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Studies in the Astronomy of the Roman Period II. Tables for Solar Longitude

by

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From Ptolemy's *Almagest* and *Handy Tables* we are familiar with an approach to computing the sun's longitude that makes direct use of the analysis of the sun's motion into two components: a uniformly increasing angular 'mean motion' tabulated proportionally for the various units of time out of which the given calendar date is composed, and a correction or 'equation' functionally dependent on the mean motion. To judge by the evidence of the Greco-Egyptian papyri, the *Handy Tables* had a wide distribution from at least as early as the third century, but for some time after that Ptolemy's work coexisted with other varieties of astronomical table that did not survive into the Middle Ages. The three fragments of papyrus tables from Oxyrhynchus discussed in this article provide the first direct glimpse of what the non-Ptolemaic solar tables of this period were like.[1]

1. P. Oxy LXI.4163.

This is the remains of a codex page that was originally about 13 cm tall (parts of the top and bottom margins are present), and

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perhaps about the same width, although as we have it the fragment has only the 5 cm or so that was furthest from the binding. On the front ('recto') side, inside a tabular framework, we have the right edge of a 25-line column of numerals, a column of index numbers tabulated only every five lines, and another 25-line column of two-place sexagesimal numbers. On the back the table continues for another 13 lines with an index column and a column of two-place sexagesimals. The remaining space on the back is taken up with a poorly preserved text concerning the calculation of dates of conjunctions and full moons, unrelated to the table. Table 1 is a translation of the contents of the table, incorporating secure restorations (bracketed) and corrections (endnoted).

The index numbers go up to 365 in the penultimate line of the table, while the sexagesimals increase by nearly constant differences of 0;57 or 0;56, except that in line 8 of column iii on the front, where we expect 30;24 or 30;23, the scribe has instead written 'Gemini', and the subsequent numbers start ascending again from 1;20. These are clearly meant to be solar longitudes in degrees and minutes on the consecutive days of a year's worth of motion. Using the legible traces of the final digits we can restore most of column i as the preceding column of longitudes, so that we have at our disposal most of the longitudes from day 303, when the sun entered Taurus, to day 365, when the sun was just about to leave Gemini (Table 1). The last line of the table, which is only partially legible, seems to round the year off with a quarter of a day's motion bringing the sun to exactly Gemini 30°, i.e. Cancer 0°.

The absence of calendrical information (months or years) and the fact that the year ends – and hence also begins – with the sun at exactly Cancer 0°, show that we are not dealing with an ephemeris of solar longitudes for specific dates, but rather with a template applicable to any year starting with the summer solstice. In other words, if in a given year the summer solstice occurs at a certain time on a particular date, then we call that day 'day 0', and we can then read off the sun's longitude at the same time on the *n*th day following the solstice in the appropriate line of the template. All that one needs in addition to the template is a method of computing the date and time of the solstice for any year, or a table of dates of solstices.

front				*back*	
[0]	*i*	*ii*	*iii*	*i*	*ii*
	[Taur]us				[18];23
	[0;5]7		24;[42]		[19];20
	[1;5]4		25;[39]	[355]	[20;1]7
[305]	[2;5]1	330	2[6;36]		21;14[2]
	[3;4]8		2[7;33]		22;11[3]
	[4;4]5		28;30		23;8
	[5;4]2		29;27		24;[x]
	[6;3]9		Gemini[4]	360	25;1
[310]	[7;3]6	33[5]	1;20	25;58[5]	26;55
	[8;3]3		[2;1]7		27;52
	[9;30]		3;14		28;48
	[10;2]7		4;11	365	29;45
	[11;2]4		5;8		30;0
[315]	[12;2]1	340	6;4		
	[13;1]8		7;1		
	[14;1]5		7;58[6]		
	[15;1]2		8;55		
	[16];9		9;52		
[320]	[1]7;6	345	10;49		
	[18];3		11;45		
	[19];0		[1]2;42		
	[19;5]7		13;39		
	[20;5]4		1[4;3x]		
[325]	[21;5]1	350	1[5;3x]		
	[22;4]8		1[6;xx]		
	[23];45		1[7;2x]		

Table 1

Two theoretical presuppositions are obvious from the structure of the table. First, the summer solstice is placed at Cancer 0°, which was the convention of Hipparchus and Ptolemy, rather than Cancer 8° as we often find in Roman era astronomy and astrology. Secondly, the pattern of the sun's anomalistic motion is assumed to be correlated with its longitude. That is, in kinematic terms, if the longitudes in the template are supposed to be tropical, then the sun's apsidal line is supposed to be tropically fixed, and likewise if the longitudes are sidereal, the apsidal line is sidereally fixed. On the face of it, the year of the template must be intended as tropical, since it begins with the date of summer solstice. But the truncation of the longitudes to one sexagesimal place means that we cannot determine from them the precise equivalent of a year in days.

