ANCIENT ASTRONOMICAL OBSERVATIONS AND THE ACCELERATIONS OF THE EARTH AND MOON

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2. BABYLONIAN MEASUREMENTS OF ECLIPSE MAGNITUDES AND TIMES

Ptolemy [ca 152] has transmitted measurements, presumably made at Babylon, concerning ten lunar eclipses. The validity of these records has been attacked, and it is desirable to consider this point first.

It is interesting to note that the validity or quality of almost all the data transmitted by Ptolemy has been questioned by some one. No one defends the accuracy of his equinoxes and his star tables. Fotheringham [1915a] stated that Hipparchus' equinox measurements, which Ptolemy transmitted, were badly made and used an argument based on this claim to explain Ptolemy's bad value of the precession; later [Fotheringham, 1918] he upheld the accuracy of Hipparchus' equinoxes and had a different explanation of the wrong precession. Newcomb [1875] rejected the validity of the occultations (see Section VI.1) while Fotheringham [1915a and 1915b] upheld it. They interchanged positions with regard to the Babylonian eclipses, which Newcomb used and Fotheringham did not.

TABLE V. 2

BABYLONIAN MEASUREMENTS OF TIMES AND MAGNITUDES OF LUNAR ECLIPSES

Identification	Chapter[a]	Magnitude, Digits and Side Eclipsed		Phase	Time at Babylon
		Area	Diam.		
-720 Mar 19 BA	IV. 5		Total	Beg.	More than 1^h after moonrise
-719 Mar 8 BA	IV. 5	3S		Mid.	Exactly midnight
-719 Sep 1 BA	IV. 5	> 6N		Beg.	After rising
-620 Apr 22 BA	V. 14		3S	Beg.	End of 11th hour
-522 Jul 16 BA	V. 14		6N	Mid.	1^h before midnight[c]
-501 Nov 19 BA	IV. 8		3S	Mid.	2/5 hour before midnight
-490 Apr 25 BA	IV. 8	2S		Mid.	Middle of sixth hour
-382 Dec 23 BA[b]	IV. 10	1? NE?		Mid. ?	1/2 hour before sunrise
-381 Jun 18 BA[b]	IV. 10	? NE?		Mid. ?	1 hour of the night
-381 Dec 12 BA[b]	IV. 10	Total		Beg.	After 4^h of the night

[a] Book and chapter number in Ptolemy [ca 152].

[b] Will not be used in final inference. See text.

[c] Fotheringham [1915] gives 3 1/3 hours after sunset. See text.

A cuneiform text [Kugler, 1909, p. 71] has been found that refers to the lunar eclipse of -522 Jul 16 (see also Table V. 2). It gives the time of the eclipse as 1 2/3 double-hours after sunset. The calculated time of sunset at Babylon for the date in question is $19^h\ 02^m$ local apparent time. Fotheringham [1915b] added $3^h\ 20^m$ (= 3 1/3 hours = 1 2/3 double-hours) to obtain $22^h\ 22^m$ for the time in the cuneiform record. The record of the same eclipse transmitted by Ptolemy says 1^h before midnight†; it is almost but not absolutely certain that this is the time of the middle. On the assumption that Ptolemy's record and the cuneiform record refer to the same phase, Fotheringham found a discrepancy of 38^m between them. On the assumption that the cuneiform record refers to the beginning and Ptolemy's to the middle, he still found a discrepancy of 38^m because the interval between the phases should be 76^m for this eclipse, according to Oppolzer's Canon.

† In the quotation of the record, Ptolemy did not say whether the hour was equal or unequal. In computations dealing with the eclipse, he took it as an equal hour, and I see no reason not to adopt this interpretation. I also accept his interpretation of the phase as the middle.

Fotheringham thereupon rejected all Babylonian eclipse records on the basis that they had been "reduced" before reaching the form that Ptolemy gave. In my opinion, an error in one record does not provide sufficient grounds for rejecting all records from an entire provenance. Further, if Fotheringham chose to reject "reduced" data, he should have rejected the Greek as well as the Babylonian records. There is little question that both the Greek and the Babylonian data have been reduced. Ptolemy's statements show this clearly. For example, in the record called -200 Sep 22 M in Table V. 5, Ptolemy states that an eclipse of the moon began half an hour before the moon rose. This statement cannot be "raw data". The meaningful question for this study is not whether the data have been reduced. It is not even whether the reduction has been done accurately, within reasonable limits. It is whether the reduction has been done in a way that would be likely to bias our results.

In the case that Fotheringham discussed, the reduction error may not be as bad as he thought. Let us assume that the time in the cuneiform record was in unequal hours. During the night of -522 Jul 16 at Babylon, 1 un. hr. = $49^m.6$ approximately. Hence the time in the cuneiform record would be $19^h\ 02^m + (3\ 1/3) \times (49^m.6) = 21^h\ 47^m$ local apparent time rather than $22^h\ 22^m$. One eq. hr. before midnight is of course 23^h. The interval would be 73^m rather than 38^m and the discrepancy would be 3^m rather than 38^m. An error of this size would be negligible†.

