Ptolemy, Babylon and the **rotation of the Earth**

John Steele finds that Ptolemy was right to believe that Babylonian observers saw the eclipse of 23 December 383 BC – which poses a problem that can be solved by invoking a large clock error or unusual atmospheric conditions.

Abstract

The recent discovery of a Babylonian astronomical text containing a report of the lunar eclipse on 23 December 383 BC confirms that the Greek astronomer Claudius Ptolemy correctly described this eclipse as having been observed in Babylon, in chapter IV of his *Almagest*. The visibility of this eclipse in Babylon implies that either present estimates of the Earth's rotational clock error are too low by around 600 seconds at that period, or, more likely, the eclipse was observed at a time of unusually high atmospheric refraction.

The ancient Alexandrian astronomer Claudius Ptolemy reports some 19 eclipses of the Moon in his astronomical treatise known today as the *Almagest* (Toomer 1984, Britton 1992, Steele 2000a, Steele 2000b). He explains that ten of these eclipses were observed in Babylon, five by earlier Greek astronomers in Alexandria and Rhodes, and the final four by Ptolemy himself in Alexandria. Since the mid-18th century these eclipses have been used extensively in the study of the Earth's slowly changing rate of rotation, or, as it was originally interpreted, the secular accelerations of the Sun and Moon (Britton 1992, Stephenson 1997). Because of the antiquity of these eclipse observations, the cumulative effect of the extremely small change in the length of the day can be easily detected in their times, irrespective of the fact that these times are only recorded with rough precision. However, it was quickly recognized that one of these eclipse reports, a Babylonian observation of a lunar eclipse on 23 December 383 BC, yielded a result for the secular accelerations that was discordant with the other eclipses. Many authors have therefore questioned Ptolemy's account of this eclipse, suggesting that either he misinterpreted a prediction for the eclipse made by Babylonian astronomers for an observation, or that he invented the observational details. However, a recently dated original astronomical text from Babylon contains a very badly preserved report of this same eclipse, indicating that Ptolemy correctly reported the eclipse as having been seen in Babylon (Hunger 2001: text no. 10; see also Steele 2001, Steele 2004).

The most extensive recent investigation into the variation in the Earth's rate of rotation is by Stephenson and Morrison (1995). By combining timed and untimed observations of lunar and solar eclipses observed in several cultures, they were able to obtain a cubic spline fit to the Earth's rotational clock error, known as ΔT, for the period back to the mid-first millennium BC. Since Stephenson and Morrison's spline fit for ΔT implies that the eclipse of 23 December 383 BC was not visible in Babylon, and yet the newly discovered cuneiform account of this eclipse confirms that Ptolemy was correct in reporting it as seen in Babylon, it is worth reinvestigating this eclipse and its significance for the Earth's variable rate of rotation. I begin by discussing Ptolemy's account of this eclipse and its interpretation by earlier investigators of Earth's rotation, then present the Babylonian account of the eclipse, before finally discussing the eclipse reports in the context of ΔT.

1: Claudius Ptolemy.

Ptolemy's account of the eclipse

Ptolemy's account of the eclipse of 23 December 383 BC appears in *Almagest* IV 11. In this chapter Ptolemy describes Hipparchus's determination of the ratio of the eccentricity from triplets of lunar eclipses, first using the eccentric model and then the epicycle model for the Moon, which differ both from each other and from Ptolemy's determination. He explains that the disagreement between Hipparchus's two determinations does not arise from the two different models, which Ptolemy knew to be equivalent, but instead to errors in Hipparchus's calculations. In all, six eclipses used by Hipparchus are reported by Ptolemy in this chapter. It is worth noting that none of these eclipses are used by Ptolemy himself elsewhere in the *Almagest*.

