ANCIENT AND MODERN UTILIZATION OF THE LUNAR DATA RECORDED ON THE BABYLONIAN GOAL-YEAR TABLETS

Mutual control of Moshier's Ephemerides program and lunar data from Goal-Year Tablets[1]

Lis Brack-Bernsen
Lehrstuhl für Wissenschaftgeschichte
Universität Regensburg
D-93040 Regensburg

Abstract

The talk demonstrated the interplay between ancient lunar data and a modern computer code. The starting point of the investigations was the discovery that the length of the anomalistic month can be derived from horizontal observations: The sum of the so called Lunar Four, observed by the Babylonians each month around opposition, varies concurrently with the lunar velocity. This was demonstrated by means of Lunar Four data calculated on a modern computer. It was also shown how the sum can be utilized to construct the Babylonian column Φ [*Brack-Bernsen 1990*].

There is textual evidence that the Babylonians did add the Lunar Four. But the question remained if their data were accurate enough for the construction of Φ. Lunar Four data collected on Goal-Year Tablets were added and their sums were checked against the values calculated by Moshier's computer code. The Babylonian Lunar Data were found to be sufficiently accurate [*Brack-Bernsen 1994*]. Next a systematic analysis of calculated lunar data leads to a conjecture how to use the Goal-Year tablets for predicting lunar phases [*Brack-Bernsen 1997*].

Finally the single Lunar Four were used for checking Moshier's program against Babylonian data. This part of the talk presented the newest and not yet published results. Therefore the emphasis of this paper is placed on presenting the control of Moshier's ephemerides program for ancient times by means of the lunar data collected on Babylonian cuneiform tables from the time 523 B.C. to 120 B.C. The tables concerned are the 13 best preserved Goal-Year tablets (LBAT 1214, 1220, 1225, 1238, 1249, 1251 and 1252, 1263, 1265 and 1266, 1268, 1285, and 1291), the two tablets LBAT 1433 and 1431, and the tablet Cambyses 400.

Except for the Cambyses text, which has been translated by Kugler [*1917, SSB I, pp. 61–75*], all these tablets are published only in cuneiform drawings in LBAT [*Pinches, Strassmaier and Sachs, 1955*]. From this drawings I have extracted and translated the lunar data. For the times covered by the tablets and using Moshier's computer code, all the full moon data of interest for the Babylonians have been calculated. A graphic comparison between the Babylonian and the computed data exhibit an astonishing accordance. This tells us that – except for a few clearly wrong values – all the Babylonian data

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are very precise. We conclude that the computer code by Moshier also at Babylonian times calculates the time differences between risings and settings of moon and sun so exactly, that the program can become an aid for dating tablets through their lunar data.

Introduction

Regularly and for more than 700 years, the Babylonian astronomers have observed lunar and planetary phenomena and tabulated them month after month. The so-called Diaries, clay tablets with cuneiform inscriptions, contain these data. The Diaries, which have survived until our days, origin from the time 652 B.C. to 61 B.C. Surprisingly, already on the very earliest tablets some of the recorded phenomena – so the text says – were not observed. They must therefore have been predicted or calculated by the Babylonians.

The Babylonians have, indeed, developed skilled methods for predicting astronomical events by means of earlier observations. The so-called Goal-Year tablets contain observations excerpted from the Diaries: raw material for the prediction of planetary and lunar phenomena for a given year Y, named the 'goal year' by A. Sachs. [*See, e.g., Sachs' discussion of the Goal-Year tablets in JCS 2 (1948), pp. 282-285.*]

For our task, the control of computer-calculated lunar data, we need as many lunar observations from consecutive months as possible. What has remained of the Diaries is quite fragmentary and does not deliver such data. To our luck, the Babylonians themselves have collected lunar data from consecutive months on special tablets – among others, on the Goal-Year tablets.

Since the purpose of most (if not all) of these tablets consisted in collecting lunar data for prediction, we shall in Section 3 shortly explain the method for predicting moon phases by means of the Goal-Year tables.

The lunar data we are concerned with are some specific time differences observed during the days around opposition (full moon). If the opposition should happen to take place exactly at sunrise, the moon will set at this very moment[2]. If not, on the last morning before opposition, the (full) moon will set some time before sunrise, while it will set some time after sunrise on the next morning. Between these two mornings, the opposition has taken place. The Babylonians measured the time differences from moonset to sunrise before opposition and from sunrise to moonset after opposition, but also the two corresponding time differences to be observed at sunset: the time from moonrise to sunset just before opposition and, on next the day, the time from sunset to moonrise. We call these four time intervals the Lunar Four. The main purpose of this work is for each of the Lunar Four to test its recorded Babylonian value against its computer calculated value.

In Section 2, we shall elucidate the Lunar Four and mention their astronomical significance plus the significance of their partial sums.

In Section 4 we present the Babylonian lunar data we are concerned with in this paper. Section 5 compares graphically the calculated and the Babylonian lunar data. In most cases, the agreement is good, while for some tablets the discrepancy is such that the dating of the tabulated months must be questioned. The problem is solved in Section 6 where we show evidence that some of the tablets record the observed data under the labels of the following month.

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[2] We are for the moment neglecting the latitude of the moon.

This for us surprising and inconsistent way of recording observational data gives us a warning: a sensitive and careful handling of the old texts is requested – we cannot expect or assume our modern standards to be used in ancient scientific data.

The Lunar Four and their partial sums

Let us repeat the definition on the Lunar Four, using the Babylonian name for the single observables:

ŠÚ is the time from last moonset before opposition to sunrise,
NA is the time from the first sunrise after opposition to moonset,
ME is the time from last moonrise before opposition to sunset, and
GE is the time from the first sunset after opposition to moonrise.

Although spectacular and easy to observe, these time intervals are very complicated quantities from a theoretical point of view. Each of the Lunar Four depends on the velocity of the moon relative to the sun, on the latitude of the moon, on the position in the ecliptic at which the opposition takes place, and on the time of the day at which the opposition takes place.

The partial sums *ŠÚ* + *NA* and *ME* + *GE*, however, are much less complicated. By the addition of *ŠÚ* and *NA* or *ME* and *GE*, respectively, the dependence of the time of opposition has been eliminated and the dependence of the lunar latitude has been strongly reduced. The sums are by and large functions of just two variables: the lunar velocity and the position in the ecliptic at which the opposition took place. Their astronomical meaning is the following: *ŠÚ* + *NA* is the setting time of a little arc of the ecliptic, while *ME* + *GE* is its rising time. This little arc of the ecliptic is situated around the point in the ecliptic where the opposition took place, and its lengths measures the motion of the moon relatively to the sun during the day of opposition. For further details see Brack-Bernsen and Schmidt [*1994*].

As a consequence, the quantities *ŠÚ* + *NA* and *ME* + *GE* are much easier to handle than each of the Lunar Four alone. Therefore we first controlled only the sums. In Brack-Bernsen [*1994, 1997 and 1997a*], the partial sums *ŠÚ* + *NA* and *ME* + *GE* originating from the Babylonian recordings were examined against their computer-calculated values, and the accordance was convincing. Then a systematic analysis of the computer calculated Lunar Four was performed. It led to a hypothesis how the Lunar Four recorded on a Goal-Year tablet can be used to predict the expected values for the goal year. A Babylonian Text, TU 11, confirmed the hypothesis [*Brack-Bernsen, 1997*].

From the control of the sums *ŠÚ* + *NA* and *ME* + *GE*, we know that the Babylonian Lunar Four data are quite exact and that they show the right structure. Therefore they may be used to estimate how exactly the Moshier computer program calculates lunar data at the time around 500-300 B.C. Instead of controlling the sums (*ŠÚ* + *NA* and *ME* + *GE*), the single Lunar Four, which are strongly dependent on the precise time of the opposition, shall now be compared with Babylonian values.

The Goal-Year tablets

The structure of all the Goal-Year tablets is the same. On the front side, planetary observations are recorded in a strict order, while most of the reverse side is covered with lunar data, always written in a schematic and similar way. After the lunar section, a colophon-title usually follows. The title states the contents of the table and its purpose, and typically reads (in Sachs' translation): "*the first day, appearances, passings, and eclipses which have been established for the year Y*", where *Y* is the goal year. The tablet is covered with observations of appearances, passings, first days of visibility, etc., from different specific years prior to year *Y*.

For each of the five known planets, the characteristic phenomena, observed in a year that precedes the actual goal year *Y* by a number of years specific for each planet, are recorded in different sections. Obviously, the Babylonians were aware that a planet returned to the same characteristic appearances after the lapse of a certain period of time; and obviously they used this knowledge for making predictions.

A concrete example may elucidate how this works in practice. In the first paragraph of the Jupiter section, the Greek-letter phenomena (i.e. the characteristic phases) observed throughout the year *Y*-71 are recorded. The text utilizes the fact that after 71 years, namely in the year *Y*, these phenomena will repeat themselves at the same date within the lunar month. However, a specific Jupiter phase will take place at the same position on the sky only after 83 years. Therefore, Jupiter's conjunctions with normal stars occurring during the year *Y*-83 are collected in a second paragraph.

All this is well known, as well as the type of data which were put together in the lunar section: lunar and solar eclipses occurring one Saros (= 223 synodic months ≅ 18 years) earlier than the goal year *Y*; the Lunar Six, month by month, during this whole year *Y*-18; and their partial sums *ŠÚ* + *NA* and *ME* + *GE* for the last six months of year *Y*-19. We know that lunar eclipses repeat themselves after one Saros; hence we understand how the Babylonians could utilize the recorded eclipse data.

Only recently it has been discovered and understood how the Lunar Six data were used for predictions. For a detailed analysis and explanation, see Brack-Bernsen [*1994, 1997 or 1997a*]. Let us here just demonstrate the Babylonian method by an example. We are concerned with the month *L* of year *Y*. The expected value of *ŠÚ* in this month was calculated from the values of *ŠÚ* and *NA* observed one Saros (=223 months) earlier: it was put equal to *ŠÚ* plus a third of the sum *ŠÚ* + *NA* of *ŠÚ* and *NA* measured in month (*L*-223). We remind the reader that the values of *ŠÚ* and *NA* found in month (*L*-223) were recorded on the Goal-Year tablet for the year *Y*. Calling the values of *ŠÚ*, *NA*, and *ŠÚ* + *NA* established for month *L* $\check{S}\acute{U}_L$, NA_L, and $(\check{S}\acute{U} + NA)_L$, respectively, we can express the method in the following way:

$$\check{S}\acute{U}_L = \check{S}\acute{U}_{L\text{-}223} + 1/3(\check{S}\acute{U} + NA)_{L\text{-}223}.$$

Similarly, the value of *NA* expected in month *L* was calculated as the *NA* measured one Saros earlier minus a third of the the sum *ŠÚ* + *NA*:

$$NA_L = NA_{L\text{-}223} - 1/3(\check{S}\acute{U} + NA)_{L\text{-}223}.$$

Of course, analogously and for all months of year *Y*, the quantities *ME* and *GE* can be found for by means of their values established for year *Y*-18 and recorded on the Goal-Year tablet for the year *Y*. That the Babylonians, indeed, knew and used this method is proved by a short passage of the text TU 11.

The Lunar Data

The lunar data we are concerned with are the Lunar Four values collected on the following tablets: the 13 best preserved Goal-Year tablets[3] (LBAT 1214, 1220, 1225, 1238, 1249, 1251 and 1252, 1263, 1265 and 1266, 1268, 1285, and 1291), the two tablets LBAT 1433 and 1431, and the tablet Cambyses 400.

Figure 1 gives an overview of the time span covered by the Goal-Year tablets. At the top of this figure, starting at lunation 0, the calculated values of *ŠÚ* + *NA* for 1650 consecutive full moons are printed as function of the lunation number *L*. Below *ME* + + *GE* is pictured in the same way. The spots below the curves mark the times from which the lunar data on the Goal-Year tablets origin.

Except for the Cambyses text (and the mentioning of some dates from Goal-Year tables in SSB by Kugler), all the tablets are published only in cuneiform transcription by Sachs [*Pinches, Strassmaier and Sachs, 1955*]. From these transcriptions the Lunar Data have been extracted and translated. These data shall be presented in the Figures 2 – 17 given below.

