excavated by Grenfell and Hunt (P.Oxy. astron. 4152-4156c). These tables contain calculated dates and positions of four phenomena of the planet: its first appearance in the morning, its last appearance in the morning, its first appearance in the evening, and its last appearance in the evening. For most of these tables it is known that the dates and positions were computed using arithmetical algorithms previously attested in Babylonian cuneiform tablets of the last three centuries B.C. The Babylonian rules for computing Mercury's phenomena are different for each phenomenon, though the algorithms are all of the variety known as "System A"[7].

In a System A algorithm, both the progress in longitude from one occurrence of a phenomenon to the next occurrence of the same phenomenon (called the *synodic arc*) and the interval of time between the two events (the *synodic time*) are functionally dependent only on the planet's longitude at the first event. There is a simple relationship between the synodic times and the synodic arcs: the difference between the times, counted in days, and the arcs, counted in degrees, is a constant. Each planet has one such constant, valid for all phenomena; for Mercury, it is approximately 1;40[8].

Towards identifying which phenomenon of Mercury is tabulated in

[6] We use the standard notation by which sexagesimal fractions (sixtieths, sixtieths of sixtieths, etc.) are separated from each other by commas and from the whole number by a semicolon.

[7] Neugebauer 1955, II, pp. 287-299.

[8] This is the constant used in the Greek epoch tables, which employ the Egyptian calendar; see Jones 1998, pp. 7-9. In Babylonian tables a different constant is used, because their fundamental unit of time was the lunar month, not the solar day.

our papyrus, we have the information from lines 2-4 that, for an event taking place somewhere in Scorpio, the synodic time until the next event is 116;10 days (hence the synodic arc should have been 114;30°), and for an event taking place somewhere in Pisces, the synodic time until the next event is 122;10 days (hence the synodic arc should have been 120;30°). Precisely these synodic arcs and times are generated by the Babylonian algorithm (called System A_2) for Mercury's last evening visibility for initial longitudes respectively in the range Scorpio 5;30° to 30° and in the whole of Pisces. None of the other Babylonian algorithms for Mercury's phenomena generates even approximately these numbers. Hence the phenomenon and the method of calculation are known.

The zodiacal signs preserved in column iii put constraints on the range within which the longitude of the event of line 1 must have been. In order to generate a sequence of longitudes and dates in agreement with all traces in the papyrus, the longitude in line 1 must have been at least Leo 0°, and less than Leo 11;30°. Any initial longitude within this range will lead to identical dates. Hence we can restore the table as follows, with the only uncertainty being that all the longitudes could be raised by some constant less than 11;30°:

Mesore	12;14	Leo 0° + x (0° ≤ x < 11;30°)
Hathyr	27;24	Scorpio 18;30° + x
Phamenoth	23;34	Pisces 13;0° + x
Epeiph	25;44	Cancer 13;30° + x
Hathyr	10;54	Scorpio 2;0° + x

In restoring the missing day number in line 1, we are assuming that the calendar year ending between lines 1-2 had only five epagomenal days; otherwise line 1 would have read Mesore 13;14.

As it turns out, we can easily show that the calendar on which our table is based is the old, unintercalated Egyptian calendar, just as in most of the other epoch tables so far identified. If the calendar was the reformed Egyptian calendar, then the sun's longitude on a particular calendar date would be roughly the same no matter what year we choose. For example, on the date in line 2, Hathyr 27, the sun's longitude (using the sidereal norm found in the astronomical papyri) would have been about Sagittarius 6°, that is, about 5° to 17° greater than Mercury's longitude on that date according to the papyrus. When Mercury is visible in the evening, however, its longitude must be *greater* than the sun's, and the elongation at last visibility would be in the neighbourhood of 20°. Thus the sun's longitude on Hathyr 27 should actually have been between roughly Libra 29° and Scorpio 10°, and this would have been the case only for the old Egyptian calendar and only in years around A.D. 70-120[9]. This is unfortunately too large an interval for us to be able to identify the specific years covered by the papyrus table with certainty, with reasonably good fits to the astronomical situation in A.D. 71-72, 84-85, 91-92, 104-105, and 111-112. As a specimen, we give below the approximate actual dates of Mercury's last visibility in A.D. 71-72 and 111-112, as computed by modern theory[10]. The dates in parentheses correspond to "missed visibilities", where Mercury failed to attain a sufficient elongation to become visible in the evening; in such cases the Babylonian algorithms generate a date anyway. These comparisons show, incidentally, that the Babylonian model is surprisingly good as a description of Mercury's behaviour.

Date of last visibility	*Longitude (tropical)*	*Longitude (sidereal)*
71 July 13 = Mesore 12	Leo 10;45°	Leo 15;20°
71 November 1 = Hathyr 28	Scorpio 28;2°	Sagittarius 2;37°
72 February 24 = Phamenoth 23	Pisces 16;11°	Pisces 20;46°
72 June 26 = Epeiph 26	Cancer 22;39°	Cancer 27;14°
(72 October, missed visibility)		
111 July 5 = Mesore 14	Leo 1;31°	Leo 5;26°
(111 late October, missed visibility)		
112 February 15 = Phamenoth 24	Pisces 7;1°	Pisces 10;56°
112 June 17 = Epeiph 27	Cancer 12;48°	Cancer 16;43°
(112 late September, missed visibility)		

[9] For solar longitudes corresponding to dates in the old and reformed Egyptian calendars, see Jones 1999a, I, pp. 349-350.

[10] Computed (for Babylon) by the program «Planet's Visibility» by Alcyone Software (http://www.alcyone.de). Visibility dates are always subject to some uncertainty. For the computation of sidereal longitudes, see Jones 1999a, I, p. 343.