The preserved part of the table covers only two months of motion, roughly centred on the date when the sun's daily progress in longitude is a minimum. Let us suppose that someone has computed a template of this kind, but with longitudes computed accurately to seconds of arc according to a kinematic model, say the Hipparchus-Ptolemy eccentre model which has eccentricity $e=\frac{1}{24}$ and apogee Gemini 5;30°. Even if we had just the longitudes in Taurus and Gemini, we could easily deduce the parameters of the assumed model with fair precision. In the first place, the line-to-line differences would gradually decrease until the sun passes its apogee, and then increase; second differences would increase fairly uniformly from negative to positive through the whole preserved part of the table, passing zero at the apogee. Simple inspection of the symmetry of this pattern locates the apogee within one degree or better (cf. Fig. 1, small circles). Secondly, the ratio of the sun's

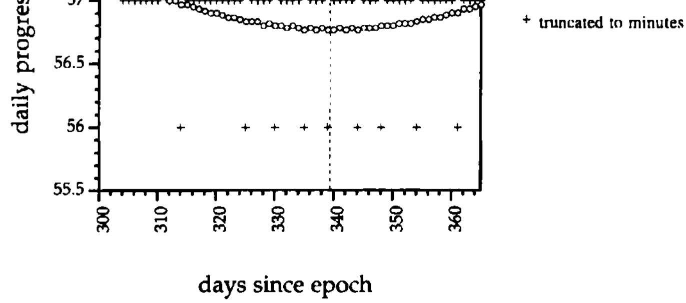

Fig. 1. Daily progress (line-to-line differences) in an ideal template computed from Hipparchus' solar model using summer solstice as epoch.

mean daily progress (0;59,8° to the nearest second) to the line-to-line difference at the apogee is approximately $(1+e)$: 1. Finally we can check that the template really was computed according to a model with this eccentricity and apsidal line by recomputing all the preserved values from the model.

Now let us imagine that the longitudes in this hypothetical template have been truncated after computation to minutes of arc. The loss of information obscures the structure of the table, and makes the recovery of the initial parameters more difficult and less precise (Fig. 1, crosses). In a template computed from the Hipparchus-Ptolemy model, the line-to-line differences will now always be one of the three values 0;58° (once only), 0;57°, and 0;56°. The symmetry about the apogee is no longer apparent in the individual differences, but can be discerned roughly by the way that the occurrences of 0;56° become more frequent as one approaches day 340, and less frequent afterwards. But it would be hard to establish the precise day when the apogee is passed. Again, around day 340 there are three or four occurrences of 0;57° for every occurrence of 0;56°. One might estimate that the minimum daily motion is about 0;56,45°, leading to $e \approx \frac{1}{23.81}$. (With one more sexagesimal place we would have 0;56,46° and hence $e \approx \frac{1}{23.99}$.)

Returning to the papyrus template, we find that the pattern of its line-to-line differences is quite different (cf. Fig. 2). Between days 303 and 333, there is not a single deviation from the constant 0;57°; even the two gaps where the terminal digits are lost can be restored using this difference throughout. After day 333, six occurrences of 0;56° must have been interspersed among the 0;57°s. Three of these can be exactly located at days 340, 346, and 364. The others fell on either day 334 or 335; on one of the days from 349 to 353; and on one of the days from 358 to 360. They seem to be quite evenly spaced; a possible restoration would have the 0;56°s on days 334, 340, 346, 352, 358, and 364, i.e. every six days. This would be the pattern of differences if the untruncated longitudes in this part of the template had increased by constant differences of 0;56,50°.

