Review essay

Lis Brack-Bernsen, *Zur Entstehung der babylonischen Mondtheorie. Beobachtung und theoretische Berechnung von Mondphasen.* Boethius, Bd. 40. Franz Steiner Verlag, Stuttgart, 1997.

The present monograph presents a generous installment of Lis Brack-Bernsen's ongoing investigations of Babylonian lunar theory, and especially the role in that theory of a set of measured time intervals known as the "Lunar Six." These include the time interval between moonrise and sunrise on the morning of the moon's last visibility, the interval between sunset and moonset on the evening of the new moon, and the four intervals between the sun's and the moon's crossing of the horizon on the mornings and evenings preceding and following full moon (the "Lunar Four").

The Lunar Six (expressed in "time-degrees" such that one day=360°) were of profound interest to the Babylonians. Already in the early first millennium B.C. simple arithmetical patterns describing the variation in the duration of lunar visibility were incorporated in the astronomical Tablet 14 of the omen compilation *Enūma Anu Enlil*, and measurements of them were recorded monthly at Babylon in the Diary texts beginning in the seventh century if not earlier. The majority of the syzygy tables that were produced by the mathematical astronomy of the last three centuries B.C. at Babylon and Uruk were directed towards the prediction of the Lunar Six. The System A and System B models that achieved this end were made possible by a decomposition of the time intervals into many periodic components exhibiting no less than four distinct periodicities, one of the most remarkable accomplishments of ancient science.

Brack-Bernsen's historical method is guided by her conviction that the Babylonian astronomers were fundamentally empirical rather than analytical, and that the meanings and derivations of the elements in their numerical models should be sought in simple, easily noticed observational facts. In place of the emphasis on the mathematical structures and properties of the models that has characterized much work on Babylonian mathematical astronomy (especially since Neugebauer's *Astronomical Cuneiform Texts*), Brack-Bernsen confronts the Babylonian models and predictive methods with the phenomena, both ancient records of observation and simulated "observational data" derived from modern theory. The yield is a series of excellent insights into the significance of the Lunar Six, especially in the socalled "nonmathematical" texts that were produced during the period preceding and concurrent with the System A and B tablets.

The most valuable of Brack-Bernsen's discoveries have to do with the Lunar Four, i.e. the measured times (i) from moonset to sunrise on the morning before opposition, called ŠÚ; (ii) from moonrise to sunset on the evening before opposition, called ME; (iii) from sunrise to moonset on the morning after opposition, called NA; and (iv) from sunset to moonrise on the evening after opposition, called GE. Each of these quantities exhibits an irregular and rapid

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fluctuation from syzygy to syzygy. Brack-Bernsen shows, however, that the sums of the pairs ŠÚ+NA and ME+GE follow comparatively regular sinusoidal patterns with the periodicity of the lunar anomaly, but also influenced in amplitude by an annual component. The latter effect turns out, however, to be opposite for the two pairs, so that it is largely cancelled out in the sun~ ŠÚ+NA+ME+GE, which can therefore be used as an index of lunar anomaly.

The Babylonians knew at least some of these facts, as Brack-Bernsen demonstrates, and they applied them to prediction of phenomena. Her first stratum of evidence lies in the "Goal Year Texts," one of the recurring formats of non-mathematical astronomical tablets. It has long been known that the Goal Year Texts present records of phenomena from past years selected with a view to predicting the corresponding phenomena for a particular "Goal Year". About half this information consists of planetary phenomena (mostly visibility dates and passages close to fixed stars) belonging to years preceding the Goal Year by standard recurrence periods specific to each planet, ranging from 8 years for Venus to 83 for Jupiter. The other half contains data pertaining to the moon and eclipses, following a structure that has up to now been less well understood than the sections for the planets. In particular, no satisfactory hypothesis had been put forward for why the Goal Year Texts give Lunar Six values (partly observed, partly predicted) for all months of the year 18 years before the Goal Year, but also the pair sums ŠÚ+NA and ME+GE for just the last six months of the year 19 years before the Goal Year.

Brack-Bernsen derives on theoretical grounds a set of simple and elegant relationships that make it possible to predict the amount of change in each of the Lunar Four after 18 years from the pair sums of the full moon at the beginning of the interval; and, more surprisingly, also the change after 18 years in the lunar visibility times at last and first visibility by using the pair sums of the full moon five and a half months before the beginning of the interval. This would explain the pair sums in the Goal Year Texts. Splendid confirmation of these principles comes out of the analysis of passages in TU 11, a difficult composite tablet containing both astronomical and astrological material that BrackBernsen has been studying in collaboration with H. Hunger. (Only a small section of the astronomical text in TU 11 had previously been explained by Neugebauer.) This part of Brack-Bernsen's book constitutes a great advance in our understanding of the development of the earliest mathematical lunar theory.

