# On the "Atypical Astronomical Cuneiform Text E"

A mean-value scheme for predicting lunar latitude

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## 1. *Introduction*

When O. Neugebauer (1955) published his *Astronomical Cuneiform Texts* (henceforth: ACT), the main work in deciphering and understanding the "mathematical astronomical texts" was completed. The mathematical computations of the ephemerides of the Seleucid period were fairly well understood and their working thoroughly explained in ACT. Of course, progress has been made since then - many important cuneiform tablets have been found and edited and almost everybody working in the field has contributed and deepened our understanding of the mathematical astronomy and its numerical methods. But we still know quite little about how the methods were developed. In his *A History of Ancient Mathematical Astronomy*, Neugebauer (1975, p. 348) summarizes the status of knowledge:

> For the cuneiform ephemerides we can penetrate the astronomical significance of the individual steps, as one may expect with any sufficiently complex mathematical structure. But we have practically no concept of the arguments, mathematical as well as astronomical, which guided the inventors of these procedures. This historical problem is still more involved because we have, beside the mathematical-astronomical material, equally extensive records in which many predicted data are embedded without these predictions being based on the contemporary mathematical methods. Hence we are very far from any "history" of Babylonian astronomy and must be satisfied to accept it as a complete system of admirable elegance and efficiency but without really understanding its development.

In other words: we understand the end product but we have rather little knowledge of the interplay between observation, prediction and formation of theory. Therefore, the big question was (and still is), how were these elegant numerical theories developed? As some progress has been made,[1] we are now much better equipped for our investigations.

Since the currently known Babylonian records of observation have been edited,[2] we know what was observed by the Babylonian astronomers, and we can check the accuracy of the observations by means of modern computer codes. Some advanced and sufficiently accurate computer codes have been developed, enabling us to reproduce lunar, planetary and solar (observational) data for the times of interest, *i.e.*, from 600 B.C. onwards.[3] Systematic analyses of such "reproduced observational data" help us to find and reconstruct empirical predicting rules.

Attempting to find the mathematical and astronomical arguments which guided the inventors of the ACT procedures, the focus of interest and of current research is the intermediate state of Babylonian Astronomy. Therefore one investigates which non-mathematical (*i.e.* non-ACT) methods existed for the prediction of astronomical phenomena. It is our hope to figure out how they worked, and to find their eventual connection to the ACT methods. Again some advancements have been made: we know now how lunar phases were predicted by a rather simple but also very easy, elegant and precise method, the "Goal-Year" method.[4] But to date we have found no direct connection between such a method and the ACT schemes. In this connection so-called "atypical" texts have come into focus of research.[5]

The atypical astronomical cuneiform texts were published by Neugebauer and Sachs (1967 and 1969), who characterized the texts as "isolated computations or didactic texts which fall outside the framework of the standard text material", confronting the authors with many difficulties.

The present paper contains a new reading of the

[1]) See for instance J. P. Britton's investigations (2002) of period relations and times and of improvements of parameters. See also Steele 2000 on eclipses as well as P. J. Huber and S. De Meis 2004. Other progress was made by Jones (2004) analyzing observed planetary passages by Normal Stars and through Swerdlow's proposal (1998) for the development of the planetary schemes.

[2]) A. J. Sachs and H. Hunger 1988, 1989 and 1996 as well as Hunger 2001.

[3]) E.g. S. S. Moshier 1992. For the moon, special use is made of M. Chapront-Touzé and J. Chapront 1988. Newest version of the code at www.moshier.net: aa200c.zip, 2005.

[4]) See L. Brack-Bernsen 1999 and L. Brack-Bernsen and H. Hunger 2002.

[5]) Following Sachs we use the term "Intermediate Astronomy" to refer to stages later than MUL.APIN and earlier than ACT, see T. G. Pinches, J. N. Strassmaier and A. J. Sachs 1955.

atypical Text E. A preliminary version was presented by L. Brack-Bernsen in 2002.[6]

## 2. *Text E*

The fifth atypical astronomical cuneiform text, published as "text E" by Neugebauer and Sachs, is a very nice and almost intact tablet belonging to the cuneiform collection of the British Museum. It is registered as BM 41004 and treats lunar latitudes and planetary periods. At this stage we are only interested in the lunar sections (1 and 4) and refer to Neugebauer's and Sachs' transliteration, translation and comments.[7]

At one point, we interpret the text differently from Neugebauer: the first part of the text mentions several times some 5°. Neugebauer sees the 5° as indicating the maximal positive (and negative) lunar latitude, resulting in an amplitude of 10° for the moon's motion in latitude. The second part gives simple arithmetic rules for a schematic linear motion in the latitude of the moon. Neugebauer remarks that the extrema are (inconsistently) chosen here to be ±6°, a parameter which is not as good as the assumed ±5° from the first part of section 1 (p. 203).