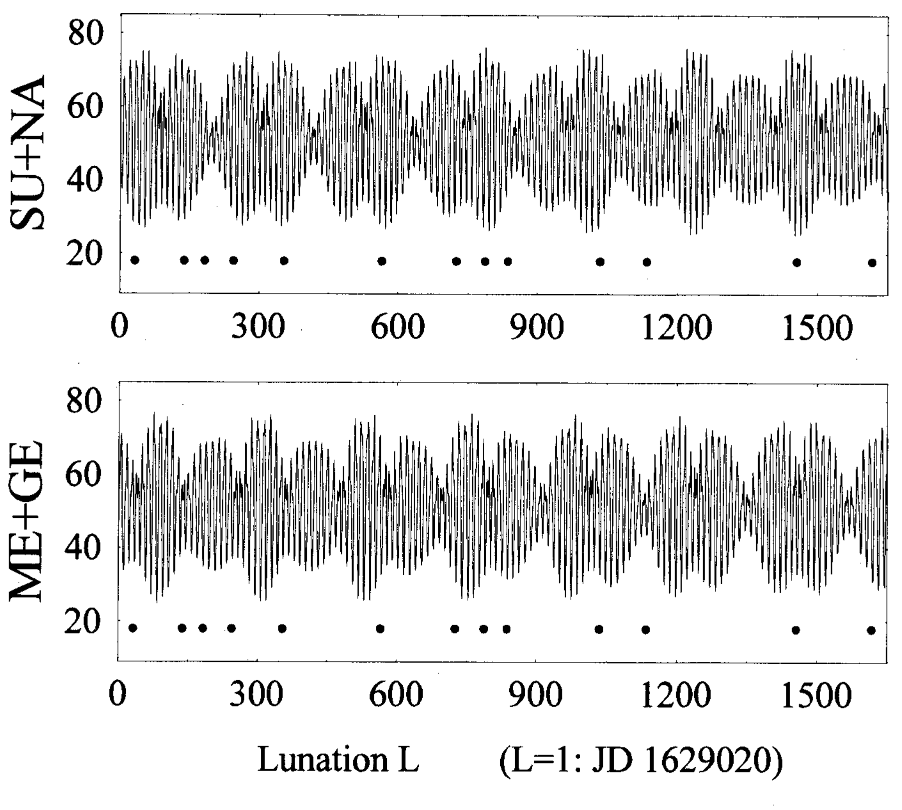

Figure 1. The calculated curves ŠÚ + NA and ME + GE reproduced for the interval of time 253 B.C. – 120 B.C. from which all the Lunar Four data on the Goal-Year tablets origin. The points below the curves indicate the time of the individual Goal-Year tablets.

[3] The tablets LBAT 1251 and 1252 represent the same year, and their data confirm and supplement each other, and so do also the tablets LBAT 1265 and 1266. From now on, only the number of the first of the pairs shall be mentioned, representing them both.

The lunation numbers

We want to perform a mutual control of computed and Babylonian lunar data. We start with the opposition of Dec. 8, 254 B.C., which we shall call lunation L=0. For all the following oppositions 1, 2, 3, ..., L, ... during the whole period covered by the Goal-Year tablets, the values of the Lunar Four have been calculated by the ephemerides computer code of Moshier [*1996*]. The calculated Lunar Four are given as functions of the number L of the opposition for which they are calculated. We call this number the 'lunation number'.

For all the lunar data recorded on LBAT 1433 and on the Goal-Year tablets, the corresponding lunation numbers have been determined. The Lunar-Four data extracted from these tablets are in Figures 3 – 15 printed as a function of the lunation number.

The tablets Cambyses 400 and LBAT 1431 origin from times earlier than the Goal--Year tablets. (According to the above counting, the Cambyses text starts at lunation –3335 while LBAT 1431 starts at lunation –859.)

Therefore, in another computer run, starting at lunation L_{old} = 0 on the opposition of Aug. 14, 759 B.C., all Lunar Four up to the time of the Goal-Year tablets have been calculated.

The months recorded on Cambyses 400 and on LBAT 1431 are numbered according to these 'old' lunation numbers L_{old}. As function of these lunation numbers, the Lunar Four excerpted from the two tablets are plotted in the Figures 2, 16 and 17.

In all figures, the Lunar Four are given in minutes. On the Babylonian tablets, they are recorded in time degrees *uš* (1 *uš* = 4 minutes).

Comparison between Babylonian and computed data

In this chapter we will compare the calculated Lunar Four against the recorded Babylonian values. This is done graphically in Figures 2 – 13, all constructed according to the same design. At the top of the figures from left to right, the calculated values of

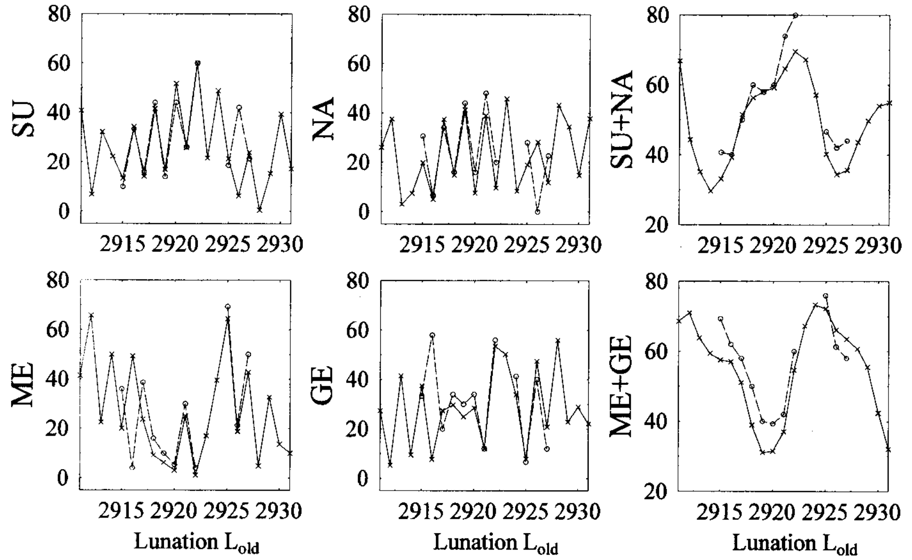

Figure 2. Comparison of the calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the tablet ***Cambyses 400*** *(circles, for consecutive months connected by dashed lines). The months from this tablet are numbered according to the "old" lunation numbers L_{old}.*

ŠÚ, *NA* and *ŠÚ* + *NA* are shown by crosses, connected by straight lines, as functions of the lunation number *L*. The Babylonian values are marked by circles, and consecutive points are connected by dashed lines. In the same way, at the bottom of the figures from left to right, the calculated and Babylonian values of *ME*, *GE* and *ME* + *GE* are depicted as functions of the lunation number *L*.

Comments on the figures

We know already that the calculated sums *ŠÚ* + *NA* and *ME* + *GE* approximate the Babylonian values quite well, and that they show the same structure. This tell us that, at least, Moshier's program calculates correctly the relative velocity of the moon and the position of the opposition; but also that the Babylonian values must be quite accurate. Looking now at the single Lunar Four for the tablets Cambyses 400, LBAT 1214, 1249, 1251, 1263, 1265, 1268, 1285, 1291, and 1431, the agreement we find is astonishing. A few Babylonian values are clearly wrongly printed on the tablet or misread. (For example from LBAT 1268, the *GE* of lunation 1159 cannot be 80 Minutes = 20 *uš*. Indeed, if the wedge for 10 in cuneiform is printed too deeply, it can easily be mistaken for two wedges, namely 20.) Another discrepancy between the computed and the Babylonian values is found several times: According to Moshier, at some full moons *ŠÚ* is about zero while *NA* is big (*NA* ≅ *ŠÚ* + *NA*); but the Babylonians tell for the same full moon that *ŠÚ* is big and *NA* nearly zero. Similarly at some moon rises, Moshier's *GE* is close to zero and *ME* is large, while according to the Babylonians, *ME* is small and *GE* is large.

The difference is not as severe as it looks. Imagine the case where the sun rises exactly at the same time as the moon sets. It is a matter of choice to say that *ŠÚ* equals zero and *NA* is to be measured one day later, or that *NA* is zero and *ŠÚ* has the value measured the day before. This discrepancy between Moshier and the Babylonians may originate from different definitions of the exact time of the sun rise or from a wrong estimation of the atmospheric refraction. In Section 7, we will go into more details about this point.

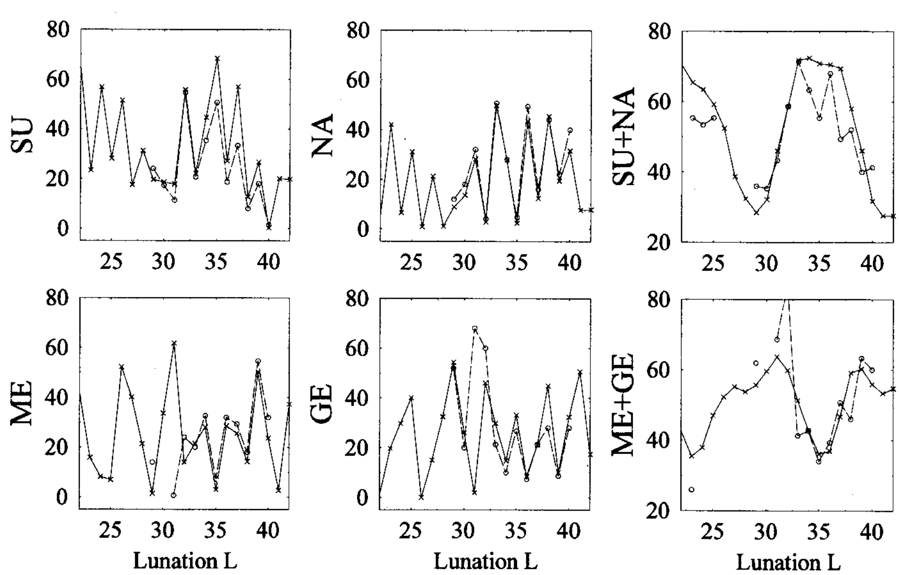

Figure 3. Comparison of the calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the Goal-Year tablet ***LBAT 1214*** *(circles, for consecutive months connected by dashed lines). The months from this and the following tablets are numbered according to the lunation numbers L.*

In case of LBAT 1225, however, the discrepancy between the two pairs of curves is so severe that one must question if the tablet has been dated correctly. As we shall see in the next section, the discrepancy can be understood and corrected. Not our dating of the tablet was wrong, but the Babylonian's way of recording lunar data is quite surprising.

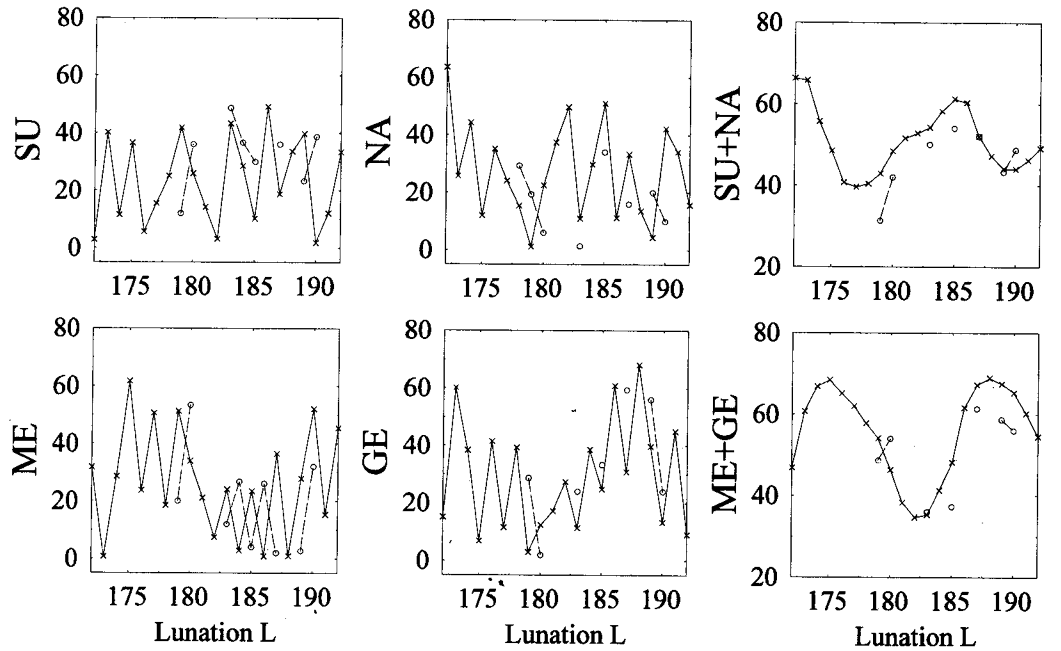

Figure 4. Comparison of calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the Goal-Year tablet ***LBAT 1220*** *(circles, for consecutive months connected by dashed lines).*

