HISTORICAL ECLIPSES AND EARTH'S ROTATION

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4.3 Investigation of the Babylonian lunar eclipses cited by Ptolemy

The ten Babylonian observations of lunar eclipses which Ptolemy discusses in his *Almagest* are all cited as textbook examples to illustrate the derivation of certain lunar parameters. For instance, several observations (from 721, 720, 383 and 382 BC) were used by Ptolemy to deduce the principal lunar anomaly, including correcting errors of calculation made by Hipparchus. Further data (from 720, 502 and 491 BC) were applied to the investigation of the Moon's mean motion in latitude, while observations in 621 and 524 BC yielded a good result ($31\frac{1}{3}$ arcmin) for the Moon's apparent diameter. These various techniques are discussed by Neugebauer (1975, pp. 81 ff., 104 ff., etc.).

Each of the Babylonian lunar eclipse observations cited by Ptolemy is investigated below. In every case, I have given the computed Julian date and eclipse magnitude, followed by a translation of the text quoted from Toomer (1984). In some cases it is not clear whether times are expressed in equinoctial hours (*horai isemerinai*) or seasonal hours (*horai kairikai*). Where necessary I have appended further comments by Ptolemy if these help clarify the main text. The Julian dates reduced by Toomer from the historical dates are given in square brackets using negative integers for years. It will be noted that when compared with the computed Julian dates, these are invariably accurate. As mentioned in chapter 1, negative years differ by unity from their BC equivalents.

In each case, Ptolemy only quotes the time of one phase of an eclipse. This is usually first contact, but on four occasions (in 720, 523, 502 and 490 BC) he implies mid-eclipse (i.e. maximal phase) instead. Fotheringham (1915), following Nevill (1906b), inferred that the times of all but the first of these latter events related to first contact. However, since Ptolemy is our most direct source, there seems little alternative to accepting his interpretation. For a valuable historical discussion, see Britton (1985).

(1) BC 721 Mar 19/20 (mag. = 1.53)

> First the three ancient eclipses which are selected from those observed in Babylon. The first is recorded as occurring in the first year of Mardokempad, Thoth [month I] 29/30 in the Egyptian calendar [−720 Mar 19/20]. The eclipse began, it [the report] says, well over an hour after moonrise and was total. Now since the Sun was near the end of Pisces, and [therefore] the night was about 12 equinoctial hours long, the beginning of the eclipse occurred, clearly, $4\frac{1}{2}$ equinoctial hours before midnight.
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> [*Almagest*, IV. 6; trans. Toomer (1984, p. 191).]

Ptolemy evidently interpreted the phrase 'well over an hour after moonrise' as implying an interval of $1\frac{1}{2}$ hours; this will be assumed here. On the supposition that sunset and moonrise occurred simultaneously, Ptolemy inferred that the eclipse began $1\frac{1}{2}$ hours after sunset. However, computation shows that the Moon would actually rise a significant time (about 0.2 hours) before sunset so that it seems preferable to specifically use moonrise as the reference moment. Whether the interval between moonrise and first contact was expressed in equinoctial or seasonal hours is unimportant since the Sun was so close to the (vernal) equinox; 1 seasonal hour would be equal to 1.01 h.

Results

First contact on Mar 19 at $1\frac{1}{2}$ hours after moonrise. LT of moonrise = 17.73 h, hence LT of first contact = 19.23 h, UT = 16.45 h. Computed TT = 22.46 h, thus ΔT = 21 650 sec.

(2) BC 720 Mar 8/9 (mag. = 0.12)

> ...The second eclipse is recorded as occurring in the second year of Mardokempad, Thoth [month I] 18/19 in the Egyptian calendar [−719 Mar 8/9]. The [maximum] obscuration was 3 digits from the south exactly at midnight. So since mid-eclipse was exactly at midnight at Babylon ...
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> [*Almagest*, IV, 6; trans. Toomer (1984, p. 191).]

Essentially the same record is to be found later in the *Almagest* (IV, 9) – Toomer, p. 208.

RESULTS

Maximal phase on Mar 8 at midnight. LT of maximum = 24.00 h on Mar 8, hence UT = 21.28 h. Computed TT = 2.56 h on Mar 9, thus ΔT = 19 000 sec.