Contrarily we propose that each time the 5° is mentioned in section 1 it refers to difference in longitude (and not in latitude) so that the inconsistency of having two different values for the extreme lunar latitude disappears. According to our understanding, the first part of section 1 (line 1 to 8a) gives the schematic motion in "longitude" of the lunar extrema and nodes, and the second part of section 1 (from line 8b on) treats lunar latitude, starting with the statement that the range of variation in latitude is 6 cubits.

To illustrate the different interpretations, we quote the translation given in the Neugebauer - Sachs paper together with a few of their remarks and then (further below) we give our new translation and point at some consequences of the new understanding of the text.

> (1) The passing(?) by(?) (of stars) by the moon. When it reaches the Pleiades at its highest latitude, (then after) 5° it will not reach Regulus; having proceeded 3 bēru (= 90°) (from when it was at maximum latitude), it is at the node. (2) (Then after) 5° it does not reach the Head of Scorpio; having proceeded 3 bēru (= 90°) (from when it was at the node), it is at minimum latitude; (3) then at 5° (variant: 9°) behind Capricorn it will be at the node. It recedes (in nodal motion) 1;40° per month. (4) At the (beginning of the) second year it is $\frac{2}{3}$ bēru (= 20°) behind the Pleiades (5) when the maximum latitude is passed by, ..., at 5° behind Gemini it is at the node; (after) 5°, (8) it does not reach Virgo, it is at minimum latitude. 1;40° (per month, recession of the node), ditto. 6 cubits is the width of the path. (9) For 1 bēru (= 30°), two disks, either going up or down. (10) After 9 years it will be at minimum latitude. ...

The (schematic) movement of the (full) moon is traced here. Lunar positions are given at three month intervals, after which period of time the place of the moon has changed by approximately 3 *bēru* (= 90°) and its latitude has changed from extrema to mean or *vice versa*.

In Neugebauer's Commentary (p. 203) to this text we read: "the motion of the moon in latitude ... is described with reference to stars and constellations, beginning with a maximum positive latitude of 5° in the Pleiades and then following the orbit through consecutive quadrants to the descending node." We agree that the moon starts at high latitude in the region of the Pleiades; but at this place the text gives no measurement for the latitude. Contrary to Neugebauer, we read the 5° as indicating longitude (the position 5° before Regulus). Not until line 8b does the text quantify the movement in latitude: "6 cubits is the width of the path". The lunar latitude is measured in cubits, and its range of variation is 6 cubits. Note that the text uses different units for measuring longitude and latitude: it gives positions in longitude in units of UŠ (1 UŠ = 1°) and *bēru* (1 *bēru* = 30 UŠ), while latitudes are given in units of cubits. Almost all the texts dealing with lunar latitude which we know give the longitude in units of degrees, while the latitude is measured in cubits (this is e.g. the case in the Star Catalog BM 36609 and in the atypical astronomical text F). Therefore we see this different choice of units as very strong support for our interpretation.

In his comments Neugebauer points at other problems: comparing the indication of lunar latitude with the longitude and latitude of the Normal stars (mentioned in the text) leads him to the following remark (p. 204): "A complete mystery remains the meaning of the repeated remark that the moon 'does not reach' (nu kur) a constellation; cf., e.g., the quadrant Pleiades - Regulus where the 'does not reach' is most unexpected in view of the actually good agreements."

We understand the (admittedly difficult) text as presenting a mean value scheme for lunar latitude. Some Normal Stars within the path of the moon (= the zodiacal band) are used to indicate how the lunar nodes and extrema move along the zodiac in the course of time - the positions being given at intervals

[6]) Workshop on "Atypical Astronomical Cuneiform Texts", held at Regensburg University in October 2002.

[7]) Neugebauer and Sachs 1967, 200-205 and 217.

of three months. The approximation used by the text is that the lunar nodes recede 1;40° per month and 20° per year (line 3 and 4). Accordingly, the recession of the nodes over 3 months is 3 × 1;40 UŠ = 5 UŠ and the recession over 1 year (= 12 schematic months) = 1;40 UŠ × 12 = 20 UŠ. The text explains how to find the position of middle and extremal lunar latitude during 3 years and it indicates, for each of these cornerpoints, the distance to the nearest Normal Star.