The first triplet of eclipses used by Hipparchus are adduced by him to be "from the ones that were brought over from Babylon, on the assumption that [these three] were observed there" (Jones in Steele 2004). Ptolemy's report of Hipparchus's account of the eclipse of 23 December 383 BC has been translated by Toomer (1984) as follows:

> *"(The eclipse) occurred in the archonship of Phanostratos at Athens, in the month Poseideon; a small section of the Moon's disc 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, $5^1/_2$ seasonal hours after midnight (since half an hour of night was remaining)."*

As he does with the other two eclipses from Babylon, and the three eclipses reported from Alexandria at the beginning of the second century BC, Ptolemy converts the seasonal time of the eclipse into equinoctial (constant) hours by determining the length of night on the day of the eclipse, and then, by estimating the duration of the eclipse from first to last contact, the time of mid-eclipse. Ptolemy takes the total duration of the eclipse to be 1½ hours based upon the remark that "a small section [of the disc] was obscured". However, the account says that the Moon set while still eclipsed so the remark "a small section was obscured" probably refers only to the extent of the eclipse when the Moon set. The actual duration of this eclipse was about 1 hour 40 minutes, so Ptolemy was not far wrong, although his stated means of getting the duration is no more than a guess. It may be that the duration was estimated by someone, possibly Ptolemy himself, who had access to the original compilation of Babylonian eclipse reports and took the duration of the eclipse one saros earlier to be almost identical to that of the present eclipse.

Ptolemy's account of the eclipse of 23 December 383 BC has come under close scrutiny since the earliest investigators of the secular acceleration of the Moon such as the Rev. Richard Dunthorne and Joseph-Jerome Lalande in the mid-18th century discovered that it required an extremely large acceleration in order to make the eclipse at all visible in Babylon (Britton 1992). Hartwig (1860) showed that, using what seemed a plausible value for the secular acceleration of the Moon, the eclipse would begin after the Moon had set. In his detailed investigation into the secular accelerations Simon Newcomb (1878), the director of the Nautical Almanac Office in Washington, concluded that the eclipse had been falsely recorded. He suggested that if the eclipse was predicted beforehand "it is quite possible that the observers may have thought they saw the Moon eclipsed in the increasing daylight, when there was really no eclipse; or, under the unfavourable circumstances, they might have been deceived by a dark region of the lunar disc being near the Moon's limb".

Other contemporary authors suggested alternate ways to interpret the eclipse. T R von Oppolzer (1881), the author of the famous eclipse canon, noted that the three Babylonian eclipses in *Almagest* IV 11 use the Athenian calendar for their dates whereas the other eclipses from Babylon reported elsewhere in the *Almagest* are dated in the Egyptian calendar, and suggested that the three in *Almagest* IV 11 were observed in Athens. Nevill (1906) assumed that the 23 December 383 BC eclipse alone was observed at Athens. However, as demonstrated by van der Waerden (1958, 1961), there is no evidence to support such an interpretation. The appearance of the Athenian calendar in the *Almagest* IV 11 eclipse reports may be because these eclipses were used only by Hipparchus, who is elsewhere known to have used the Callippic calendar, which was based upon the Athenian calendar, not by Ptolemy himself. Newton (1977) claims that the eclipse, along with all of the other eclipses reported in the *Almagest*, was fabricated by Ptolemy. A more plausible explanation, suggested for example by Britton (1992), was that a Babylonian prediction of the eclipse was mistaken for an observation when transmitted to the Greek astronomers. However, the discovery of a Babylonian report of an observation of the same eclipse implies that Hipparchus and Ptolemy faithfully reported the Babylonian account of the eclipse.

The earliest extant Astronomical Diary comes from 652 BC and examples are preserved down to the mid-first century BC