The sun's velocity in the untruncated template was thus not a continuously varying function such as one would obtain by computing all the longitudes according to a kinematic model, but was

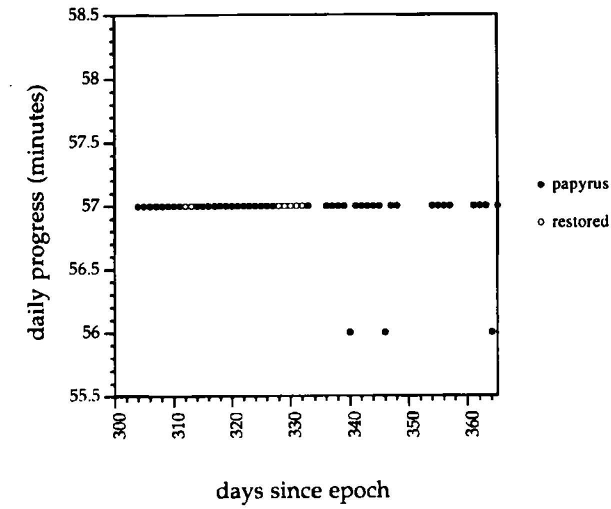

Fig. 2. Daily progress in *P. Oxy.* LXI.4163.

kept constant over intervals of about a month at least. I suspect that the transitions were placed approximately at the boundaries of the zodiacal signs, so that the velocity assigned to Taurus was exactly 0;57° per day, and that for Gemini was exactly 0;56,50° per day. Such a scheme would resemble in structure the Babylonian System A variety of predictive model, in which the progress of a heavenly body from event to event is constant within fixed zones of the ecliptic. The well known System A model for solar motion in the lunar tables ('column B') has only two zones, and specifies the solar progress per true synodic month, not per day. However, we know from procedure texts of schemes that assigned a daily motion to each zodiacal sign, following an arithmetical pattern symmetrical around the signs Gemini and Sagittarius, which have respectively the minimum and maximum velocities.[7] The minimum daily progress in Gemini according to these schemes was between 0;55° and 0;56°, significantly less than in the papyrus. An Indian scheme of the same kind, however, comes closer to our template by prescribing a velocity of 0;57° per day for the four signs Aries through Cancer.[8] It is interesting that an average daily progress of 0;56,50° in Gemini is correct to the nearest second according to the Hipparchus-Ptolemy model; unfortunately the model yields an average of only 0;56,56° per day in Taurus. It is possible that the parameters of the scheme by which the template was computed were based in some way on the Hipparchus-Ptolemy model or some other Greek kinematic model of solar motion, but without more of the table we cannot be sure.

2. P. Oxy. LXI.4162.

This fragment too was a page of a codex, originally about 20 cm square, but now only 14 cm wide because of the loss of the part of the page furthest from the binding. What is left has suffered much from perforations and rubbing. On both sides are parts of a table laid out in sets of three columns of 30 lines inside a tabular framework ruled in red. Three sets are preserved on the front, two (including the end of the table) on the back (Table 2); two intervening sets are missing.

The table is very similar in arrangement to *P. Oxy.* 4163, and is obviously also part of a solar template. The first column of each set holds index numbers counting days up to 365, tabulated only every five lines. The second and third columns contain the degrees and minutes of solar longitude; when a new zodiacal sign is entered, its name is written in the index column. The preserved part of the template covers the sun's motion for days 150 through the end of the year, in the signs Taurus through Sagittarius. The longitude on day 365 is Sagittarius 13;16°; below this is written 13;30°, the longitude of day 0 regained after 365 1/4 days.

The choice of Sagittarius 13;30° for the initial longitude of the template is a clue to its theoretical basis. In the Hipparchus-Ptolemy solar model, the apogee is located at Gemini 5;30°, and the perigee at Sagittarius 5;30°, following the convention that the vernal equinoctial point is Aries 0°. There is much evidence, however, for widespread Greek use of the Babylonian System B convention placing the equinoctial point at Aries 8°.[9] Since Hipparchus deduced the parameters of his solar model from the lengths of the seasons, anyone who wished to use the model together with the System B norm would need to shift the apsidal line 8° forward.