## 3. *An observational rule of thumb*

Before giving our translation and interpretation of the text, let us present our heuristic understanding of what is going on here. There are traces of observational experience and practice together with indications which may lead to the construction of a linear zigzag function for the lunar latitude.

The text gives rules for finding the corner-points of the moon's movement in latitude. By "cornerpoint" we mean the points of maximal, middle and minimal latitude. The method is exemplified by assuming that the moon starts with the highest latitude in the region of the Pleiades. Then the movement of the cornerpoints along the path of the moon is followed by means of Normal Stars. A very simple rule of thumb is used: you come from one cornerpoint to the next by going 5° = 5 UŠ back and a right angle (= 3 *bēru*) forward. From maximal latitude to "the node", go 5° less than 90° forward, and the same amount for coming from the node to the position of minimal lunar latitude, etc. (Note: our rule of thumb is just the simple consequence of indications given in line 3 and 4 of the text, that the node recedes 1;40 UŠ per month and 20 UŠ per year.) The position of the cornerpoints is given with respect to the nearest Normal Star. The first part of the text is hence only concerned with "longitude" while latitude is treated further down, from line 8b onwards: the amplitude of the moon's movement in latitude is said to be 6 cubits (= 144 fingers),[8] a value which is known from ACT and many other texts.

At the Regensburg workshop,[6] N. Roughton presented a Late Babylonian Normal and *ziqpu* Star text. Additional fragments of this text, BM 36609+, have been found since then and the whole text has been translated and commented in a common paper by Roughton, Steele and Walker (2004). This very important text has given us a much deeper insight into Normal Stars and *ziqpu* stars and their role within Babylonian astronomy. Some new Normal Stars have been identified - in parts of the zodiac where the reference points (*i.e.* the Normal Stars known so far) were very far apart. One section of the text gives rising times of zodiacal signs by means of culminating *ziqpu* stars. Another section gave (when complete) a full listing of Normal Stars together with their approximate position (in degrees) within the appropriate zodiacal signs. A further section lists the (rounded) distances in *bēru* and UŠ between stars and star-groups. Note that such lists are handy tools for converting positions observed with respect to Normal Stars into zodiacal longitude. And, finally, Sections 12 and 13 contain a list of distances in cubits above and below Normal Stars. J. Steele has shown that the distances above and below the Normal Stars refer to the extreme points of the moon's band of latitude (which within Babylonian astronomy was assumed to be 6 cubits). All this supports our new interpretation of Text E and deepens our understanding. Some of the stars, still visible in the list of Section 12 and 13, are the same as those in our Text E, and the width of the band is equal to 6 cubits as in our text. In the region of the Pleiades, the minimal latitude is listed as 5 cubits below MUL.MUL (= Pleiades) so the maximal latitude would be 1 cubit above that star.[9] It is not hard to imagine the use of such schemes in tracing the movement of the (full) moon when it passes a Normal Star, e.g., Pleiades. The notion that it passes Pleiades implies that the position of the moon in longitude is known while its distance - measured above or below that Normal Star - would give the lunar latitude at that moment.

The text BM 36609 has hence confirmed our assumption that the Normal Stars were used to indicate the positions (in longitude) of the cornerpoints (of lunar latitude), and to trace their movement with time. The list of Normal Stars and their respective distances, together with the section listing the positions of Normal Stars within the zodiacal signs, give witness that (and how) these stars were used to indicate positions (in longitude); Section 12 and 13 giving the distances above and below (a list of) stars have shown how the lunar latitude was traced by means of these stars. For each of these special stars, the Babylonian astronomer knew the interval of 6 cubits within which the variation in lunar latitude took place. Our rule of thumb is completely in line with the astronomical concepts and practices hidden in the schemes of BM 36609. We see Text E as a primer of lunar latitude. The rule of thumb

[8]) From Late Babylonian (LB) times onward, 1 cubit was equal to 24 fingers, and 12 fingers was at that time the equivalent of 1°, so we have here a quite high value of 12° for the amplitude of lunar latitude. See p. 284 in J. M. Steele 2003.

[9]) See N. A. Roughton, J. M. Steele and C. B. F. Walker 2004, and a forthcoming paper by Steele (2005), where he argues that the movement of the moon was surveyed along a "zodiacal band" identified by means of Normal Stars. See also Swerdlow 1998, 34 where he was the first to introduce the idea of a "zodiacal band".

models nature roughly and gives an easy way of surveying the moving cornerpoints by means of normal stars.