Babylonian account of the eclipse

Several hundred references to lunar and solar eclipses are preserved in Late Babylonian astronomical texts (for a classification of these texts, see Sachs 1947, Hunger 1999, and Hunger and Pingree 1999). These texts are written in cuneiform script on clay tablets that have been recovered from the archaeological sites of the ancient cities of Babylon and elsewhere in present-day Iraq and date to the last seven-and-a-half centuries BC. Roughly a third of the eclipse records describe observations; the remaining two-thirds refer to predicted eclipses that should either be watched for, or that were not seen (often because they were predicted for when the eclipsed luminary was below the horizon). The two largest sources for eclipse records are the so-called "Astronomical Diaries" and the "Eclipse Texts". The Diaries, all dated examples of which have been edited and translated into English by Sachs and Hunger (1988, 1989, 1996), contain night-by-night reports of astronomical observations such as passages of the Moon and planets by certain reference stars (known today as "Normal Stars"), the lunar six (a group of six time intervals between the Sun and Moon crossing the horizon made around new and full Moon each month), and the dates of first and last visibilities and stationary points of the planets. Typically a Diary covers a six or seven month period. The earliest extant Diary comes from 652 BC and examples are preserved with increasing frequency down to the mid-first century BC. Throughout this period Babylonian astronomers used a scheme that incorporated the saros cycle of 223 synodic months (after which the Moon is almost precisely back to the same position in its cycles of anomaly and nodal elongation) to identify months containing eclipse possibilities (Steele 2000c). Thus, when complete, the Astronomical Diaries contained either an observation of an eclipse or the calculated time of an invisible eclipse for every eclipse possibility they identified (which occur every six or occasionally five months).

The Eclipse Texts, which have been edited and translated by Hunger (2001), generally contain collections of either lunar and solar eclipses records over several years or occasionally extended details of a single observed eclipse. Preserved examples contain eclipse observations ranging in date from 747 BC to 10 BC. The texts containing compilations of eclipses fall into two main categories: straightforward lists of consecutive eclipse possibilities and lists of consecutive eclipse possibilities arranged in 18-year saros cycles, classed as categories i and ii respectively by Steele (2001) (see also Walker 1997 and Huber and De Meis 2004). The difference between the two categories of text is immediately apparent upon visual inspection (see the plates in Hunger 2001). All of the compilations arranged in saros cycles are laid out in a strict matrix format, with each eclipse possibility placed within a cell of a large matrix. Horizontal and vertical rulings on the clay tablet delineate these cells. By contrast, the category i compilations are set out as a normal prose cuneiform text. Each eclipse record takes up only as much space as necessary. After the account of the eclipse, a horizontal line may be ruled to separate one eclipse from the next. When one column is complete, the scribe may then continue into the next column with consecutive eclipse possibilities. The columns are usually separated by a vertical line, but any horizontal lines separating eclipses within a column do not extend across to the next column. All known examples of these two types of eclipse compilation strictly adhere to these rules of layout.

The cuneiform tablet BM 37088+37652, published by Hunger (2001: text no. 10), displays the characteristic layout of a category ii text: we find rulings dividing up the only preserved side of the tablet into a grid format. Thus we can safely conclude that the text contains a compilation of lunar eclipses arranged in saros cycles where entries within each column correspond to successive eclipse observations or predictions and entries in the same row are separated by one saros of 223 synodic months, or just over 18 years. Sadly BM 37088+37652 is badly damaged: only parts of two columns are preserved, one of which is almost completely lost. Although a full statement of the date of the eclipses is missing, the preserved partial dates are sufficient to fix a unique date for the text. BM 37652 was first identified as being set out in saros cycles and dated by Sachs (1955). At the request of H Hunger, I established the date of the text independently, obtaining the same result. Subsequently, I dated the small fragment BM 37088 to the same time period and this text was then found to join BM 37652,

Table 1: Dates of all eclipses on BM 37088+37652

left-hand column	right-hand column
23 December 383 BC	2 January 364 BC
18 June 382 BC	29 June 364 BC
12 December 382 BC	23 December 364 BC
(tablet broken)	18 June 363 BC
(tablet broken)	12 December 263 BC
(tablet broken)	7 June 362 BC

Table 2: Dates of eclipses in right-hand col. of BM 37088+37652

Lines	Babylonian Date	Julian Date
1′–3′	Artaxerxes II year 40 Month X day 14	2 January 364 BC
4′–5′	Artaxerxes II year 41 Month III day 14	29 June 364 BC
6′–8′	Artaxerxes II year 41 Month IX day 14	23 December 364 BC
9′–10′	Artaxerxes II year 42 Month III day 14	18 June 363 BC
11′–13′	Artaxerxes II year 42 Month IX day 15	12 December 363 BC
14′–15′	Artaxerxes II year 43 Month III day 13	7 June 362 BC