It is also Brack-Bernsen's contention that the Babylonians worked not only with the pair sums of the Lunar Four, but also with the sum ŠÚ+NA+ME+GE, and that the column called Phi in the System A syzygy tables is a representation of this sum. Column Phi, which has a prominent position in the tables to the immediate right of the first calendrical column, regulates all elements of the calculation that vary with lunar anomaly. Phi is a linear zigzag function, oscillating precisely in phase with the moon's apparent velocity about a mean value of 127 units. The function's period is therefore that of the moon's apparent velocity "sampled" at syzygy, approximately 14 months. For the purposes of computing the syzygy tables, Phi is ostensibly nothing more than an index of the current stage in the moon's anomalistic cycle. Column G (one of the two periodic components of the duration of the preceding synodic month) is determined from the current value and trend of Phi by interpolating in an auxiliary table. Any zigzag or sawtooth function with the same period would have served just as well. What Phi actually means in astronomical terms was a matter of speculation as late as the publication of *Astronomical Cuneiform Texts* (1955).

Neugebauer's paper (Neugebauer [1957]) on the so-called "Saros Text" (a cryptic procedure text concerning the System A lunar theory) initiated a line of investigations out of which arose the now widely accepted interpretation of Phi as a measure of the duration of the "Saros" interval beginning with the current syzygy and ending with the syzygy 223 synodic months later. Brack-Bernsen raises objections to this interpretation (we will come to these presently), and offers her conjecture that Phi was derived from the sum of the Lunar Four as a more plausible alternative. Hence except for Neugebauer's original paper the studies of Phi that built on the evidence of the Saros Text are here given only glancing references.

It needs to be stressed that what is at issue cannot be the astronomical meaning of Phi within the workings of the System A lunar theory. This was established cogently, though in several steps. In his 1957 paper, Neugebauer was led by the Saros Text to the realization that, subject to certain restrictions, the line-to-line change in the value of Phi is exactly the change in the value of G over 223 lines, i.e. one Saros. Hence also the units of Phi are the same as those of G, i.e. time degrees, and Phi's value is always close to one third of a day. Then van der Waerden ([1966] 152–153) showed that this relation implied that Phi theoretically maintains a constant difference with the sum of 223 consecutive values of G. This means that some constant time interval plus Phi represents the duration of the Saros insofar as a constant plus G represents the duration of the synodic month, i.e. disregarding the influence of the sun's anomaly. Because the length of 223 synodic months is approximately 6585 1/3 days, van der Waerden conjectured that the constant in question was a whole number of days, namely 6585, just as G is sunnosed to be added to 29 whole days. Van der Waerden further remarked that the restrictions on the relation between the line-to-line differences of Phi and the Saros-interval differences of G would be effectively eliminated if all values of Phi above and below certain constant limits were replaced by those limiting values, producing a "truncated" version of Phi. Soon afterwards, Aaboe ([1968] and Aaboe-Sachs [1969]) discovered just such a truncated version of Phi in a few texts that came to light after the completion of *Astronomical Cuneiform Texts*. The upper limiting value turned out to be a number that is used in procedure texts as a nickname for Column Phi itself, even in its more familiar untruncated form. This very pleasing confirmation of van der Waerden's *a priori* deduction of the truncated Phi also lends great weight to the hypothesis that Phi (in this form) measures the Saros.

For Brack-Bernsen, however, several facts stand in the way of accepting that Phi originally and fundamentally had this astronomical meaning. (1) The maxima of actual, observed Saros intervals occur at annual intervals, not at the 14-month intervals exhibited by Phi. (2) The postulated function S required to correct Phi for the solar component has never been found in any Babylonian text. (3) In the so-called "Text S," a canon of solar eclipse possibilities covering part of the first half of the fifth century B.C., Phi appears together with a solar model that is more primitive than the model used in System A. Yet the hypothetical function S depends on that model. (4) On the contrary, the sum of the Lunar Four for a series of full moons is a quantity that the Babylonians are likely to have investigated. It is a function with identical periodicity and phase, and similar amplitude, to Phi.

These are valid observations. Point (1) tells us that the original derivation of Phi was not direct measurement of the Saros; there must have been some other line of reasoning that filtered out the fluctuations due to the solar component. (2) is an argument from silence, and perhaps not a weighty one, since almost all the extant texts that involve Phi use it only as an index of lunar anomaly, so that there is no call for S.

Point (3) presents a thorny problem. If Phi has a high mean value so that it can be corrected by a never-positive S, how could it have existed before the solar theory on which S depended? Britton [1987] has tried to resolve the dilemma by finding a series of operations that lead to the parameters of Phi independently of a solar theory (see also Britton [1990]). He suggests that the Babylonians discovered the effect of the lunar anomaly on the length of the synodic month from observed durations of the 235-month "Metonic" period, which is almost exactly 19 years and therefore practically eliminates the solar component. Phi would then have been obtained by consideration of a 235-month interval divided into two parts of 12 and 223 months. Brack-Bernsen believes that this derivation – which in its details is indeed very complicated – was probably beyond the resources of the Babylonians. Brack-Bernsen's derivation of Phi from the Lunar Four itself runs into a difficulty here, because, as she concedes, it so far fails to explain why Phi is always about 100° larger than the sum of the Lunar Four.

Whether or not Brack-Bernsen's continuing research eventually vindicates her original interpretation of Phi, it has already amply proved fruitful by motivating the remarkable investigations of the Lunar Six and composite periodic phenomena presented in this book. The argument throughout is presented with a clarity and simplicity of expression reminiscent of van der Waerden.

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