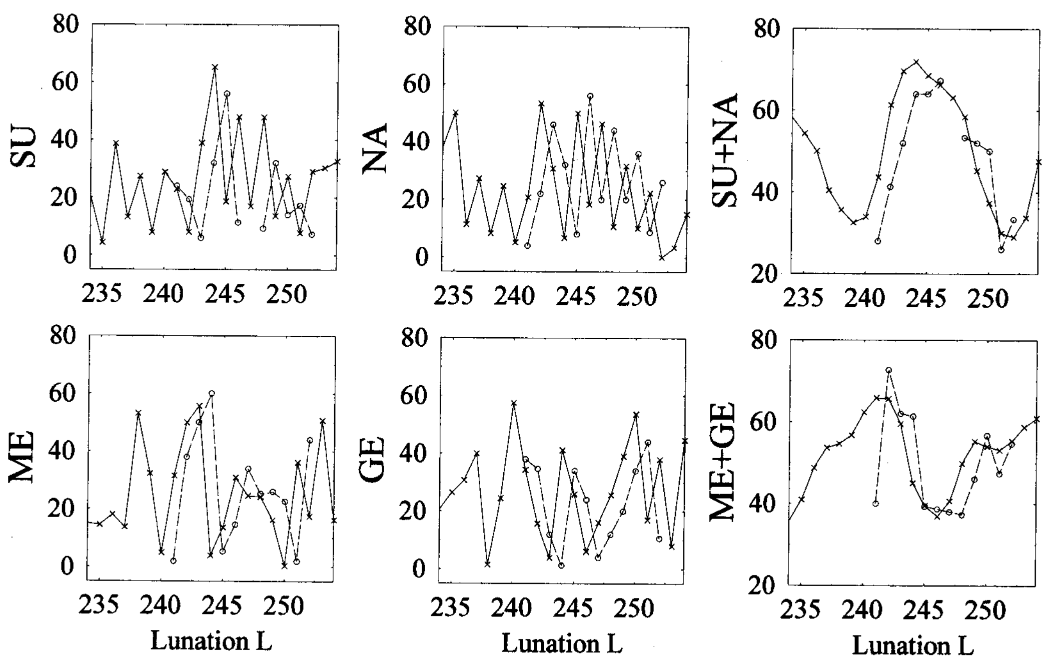

Figure 5. As Fig. 4, for the tablet ***LBAT 1225.***

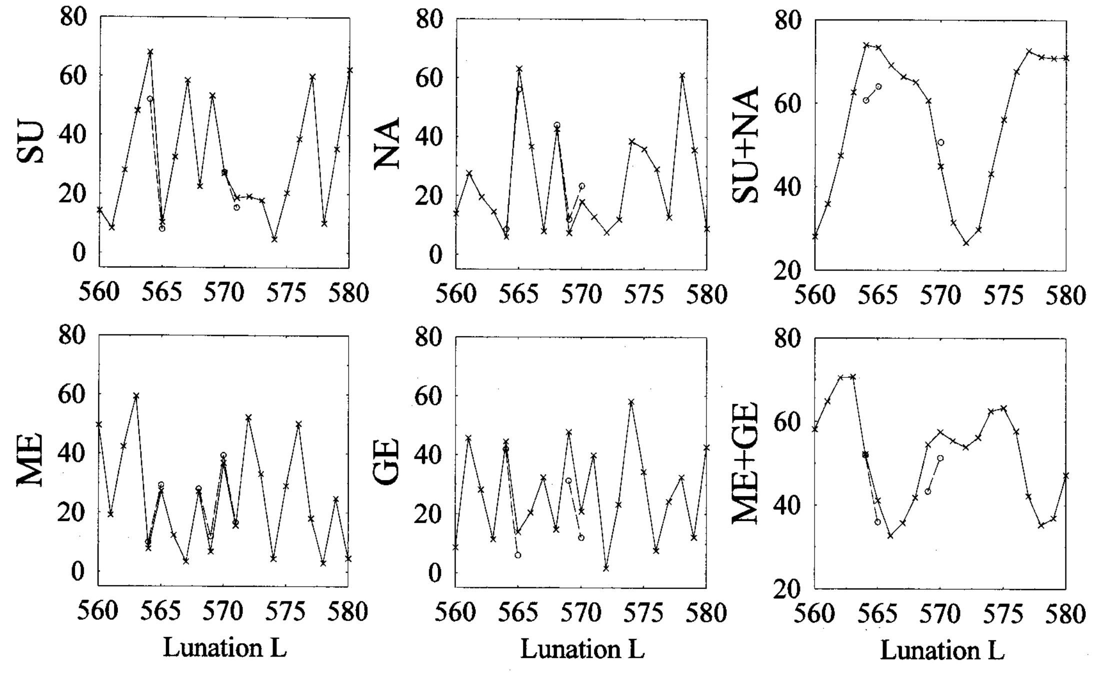

*Figure 6. Comparison of calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the Goal-Year tablet **LBAT 1238** (circles, for consecutive months connected by dashed lines).*

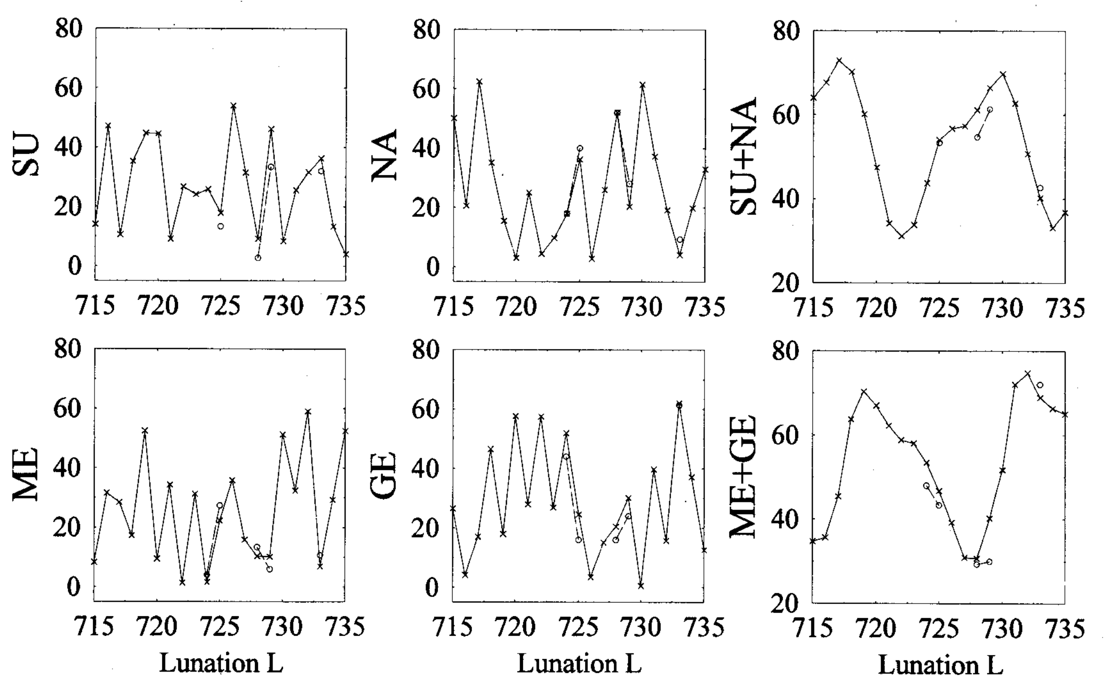

*Figure 7. As Fig. 6, for the tablet **LBAT 1249**.*

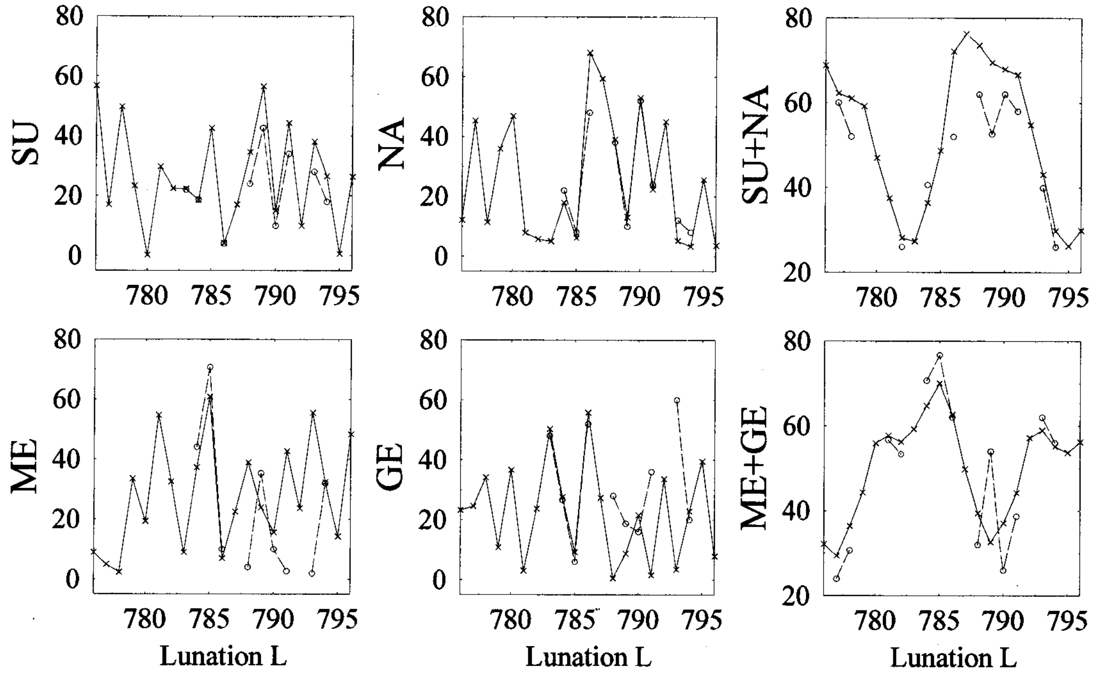

*Figure 8. Comparison of calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the Goal-Year tablet **LBAT 1251** and **1252** (circles, for consecutive months connected by dashed lines).*