(3) BC 720 Sep 1/2 (mag. = 0.50)

> ...The third eclipse is recorded as occurring in the (same) second year of Mardokempad, Phamenoth [month VII] 15/16 in the Egyptian calendar [−719 Sep 1/2]. The eclipse began, it says, after moonrise, and the [maximum] obscuration was more than half [the disk] from the north ...The beginning of the eclipse was about 5 equinoctial hours before midnight (since it began after moonrise) ...
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> [*Almagest*, IV, 6; trans. Toomer (1984, p. 192).]

Ptolemy's rough inference that the eclipse began 'about 5 equinoctial hours before midnight' will be ignored since this is not based on measurement. However, the observation that commencement did not occur until *after* moonrise sets a limit to the value for ΔT.

RESULTS

First contact on Sep 1 after moonrise. LT of moonrise = 18.52 h, hence LT of first contact > 18.52 h, UT > 15.58 h. Computed TT = 21.52 h, thus $\Delta T < 21\,400$ sec.

(NB for values of $\Delta T > 21\,400$ sec, the Moon would rise already eclipsed.)

(4) BC 621 Apr 21/22 (mag. = 0.15)

> In the fifth year of Nabopolassar, which is the 127th year from Nabonassar, Athyr [month III] 27/28 in the Egyptian calendar [−620 Apr 21/22], at the end of the 11th hour in Babylon, the Moon began to be eclipsed; the maximum obscuration was $\frac{1}{4}$ of the diameter from the south. Now since the beginning of the eclipse occurred 5 seasonal hours after midnight...
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> [*Almagest*, V, 14; trans. Toomer (1984, p. 253).]

A time 5 seasonal hours after midnight corresponds to the end of the 11th (seasonal) hour. Hence the measured time will be taken as exactly 11 seasonal hours after sunset.

RESULTS

First contact on Apr 22 at 5 seasonal hours after midnight. LT of sunset = 18.48 h, hence length of night = 11.04 h. 1 seasonal hour = 0.92 h, thus LT of first contact = 4.60 h, UT = 1.60 h. Computed TT = 6.54 h, thus ΔT = 17 800 sec.

(5) BC 523 Jul 16/17 (mag. = 0.53)

> ...Again in the seventh year of Kambyses, which is the 225th year from Nabonassar, Phamenoth [month VII] 17/18 in the Egyptian calendar [−522 Jul 16/17], 1 [equinoctial] hour before midnight at Babylon, the Moon was eclipsed half its diameter from the north. Thus the eclipse occurred about 1 $\frac{5}{6}$ equinoctial hours before midnight at Alexandria.
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> [*Almagest*, V, 14; trans. Toomer (1984, p. 253).]

It seems evident from the text that the time of maximal phase is recorded. Since Ptolemy adopted a longitude difference between Alexandria and Babylon of $\frac{5}{6}$ of an equinoctial hour [IV, 6], it is apparent that the time of mid-eclipse in Babylon was measured in equinoctial hours.

The extant cuneiform record of this same eclipse seems to contain predicted rather than observed details (see chapter 6).

RESULTS

Maximal phase on Jul 16 at 1 equinoctial hour before midnight. LT of mid-eclipse = 23.00 h, UT = 20.05 h. Computed TT = 1.40 h on Jul 17, thus ΔT = 19 250 sec.

(6) BC 502 Nov 19/20 (mag. = 0.19)

> ...The second, which Hipparchus too used, occurred in the twentieth year of that Darius who succeeded Kambyses, Epiphi [month XI] 28/29 in the Egyptian calendar [−501 Nov 19/20], when $6\frac{1}{3}$ equinoctial hours of the night had passed; at this eclipse the Moon was, again, obscured from the south $\frac{1}{4}$ of its diameter. The middle of the eclipse was $\frac{2}{5}$ of an equinoctial hour before midnight in Babylon (for the length of half the night was about 6 $\frac{3}{4}$ equinoctial hours on that date) ...
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> [*Almagest*, IV, 9; trans. Toomer (1984, p. 208).]

It is evident from the times given by Ptolemy in the last sentence of the above quotation that he assumed that the phase which was observed 'when $6\frac{1}{3}$ equinoctial hours of the night had passed' was maximal eclipse.

RESULTS

Maximal phase on Nov 19 at $6\frac{1}{3}$ equinoctial hours after sunset. LT of sunset = 17.26 h, hence mid-eclipse = 23.59 h, UT = 20.46 h. Computed TT = 1.72 h on Nov 20, thus ΔT = 18 950 sec.