line	*front* *i*	*(beginning)* *ii and iii*	*iv*	*v and vi*	*vii*	*viii and ix*
	150	12;[3]3		10;[x]		7;34
		[1]3;30	[180]	1[1;x]		8;3[x]
		14;27		[11];58	210	9;2[x]
		15;24		12;5[x]		10;[2x]
5		[1]6;21		13;52		11;[2x]
	155	17;18		14;49		12;1[x]
		[1]8;[1]5	[185]	15;4[x]		13;16
		19;12		16;42	[215]	[14];1[x]
		20;9		17;39		15;10
10		21;6		18;36		16;7
	160	22;3		19;33		17;5
		23;0	[1]90	20;30		18;2
		23;57		21;27	220	18;59
		24;54		22;24		19;56
15		25;51		2[3];21		20;54
	165	26;[4x]		2[4];17		21;51
		27;44	19[5]	[2]5;[1]4		22;48
		28;41		[2]6;11	225	23;45
		29;38		[2]7;8		24;43
20	Gemini			28;5		25;40
		[0;3x]		29;2		26;38
	[170]	[1;3x]	[200]	29;[5]9		27;35
		2;[2x]	Cancer		230	28;32
		3;[2x]		0;56		29;30
25		4;[2x]		1;53	Leo	0;2[x]
		5;19		2;50		1;25
	175	6;[1x]		3;46		2;22
		7;13	205	4;[4]3	235	3;19
		8;10		5;[xx]		4;17
30		9;7		6;[3]7		5;15

Table 2

Clearly, then, our template takes as its epoch date the moment when the sun is at its perigee, and its construction assumes that the equinoctial point is Aries 8° and, with Hipparchus, that the solar apogee is 65;30° beyond the equinoctial point. The juxtaposition of the Babylonian convention and the Hipparchian model is the more interesting because the placement of the equinoctial and

line	*front* *x*	*(concluded)* *xi and xii*	*back* *i*	*ii and iii*	*iv*	*v and vi*
		[6;1x]		[4];1x		[4;x]
		[7;1x]		[5];21		5;[x]
	[240]	[8,x]		[6;2x]		6;[x]
		[9,x]	[330]	[7;2]3		7;6
5		[10;x]		[8];24	[360]	8;8
		[11;x]		[9];25		9;[x]
		[12;x]		[10];27		[10;1x]
	[245]	[12;5x]		[11;2]8		[11;1x]
		13;[5x]	335	12;29		12;14
10		14;[5x]		13;31	365	13;16
		15;[5x]		14;32		13;30
		16;[4]9		15;34		
	250	17;47		16;35		
		1[8];45	340	17;3[x]		
15		1[9];44		18;38		
		[20];42		19;39		
		21;40		20;41		
	25[5]	22;38		[2]1;42		
		23;36	345	[2]2;44		
20		24;35		[2]3;46		
		[25;3]3		[24];47		
		[26;3x]		[25];48		
		remaining lines lost or illegible				

Table 2 (contd)

solstitial points in the 8th degree of their signs is usually associated with the use of sidereal longitudes.

The parts of the template surviving on the papyrus include the interval from about one month before apogee to about two and a half months after, and a little more than a month leading up to the perigee. A template accurately computed to seconds according to the Hipparchus-Ptolemy model would show the pattern of line-to-line differences indicated by the small circles in Figs. 3–4. The crosses in the same figures represent the differences that result if this ideal template is truncated to minutes. The patterns of differences in the papyrus are at least qualitatively similar (Figs. 5–6), and there is no question of the prolonged linear motion that we

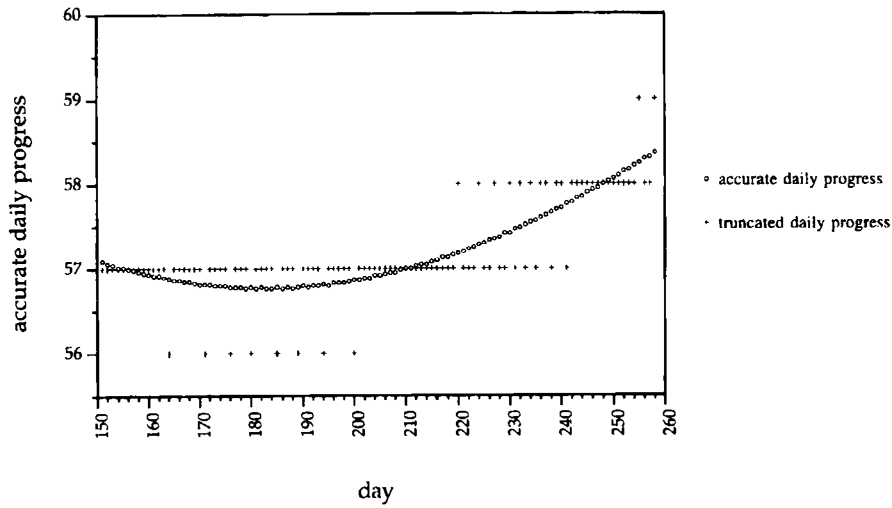

Fig. 3. Daily progress in an ideal template computed from Hipparchus' solar model using perigee as epoch.