2.

PSI inv. 2 — Tav. I.b

Oxyrhynchus — cm 5,0 x 7,6 — II^p ?

The fragment preserves about 1 cm bottom margin, the other sides being broken. The table is written in a semiliterary hand in a black tabular ruling. The back is blank except for traces of ruled lines that may be offsets from a lost part of the table. The names of zodiacal signs in cols. iv-v are broken by one of the vertical rulings, suggesting that the ruling was originally intended to allow for one more narrow column (of numerals?) between the numerals of col. iii and the zodiacal signs.

i	ii	iii	iv	v
̣ ̣	̣	[ ]	̣	[
ο̲	μβ	λ	τα	υρου
μη	μβ	λ	δι	δυμω̣ν̣
λ̣ς̣	μβ	λ	δι	δυμ[ων
κδ	μβ	λ	[κα]	ρκινο[υ
ιβ	μβ	λ	[κα]	ρ̣[κινου
[ο̲]	[μ]β̣	[λ]	[κα]	ρκινο[υ
[μη]	μ̣β̣	λ̣	[λε]	οντοc̣
λς	μβ	λ	λε̣	οντοc
κ̣δ̣	μβ	λ	πα	ρθενο̣[υ

1 traces probably belong to the line of tabulated data preceding line 2, but too slight for identification 2 ο̲ : for this less common inverted version of the sign for zero (ō) see Jones 1999, I, pp. 61-62

Again we are dealing with an epoch table, with longitudes of some event tabulated in columns iv-v and further lost columns (degrees and fractions of a degree) to the right. The numerals in cols. i-iii appear to be sexagesimal fractions, and could have belonged either to the date of the event, or the progress in longitude since the preceding event.

The phenomenon progresses slowly in longitude, taking two or three occurrences to move through a single zodiacal sign. This is characteristic of Saturn, which takes about thirty years to make the circuit of the zodiac while going through twenty-nine cycles of its synodic phenomena[11]. There are two known Babylonian algorithms for computing Saturn's phenomena, with each algorithm being used for all five phenomena. One algorithm is of the System A variety, that is, the synodic arcs and times between successive events are functionally dependent on the longitude at the first event. The other algorithm is of the variety called System B, according to which the synodic arcs and times alternately increase and decrease by constant differences between a set minimum and maximum. The only previously identified epoch table for Saturn, P.Oxy. astron. 4161, appears to be based on System B, although unfortunately all dates and positions in that papyrus are given without fractions, which makes it impossible to be sure of the numerical details of the underlying calculations. In the present papyrus it is easy to confirm by inspection that System B was used, since the numbers in cols. i-iii behave exactly as the fractional parts of the synodic arcs (since the preceding event) according to the System B algorithm. The defining parameters of the System B algorithm for Saturn's synodic arcs are:

Minimum (m)	11;14,2,30° (around Scorpio)
Maximum (M)	14;4,42,30° (around Taurus)
Increment/decrement (d)	0;12°

There is a unique possible restoration of the synodic arcs in cols. i-iii and the preceding lost column (containing the whole numbers of degrees); the actual longitudes in cols. iv-v and the lost subsequent columns can be restored within a margin of a little less than 4° for all values. The following reconstruction gives the lowest possible sequence of longitudes:

Synodic arc	*Longitude*
14;0,42,30°	Taurus 19;9,52,30° + x ($0 \le x < 3$; 46,35,0°)

[11] The five synodic phenomena of Saturn are first morning visibility, first stationary point, acronychal rising near opposition, second stationary point, and last evening visibility.

13;48,42,30°	Gemini 2;58,35,0° + x
13;36,42,30°	Gemini 16;35,17,30° + x
13;24,42,30°	Cancer 0;0,0,0° + x
13;12,42,30°	Cancer 13;12,42,30° + x
13;0,42,30°	Cancer 26;13,25,0° + x
12;48,42,30°	Leo 9;2,7,30° + x
12;36,42,30°	Leo 21;39,0,0° + x
12;24,42,30°	Virgo 4;3,42,30° + x

If we extrapolate the sequence of synodic arcs and longitudes backwards, we find that 43 events back from the event of line 2 of the papyrus, the epoch table would have read

11;14,2,30°	Scorpio 13;7,25,0° + x

where the synodic arc is the minimum *m* exactly. This was probably the first line of the table.

Unfortunately there is no basis for deciding which of Saturn's phenomena was tabulated in this papyrus. Since Saturn returns to about the same longitudes every thirty years, there is also no way to establish the dates that it covered.

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BIBLIOGRAPHICAL REFERENCES

Jones 1998 = A. Jones, *Studies in the Astronomy of the Roman Period. III. Planetary epoch tables*, Centaurus 40 (1998), pp. 1-41

Jones 1999a = A. Jones, *Astronomical Papyri from Oxyrhynchus*, Philadelphia 1999 (American Philosophical Society, Memoirs 233), I-II

Jones 1999b = A. Jones, *A Classification of Astronomical Tables on Papyrus*, in «Ancient Astronomy and Celestial Divination», N.M. Swerdlow (ed.), Cambridge (Ma) 1999, pp. 299-340

Knudtzon - Neugebauer 1947 = E.J. Knudtzon - O. Neugebauer, *Zwei astronomische Texte*, Bulletin de la Société royale des lettres de Lund 1946-1947, part 2, pp. 77-88 (pll. 1-2)

Neugebauer 1955 = O. Neugebauer, *Astronomical Cuneiform Texts*, London 1955, I-III

a. PSI inv. 1

b. PSI inv. 2