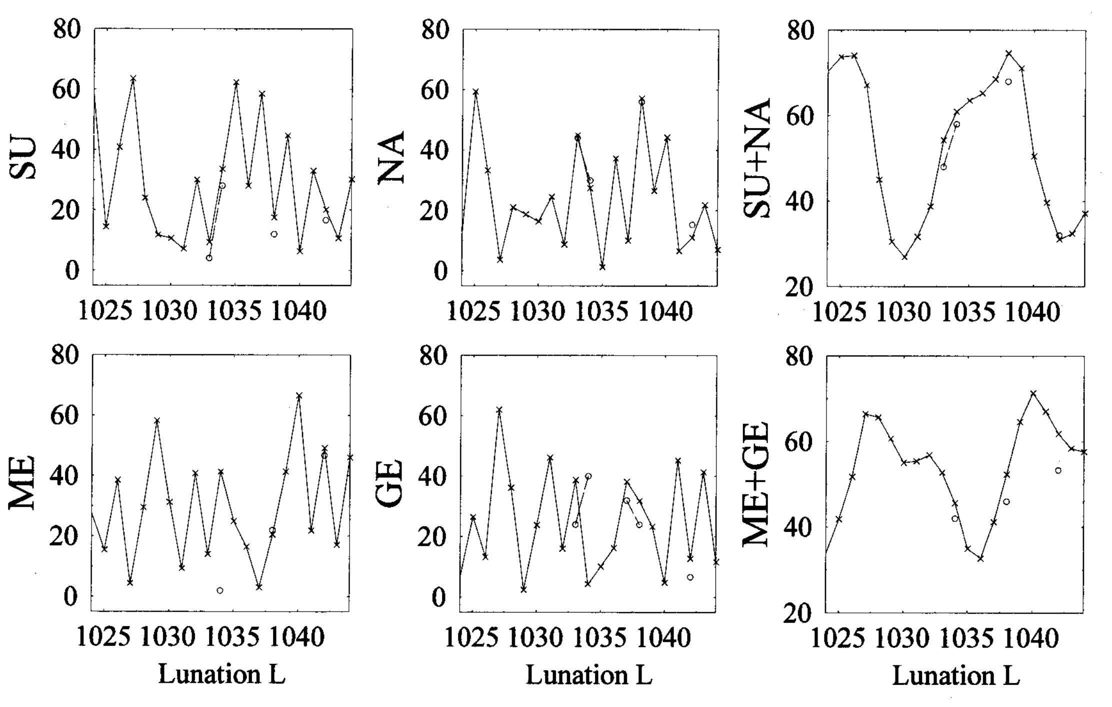

*Figure 9. As Fig. 8, for the tablet **LBAT 1263**.*

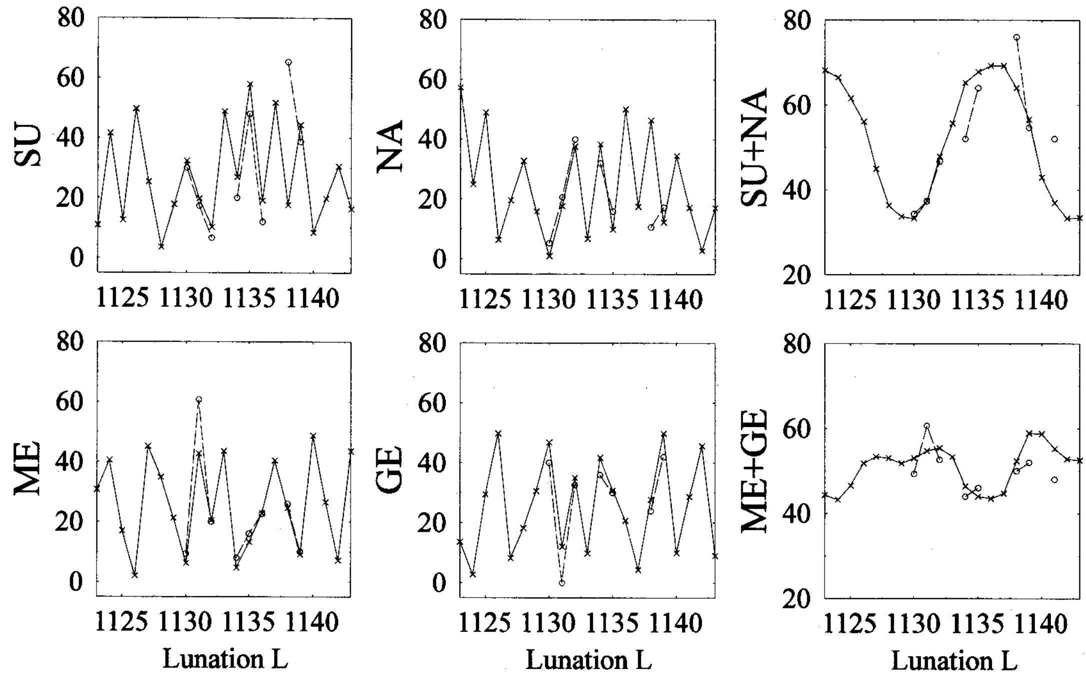

*Figure 10. Comparison of calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE with the corresponding data recorded on the Goal-Year tablet **LBAT 1265 and 1266**.*

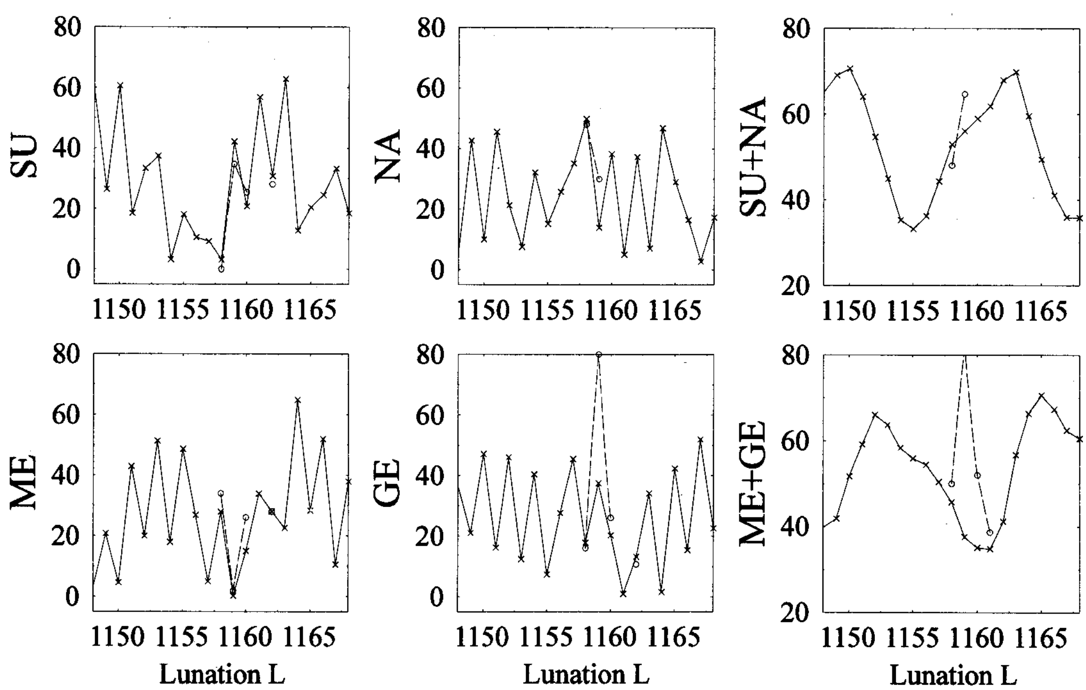

*Figure 11. As Fig. 10, for the tablet **LBAT 1268**.*

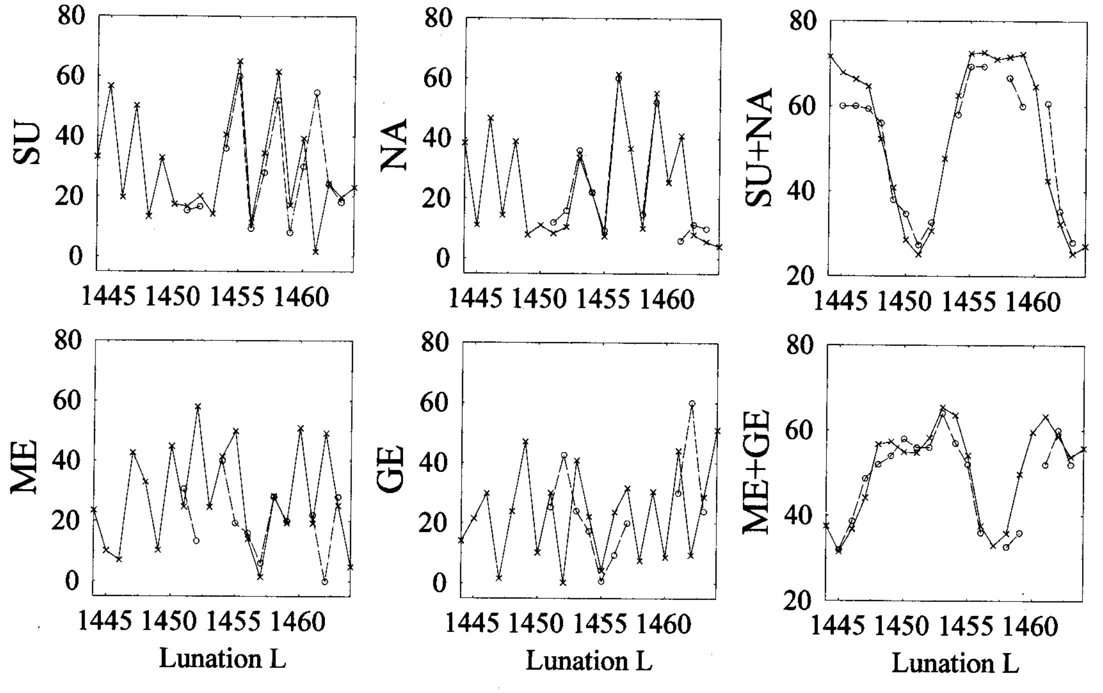

*Figure 12. Comparison of calculated lunar observables ŠÚ, NA, ŠÚ + NA, ME, GE, and ME + GE with the corresponding data recorded on the Goal-Year tablet **LBAT 1285**.*

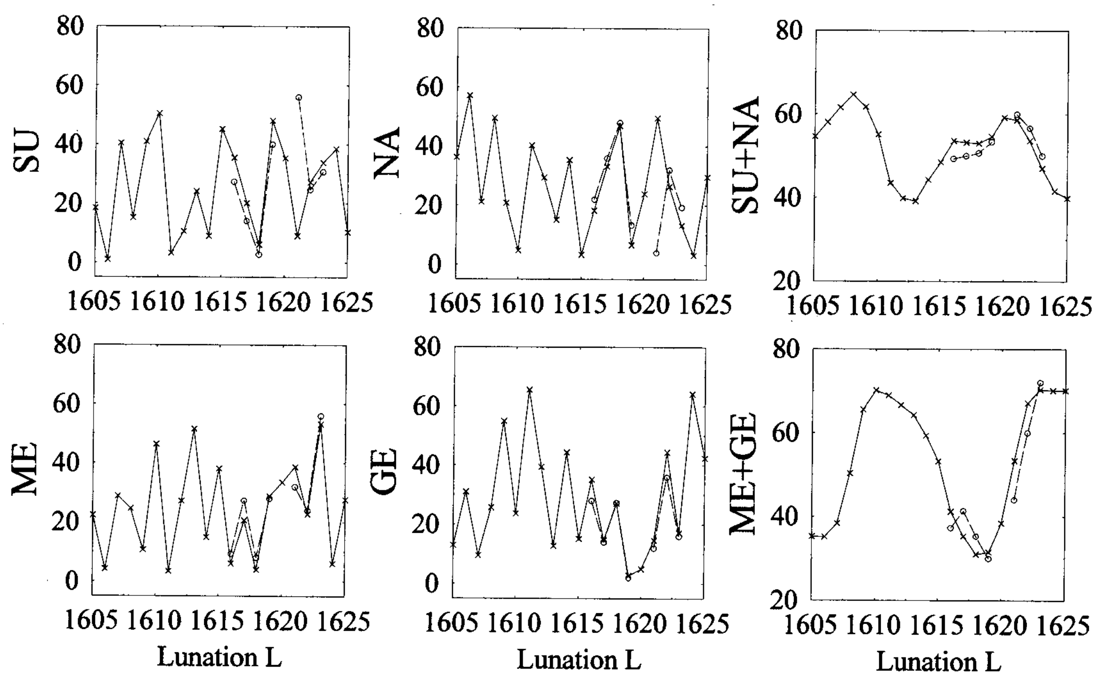

*Figure 13. As Fig. 12, for the tablet **LBAT 1291**.*

The tablets LBAT 1431 and 1433 record Lunar Six data for at least five and three consecutive years, respectively.

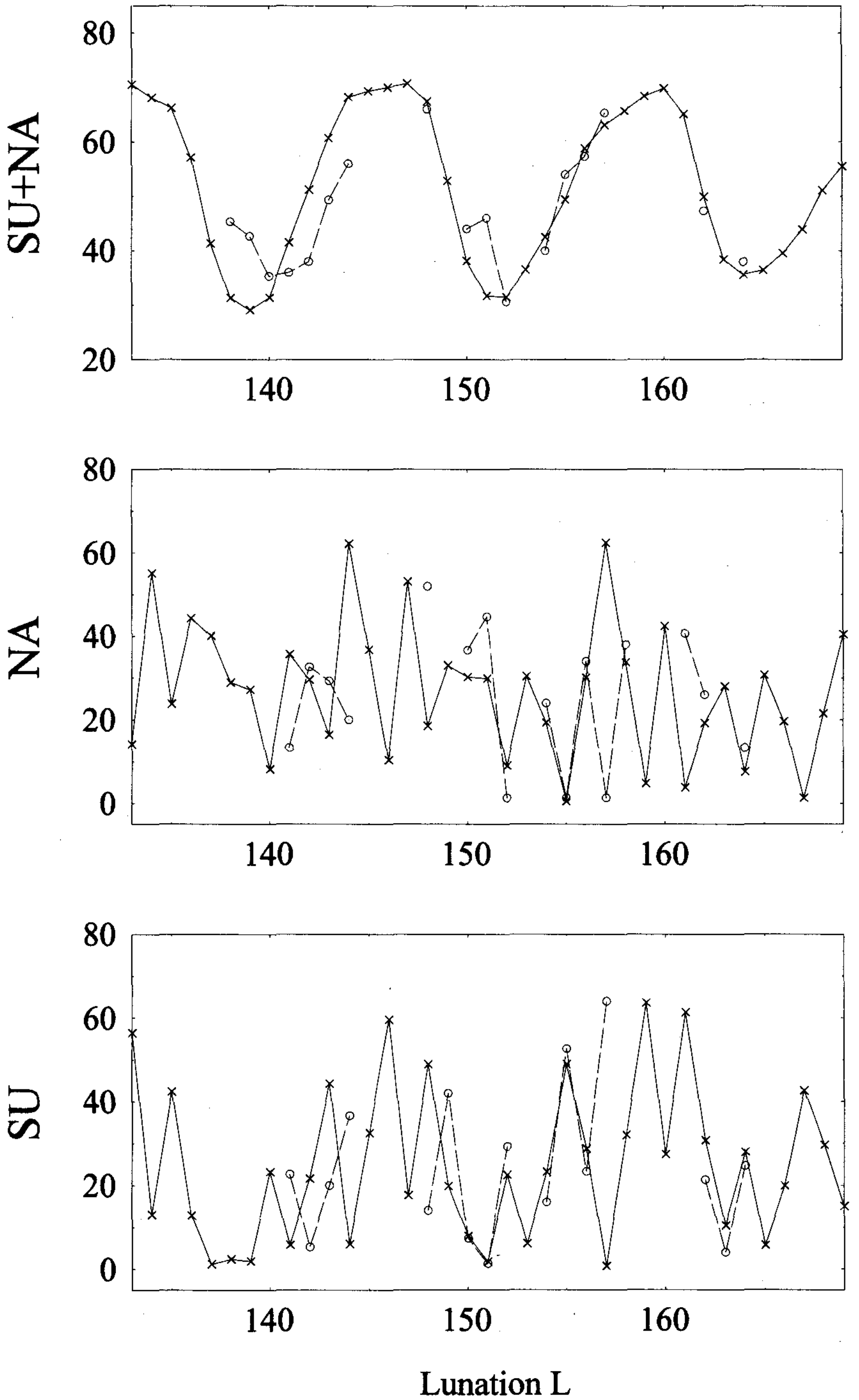

*Figure 14. Comparison of calculated lunar observables ŠÚ, NA, and ŠÚ + NA (crosses, connected by solid lines) with the corresponding data recorded on the tablet **LBAT 1433** (circles, for consecutive months connected by dashed lines). The months from this tablet are numbered according to the "normal" lunation numbers L.*