† An explanation in the literature needs comment. It has three main steps: (a) a cuneiform inscription sometimes called the "ivory prism" carries an inaccurate table for converting equal to unequal time units; (b) a Babylonian astronomer used the table to convert 1 2/3 equal double-hours into unequal hours; and (c) Ptolemy ultimately obtained the converted record rather than the original. This explanation increases the discrepancy. It rests upon a particular interpretation of the table on the ivory prism. The columns in the table are not labelled, and it is not certain that they deal with equal and unequal time. For example, Neugebauer [1947] thinks that the table deals with

It does not need to excite comment that Ptolemy gave the time of the middle phase in equal hours if the cuneiform record gave the time of beginning. Ptolemy used the middle, presumably as an approximation to opposition, in equal hours in his calculations with all the eclipse records; sometimes he gave the details of how he found the middle time and sometimes not. It is marginal whether he would have tried to preserve an accuracy of 3^m in his calculations and statements. Thus it seems plausible to me that the calculation just outlined is the one that Ptolemy used. Whether it is correct that "1 2/3 double-hours" was in unequal time is another matter†; Ptolemy could have misread the record.

The possibility that the cuneiform time was in unequal time is denied implicitly by Fotheringham [1915b] and explicitly by Kugler [1909, p. 63], Neugebauer [1955, v. 1, p. 39], and van der Waerden [1956, p. 88]. I do not understand the basis for so much assurance. Back of it are assumptions about uniformity of human conduct and uniformity of word usage at all times in all contexts that go beyond my experiences of human consistency. A corollary of the assurance is that the cuneiform text in question can be read with no ambiguity in the technical terms involved. We can test this corollary by comparing independent translations of the (transcription of the) cuneiform record. Kugler and Sachs‡, respectively, give the

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the weight of water needed in a water clock at various seasons. Finally, the errors in the table are unreasonably large if it deals with equal and unequal hours.

†It should be noted that a consistent error of misreading equal hours as unequal hours produces a mean error that approaches zero as the sample size increases. Hence the possibility of an error in the kind of time does not justify rejecting the records.

‡Kugler's translation appears in [Kugler, 1909, p. 71]. Sachs' translation is contained in a private communication from Prof. A. J. Sachs to Britton and appears in [Britton, 1967, p. 82]. Kugler's translation is into German. It will appear that uncertainties caused by translating this translation are negligible.

following translations, in which the year number is the year of the reign of Cambyses II and Duzu is the fourth month of the Babylonian calendar:

> Year VII, Duzu, night 14, 1 2/3 double-hours after beginning of night, a lunar eclipse; entire course visible; it extended over the northern half of the disk.
>
> Year VII, month IV, night of the 14th,1 2/3 double-hours in the night a "total" lunar eclipse took place [with only] a little remaining [uneclipsed]. The north wind blew.

When there is this much divergence between excellent scholars, I hesitate to be sure about the precise meaning of Babylonian terms.

Even if the authorities should be able to establish that the Babylonian inscriber intended "double-hour" to be a unit of equal time, they would be unable to show that Ptolemy read it that way.

The difference between assigning the middle of the eclipse to 1 eq. hr. before midnight and assigning the beginning to 1 2/3 equal double-hours after sunset is only 38^m. The difference between ephemeris time and solar time at the epoch in question is probably about four or five hours. An uncertainty of 38^m out of several hours, for one record only, is not important for the purposes of this study. I have spent this much time on the record -522 Jul 16 BA only because the controversy about it bears on the question of whether to accept Ptolemy's versions of the Babylonian records. Since Ptolemy (or some earlier Hellenistic astronomer) was closer in time and place to Babylon than we are, I am as willing to accept his translations (but not necessarily his interpretations) as those of anyone else, in spite of problems about this record.

The identifications of the Babylonian eclipses and the chapter of Ptolemy in which the record is found are

listed in the first two columns of Table V. 2. Some of the records are straightforward and need no comment beyond that furnished by the table; some need explicit comment.

-522 Jul 16 BA. This record has already been discussed in part. The text reads ". . . at one hour before midnight . . at Babylon one saw the moon eclipsed by half its diameter in the northern part." As it stands, this is a record of the time when the magnitude reached a particular value. It is not explicitly stated either that the time is the middle or that the phase is greatest. Not until an Islamic measurement on 1004 Jan 24 do we find another record when the times of specific magnitudes were measured. Therefore I assume that the time is that of the middle and that the magnitude is the maximum.

-501 Nov 19 BA. The text reads: "The eclipse . . . occurred at 6 1/3 eq. hr. of this night. The moon was eclipsed by 1/4 of its diameter on the southern side, and the middle was at 2/5 of an hour before midnight for Babylon." The manner of reporting the time of this eclipse is quite different from the manner used for eclipses surrounding this one in time, so the times have probably been edited. Also the text is not clear about what phase occurred at 6 1/3 eq. hr.