Table 3:The left-hand column and its translation

1′	[...] ⌜x⌝ ALLA	[...] Cancer
2′	[...] ⌜x⌝	[...] ...
3′	[... GI]N 2/3 ḪAB	[...] ... two thirds of the disc
4′	[...] *ád*	[...] it was eclipsed
5′	[...] *gab* ŠÚ	[...] all was covered
6′	[...]	[...]
7′	[... MAŠ-MAŠ] ⌜IGI *ád*⌝	[... α Gemin]orum it was eclipsed

Translation of the left-hand column by Hunger (2001). The horizontal lines reflect the horizontal rulings on the tablet that separate consecutive eclipses.

providing a confirmation of the dating (Steele in Hunger 2001).

The date of the tablet is established by the eclipses in the right-hand column. Six entries are preserved in this column, four observed eclipses and two predicted eclipses. Although the name of the reigning king is not preserved, we do find the year number and month name of the eclipses (in some cases these are restored with certainty from the context, for example line 4' mentions year 41 and line 14' year 43, so clearly the damaged year number in line 9' must be 42). As the concordance of the Babylonian luni-solar calendar with the Julian calendar of 365-day years (366 in leap years, which occur every four years) is well known for the Late Babylonian period (Parker and Dubberstein 1956), it is easy to establish that only during the reign of Artaxerxes II does the pattern of months containing eclipse possibilities agree with the eclipses that actually took place (for a detailed discussion of the dating of this text, see Steele in Hunger 2001: 41). These eclipses are shown in tables 1–3.

These eclipses do not contradict the assumption that the accounts Ptolemy gives are based upon authentic Babylonian records

The left-hand column of BM 37088+37652 is very badly preserved. Only the ends of seven lines remain. These lines correspond to lines 1' to 7' of the right-hand column. Because the compilation is set out in saros cycles, we can therefore establish the dates of each of these eclipses simply by going one saros – or 223 months – back from the date of the corresponding eclipse in the right-hand column. The resulting dates are shown in table 1. The three preserved eclipses in the left-hand column are the same three eclipses used by Hipparchus that Ptolemy describes in *Almagest* IV 11.

We can now compare the Babylonian accounts of these eclipses with the reports given by Ptolemy. Unfortunately, only scant details of the eclipses are preserved in the Babylonian record. The third eclipse, on 12 December 382 BC, is said by Ptolemy to have been total, beginning from the north-east, and to have taken place when 4 hours of night had passed; the statement that the eclipse was total is in accord with the Babylonian record. The second eclipse, on 18 June 382 BC, is said by Ptolemy to have begun from the north-east "when the first hour [of night] was well advanced" (Toomer 1984); this account neither confirms nor contradicts the Babylonian account. These two eclipses therefore do not contradict the assumption that the accounts Ptolemy gives are based upon authentic Babylonian records.

The Babylonian account of the first eclipse, the eclipse on 23 December 383 BC which is of concern to us here, is sadly almost completely destroyed. Indeed, only one cuneiform sign can be read; nevertheless, this one sign provides us with important information about the eclipse. The sign ALLA may be translated as "the crab", and is used on its own to indicate the zodiacal sign Cancer and as the final part of the names of several stars or star groups in the constellation of Cancer such as MÚL.MEŠ *ár*.MEŠ *šá* ALLA "the rear stars of the crab" (γ and δ Cancri). This one preserved sign alone allows us to be confident that the report refers to an observation of the eclipse (see box 1: Babylonian observations and predictions of eclipses).

The Earth's rotation

We have now established that Ptolemy correctly reports the eclipse of 23 December 383 BC as being recorded as observed in Babylon. His report provides two pieces of data that can be used to investigate the variations in the Earth's rate of rotation: (i) the eclipse was seen to begin before the Moon set and (ii) the eclipse began "when half an hour of night was remaining". Item (i) must be considered more significant as Ptolemy's account is confirmed by the original Babylonian text, which at least implies that the eclipse was visible in Babylon, whereas item (ii) is less certain as we do not have this information preserved in the cuneiform source, and Ptolemy's reporting of the time has already been through a process of conversion from Babylonian units of time-degrees to the Greek seasonal hours, which may well have introduced inaccuracies (Steele 2000a).