(7) BC 491 Apr 25/26 (mag. = 0.09)

> The first eclipse we used is the one in Babylon in the thirty-first year of Darius I, Tybi [month V] 3/4 in the Egyptian calendar [−490 Apr 25/26], at the middle of the sixth hour [of night]. It is reported that at this eclipse the Moon was obscured 2 digits from the south ... For the time of mid-eclipse was $\frac{1}{2}$-hour before midnight at Babylon, and [hence] $1\frac{1}{3}$ equinoctial hours before midnight at Alexandria ...
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> [*Almagest*, IV, 9; trans. Toomer (1984, pp. 206-7).]

Use of an ordinal numeral to fix the time (i.e. 'at the middle of the sixth hour') suggests seasonal hours; this was Ptolemy's normal practice. However, since the Sun was close to the equinox, the choice of units is unimportant: half a seasonal hour before midnight would be equal to 0.45 equinoctial hours. A local time of 23.55 h will be assumed.

RESULTS

Maximal phase on Apr 25 at 1/2 seasonal hour before midnight. LT of mid-eclipse = 23.55 h, hence UT = 20.53 h. Computed TT = 0.37 h on Apr 26, thus ΔT = 13 800 sec.

(8) BC 383 Dec 22/23 (mag. = 0.21)

> He (Hipparchus) says that these three eclipses which he adduces are from the series brought over from Babylon, and were observed there; that the first occurred in the archonship of Phanostratos at Athens in the month Poseidon, a small section of the Moon's disk was eclipsed from the summer rising-point [i.e. the north-east] when half an hour of night was remaining. He adds that it was still eclipsed when it set. Now this moment is in the 366th year from Nabonassar, in the Egyptian calendar (as Hipparchus himself says) Thoth 26/27 [−382 Dec 22/23], $5\frac{1}{2}$ seasonal hours after midnight (since half an hour of night was remaining).
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> [*Almagest*, IV, 11; trans. Toomer (1984, pp. 211–2).]

Further remarks by Ptolemy indicate that he understood the moment when 'a small section of the Moon's disk was eclipsed' as meaning first contact. His statement that this occurred '$5\frac{1}{2}$ seasonal hours of night after midnight since half an hour of night was remaining' implies that the time before the end of night (i.e. sunrise) was also expressed in seasonal hours. The fact that the Moon set eclipsed provides independent limits to the value for ΔT. In order to determine these, it seems best to ignore the recorded times (in case of possible scribal error) and simply assume that the Moon set at some time between first and last contact.

NB Phanostratos was *archon* (chief magistrate) at Athens in the year 383/2 BC. (For a list of the Athenian archons, each of whom held office for one year, see Bickerman, 1980, pp. 138–9.)

RESULTS

(i) First contact on Dec 23 at $\frac{1}{2}$ seasonal hour before sunrise. LT of sunrise = 7.00 h, hence length of night = 14.00 h. 1 seasonal hour = 1.17 h, thus LT of first contact = 6.41 h, UT = 3.50 h. Computed TT = 8.43 h, thus $\Delta T = 17\,750$ sec.

(ii) Moon set eclipsed. (a) First contact: LT of moonset = 6.98 h on Dec 23, hence for Moon to set eclipsed after first contact, LT < 6.98 h, UT < 4.07 h. Computed TT = 8.43 h, thus $\Delta T > 15\,700$ sec. (b) Last contact: LT of moonset = 7.05 h, hence for Moon to set eclipsed before last contact, LT > 7.05 h, UT > 4.14 h. Computed TT = 10.10 h, thus $\Delta T < 21\,450$ sec. Combining these limits, one obtains $15\,700 < \Delta T < 21\,450$ sec. (NB the LT of moonset has been computed iteratively for each contact, as explained in chapter 3.)

(9) BC 382 Jun 18/19 (mag. = 0.49)

> ...He (Hipparchus) says that the next eclipse occurred in the archonship of Phanostratos at Athens in the month Skirophorion, Phamenoth 24/25 in the Egyptian calendar, and that the Moon was eclipsed from the summer rising-point [i.e. the north-east] when the first hour [of night] was well advanced. This moment is in the 366th year from Nabonassar, Phamenoth [month VII] 24/25 [−381 Jun 18/19], about $5\frac{1}{2}$ seasonal hours before midnight.
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> [*Almagest*, IV, 11; trans. Toomer (1984, pp. 212).]