6 1/3 eq. hr. of the night for this date at Babylon is about $23^h\ 18^m$ local mean time. Midnight apparent time is about $23^h\ 45^m$ mean time and 2/5 of an unequal hour is about 27^m in equal time, so that 2/5 of an hour before midnight is also $23^h\ 18^m$ local mean time. The exact agreement is surely fortuitous, but it is clear that only the time of the middle phase is reported. A late editor probably calculated the time measured in equal hours and inserted it into the record.

-382 Dec 23 BA, -381 Jun 18 BA, and -381 Dec 12 BA. These records share several peculiarities. They refer to consecutive eclipses. They are the only records that Ptolemy transmitted from the -4th century, and they are the only Babylonian records in Chapter IV. 10. They are the only Babylonian records whose dates are given in

terms of the Athenian calendar. Records from this chapter, whether Babylonian or Greek, are the only ones in which a measured magnitude is not given for partial eclipses (see the discussion of the record -309 Aug 15b M (Hipparchus)). They all use, and are the only ones that use, the phrase "eclipsed from the side of the summer rising". Finally, Ptolemy describes them as "three eclipses out of the number of those brought from Babylon as having been observed there."

Ginzel [1899] and others doubt that the eclipses were actually observed at Babylon. It has been suggested that they were observed in a Greek city and the records taken to Babylon where the times were converted to Babylon time. Britton [1967, p. 88] suggests that they represent attempts to predict eclipses. If either suggestion is correct, the records could introduce bias into the results, and we must proceed carefully.

van der Waerden [1958] feels strongly that the three eclipses were observed in Babylon and that the first two should receive more than average weight, but I cannot share this feeling. For example, an argument on which he seems to place much weight is that the eclipse of -381 Jun 18 would have had to begin before sunset in Athens or any other likely city of the Greek culture, and hence that the record could not have come from any likely Greek city. However, we cannot conclude that an eclipse time would not be recorded simply because it was not observed. The Greek record -200 Sep 22 M explicitly states that a lunar eclipse began half an hour before moonrise.

The record -382 Dec 23 BA seems internally inconsistent to me if we assume that the observations back of it were made in Babylon. Ptolemy quotes the record as saying, after giving the date, that "a small part of the disk was eclipsed from the side of summer rising† when half an hour was left of the night, and the moon set still eclipsed." It seems to me that this explicitly denies that the observed phase was the beginning; however, Ptolemy assumed that

†Northeast?

the eclipse began at the time stated. He later said, in connection with finding the middle time, that "since only a small part entered the shadow, the entire duration of the eclipse must have been at most 1½ hours." If the eclipse began at the time stated, it would have been impossible to know by observation either the magnitude or the duration, because of the interposition of moonset and sunrise.

It seems to me either that some or all of the circumstances of the eclipse were calculated, as Britton suggests, or that Ptolemy had a record of the eclipse from somewhere other than Babylon†, or that the observed phase was the middle. In any case, there are questionable circumstances surrounding the records. It is safest not to use them, since the risk in using them is the introduction of bias, not of mere random error. The eclipses will be calculated, primarily in order to reach a judgment about whether they were observed at Babylon.

The accuracy of the magnitude measurements was estimated in Section V. 1. It is also useful to have an a priori estimate of the timing accuracy.

We have no direct knowledge of the way in which the times in Table V. 2 were measured. The water clock was almost surely a well known item by the times of the first eclipses in Table V. 2. Neugebauer [1947] discussed a cuneiform text that is probably roughly contemporaneous with the first entries in the table. It gives some instructions concerning water clocks; Neugebauer speculated from the instructions that the water reservoir had a constant cross section, so that the rate of flow changed with the hour.

It is a reasonable speculation that a water clock was used to measure the times. If so, we do not know how

† Leaving open the possibility that he had a Babylonian record also. Since Hipparchus used these eclipses [Ptolemy, ca 152, IV. 10], it may be that Ptolemy had both Hipparchus' statements of the records and additional independent records.

accurate it was. What is worse, we do not know the doctrine of use. There are two plausible doctrines. The clock for the night could have been started each sunset and the times read directly from it. This doctrine would make the error roughly proportional to the interval since sunset. Alternately, the clock could have been started at sunset and read at dawn and the observations adjusted according to the dawn reading.

To us it is clear that the latter doctrine is more accurate, but we do not know whether it was followed or not. It will be assumed arbitrarily that it was, and it will be explicitly assumed that the standard deviation of a time measurement is 10 percent of the interval from sunset or sunrise, whichever is nearer.

It will be assumed that rounding error in reporting the time is an additional independent error. Inspection of the times in Table V. 2 suggests that the Babylonians rounded to thc nearest half hour. The standard deviation corresponding to this rounding is about 9^{m}.