According to Stephenson (1997), for the eclipse to have begun before the Moon set (item i) the Earth's rotational clock error, ΔT, must have been within the limits $15\,700\,\mathrm{s} < \Delta T < 21\,450\,\mathrm{s}$, and Ptolemy's statement that the eclipse began half a seasonal hour before sunrise (item ii) implies a value of 17 750 s for ΔT. Since as noted above we must place more significance in item (i) than (ii), the eclipse observation implies that ΔT was around or just above 15 700 s on the date of the eclipse. However, Stephenson and Morrison's (1995) spline fit for ΔT gives a value of 15 065 s for this date with a standard error of just under 390 s (see figure 2) (Morrison and Stephenson 2004). Thus we must assume that either Stephenson and Morrison's (1995) spline fit is incorrect by roughly twice its standard error, or there is some other factor affecting the observation. I can think of three possibilities, two of which concern the report

Babylonian observations and predictions of eclipses

Babylonian reports of observations of lunar eclipses usually give considerable detail about the eclipse. For example, the record of the eclipse of 22 November 353 BC found on the tablet BM 32238 reports the time the eclipse began in degrees (1 degree = 4 minutes) of time, the duration of the phases of the eclipse (first contact to totality, totality and end of totality to last contact), the colour of the eclipse, the direction of the eclipse shadow, the location of the Moon near to a bright star, the visibility of planets during the eclipse, and the direction of the wind during the eclipse:

> *"Month VIII, the 14th. When it began on the south and east side, in 23 degrees all was covered. 18 degrees maximal phase. (After) 16 degrees of night, one-fourth on the east side cleared; it set eclipsed. The eclipse was red.* $1\frac{1}{2}$ *cubits behind* ζ *Tauri it was eclipsed. During the eclipse Saturn stood there; the remainder of the planets did not stand there. The north wind, which was slanted to the west blew. At 47 degrees before sunrise."* (Translation by Hunger 2001).

In some other examples additional information such as the sign of the zodiac in which the Moon was located during the eclipse is given. By contrast, records of predicted eclipses are very brief, as can be seen from a report of the eclipse one saros later on the tablet quoted above:

> *"Month IX, the 14th, (eclipse) which was omitted. At 60 degrees before sunset."* (Translation by Hunger 2001).

Nothing more than the expected time of the eclipse is given. Indeed, with the exception of five cases where an estimate of the expected magnitude of the eclipse is recorded, and one case where it is said that the Moon will set during the eclipse, all of the several hundred preserved reports of predicted lunar eclipses from Babylon known to me simply state the expected time of the eclipse. From Babylon we find not a single reference to either the zodiacal sign in which the luminary was situated during the eclipse or a star or star group. According to Sachs (1947) an unpublished Almanac from the city of Uruk in southern Mesopotamia, MLC 2195, mentions the signs of the zodiac in which a predicted eclipse will take place. However, astronomical texts from Uruk often include different information than their Babylonian counterparts; for example, Normal Star Almanacs from Uruk contain the dates of the entrances into zodiacal signs but this data is never provided in Normal Star Almanacs from Babylon. Thus, the single example of a predicted eclipse including a reference to a zodiacal sign from Uruk does not have any significance when discussing texts from Babylon.