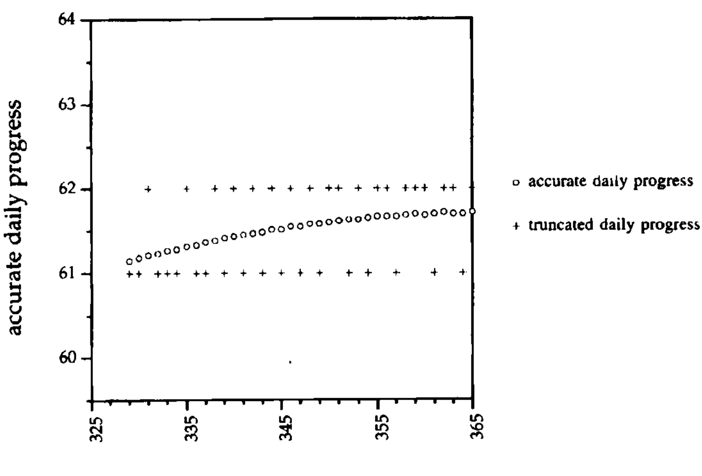

Fig. 4. (Continued from Fig. 3)

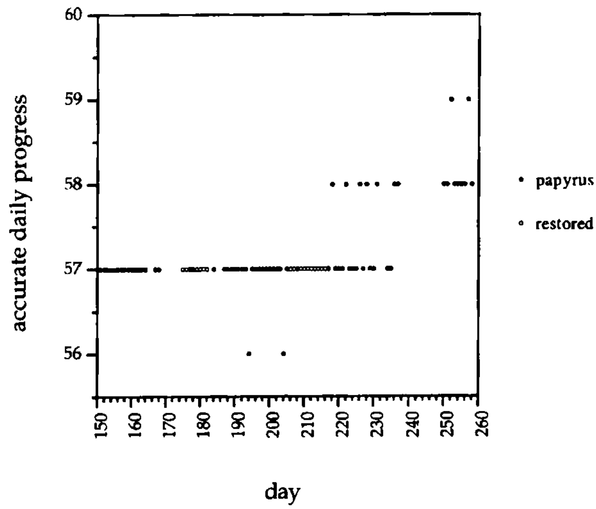

Fig. 5. Daily progress in *P. Oxy.* LXI.4162.

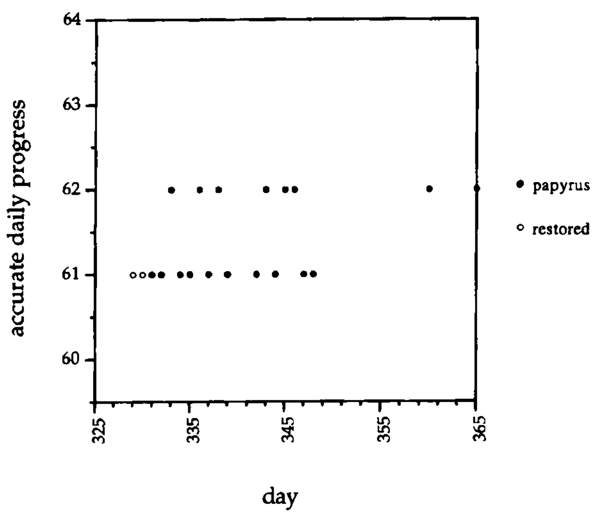

Fig. 6. (Continued from Fig. 5)

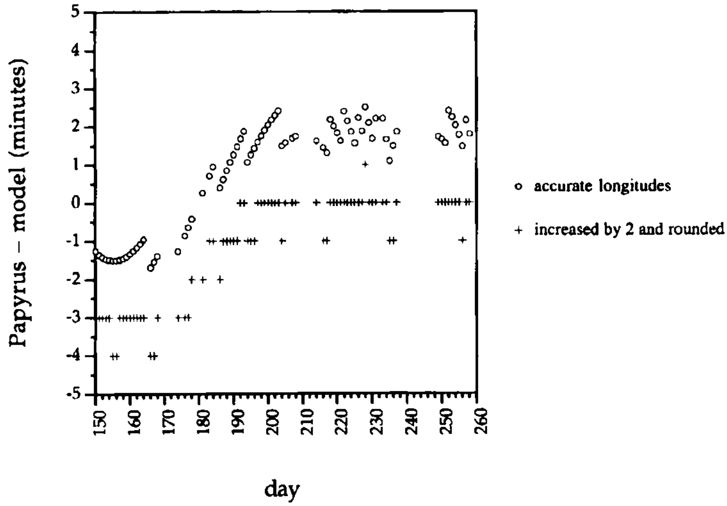

Fig. 7. Divergence between longitudes in *P. Oxy.* LXI.4162 and ideal template.