In the following section 4, we will present a new translation of the whole Text E. Those parts of the text which are concerned with lunar latitude will be repeated in sections 5 and 6 together with our interpretation and comments.

## 4. *New translation of Text E*

### Upper edge

(3) At the command of Bel and Beltija may it go well.

### Obverse

#### Section 1

(1) The ...[10] of the moon. In the place[11] of Pleiades it reaches highest[12] (latitude). It does not reach Regulus (by) 5°, it goes 3 *bēru* and (is at) middle (latitude).

(2) It does not reach the head of Scorpius (by) 5°, it goes 3 *bēru* and (is at) lowest[13] (latitude).

(3) 5° (variant: 9°) behind Capricorn (it is at) middle (latitude). (Each) month, it recedes 1° 40'.

(4) In the second year, it recedes $\frac{2}{3}$ *bēru* from Pleiades, and

(5) (it) takes up highest (latitude). 5° behind Cancer (it is at) middle (latitude). It does not reach Libra (by) 5° (and is at) lowest (latitude).

(6) It passes (or: takes up)[14] 5° (of) Capricorn, and (is at) middle (latitude). 1° 40', ditto (= it recedes). In 3 years[15],

(7) it does not reach the ribbon of the Fishes (by) 5°, and takes up highest (latitude). 5° behind Gemini (it is at) middle (latitude).

(8) It does not reach Virgo (by) 5° (and it is at) lowest (latitude). (Each) month, 1° 40' ditto (= it recedes). 6 cubits is the width of the path.

(9) When for 1 *bēru* it goes up[16] or goes down two (lunar) disks,

(10) in 9 years it goes up (= reaches highest latitude), in 9 years it goes down (= reaches lowest latitude).

(11) For you to make (= calculate) the highest and lowest point of the moon(’s motion): the size of the moon is 12 fingers.

(12) In a month, the moon goes up or goes down one-ninth of it size.

(13) $\frac{1}{9}$ of 12 fingers is a finger and $\frac{1}{3}$ finger. Until 12 months, 16 fingers, (*i.e.*) $\frac{2}{3}$ cubit.

(14) In a year, it goes up or down $\frac{2}{3}$ cubit. You multiply $\frac{2}{3}$ cubit by 9,

(15) in 9 years it goes down 6 cubits, the width of the path, from highest point to lowest point, and

(16) reaches its lowest point. In 9 years, the remainder of the 18 years,

(17) it turns[17] to (*i.e.*, moves to) the highest point, and reaches its highest point. Secondly (variant): 0;2 (*bēru*, *i.e.*) 12 fingers. With the table(?)

(18) you compute it as before. Secondly (variant): 0;2 (*bēru*, *i.e.*) 12 fingers. 0;00,13,20 is one-ninth (of it).

(19) You multiply 0;00,13,20 by 12, and (it is) 0;02,40 (*bēru*, *i.e.*) 16 fingers. $\frac{2}{3}$ cubit

(20) you multiply by 9, (which means) 0;02,40 (*bēru*) times 9 is 0;24 (*bēru*), so it completes 6 cubits, the width of the path,

(21) (and) is at the lowest point. It turns to (move to) the highest point, and for the remainder of the 18 [years, it is the same.]

(22) The moon [returns to the same] place in 82 days.

#### Section 2

(23) For you to make (= calculate) the close approaches(?). If one first revolution 1 cubit [...]

(24) a planet it passes(?). In the second revolution, what is behind it ... [...]

(25) planet comes close to planet. If a revolution [...]

(26) comes close to a planet. In the second, it moves away(?) $\frac{1}{2}$ cubit [...]

### Reverse

#### Section 3

(1) [The passing]s of Jupiter by the Normal Stars. In 12 years,

(2) it lacks [7(?) days] to your year. Secondly, in 12

[10]) The first sign is slightly damaged. John Steele proposes to read the traces BAR, which according to Sachs’ copy is equally possible. According to collation by Ch. Walker, the traces do not support a reading DIB. BAR occurs in ACT in connection with the nodes and the “nodal zone”; its reading is however still unknown.

[11]) This word is used both for “area” and for what we call “position”, e.g. in longitude.

[12]) This is a noun meaning “height”, “high place”.

[13]) Again, this is a noun meaning “depth”, “low place”.

[14]) The sign can be used both for “to pass” and for “to take, to seize”. Both could be meant here.