Among the reports of solar eclipses in the Astronomical Diaries and related texts from Babylon there are no cases where anything more than the expected time of the eclipse is recorded. Signs of the zodiac are sometimes included in eclipse reports contained in horoscopes; many of these reports may refer to observed eclipses, but in at least one case (BM 41301 rev. 7', see Rochberg 1998) a solar eclipse prediction is given with a zodiacal sign. Again, however, the horoscopes display several different features in their recording of astronomical data to the Eclipse Texts, and I do not believe that the inclusion of a zodiacal sign for a solar eclipse prediction, which can easily be estimated simply by turning the number of the month of the year into the *n*th zodiacal sign, and is of particular importance for horoscopic astrology, is of significance to the text under discussion. We can therefore say with certainty that the reference to "the crab" in the report of the eclipse of 23 December 383 BC, whether it be used as a star name or a sign of the zodiac, implies that the record describes an eclipse observation, not a prediction. For reference, the longitude of the Moon at the beginning of the eclipse was about 86 degrees, about 4 cubits from the four stars that make up the Crab, and within the zodiacal sign of Cancer assuming the Babylonian norm for the zero-point of the zodiac (Huber 1958).

itself, the other the physical conditions under which the observation was made.

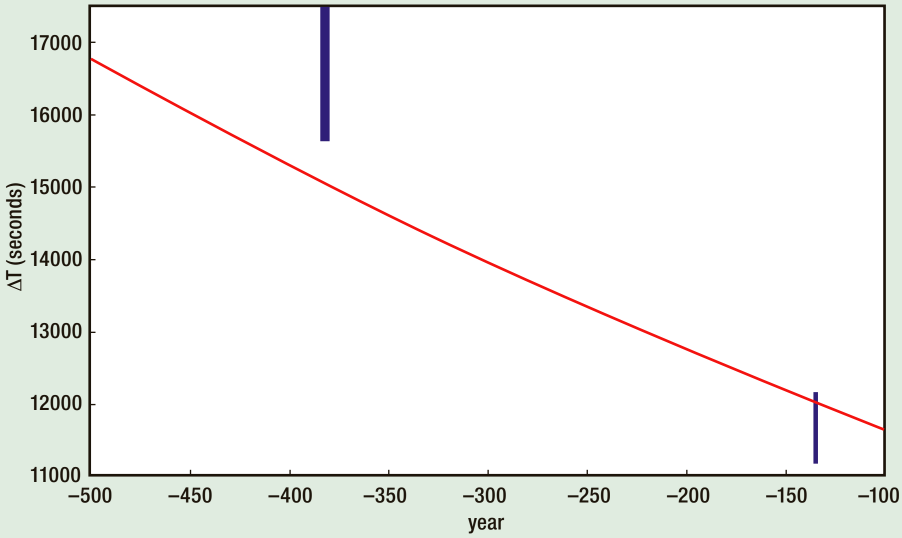
First of all, the Babylonians may simply have been mistaken in believing the eclipse had begun before the Moon set. From our knowledge of Babylonian astronomy we know that the night of 23 December 383 BC would have been identified in advance as a syzygy at which an eclipse might occur, and the time at which the eclipse was expected to begin estimated. The method by which this was done uses a detailed understanding of the saros cycle so that all eclipse possibilities, not just those one saros after a visible eclipse, could be identified (Steele 2000c). In this case, however, the eclipse one saros earlier, on 11 December 401 BC, would have been visible in Babylon, so the astronomers would have known in advance that this saros series was still "active". (Because the saros relationship of 223 synodic months $\approx$ 242 draconitic months is not exact, saros series do not continue forever. This fact was known to Babylonian astronomers who used different terminology to designate those eclipse possibilities still in active saros series from those in dead series which nevertheless need to be recorded to keep the whole prediction scheme going. See Steele 2001–2002). Furthermore they could have used their timing of the 401 BC eclipse when deducing the expected time of the eclipse in 383 BC (for possible ways this may have been done, see Steele 2002, Brack-Bernsen and Hunger 2002 and Brack-Bernsen and Steele 2005). Expecting the eclipse around sunset, it is therefore possible that the astronomers made a false sighting of what they thought was the beginning of the eclipse when the Moon was low on the horizon and very deep in the Earth's penumbral shadow. Huber and De Meis (2004: 22–24) have argued that the Babylonians systematically observed the moment of first contact slightly early and have proposed an empirical correction to the Earth's shadow diameter that, when combined with their preferred approximation to ΔT, results in this eclipse taking place moments before the Moon set. Furthermore, modern observing practice shows that false sightings of objects near the horizon such as the thin lunar crescent at first visibility are commonly made. For example, Doggett and Schaefer (1994) have shown that up to 15% of observers will honestly report false positive observations of the new Moon. However, I am cautious about applying such statistics to Babylonian observers with a large amount of experience of naked-eye observation. Thus, although I do not rule out the possibility of a mistaken observation, I consider it unlikely.