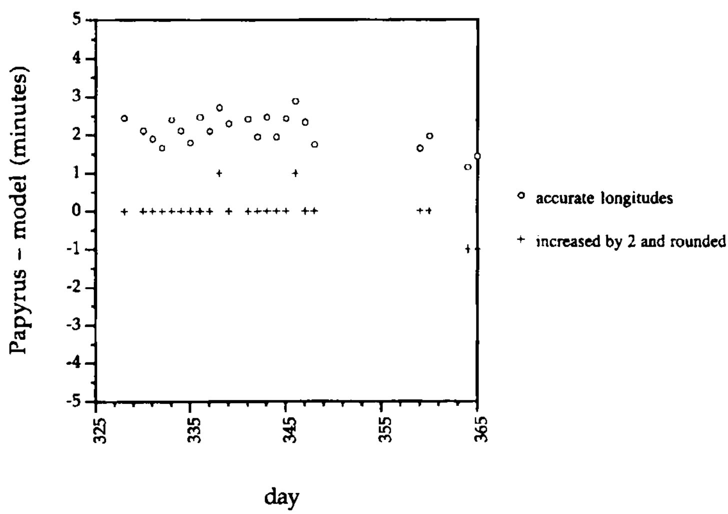

Fig. 8. (Continued from Fig. 7)

found in *P. Oxy.* LXI.4163. The actual longitudes in the papyrus, however, show systematic deviations from the values calculated according to the model. In the half of the template following day 183, that is, the part corresponding to the sun's motion from apogee to perigee, the template's longitudes are consistently a little too high, whereas before the passage of the apogee the longitudes are a little too low (Figs. 7–8, small circles). Except for a transitional interval of about ten days before and after the apogee, the divergence between the recorded and recomputed values stays more or less constant in each half, the fluctuations being due to the fact that we are subtracting values computed to seconds from values truncated to minutes. From apogee to perigee, we can reproduce most of the values in the papyrus by adding 0;2° to the recomputed longitudes and rounding to the nearest minute (or equivalently, by adding 0;2,30° and truncating; cf. Fig. 7–8, crosses). From the little of the section from perigee to apogee that survives, it would seem that the recorded longitudes in this half can be reproduced by subtracting 0;1° from the recomputed longitudes before rounding (or by subtracting 0;0,30° and truncating).

One way to obtain longitudes that are too small from perigee to apogee and too large from apogee to perigee would be to compute them from a model with a smaller eccentricity than Hipparchus' $e=\frac{1}{24}$. In this case we would expect the deviations to be insignificant near the apsidal line, and to increase gradually with distance from it. Here, however, the deviations make a fast transition from the negative to positive side, and then stay more or less constant until the end of the table. It is remarkable that even the last entry, for day 365, is only 0;14° short of the perigee even though the progress here is larger than 1° per day, or 0;15° per quarter day. I think that the discrepancies must have been caused by imprecision or truncation in the computation of the longitudes. It is possible that the longitudes for the first half of the template were independently calculated from the model, with a systematic error tending to reduce the numbers, and then those for the second half were obtained by symmetry, i.e. the longitude for day (365-*n*) is a quarter of a day's motion further from the perigee than the longitude for day *n*.

The papyrus templates for lunar and planetary motion known to date all employ arithmetical sequences to derive their series of tabulated longitudes. *P. Oxy.* LXI.4162 is noteworthy as the expression of a kinematic model in a format elsewhere associated with arithmetical methods. It would be interesting to know whether the computer of the template worked from Ptolemy's mean motion and equation tables or derived the longitudes by direct trigonometrical calculation from the model. Unfortunately the writing cannot be dated on paleographical grounds precisely enough to determine whether or not it is older than Ptolemy. The systematic errors in the papyrus do not arise if one makes correct use of the solar tables in the *Almagest* or the *Handy Tables.* On the whole it appears more likely that this is an independent exploitation of Hipparchus' parameters uninfluenced by Ptolemy.