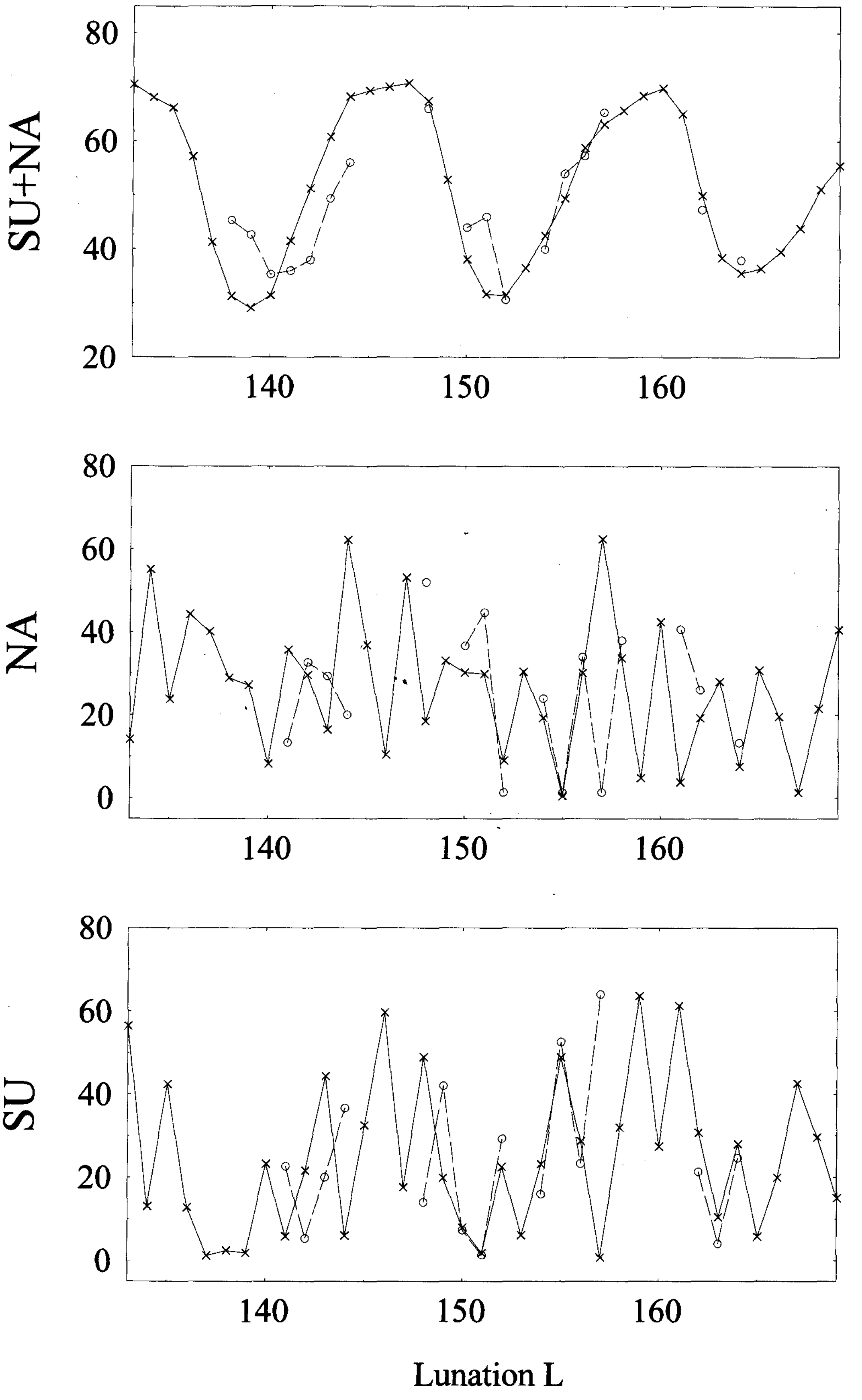

*Figure 15. Comparison of calculated lunar observables ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the tablet **LBAT 1433** (circles, for consecutive months connected by dashed lines). The months from this tablet are numbered according to the "normal" lunation numbers L.*

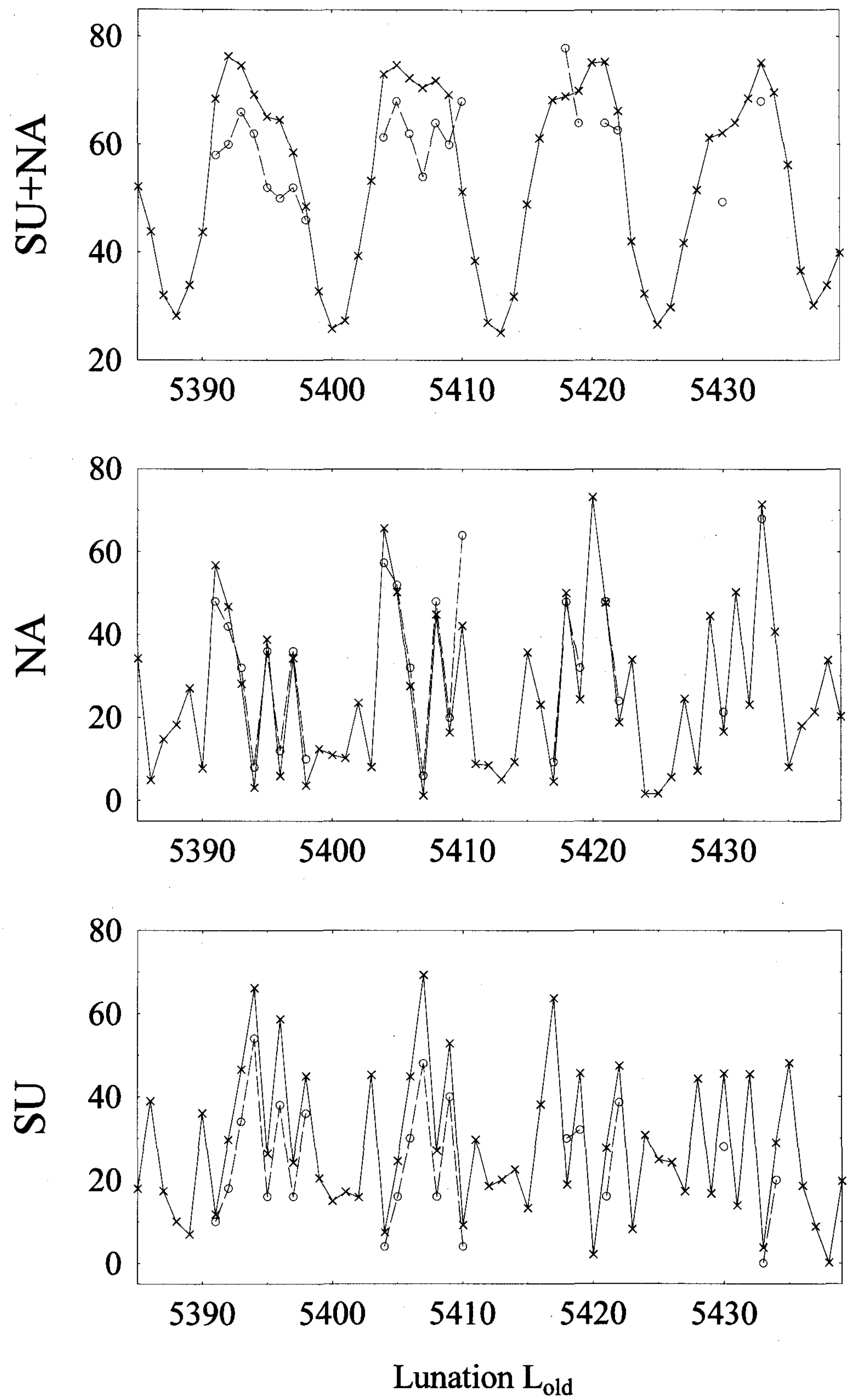

Figure 16. Comparison of calculated lunar observables ŠÚ, NA, and ŠÚ + NA (crosses, connected by solid lines) with the corresponding data recorded on the tablet ***LBAT 1431*** *(circles, for consecutive months connected by dashed lines). The months from this tablet are numbered according to the "old" lunation numbers* L_{old}.

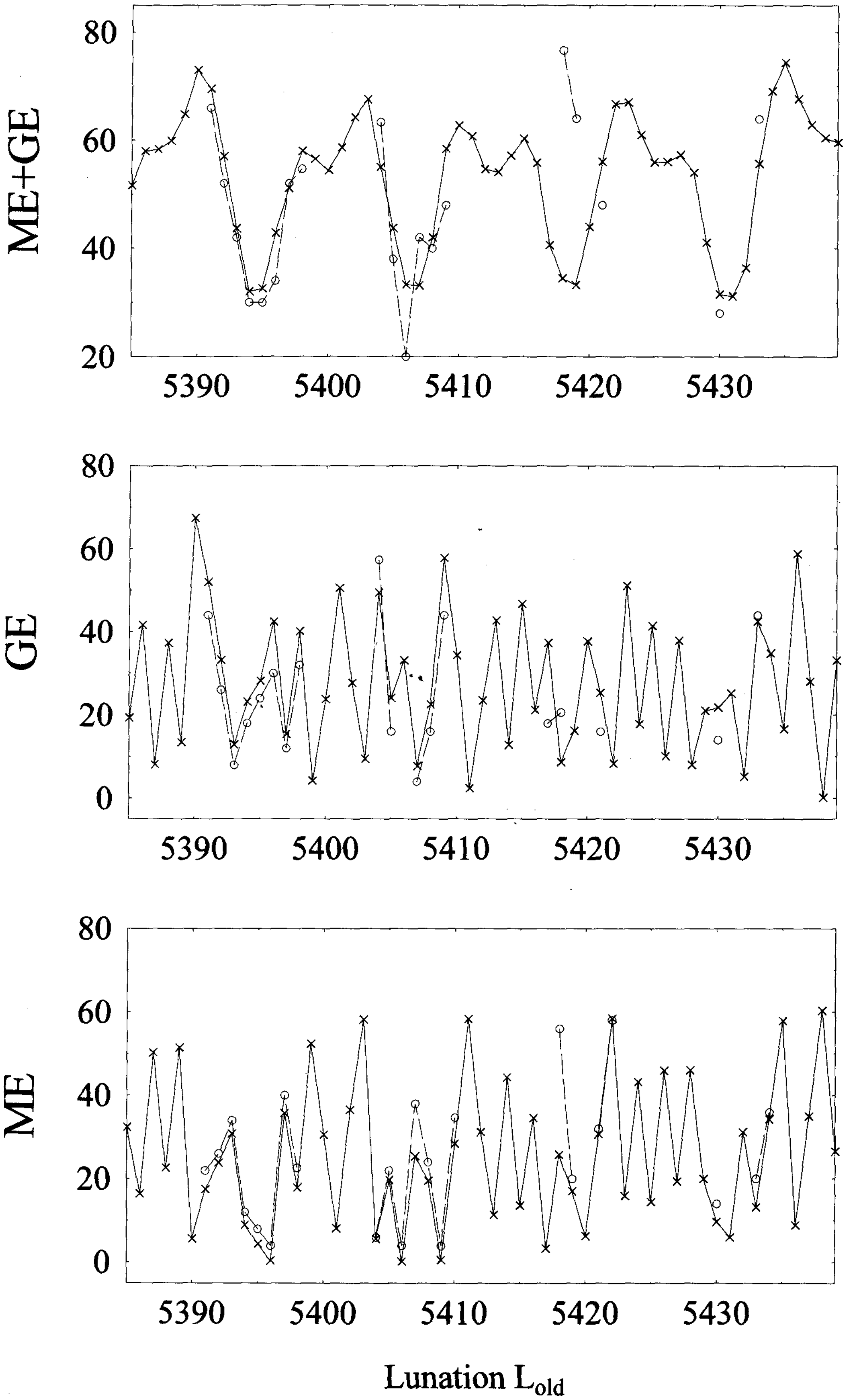

*Figure 17. Comparison of calculated lunar observables ME, GE, and ME + GE (crosses, connected by solid lines) with the corresponding data recorded on the tablet **LBAT 1431** (circles, for consecutive months connected by dashed lines). The months from this tablet are numbered according to the "old" lunation numbers L_{old}.*

Month of observation versus goal month

In this section we shall first demonstrate how the Babylonian numbers guide us to a possible solution of our problem. Then we show how clearly the comparison of Babylonian observations with computed Lunar Four values can tell if a dating of a tablet is wrong. We are concerned with the data on tablet LBAT 1225.

