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Eclipse Prediction in Mesopotamia

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General methods of eclipse prediction

With respect to the fixed background of stars, the moon moves around the Earth in an approximately circular orbit with an average period of 27.3216 days, known as the sidereal month. However, from the Earth the sun also appears to circle us returning to the same location relative to the fixed stars in a period of 365.2564 days, known as the sidereal year. Therefore, over the course of a sidereal month the sun has moved slightly ahead of the fixed stars, and so it takes a little more than another 2 days for the moon and sun to reach conjunction. The average time interval between two conjunctions or oppositions of the moon and sun is equal to 29.5306 days and is known as the synodic month.[5]

There are two types of eclipses: lunar and solar. Lunar eclipses occur when the moon at opposition passes through the Earth's shadow, whereas solar eclipses may occur whenever the moon at conjunction covers some part of the suns disc.[6] If the two planes in which the moon and sun move were the same then one luminary would be eclipsed every conjunction or opposition. However, these two planes are in fact inclined at an angle of about 5° to one another, intersecting at points called nodes. The average

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[4] See A. Sachs, "Babylonian Observational Astronomy," *Philosophical Transactions of the Royal Society of London* 276 (1974), 43–50.

[5] It is worth noting that while we have no evidence that the Babylonians possessed a physical theory of eclipses, all of the concepts used in the following discussion (syzygy, nodes, anomaly, etc.) were, or became, familiar to them.

[6] The situation for solar eclipses is complicated by the fact that, due to the relative sizes of the Earth, moon and sun, the moon's umbral shadow only falls on a small part of the Earth's surface. Thus the prediction of solar eclipses for any given site requires knowledge of the geometry of the Earth-moon-sun system, and of the geographical location on the Earth's surface of the observation site. There is no evidence that the Babylonian astronomers were able to take this into account. Instead, I agree with Aaboe in suggesting that the Babylonians may have been content to distinguish between those conjunctions at which solar eclipses were *possible*, and to exclude those at which they were not. See A. Aaboe, "Remarks on the Theoretical Treatment of Eclipses in Antiquity," *Journal for the History of Astronomy* 3 (1972), 105–118.

interval between successive passages of the moon by a given node, known as a dracontic month, is equal to 27.2122 days. Only when the Earth's shadow at opposition (for a lunar eclipse) or when the sun at conjunction (for a solar eclipse) is near to a node will an eclipse be possible. This is equivalent to saying that eclipses only occur when the latitude of the moon is sufficiently close to zero at the moment of conjunction or opposition. Due to the different lengths of the synodic and dracontic months, the lunar node recedes in longitude by about 1;34° per month.[7] During this same month, the sun on average travels about 29;6° forward in longitude. Therefore, the difference in longitude between the node and the sun (or the Earth's shadow) at syzygy increases by roughly 30;40° per month. If we assume that eclipses do not occur in consecutive months, as it is apparent that the Babylonian astronomers did, it is possible to define an "eclipse possibility" as the syzygy at which the Earth's shadow or the sun is closest to the node every time it passes by that node. The average interval between successive eclipse possibilities is equal to about 5;52,7,44 months.[8] Of course, this does not imply that eclipses possibilities occur every 5;52,7,44 months, for then moon and sun would not be at syzygy, but rather that eclipses occur every six months, with a five month interval every now and again.

This rule that eclipses can be predicted by simply moving on by 6 or occasionally 5 lunar months from the preceding eclipse possibility is the most basic scheme for calculating eclipses that can be identified. Its use is complicated by the uncertainty as to when the 5 month interval is needed. However, once the months of eclipse possibilities have been identified it is even possible to make a rough estimate of the time of the expected eclipses by measuring the time interval during which the moon and sun had been seen together on the days running up to syzygy. It is easy to see how such a basic method would work. On the expected day of an eclipse the latitude of the moon must be close to zero. To a first approximation, therefore, the time interval during which the moon and sun were both above the horizon on the last evening before opposition or conjunction is dependent upon the difference in longitude between the sun and the moon.[9] As the moment of syzygy occurs when this difference in longitude is either 0° or 180°, clearly if the time interval is great then syzygy is far off and may occur during the following day when the moon is below the horizon, whereas if it is small then the syzygy is close by and will occur during the night.

To predict eclipses more reliably, one must use one of two basic methods. The first is to calculate the latitude of the moon at every syzygy and then to declare that those with the latitude closest to zero are eclipse possibilities; this is the basis of the method used in the Babylonian mathematical astronomy of the Seleucid period. However, to do so

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[7] Here and elsewhere I am transcribing sexagesimal numbers using commas to separate places and a semicolon to separate integers from fractions.

[8] I am here following the discussion given by J. P. Britton, "An Early Function for Eclipse Magnitudes in Babylonian Astronomy," *Centaurus* 32 (1989), 1–52. For further details I refer the reader to his article.