3. P. Oxy. LXI.4148

The two templates discussed above enable one to find the sun's longitude immediately from the number of days elapsed since an epoch, in the one case the summer solstice, in the other the sun's passage of perigee. Hence the user of the tables would first need to know when the epoch fell in a given year, either by a rule or from a table of epoch dates. An example of a rule is lines 57–74 of *P. Ryl.* I.27.[10] This text cites Ptolemy's dates for the solstices and equinoxes in the third regnal year of Antoninus Pius, and specifies that the dates in successive years are at intervals of 365;14,48 days, which is Ptolemy's value for the length of the tropical year.

The sign of a solar epoch table would of course be the listing of dates separated by intervals of one solar year; there would be no need of longitudes, since by hypothesis the sun's longitude is the same at every epoch. *P. Oxy.* LXI.4148 is the only example of a solar epoch table that has so far come to light. The better side of the papyrus (the side with the fibres running horizontally) has been reused for a record of accounts, with mention of dates in A.D. 305 and 307. Although the table is on the side with vertical fibres, which was almost always the second side of a papyrus roll to be used, it is unlikely to have been written much later than the middle of the third century. Possibly there used to be a third document, still earlier, on a lost part of the front side.

In *P.Oxy.* LXI.4148 parts of three sets of columns of the solar epoch table are preserved. (To the left of the first set, along the edge of the fragment, are traces of numerals that must have belonged to a different table.) Each set consists of four columns. The first contains, written at intervals of four lines, consecutive numbers beginning at 47. To the right of this is a column for the consecutive years A.D. 160/161 through 237/238, expressed as the regnal years of the emperors Antoninus Pius, Severus, Elegabalus, Alexander, Maximinus, and Gordianus. Then follows a column containing the name of an Egyptian calendar month and a four place sexagesimal number representing the date and fraction of a day. A few lines from the first set of columns will suffice to illustrate the structure of the table (see Table 3).

The difference between successive epoch dates is consistently 1 calendar year plus 0;15,33,46 days.[11] Obviously, therefore, the calendar year must always be 365 days, that is, we are dealing with the old Egyptian calendar rather than the civil 'Alexandrian' calendar with its intercalary day every fourth year. The first column turns out to be the number of days that one has to add to the civil date to obtain the equivalent in the Egyptian calendar, which increases by one after every civil intercalation. The only reason for the survival of the Egyptian calendar in such tables, of course, was

line	*ii*	*iii*	*iv*	*v*
		Antoninus and Lucius		
		1	Mesore	20;16,[5]5,40
		2	Mesore	20;32,29;26
		3	Mesore	20;48,3,12
5	[4]7	4	Mesore	21;3,36,58
		5	Mesore	21;19,10,44
		6	Mesore	21;34,44,30
		7	Mesore	21;50,18,16
	[48]	8	Mesore	22;5,52,2

Table 3

its lack of intercalations, which made it easier to keep track of the running totals of the time intervals.

For the sake of identifying what stage of the sun's motion the epochs represent, we may choose any of the dates, for example the first, Antoninus Pius 1, Mesore 20 in the Egyptian calendar. The counterpart of this date in the Alexandrian calendar was Antoninus 1, Epeiph 4, which is equivalent to A.D. 161 June 28. There can be no doubt that this date, and hence all the epochs, are meant to be summer solstices, although we may be surprised by the discrepancy between the tabulated date and the actual solstice, which is fully five days.[12]

At least part of this lag is accounted for by a still more unexpected feature of the table: the time interval between consecutive solstices is 365;15,33,46 days, which is much too long for the tropical year (approximately 365;14,32 days) but a fair approximation of the *sidereal* year (approximately 365;15,23 days). A year length of 365;15,33,46 is not known from other ancient sources, nor have I succeeded in deriving this precise number from other attested parameters. But it is close to the sidereal year implicit in Hipparchus' 345-year eclipse period and to the year that one obtains by combining the Babylonian standard parameter for the number of synodic months in a year with the System B parameter for the number of days in a mean synodic month:[13]

Hipparchus:
126007 days + 1 equinoctial hour = 345 sidereal years $-7;30°$
1 sidereal year ≈ 365;15,35,30 days

Babylonian:
12;22,8 syn. m. × 29;31,50,8,20 days/syn. m. ≈ 365;15,38,18 days

Closest of all is a year obtained entirely from System B parameters: the mean synodic month already mentioned, and the mean solar progress in longitude per synodic month (Column A):[14]

29;31,50,8,20 days × 360°/29;6,19,20° ≈ 365;15,34,18 days

But it is not the origin of the specific year length in the papyrus that is interesting so much as the mere fact that a sidereal year is being used as if it were tropical. It is hard to evade the conclusion that the solar scheme of which this papyrus was one component was uninfluenced by the discovery of precession, and assumed that the tropical as well as the anomalistic years were the same as the sidereal year.