In Figure 5, the discrepancy between the curves representing the computed with the Babylonian values clearly indicates that something must be wrong. Of the tablet LBAT 1225, all those parts are eroded or broken away on which the relevant years had been imprinted. Following Sachs in LBAT, p. [xxv], the goal year of the tablet is year 96 of the Seleucid era (SE)[4].

We now trust Sachs' dating, accepting that the lunar dates on this tablet among others were used for predicting the Lunar Four throughout year SE 96. Therefore, the recorded Lunar Four data must origin from year SE (96-18) = SE 78. In Figure 5, the Babylonian sums *ŠÚ* + *NA* and *ME* + *GE* seem just to be displaced by one month to the right of the computed curves. However, the first readable month is clearly GU_4 = II, and month II of year SE 78 corresponds to our lunation number 241 (the full moon of June 3, 234 B.C.), and not to lunation number 240 (months II in SE 96 has namely the lunation number 463). But 240 would give a better fit.

Now, in order to predict the Lunar Four of, say, month II in the goal year 96 SE, the Babylonians applied the Lunar Four values established for the full moon 223 synodic months earlier. It turns out that this full moon took place in month I of year 78 SE, which has the lunation number 240. We surmise that the Babylonians, well knowing that data of month I were used for prediction in month II, have listed the Lunar Four from month I, year 78 SE, under the entry for month II.

In order to express ourselves more generally, let us introduce the following nomenclature:

— The 'goal month' G is the month for which the Lunar Four can be calculated from an apropriate Goal-Year tablet.
— The 'observation month' O is situated 223 months earlier; it is hence the month for which the Lunar Four shall be known (observed) and used for prediction in month G.
— The 'tablet month' is the name of the month under which the lunar data, to be used for prediction of the Lunar Four of month G, are recorded.

In most cases, observation month and goal month have the same labels. But sometimes, due to the regular intercalation[5] of a thirteenth month, observation month and goal month did not have the same labels. They were shifted against each other by one unit, as in the case of LBAT 1225 mentioned above.

We therefore propose the following hypothesis:

When goal month and observation month are shifted against one another, then the Babylonians sometimes recorded the observed lunar data not under the label of the

[4] On the reverse side of the tablet, one can decipher the Babylonian months and days for several characteristic phases of the planets. This information suffices for identifying the goal year of the tablet.

[5] Since the lunar year was about eleven days shorter than the solar year, the Babylonians regularly intercalated a thirteenth month. By so doing they achieved that the New Year's day did fall near the spring equinox.

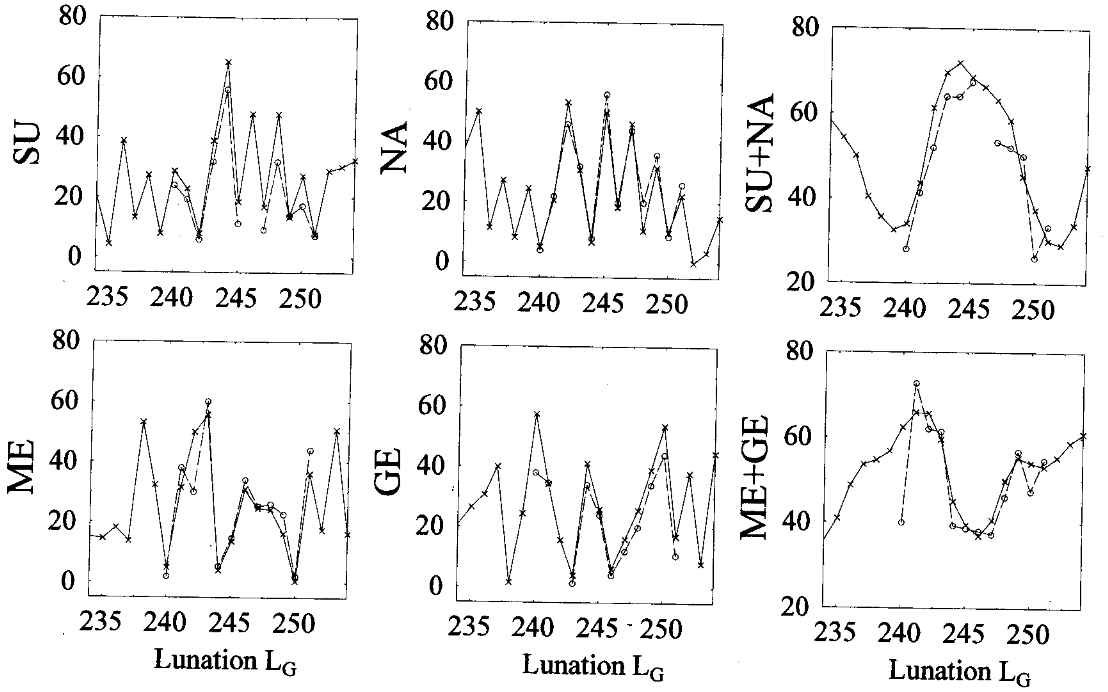

*Figure 18. Same data of tablet **LBAT 1225** as in Fig. 5, but shown versus the shifted lunation number L_G here = L - 1 (see text).*

observation month but under the goal month. Or, expressed in another way: sometimes the Babylonians chose as tablet month the goal month and not the observation month. Of course, when goal month and observation month have the same label, there is no problem and the tablet month will also have this label.

In order to test this hypothesis, we have in Figure 18 interpreted all the months recorded on the tablet LBAT 1225 not as the observation month but as the goal month. This means that we assume that the data written under month II in reality originate from month I of year 78, the data from month III originate from month II, and so on. Correspondingly, we just have to reduce each of the lunation numbers by one. After this change, we again compare in figure 18 the Babylonian and computed Lunar Four data. Now the agreement is perfect, supporting our hypothesis. As another hint, it may be mentioned that on LBAT 1225 all the lunar data are recorded for a thirteenth month labeled XII_2. However, the year SE 78 does not have such an intercalary month, whereas the year SE 96 does.[6]

We conclude: the tablet months of LBAT 1225 are the goal months and not the observation months.

Now, of course, we have to examine all tablets again and check if the goal month and observation month differ. If they differ, we must investigate if the figures might need a correction.

[6] In Parker and Dubberstein (PD) [1956], all Babylonian years and months for the period from 626 B.C. to 75 A.D. are listed together with the corresponding Julian dates. This list also indicates the years who had an extra intercalary month.

In case of the tablets LBAT 1214, 1238, 1249, 1263, 1265+66, all observation months have the same labels as the goal months. Therefore we can trust the lunation numbers in the in Figures (3, 6, 7, 9, and 10), respectively. Tablet Cambyses 400 collects lunar and planetary observations from one and the same year (Cambyses year 7). It is obviously not organized as a Goal-Year tablet. Still, even if the lunar data may have been used for prediction in a goal year of 1 Saros later, no adjustment is needed since the observation and goal months have the same labels.

For the rest of the tablets, there are discrepancies between observation and goal months. But on these tablets, the Babylonians *seem to have followed two different strategies*. For the tablets LBAT 1225, 1220, and 1433 we get a much better fit between computed and Babylonian Lunar Four if we read all the table month as the goal month and not as the observation month. This is seen from Figures 18 – 21 in which the lunation numbers have been changed correspondingly.

The fact that the Lunar Four data on LBAT 1433 ask for a correction from observation month to goal month indicates again that these data were intended to be used in Goal-Year texts. Sachs drew the same conclusion [*LBAT, p. xxxii*], guided by the fact at the beginning of this table, the sums *ŠÚ* + *NA* and *ME* + *GE* were recorded for six months.

For the tablets LBAT 1251, 1268, 1285, 1291, and 1431, there is a good agreement between computed and Babylonian values, an agreement that would be destroyed if we would shift the lunation numbers by one. Therefore it looks as if the Babylonians on these Goal-Year tables chose to list their data under the months of observation and not under the labels of the goal months.

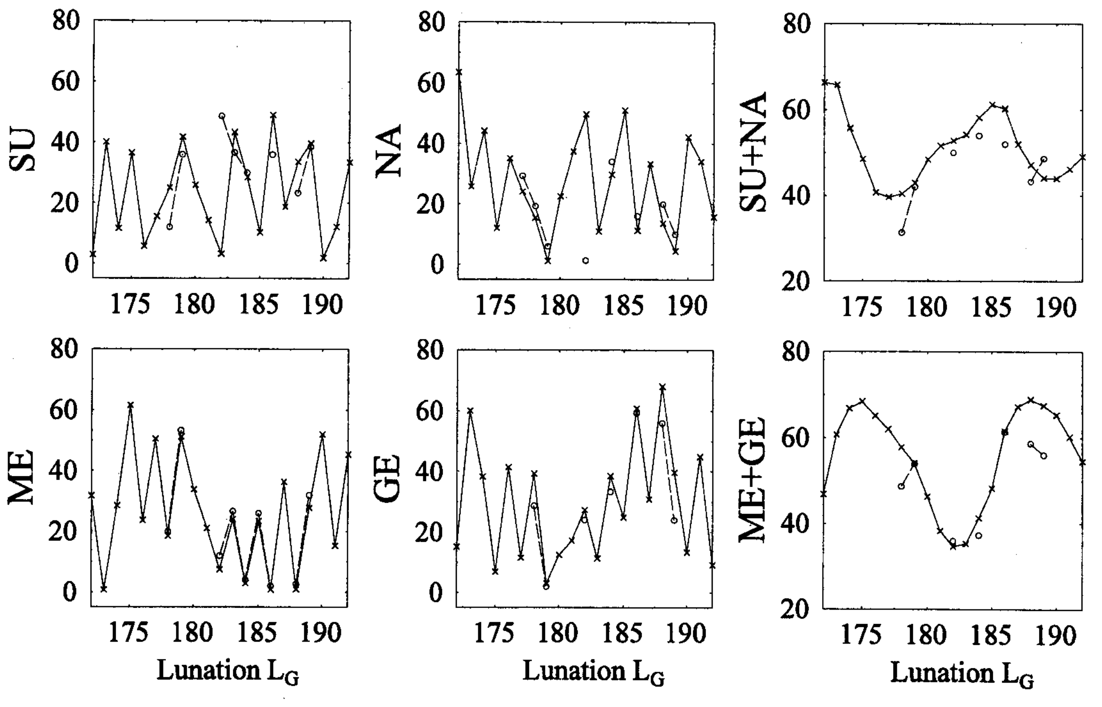

Figure 19. Same data of tablet ***LBAT 1220*** *as in Fig. 4, shown versus the shifted lunation number* $L_G = L - 1$ *(see text).*