Modern observing practice shows that false sightings of objects near the horizon are commonly made

A second possibility is that the report of the eclipse observation was placed in the eclipse compilation by mistake. We know of a handful of very early examples of "wrongly filed" eclipses in the large compilations arranged in saros cycles (Huber and De Meis 2004: 68, Steele 2000a: 244), but again I think this unlikely, especially for an eclipse in the fourth century, probably not long before the compilation was made.

The third possibility is that unusual observing conditions caused the Moon to be seen above the horizon when modern computations would place it below. The altitude of bodies near the horizon is greatly affected by atmospheric refraction, and the amount of refraction itself depends upon the local conditions such as purity of the atmosphere, temperature, humid-

2: Stephenson and Morrison's (1995) spline fit for ΔT is shown as the red line. The purple vertical line shows the tight constraints placed on ΔT by the occurrence of a total solar eclipse seen in Babylon in 136 BC. The heavy vertical line shows the range of ΔT necessary for the eclipse of 23 December 383 BC to have been seen in Babylon before the Moon set.



ity and the temperature gradient. Normally, at Babylon, celestial objects on the horizon are refracted such that they appear about ½° higher in altitude than had they not been refracted. Huber (2000) has estimated the RMS variability in refraction from Babylonian lunar six observations of the time intervals between the Moon and Sun crossing the horizon to be 0.20°. In extreme cases, however, the refraction can reach more than 1½° at the geographical latitude of Babylon (Young 2004, Schaefer and Liller 1990). This could cause the time of moonset to be delayed by several minutes. With the eclipse of 23 December 383 BC, several minutes might be enough to allow the beginning of the eclipse to be seen just moments before the Moon set (particularly as the eclipse begins on the eastern side of the Moon, the upper part of the Moon as it sets). A similar situation is presented by the observation of an eclipse just before sunrise on 3 November 240 BC in Babylon (Stephenson 1997, Huber and De Meis 2004). Calculation using Stephenson and Morrison's (1995) spline fit for ΔT would have the eclipse beginning just after the Moon set; once more, anomalous refraction may have delayed moonset by a sufficient period of time that the eclipse shadow was seen to cover the upper edge of the Moon before it set.

Conclusions

In conclusion it seems that Ptolemy correctly reported a Babylonian record of an observed eclipse on 23 December 383 BC. The visibility of this eclipse in Babylon before the Moon set implies that either or both Stephenson and Morrison's (1995) spline fit for ΔT is too low by about 600 seconds in the early part of the fourth century BC (which would seem discordant, though not completely incompatible, with the many other Babylonian eclipse observations from around this period), or the eclipse was seen during extreme atmospheric conditions. ●

In conclusion it seems that Ptolemy correctly reported a Babylonian record of an observed eclipse on 23 December 383 BC

J M Steele, Dept of Physics, University of Durham, DH1 3LE.

Acknowledgments. I would like to thank F R Stephenson for many useful discussions during the writing of this paper and for offering helpful comments on an earlier draft. I also thank the Royal Society for its generous provision of a University Research Fellowship which made this work possible.