[15]) Which we take to mean “in the third year”.

[16]) The words for “to go up” or “to go down” are from the same root as the ones translated as “highest” and “lowest” point, respectively.

[17]) Lit., it sets its face to.

years it lacks a month to your year.

(3) In 12 years - new break - it passes its place 5° to the east. In 71 years, [you see(?)] (the same) day for the day.

(4) In 83 <years>, it lacks 7 days to your year.

(5) The passings of Venus by the Normal Stars. In 12 (error for: 8) of your year (error for: years), it lacks 4 days to your year.

(6) Secondly: in 16 years, it lacks 2 days to your year. Thirdly: in 48 years, it goes 4 days

(7) on top of your year. Fourthly: in 64 years, it goes 1 day (or) 2 days on top.

(8) In 8 years, Venus moves its place 4 degrees to the west. In 16 years,

(9) Venus moves its place 2 degrees back to the west. In 8 years, it lacks 4 days.

(10) The passings of Mars by the Normal Stars. In 32 years, it lacks 5 days to your year.

(11) Secondly: in 47 years, it goes 4 days on top of your year.

(12) Secondly: in 64 years, it goes 4 days on your year. Thirdly: in 126 years, you see <the same day for the day.>

(13) The passings of Saturn by the Normal Stars. In 59 years, it lacks 6 days to your year.

(14) In 30 years, it will go 9 days on top of your year. In a year, Saturn moves 12 (degrees).

(15) In 30 years, it passes its place to the east by 7° 20'. In 147 <years>, you see the (same) day for the day.

(16) The passings of Mercury by the Normal Stars. In 13 years, it lacks 3 days to your year.

(17) In 46 years, it lacks 1 day to your year. Thirdly: in 125 years, you see the (same) day for the day.

Section 4

(18) In 19 years the moon will come close to the place of the Normal Stars where it came close (before). Where the moon made an eclipse, it will make (one again).

(19) When it took a highest (position) (or) when it took a lowest (position), it will repeat(?)[18] it in your year. You determine the full[19] (months) and the hollow[20] (ones).

(20) In 27 days the moon repeats(?) the place of the Normal Stars. If for a close (approach), it will fall behind 4 *bēru*.

(21) In 82 (days), the moon will repeat(?), day for day, the place of the Normal Stars (where it was). Or else, in 3 months it lacks 8 days.

(22) [In] 7 days highest point, in 7 days middle, in 7 days it takes the lowest point. In 3 months the moon(!) takes up the highest point, remainder(?),

(23) in 3 months middle, in 3 months it takes the lowest point. Going up and going down of the width of the path

(24) of moon and sun, high and low for you to see: in a month, the moon goes 10 degrees up and down.[21]

Upper Edge

(1) Written from a waxed wooden tablet. Tablet of Marduk-šapik-zeri, son of Bel-apla-iddin,

(2) descendant of Mušezib. Hand of Iddin-Bel, son of Marduk-šapik-zeri, descendant of Mušezib.

## Comments on the translation

There is an obvious inconsistency in the expressions of this text. E.g., the so-called "corner points", *i.e.* the maximum and minimum latitude and the nodes, are in most instances simply mentioned, without using a verb, e.g. end of line 1: "it (the moon) goes 3 *bēru* and middle (= zero latitude is reached)". Or at the end of line 5: "5° Libra not reached, lowest (latitude)". The very first such statement, however, is NIM KUR "it reaches highest (latitude)". KUR for "reaching" a corner point of latitude is not used elsewhere, but in l. 5 we find NIM DIB-*at* "it takes up the position of highest (latitude)"; the same expression occurs in l. 7. There is simply no consistent terminology. Another problem lies in the same word "to reach", represented in transliteration by KUR. In this text it is always written as a word sign, without indication of its pronunciation in Akkadian. Five times it is said that the moon "5° does not reach" a certain star or constellation, after which extreme latitude or zero latitude takes place. We take this to mean that the moon has not reached the longitude of the star mentioned but has a longitude of 5° less. The relation between "5°" and the star is not specified by the Akkadian expression. If it is taken as "5° of the star", then the star would have an extension in longitude which is only possible if it represents a constellation (and some of the names are indeed constellation names). Then the text would literally say that the moon does not reach a point 5° into that constellation. That would raise the question of constellation boundaries: are they as in the zodiac? So it seems to us more likely that the reference is to single stars, and to a longitude of 5° less than the star's. This assumption is supported by another expression in the text: three times one of the corner points is said to occur "5° behind" a star or constellation, so the moon's longitude is 5° more than the star's. In these cases there is no ambiguity. This

[18]) Such an understanding of the sign GI written here is possible if uncommon.