Since the calculated dates of solstice fall progressively later with respect to the true solstice, it is reasonable to hypothesize that the scheme had a base epoch, several centuries before the earliest date in the papyrus, that was more nearly in line with the correct solstice. We cannot establish with much precision when this base epoch was. In the first place, we do not know when the days of the papyrus scheme began, i.e. what time of day is represented by a zero fraction following the day number. The most likely guess is that the day was counted from 'sunset', i.e. six equinoctial hours past noon, since this was the reference time for the epoch tables of the Standard Lunar Scheme.[15] Secondly, we have little control of the accuracy with which solstices could be determined, whether by direct observation or from calculation, during the Hellenistic period.

We do know that Hipparchus determined the dates of certain summer solstices within his lifetime, the one sure instance being the solstice of −127, which he believed to have occurred one June 26 (Egyptian Payni 6) about sunrise. Counting from 'sunset', we can express this date as Payni 5;30. Now if we count back 288 years from A.D. 161, subtracting 0;15,33,46 per year from papyrus' date for that year (Mesore 20;16,55,40), we extrapolate that the solstice of −127 occurred on Payni 5;34;50,52, which is just under two hours later than Hipparchus' solstice. Hence it is possible that the scheme of the papyrus was based in part on Hipparchus' solstice dates. Exact agreement with any observation from this earlier period cannot be expected, because the epochs have been adjusted in order to make the epoch immediately preceding the first regnal year of Augustus (−29) exactly Epeiph 1;0,0,0. This shows that we are dealing with an invention of the Roman period.

4. *General comment*

The solar tables discussed in this article have a number of points of resemblance to the lunar tables of the Standard Scheme. In both cases, the problem is to represent the daily progress of a body that is assumed to exhibit a single, periodic anomaly, and the solution is to provide two tables: a table of epochs corresponding to moments when the body is at a particular stage in its anomalistic cycle, and a template describing the pattern of motion from any epoch to the next one. Even in details of layout the solar tables are similar to their lunar counterparts. The most striking difference apparent so far is that for two centuries or more the Standard Scheme tables were, indeed, standard. The lunar epochs were always days of least motion, calculated according to the same rules, with only small variations in the epoch longitudes; the templates are all based on the summation of the same linear zigzag function. With just three solar tables, on the other hand, we already find two kinds of epoch (summer solstices and perigees), two conventions for the longitudes (equinoctial and solstitial points at 0° and 8° of their signs), and two ways of computing the template (linear motion and continuous trigonometrical calculation). One of the extant templates could not be used in conjunction with the extant epoch table because they count the anomalistic year from different moments, and it is not at all certain that the other template was the intended companion of the epoch table either. The discovery of further examples of such solar tables might bring us closer to the point where we can reconstruct one of the versions of the scheme, but could just as well add to the variants.

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NOTES

1. Full texts, translations, and textual commentary will appear in Jones, *APO*.
2. Corrected from 21;24.
3. Corrected from 22;21.
4. The scribe omitted the number for this line, which would have been either 0;24 or 0;23.
5. The scribe by mistake skipped this number, then wrote it as shown in the index column.
6. Corrected from 7;8.
7. Neugebauer [1975] 530–531.
8. Varāhamihira, *Pañcasiddhāntikā* III 17; cf. Neugebauer [1975] 531.
9. Neugebauer [1975] 594–598.
10. See Appendix 2 of the foregoing article.
11. In the fourth (and last) regnal year of Elegabalus the epoch date in the table had reached the last quarter of the last day of the year, Epagomenae 5;50,41,40. The next epoch should therefore have been on the first day of the *second* regnal year of Severus Alexander. The scribe appears to have neglected to skip over his first regnal year, so that it is likely that all the subsequent epoch times were about a quarter of a day later than the scheme intended. We cannot check this because all the epoch times from the last two sets of columns are lost.
12. The solstice in A.D. 161 occurred about sunset of June 23, Alexandria time.
13. Ptolemy, *Almagest* IV 2, Aaboe [1955].
14. Neugebauer [1955] 70–71.
15. See my 'Studies in the Astronomy of the Roman Period, Part I: The Standard Lunar Scheme', *Centaurus* 39 (1997).