References

Brack-Bernsen L and Hunger H 2002 *SCIAMVS* **3** 3–90.
Brack-Bernsen L and Steele J M 2005 Eclipse Prediction and the Length of the Saros in Babylonian Astronomy *Centaurus* in press.
Britton J P 1992 *Models and Precision: The Quality of Ptolemy's Observations and Parameters* (Garland, New York).
Doggett L E and Schaefer B E 1994 *Icarus* **107** 338–403.
Hartwig E 1860 *Astronomische Nachrichten* **52** 257–264.
Huber P J 1958 *Centaurus* **5** 192–208.
Huber P J 2000 *Centaurus* **42** 223–234.
Huber P J and De Meis S 2004 *Babylonian Eclipse Observations From 750 BC to 1 BC* (IsIAO-Mimesis, Milan).
Hunger H 1999 in *Ancient Astronomy and Celestial Divination* ed. N M Swerdlow (MIT Press, Cambridge, Mass.) 77–96.
Hunger H 2001 *Astronomical Diaries and Related Texts from Babylonia, Volume V: Lunar and Planetary Texts* (Österreichischen Akademie der Wissenschaften, Vienna).
Hunger H and Pingree D 1999 *Astral Sciences in Mesopotamia* (Brill, Leiden).
Morrison L V and Stephenson F R 2004 *Journal for the History of Astronomy* **35** 327–336.
Nevill E 1906 *MNRAS* **67** 2–13.
Newton R R 1977 *The Crime of Claudius Ptolemy* (Johns Hopkins University Press, Baltimore).
Newcomb S 1878 *Researches on the Motion of the Moon, Part 1* Washington Observations for 1875, Appendix 2.
Oppolzer T R von 1881 *Syzygientafeln für den Mond nebst aüsfuhrlichen Anwersung zum Gebrauch derselben* (der astronomischen Gesellschaft, Leipzig).
Parker R A and Dubberstein W H 1956 *Babylonian Chronology 626 BC – AD 75* (Brown University Press, Providence).
Rochberg F 1998 *Babylonian Horoscopes* (American Philosophical Society, Philadelphia).
Sachs A J 1948 *Journal of Cuneiform Studies* **2** 271–290.
Sachs A J 1955 *Late Babylonian Astronomical and Related Texts* (Brown University Press, Providence).
Sachs A J and Hunger H 1988 *Astronomical Diaries and Related Texts from Babylonia, Volume I: Diaries from 652 BC to 262 BC* (Österreichischen Akademie der Wissenschaften, Vienna).
Sachs A J and Hunger H 1989 *Astronomical Diaries and Related Texts from Babylonia, Volume II: Diaries from 261 BC to 165 BC* (Österreichischen Akademie der Wissenschaften, Vienna).
Sachs A J and Hunger H 1996 *Astronomical Diaries and Related Texts from Babylonia, Volume III: Diaries from 164 BC to 61 BC* (Österreichischen Akademie der Wissenschaften, Vienna).
Schaefer B R and Liller W 1990 *PASP* **102** 796–805.
Steele J M 2000a *Observations and Predictions of Eclipse Times by Early Astronomers* (Kluwer Academic Publishers, Dordrecht).
Steele J M 2000b *Centaurus* **42** 89–108.
Steele J M 2000c *Archive for History of Exact Sciences* **54** 421–454.
Steele J M 2001 Appendix: The Eclipse Texts in *Astronomical Diaries and Related Texts from Babylonia, Volume V: Lunar and Planetary Texts* ed. H Hunger (Österreichischen Akademie der Wissenschaften, Vienna) 390–399.
Steele J M 2001, 2002 *Archiv für Orientforschung* 48–49, 107–112.
Steele J M 2002 in *Under One Sky: Astronomy and Mathematics in the Ancient Near East* ed. J M Steele and A Imhausen (Ugarit-Verlag, Münster) 405–420.
Steele J M 2004 *Journal for the History of Astronomy* **35** 337–355.
Stephenson F R 1997 *Historical Eclipses and Earth's Rotation* (Cambridge University Press, Cambridge).
Stephenson F R and Morrison L V 1995 *Phil. Trans. Roy. Soc. London* Series A 351, 165–202.
Toomer G J 1984 *Ptolemy's Almagest* (Duckworth, London).
van der Waerden B L 1958 *Museum Helveticum* **15** 106–109.
van der Waerden B L 1961 *AJ* **66** 138–147.
Walker C B F 1997 in *Mesopotamia and Iran in the Persian Period: Conquest and Imperialism 539–331 BC* ed. J Curtis (British Museum, London) 17–25.
Young A T 2004 *AJ* **127** 3622–3637.