[19]) Lit., "confirmed".

[20]) Lit., "returned".

[21]) The 10 degrees must be an error for 12 degrees.

interpretation is further supported by the star catalogue published by Roughton, Steele and Walker 2004, where we find in obv. iii 20: TA 5 UŠ *kin-ṣa* NU KUR. From the context there it is evident that this means "5° in front of the star *kin-ṣa*". Finally, there is one expression which is not clear to us: we have translated in line 5 "it passes 5° of Capricorn", but the sign DIB could also mean "it takes up (a position)". Whatever the exact translation, we expect here NU KUR which is used elsewhere in the text, *i.e.* a position in front of Capricorn. This case has to be considered an error, see below. One more grammatical problem is that the deplacement of the moon by 3 *bēru* (or a right angle) is mentioned after the position "5° of a star not reached" is noted; in other words, the position of the moon is described with reference to a star, and only then is the moon said to have moved to it; we would expect it to be the other way around. This movement by 3 *bēru* occurs only in the first two lines, and only twice. It could just as well have been left out, because the position of the moon in longitude is anyway given with reference to stars. The clearest statements are those at the end of each yearly paragraph: in a month, it (*i.e.*, the moon's position at extremal or zero latitude) recedes 1° 40'. From this the scheme can be constructed.

## 5. *Lunar latitude in Text E, a new interpretation*

The first half (line 1-8a) of section 1 follows the "longitude"-movement of the lunar cornerpoints during a period of three years. The positions (of cornerpoints) along the zodiacal band are indicated by Normal Stars and given at intervals of three months. The second half (line 8b-17) of section 1 delivers the numerical values of lunar latitude. How these two sets of information can be combined to deliver the numerical equivalent of a linear zigzag function shall be treated in section 6.

We start out by testing the data against the approximation mentioned in the text, that the node recedes 1;40 UŠ per month and 20 UŠ per year. The "schematic" or "ideal" full moon moves 1 *bēru* per month and 12 *bēru* per year. Starting at highest latitude, the full moon will (in a first approximation) reach mean latitude after three months, lowest latitude after six months, mean latitude after nine months and be back at high latitude after 12 months; however, a little correction is needed since the node recedes 20 UŠ per year. Accordingly, the recession of the node after three months is 5 UŠ. Therefore, starting at highest latitude, the full moon will reach mean latitude after some 3 months, having moved 3 *bēru* less 5 UŠ = 90 UŠ - 5 UŠ = 85 UŠ. This approximation is equivalent to our rule of thumb.

In Appendix B of Roughton, Steele and Walker 2004 the stars named in the different cuneiform texts are identified and listed together with their celestial coordinates calculated for the time 300 B.C. (pp. 565-570). We use this list for finding the longitude of the cornerpoints as given in section 1 by means of stars. For comparison, in the scheme below, we have also calculated the longitudes of the cornerpoints according to our rule of thumb. We start at the position of high (or maximal) latitude by MUL.MUL which had a longitude of 28° and find the longitude of the following cornerpoints by successive additions of 85°.

| Position given by Normal Star | Identification of the star | corresponding longitude | Lunar latitude | Rule of thumb |
|---|---|---|---|---|
| ki múl.múl | η Tauri | 28 = 28° | high | 28° |
| múl.lugal - 5 UŠ | 5° from α Leonis | 118 - 5 = 113° | middle | 113° |
| sag gír-tab - 5 UŠ | δ + β Scorpii - 5° | 211 - 5 = 206° | low | 198° |
| 5 UŠ ár máš | 5° behind β Cap. | 272 + 5 = 277° | middle | 283° |
| [9 UŠ ár máš | 9° behind β Cap. | 272 + 9 = 281° | middle | 283°] |
| 20 UŠ mul.mul | 20° from η Tauri | 28 - 20 = 8° | high | 8° |
| 5 UŠ *ár-ki* alla | 5° behind Cancer | 95 + 5 = 100° | middle | 93° |
| giš-rín - 5 UŠ | 5° from α Lib.? | 193 - 5 = 188° | low | 178° |
| 5 UŠ máš | 5° from β Cap. | 272 - 5 = 267° | middle | 263° |
| dur *nu-nu* - 5 UŠ | 5° from η Pisc. | 355 - 5 = 350° | high | 348° |
| 5 UŠ *ár* maš-maš | 5° behind γ Gem. | 67 + 5 = 72° | middle | 73° |
| absin - 5 UŠ | 5° from γ Virginis | 159 - 5 = 154° | low | 158° |

Some comments to the scheme: the place indicated by stars comes quite near to the position found by means of our rule of thumb. Note that the positions in Text E were only given to a precision of 5°, so the agreement between the longitudes in column 3 compared to those in column 5 is reasonably good.