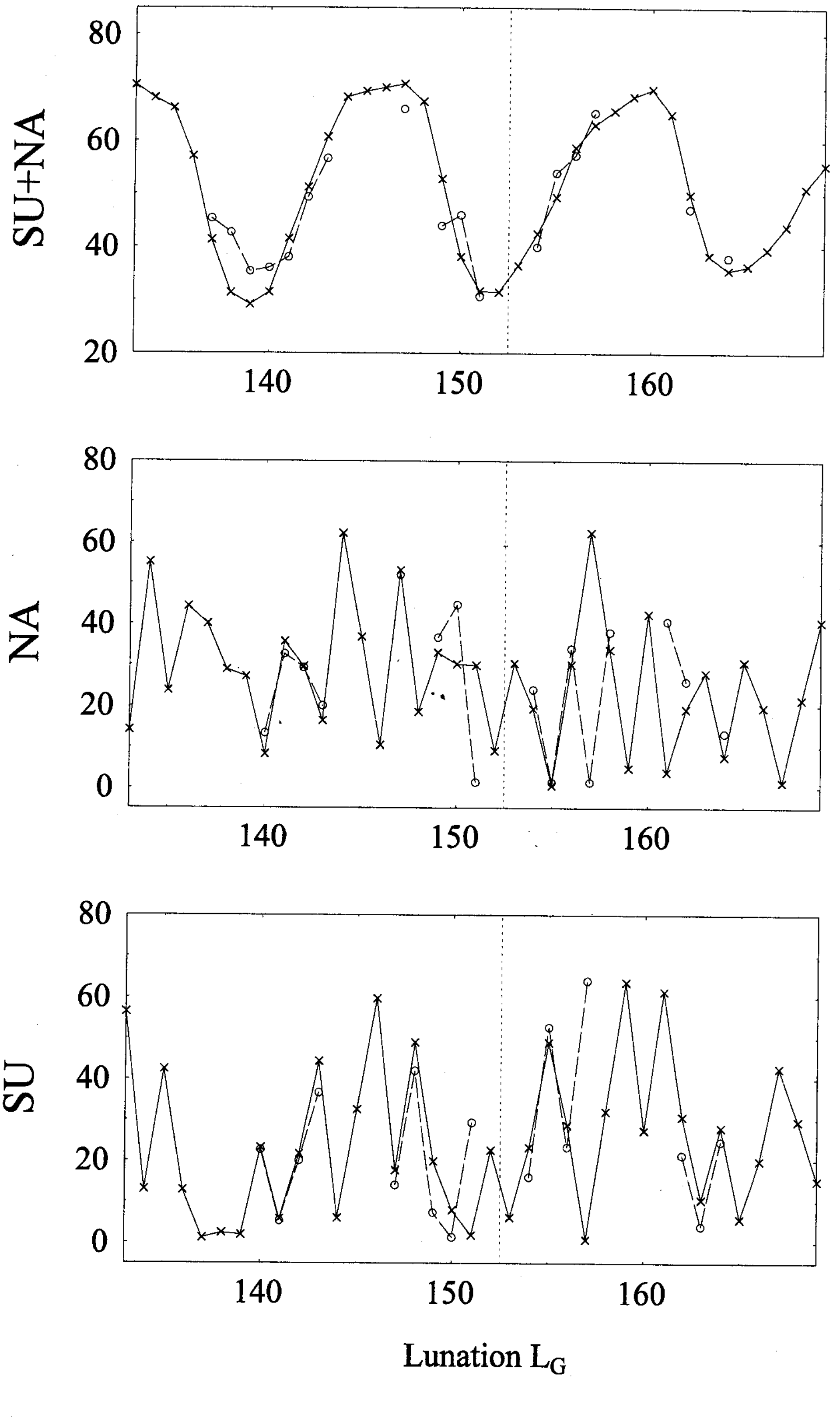

*Figure 20. Comparison of calculated lunar observables ŠÚ, NA, and ŠÚ + NA (crosses, connected by solid lines) with the corresponding data recorded on the tablet **LBAT 1433** (circles, for consecutive months connected by dashed lines). Here we have used the lunation numbers LG as defined in the text. The correction shifts all data with L < 152 (i.e., those to the left of the dotted vertical line) by one unit towards the left side.*

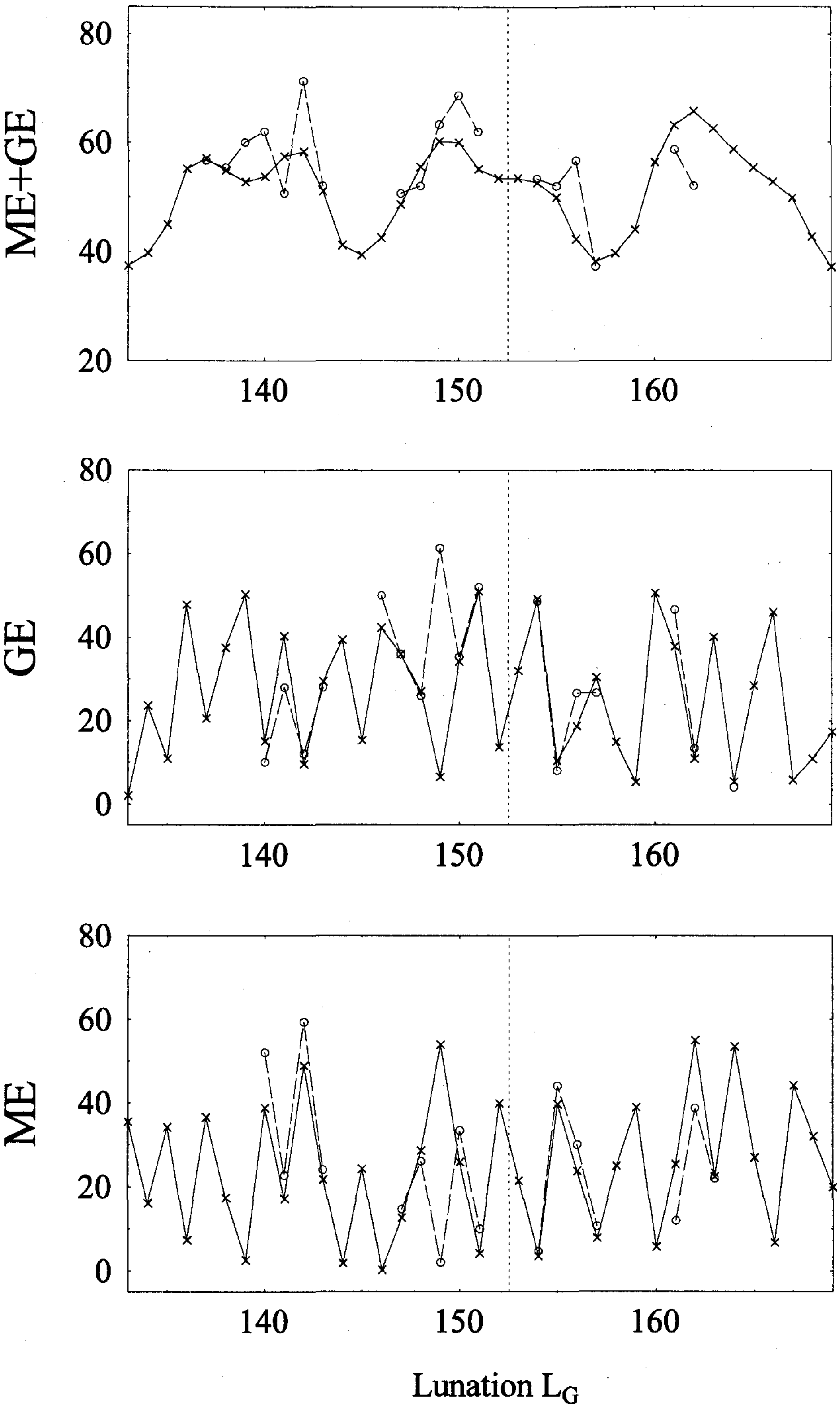

*Figure 21. Lunar observables ME, GE, and ME + GE of the tablet **LBAT 1433**. As in Fig. 20, the data with L < 152 (i.e., those to the left of the dotted vertical line) are shifted by one unit towards the left side.*

That the Babylonian indeed did follow these two different strategies, handling their observational data quite inconsistently, can in some of the cases be confirmed by textual evidence from the tablets themselves:

— As mentioned above, on LBAT 1225 the month XII_2 occurs under year 78; but only SE 96 has a thirtheenth month and SE 78 does not.

— Similarly, LBAT 1220 has in the year SE 73 an entry for a month XII_2. However, only the goal year SE 91, but not the observation year 73, has this intercalated month.

— LBAT 1433 starts (as a Goal-Year tablet) with the sums *ŠÚ* + *NA* and *ME* + *GE* for the last month of a year, here of year SE 69. Immediately after *ŠÚ* + *NA* and *ME* + *GE* of month XII (SE 69) follows month I (SE 70). The month XII_2 of year SE 69 is missing. However, the observation month of the goal month I (SE 88) is the missing month XII_2 SE 69. According to our interpretation, the data observed in this month are recorded on this tablet under month I, SE 70. This explains the missing month.

— The two tablets LBAT 1251 and 1285 exhibit another practice: in the entry designed for prediction in the first month I of the goal year, they record lunar data from a month XII_2. In both cases, the intercalary month really exists in the recorded year and is the observation month for the goal month I. In both cases, the observation year and not the goal year has an intercalary month XII_2; and in both cases this month is the observation month for the the first goal month I.

— Similarly, LBAT 1291 correctly has an entry for lunar data of a month VI_2. This month, intercalated in the observation year, served as observation month for the goal month VII of year SE 207.

We summarize. When observation month and goal month differ, the Babylonians used two different practices: On LBAT 1220, 1225 and 1433, the tablet month was chosen to be the goal month; while on LBAT 1251, 1285 and 1291, the lunar data were tabulated under the label of the observation month.

The only other possible explanation we can think of for a shift of the lunation numbers is the following. The intercalation scheme, as given in Parker and Dubberstein (PD), might be wrong. In contradiction to PD, the years SE 71 (from 1220) and SE 78 (from 1225) were leap years and contained both the intercalated month XII_2. And the year SE 69 (from 1433), also in contradiction to PD, did not have the thirteenth month XII_2. Another distribution of the intercalated months than that given in PD may shift the lunation numbers by one.

After I finished these investigations, P. Huber kindly drew my attention to the fact that already Kugler [*SSB II p. 459 ff*] with a different approach had arrived to exactly the same conclusions. Kugler analyzed tablets for which the goal year Y had a leap month VII_2 (or XII_2). He remarked that on the Goal-Year tablets for year Y (Y = SE 88, SE 91, SE 96), a leap month also occurred under the entries for the planets or the moon in spite of the fact, that the corresponding years (Y-71 for Jupiter, Y-8 for Venus or Y-18 for the moon) did not have such a leap month. He concluded that on the tablets (now known as LBAT 1220 and 1225) the observations had been transferred and recorded under the name of the goal month. For some later Goal-Year tablets (among others LBAT 1251, 1264 and 1285), however, the observations were recorded under the right name, in spite of the fact that the goal months had a different name. Analyzing the Lunar Four, I came to exactly the same conclusions as Kugler.

In order to demonstrate how clearly the Lunar Four data can demonstrate that the dating of a tablet is wrong, I will show the detour I made before realizing that the data on 1225 just were recorded under the next month's name.

Neglecting Sachs' dating of the tablet LBAT 1225 and the planetary information from its front side, we have tested if some other dating of this tablet is possible, based only on the inscriptions on its back side. The colophon at the lowest part of the tablet is eroded, but still it seems to state the goal year to be [..]31. There are several possibilities for reconstructing the goal year. (We follow here the convention to mark leap years by stars: by one star when a second month XII was intercalated, and by two stars when a second month VI was intercalated.) We denote the possible datings by the letters B, C, D, and E.

B: 31 = 31 SE*, in which case the observation year was SE 13.
C: 1 31 = 91 SE*, the observation year being SE 73.
D: 1 Me 31 = 131 SE; in this case the observation year was 113 SE**.
E: 2 31 = 151 SE**, the observation year being SE 133.

For all these alternatives the corresponding lunation numbers have been determined, and in Figures 22 – 25 the Babylonian data are compared to the computed data. The discrepancies are convincing: none of these readings is possible.