Since Ptolemy inferred that the eclipse began 'about $5\frac{1}{2}$ seasonal hours before midnight', he presumably understood that 'the first hour [of night]' was also expressed in the same units. As mentioned above, use of ordinal numerals for times quoted in seasonal hours was his customary style. Ptolemy thus interprets the clause 'when the first hour [of night] was well advanced' to mean half an hour after sunset, and this will be assumed.

In addition to the timed observation, which yields an estimate of the value of ΔT, the fact the eclipse began soon after sunset may set a useful limit to ΔT.

RESULTS

(i) First contact on Jun 18 at $\frac{1}{2}$ seasonal hour after sunset. LT of sunset = 19.15 h, hence duration of night = 9.70 h, 1 seasonal hour = 0.81 h.

LT of first contact = 19.56 h, UT = 16.51 h. Computed TT = 21.06 h, thus ΔT = 16400 sec.

(ii) First contact after sunset. LT of contact > 19.15 h, UT > 16.10 h. Computed TT = 21.06 h, thus $\Delta T < 17850$ sec.

NB for values of $\Delta T > 17850$ sec the eclipse would have already begun *before* sunset (the Moon would rise several minutes before sunset).

(10) BC 382 Dec 12/13 (mag. = 1.48)

> ...He (Hipparchus) says that the third eclipse occurred in the archonship of Euandros at Athens, in the month Poseidon I, Thoth 16/17 in the Egyptian calendar, and that (the Moon) was totally eclipsed, beginning from the summer rising-point [i.e. the north-east], after four hours [of night] had passed. This moment is in the 367th year from Nabonassar, Thoth [month I] 16/17 [−381 Dec 12/13], about $2\frac{1}{2}$ hours before midnight. Now when the Sun is about two-thirds through Sagittarius, one hour of night at Babylon is about 18 time-degrees. So $2\frac{1}{2}$ seasonal hours produce 3 equinoctial hours. Therefore the beginning of the eclipse was 9 equinoctial hours after noon on the 16th ...
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> [*Almagest*, IV, 11; trans. Toomer (1984, pp. 213).]

As Toomer (p. 213n) remarks, the statement that the eclipse began 'after four hours of night' is incompatible with Ptolemy's interpretation that it commenced 'about $2\frac{1}{2}$ hours before midnight'. Ptolemy consistently assumes $2\frac{1}{2}$ hours before midnight in his subsequent argument and it seems only reasonable to follow him. From Toomer, inspection of the various extant manuscripts of the *Almagest* does not clarify this issue since all give identical readings here.

NB Euandros was *archon* at Athens in the year 382/1 BC.

RESULTS

First contact on Dec 12 at $2\frac{1}{2}$ seasonal hours before midnight. LT of sunset = 17.03 h, hence length of night = 13.94 h, 1 seasonal hour = 1.16 h. LT of first contact = 21.10 h, UT = 18.10 h. Computed TT = 22.55 h, thus ΔT = 16000 sec.

In table 4.2 are summarised the ΔT results obtained from each individual observation discussed above. Years are given in terms of the Julian calendar – using a negative integer rather than BC (see chapter 1). It should be noted that −719a refers to the first eclipse in the year −719 (i.e. Mar 8/9), etc. In this table, Ct stands for contact and M for mid-eclipse.

The various values for ΔT listed in the above table are plotted in figure 4.3. It can be seen from this diagram that with only a single exception (−490), the results are fairly self-consistent, bearing in mind that – as

Table 4.2 ΔT results from Babylonian lunar eclipse observations recorded in the Almagest.

Year	Ct	ΔT (s)
−720	1	21 650
−719a	M	19 000
−719b	1	<21 400
−620	1	17 800
−522	M	19 250
−501	M	18 950
−490	M	13 800
−382	1	17 750
−382	1	>15 700
−382	4	<21 450
−381a	1	16 400
−381a	1	<17 850
−381b	1	16 000

reported in the *Almagest* – the measured times are not expressed in their original form and are further only quoted to the nearest half hour or so. In particular, the observations in −382 and −381 set rather narrow limits to ΔT ($15\,700 < \Delta T < 17\,850$ sec) at this specific epoch.