[9] More generally, this time interval is a very complicated function dependent upon a number of factors including the moon's longitude, latitude and velocity, and the visibility conditions. See O. Neugebauer, *The Exact Sciences in Antiquity* (Brown University Press, Providence, 1957), 107–110, and L. Brack-Bernsen and O. Schmidt, "On the Foundations of the Babylonian Column Φ: Astronomical Significance of Partial Sums of the Lunar Four," *Centaurus* 37 (1994), 183–209.

requires a lunar theory capable of calculating latitudes for every conjunction and opposition. Before the development of such a theory, early astronomers had to rely on simpler schemes which made use of the periodicities in the moon's motion. Let me discuss the case for lunar eclipses; solar eclipse possibilities can be treated analogously. Once an eclipse has occurred, it is clear from the rules discussed above that another eclipse will take place when (a) the moon is in the same phase again, and (b) the moon is at its same position in its orbit with respect to the node. In other words, an eclipse will occur after there has been both a whole number of synodic months and a whole number of dracontic months. Although there is no reasonably small integral common multiple for these two intervals, a number of short periods are close. For example, 47 synodic months is only one tenth of a day different from 51 dracontic months, and 135 synodic months is about half a day more than 146 dracontic months. The most useful of these periods, however, is 223 synodic months, which is very close to 242 dracontic months. This period is useful because it is also very close to 239 anomalistic months,[10] which means that the recurring eclipses will have similar magnitudes and durations. This period, which is equal to about 6585 1/3 days or slightly more than 18 years, has become known as the "Saros."[11] Its excellence in predicting eclipses is illustrated by Table 1 which lists, for three groups of eclipses, the magnitudes and local times of first contact for Babylon and the differences between the circumstance of each eclipse and its predecessor one Saros before.[12] The first series is about as poor as the Saros gets, whereas the second is about the best. Evidently, there is some variation in the stability of the Saros between the three groups, but in general the magnitude changes by less than about 0.1 of the lunar diameter for each eclipse, and the local time increases by approximately 8 hours per eclipse. The average interval between eclipse possibilities in the Saros is 5;52,6,18, quite close to the theoretical value of 5;52,7,44. A period with an even closer approximation to the theoretical value of the average eclipse interval is given by combining the 135 and 223 month periods to obtain 358 synodic months yielding 5;52,7,52.[13] However, there is a relatively large variation in lunar anomaly between successive eclipses separated by this period and so it is of little or no use for predicting the time of an eclipse.

It will be useful at this point to define a number of terms that I shall use when discussing the Saros. By "Saros cycle," I mean the period of 223 synodic months containing 38 eclipse possibilities. By "Saros series," I am referring to a collection of eclipse possibilities each separated by one Saros of 223 synodic months from the preceding eclipse possibility. A "Saros scheme" will be taken to mean the particular distribution of eclipse possibilities within a Saros cylce at a given time.

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[10] Because the moon's orbit is not exactly circular its distance from the Earth varies. The average interval between successive closest approaches to the Earth is known as an anomalistic month and is equal to 27.5545 days.

[11] As has often been noted, the term "Saros" is modern. To the Babylonians this period was simply called 18 MU.MEŠ "18 years." See O. Neugebauer, *The Exact Sciences in Antiquity* (Brown University Press, Providence, 1957), 141–143 for a history of the term "Saros."

[12] Throughout this paper, magnitudes are given as a fraction of the lunar or solar diameter, and local times in hours and decimals.

[13] For details of these eclipse periods, see J. P. Britton, "An Early Function for Eclipse Magnitudes in Babylonian Astronomy," *Centaurus* 32 (1989), 1–52.

Table 1. Three Sample Saros Series

Cycle	Date	Magnitude	Δ Magnitude	Local Time	Δ Local Time
1	−746 Feb 6	0.92		2.37	
2	−728 Feb 17	0.86	−0.06	9.80	7.43
3	−710 Feb 27	0.77	−0.09	17.13	7.33
4	−692 Mar 10	0.67	−0.10	0.33	7.20
5	−674 Mar 21	0.56	−0.11	7.43	7.10
6	−656 Mar 31	0.44	−0.11	14.44	7.01
1	−536 Oct 17	1.50		5.70	
2	−518 Oct 28	1.48	−0.02	13.82	8.12
3	−500 Nov 7	1.47	−0.01	22.03	8.21
4	−482 Nov 19	1.47	−0.00	6.29	8.26
5	−464 Nov 29	1.46	−0.01	14.55	8.26
6	−446 Dec 11	1.46	−0.00	22.80	8.25
1	−218 Sep 12	0.78		10.56	
2	−200 Sep 22	0.73	−0.05	18.35	7.79
3	−182 Oct 4	0.69	−0.04	2.31	7.96
4	−164 Oct 14	0.66	−0.03	10.40	8.09
5	−146 Oct 25	0.64	−0.02	18.62	8.22
6	−128 Nov 5	0.62	−0.02	2.90	8.28