There is one little inconsistency within the Babylonian scheme: from year to year, the cornerpoints will regress by 20 UŠ in comparison to those from the year before, according to the rule. This is true for all but one pair of indicated positions; those given with respect to MÁŠ = Capricorn. In the first year the point of high latitude was at MÚL.MÚL and after 3 steps the text came to middle latitude (ascending node) at 5 UŠ behind MÁŠ (in line 4 of the scheme). In the second year the point of high latitude having regressed by 20 degrees, was at 20 UŠ before MÚL.MÚL, consequently the point of ascending node in year two should also have regressed by 20 UŠ in comparison to its position the year before. It should of course have been 15 UŠ before MÁŠ - or the position in line 4 should have been 15 UŠ behind MÁŠ. Or it could be that the text is just not that accurate. [A parallel text gives the third position in year 1 to be 9 UŠ behind MÁŠ, this is introduced into the scheme in brackets]. We see the inconsistency as a scribal error.

The general agreement leads to the following interpretation: the first part of Section 1 describes how the position of extremal and mean lunar latitude (cornerpoints) can be traced with time by means of some nearby Normal Stars. A simple rule seems to lie behind the positions found: from one cornerpoint go 3 *bēru* less 5 UŠ (= 85°) forward in order to find the next cornerpoint.

The recession of the cornerpoints is 5 UŠ per 3 *bēru*, therefore the recession will be 1;40 UŠ for 1 *bēru*. However, the text says: each month it recedes 1;40 UŠ. Apparently the text does at this place identify the month with the movement of 1 *bēru* = 30 UŠ. This indicates that the text utilizes the ideal year of 12 months of 30 days as a practical approximation to real months (of varying length), and that it (like the Dodekatemoria scheme) lets moon and sun change their positions by 30 UŠ per month.[22]

The second part of this section, lines 8b-17, gives information on the changing latitude, using the units cubits and fingers and an amplitude of 6 cubits:

> "(8) ... 6 cubits is the width of the path. (9) For 1 *bēru* (= 30°), the two disks, either going up or going down. (10) After 9 years it will be at highest latitude, (or) after 9 years it will be at minimum latitude. (11) To compute the maximum or the minimum latitude of the moon: the size of the moon is 12 fingers. (12) In a month the moon goes up or goes down $\frac{1}{9}$ of its size. (13) $\frac{1}{9}$ of 12 fingers is a finger (and) $\frac{1}{3}$ of a finger. During 12 months: 16 fingers, (namely) $\frac{2}{3}$ cubit. (14) (In other words), in a year it goes up or down $\frac{2}{3}$ cubit. Multiply $\frac{2}{3}$ cubit by 9, (15) (with the result that) in 9 years it goes down 6 cubits, the width of the path, from highest latitude to minimum latitude, (16) reaching its minimum latitude. In the 9 years remaining (to) 18 years, (17) it changes direction towards the highest latitude and reaches its highest latitude."

Since 6 cubits is the width of the path, the change from extrema to node or from mean to extrema is 3 cubits and it corresponds to the change in lunar position of 85° (= 3 *bēru* less 5°). Therefore a change in latitude of 1 cubit must take place over 28;20° (= 1 *bēru* less 1;40 UŠ). Over the distance of 1 *bēru* (≈ 1 schematic lunar month), the change in latitude will become a little larger - by an amount corresponding to the change over 1;40 UŠ. The text splits the change in latitude over 1 *bēru* up into two parts saying first in (9): for 1 *bēru*, two discs, either going up or down, and secondly in (12): in a month the moon goes up or goes down $\frac{1}{9}$ of its size = $1\frac{2}{3}$ fingers.[23] Adding the two contributions one gets:
In a month, the moon goes up or down 1 cubit plus $1\frac{2}{3}$ fingers. During 12 months (= the schematic year) the moon goes up or down $12 \times (1 \text{ cubit} + 1\frac{2}{3} \text{ finger})$ = 12 cubit (*i.e.*, the whole cycle) plus $12 \times 1\frac{2}{3}$ finger. The correction for 12 months, $12 \times 1\frac{2}{3}$ finger = 16 fingers = $\frac{2}{3}$ cubit, is found in (13) and identified with the correction for 1 (schematic) year in (14). The changes in latitude after 9 and 18 years are calculated. The simple linear scheme is used for tracing the cornerpoints which are moving slowly with time. After 9 years they have moved so far that a point of highest latitude will after 9 years become the place for lowest latitude; and after 18 years it will again be the position of highest latitude. The period of this latitude function is 18 years.