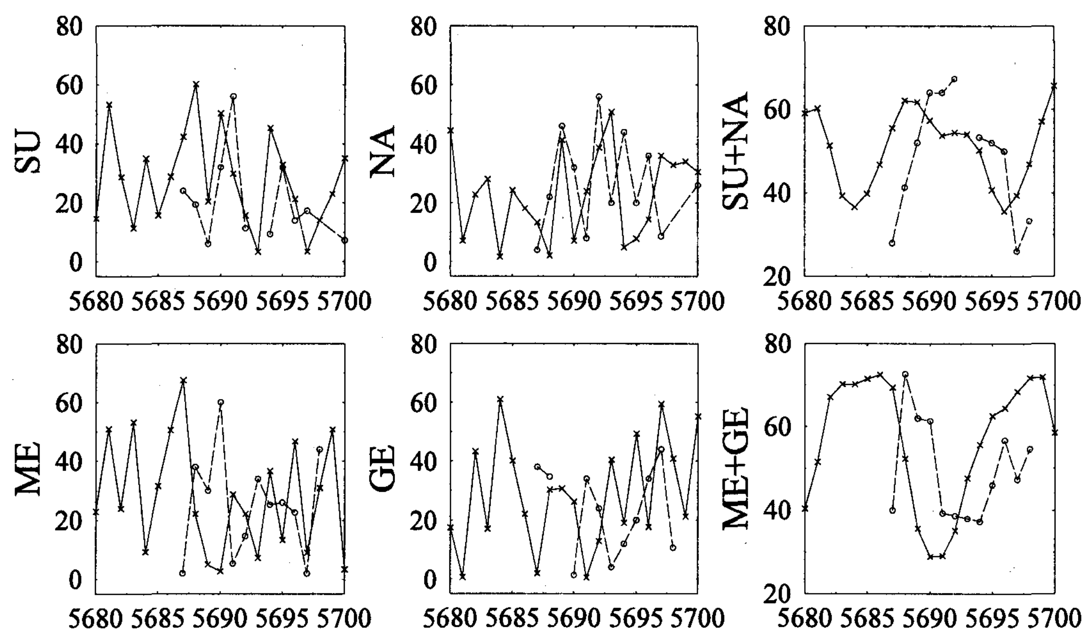

Figure 22. Test of the dating B of LBAT 1225, assuming that the goal year of this tablet was SE 31. The lunation numbers L_B are 5687 – 5698 according to the 'old' counting. This dating is clearly wrong.

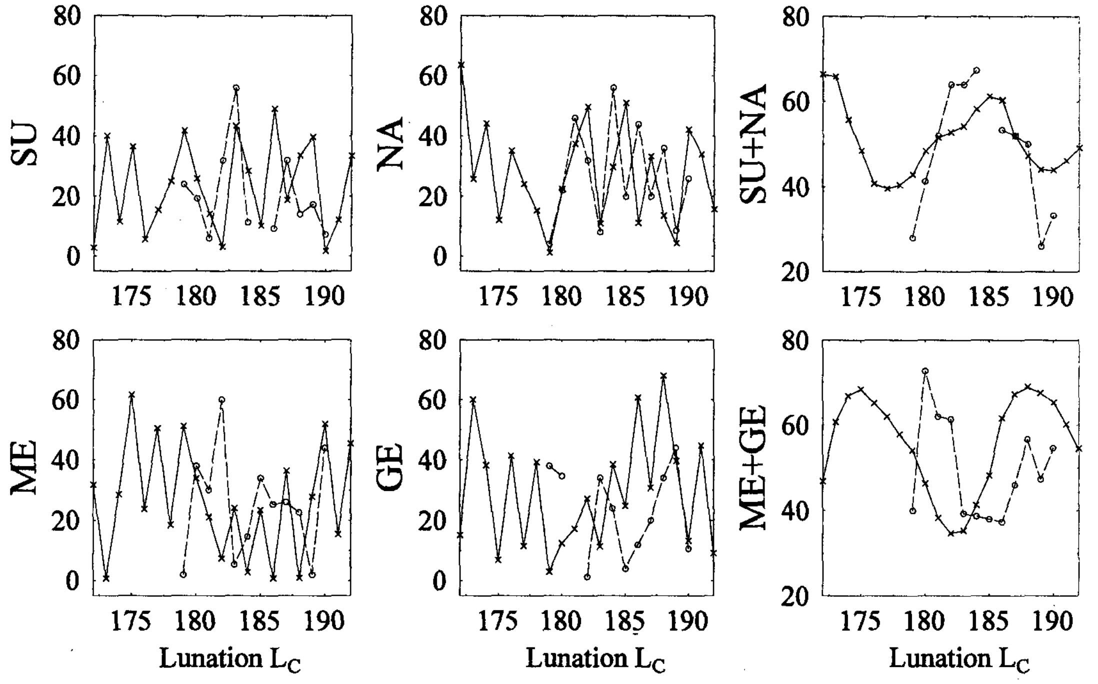

Figure 23. As Fig. 22, but here we test the dating C of LBAT 1225.

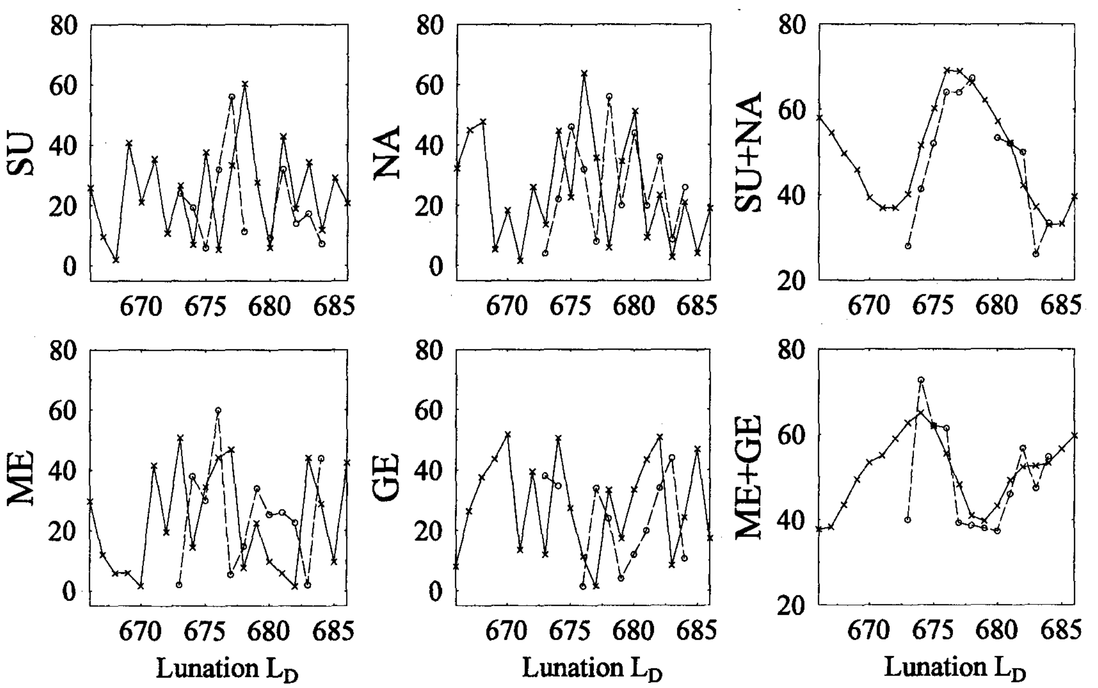

Figure 24. As Fig. 22, but here we test the dating D of LBAT 1225.

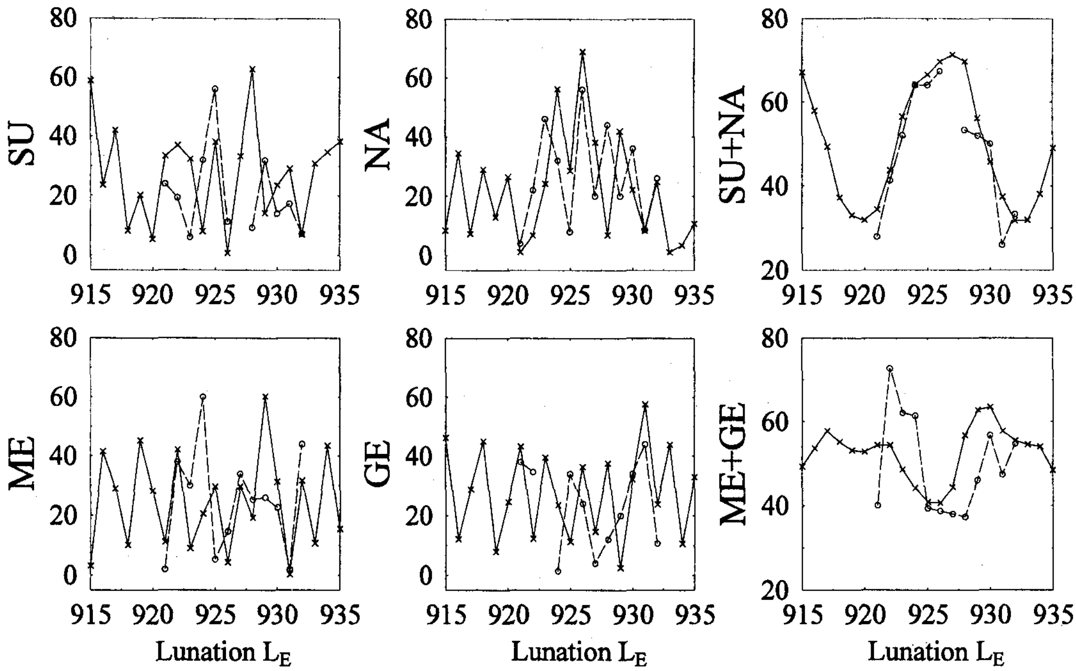

Figure 25. As Fig. 22, but here we test the dating E of LBAT 1225.

Disagreements on the day of observation

We now focus on another discrepancy frequently occurring between the computed and the Babylonian data. According to Moshier's program, *ŠÚ* is close to zero while *NA* is large (*NA* ≅ *ŠÚ* + *NA*) at some full moons, but the Babylonians tell for the same full moon that *ŠÚ* is large and *NA* nearly zero. This is true for the lunations L = 1138, 1461, and 1621, all from the Seleucid time, and for the 'old' lunation L_{old} = 2926 from the time of Cambyses. In all of these cases, the Babylonians measured *ŠÚ* on the day before it had occurred according to Moshier's program, and never one day after. This fact could look like a systematic error in Moshier's program, namely that the computed time of the corresponding oppositions is slightly too late. Such an error would result in the observed discrepancy. (Imagine that the full moon sets shortly after the opposition. Then on this morning the Babylonians will measure a small value of *NA*. If the computed time of opposition happens to be too late, i.e., shortly after moonset instead of shortly before, then the 'computed moon' sets just before sun rise. Therefore on this morning the program would predict that a small value of *ŠÚ* is measured while *NA* should be seen on the next day.) Similarly, for the evening observations, the Babylonians would sometimes measure *ME* one day earlier than predicted by Moshier's program. This, however, is never the case. On the contrary, for the lunations L = 31, 788, 791, 793, 1034, 1452, and the 'old' lunation L_{old} = 2916, the calculated *ME* is found on the day before the Babylonian measurement. We must conclude, therefore, that the discrepancy between the Babylonian and the computed Lunar Four values cannot be explained as the consequence of a slightly displaced opposition.

A possible explanation for these disagreements on the day of observation could be given by different definitions of the times of rising and setting. As far as we know, the

Babylonians never recorded exactly at which time they considered the sun or moon to rise or set. It is usually assumed that it was the time when the upper limb of the disc touched the horizon. A program calculating risings and settings at the moment when the center of the disc passes the horizon would produce the same kind of deviation as the ones we are concerned with here. But this explanation does not seem to apply, since Moshier writes: "*For Sun and Moon, rise and set times are for the upper limb of the disc.*"

Another plausible explanation has been given by P. Huber who controlled the visibility conditions of more than 600 occurrences of the crescent. He concluded that the discrepancies can be due to an underestimation of the atmospheric refraction for objects under the horizon [*1982, and private communication, 1997*].

Summary

The systematic comparison of Lunar Four data computed by Moshier's ephemerides program with their Babylonian values shows that the Babylonian data are very precise and that Moshier's program is so exact that we can trust it also at antique times. We present evidence that the Babylonians in their Goal-Year tablets sometimes tabulated lunar data under the label of another month than the one in which they were observed.

Acknowledgements

I am very grateful to Prof. P. Huber for the communication of a variety of unpublished material on the Lunar Four data. He pointed out that already A. J. Sachs had extracted a list of lunar data (mainly from the Diaries but also from Goal-Year tablets) and controlled them using a computer code by F. R. Stephenson. He kindly sent me Sachs' unpublished list of controlled lunar data. Of the 16 tablets examined in the present paper, only the data from LBAT 1214, 1220 and 1225 occurred. (For these tablets we agree on the readings and by and large on the accuracy.) P. Huber also kindly drew my attention to the fact that Kugler had already remarked how the Babylonians on some tablets used the "goal month" instead of the "observation month".

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