[22]) The Dodekatemoria was a crude scheme for lunar motion. It is based on the ideal year of 12 months of 30 days during which the sun moves forward one degree per day (and the moon moves 12 degree faster, *i.e.*, 13 degrees per day). On day D of Month M, the sun will be at degree D in sign M. During one month, the sun has moved 30° and the moon 390°, which is one complete revolution plus one sign = 30°. See L. Brack-Bernsen and J. M. Steele 2003, 104 and 118.

[23]) The units of lunar disc have in (13) been converted to cubits and fingers: two lunar discs = 2 UŠ = 24 fingers = 1 cubit, and $\frac{1}{9}$ disc = $\frac{1}{9}$ UŠ = $\frac{1}{9} \times 12$ fingers = $1\frac{1}{3}$ finger. In Late Babylonian times, the lunar disc was calculated as 1 UŠ, and the UŠ put equal to 12 fingers.

The same calculations are worked out in the following lines (17b-21); now by means of a [multiplication] table that uses sexagesimal fractions of *bēru* instead of cubits and fingers. Using the following conversion: the disc of the moon = 12 fingers = 1 UŠ = 0;02 *bēru*, the corrections or changes appropriate for 1 month, 12 months and 9 years are calculated again:

The correction for 1 month equals $\frac{1}{9}$ of the lunar disc

= $\frac{1}{9}$ × 0;02 = 0;00,13,20 (*bēru*).

The change after 12 months equals 12 × 0;00,13,20 = 0;02,40 (*bēru*) = 16 fingers.

The change after 9 years equals 9 × 0;02,40 = 0;24 (*bēru*) (= 12 UŠ) = 6 cubits, which is the width of the path.

## 6. *Mathematical comments and speculations*

Text E gives advice on how to calculate the lunar latitude from month to month by a simple linear scheme (a linear zigzag function which moves retrograde along the ecliptic by a constant amount per lunation). Below we speculate which linear zigzag function would emerge if we use the information from the text for its construction. As already mentioned above, the text seems to make much use of the ideal year, so we shall do that, too.

The recession of the lunar nodes over the period of a year is said to be 20 UŠ. (At the beginning of the next year the maximal latitude will be 20 UŠ before the Pleiades). If we use the schematic year of 12 months of 30 days and identify 30° with the schematic month of 30 days, then we get the values mentioned in the text. The recession of the node per month is 1;40 UŠ = 20 UŠ × $\frac{1}{12}$ and the recession per 3 *bēru* (*i.e.*, per 3 months) equals 5 UŠ.

At a first glance, it may sound quite strange to identify times with positions. Such a practice has, however, been found in different types of cuneiform texts, for example, in some Kalendertext schemes, where the zodiacal sign is replaced by the corresponding month's name.[24] It comes from the fact that the Sun roughly travels 1° each day and 360° per year in combination with a schematic year of 12 months of 30 days = 360 days.[25] Inspired by such a usage, we just read one month as corresponding to a displacement of 30°, and three months as 90°. In this way, the indications given in line 12-17 make sense and can be seen as instructions for finding latitudes according to a linear zigzag function. In a first approximation, the period of lunar latitude is taken to be 360° ≈ 1 year, and its variation over that period of time to amount to 12 cubits, however with a correction of 20° at the end of the year. In line 8 and 9, the text gives the amplitude of the moon's movement in latitude, and its variation after one month:

> Obv. (8) 6 cubits is the width of the path. (9) For 1 *bēru* (= 30° = 1 month), two discs either going up or going down.

As Neugebauer (1967, 203) and more recently also Steele (2003, 284), have pointed out, these statements are coherent if we accept the rather large value of 1 UŠ = ½ cubit for the lunar diameter. If the variation over 360° equals 12 cubits = 2 × 6 cubits, then the variation over 30° (corresponding 1 month) becomes 12 cubits × $\frac{1}{12}$ = 1 cubit = two lunar discs. This is the first approximation, a correction to it is given in line 12. The correction comes from the fact that the latitude period is 20° less than 360°, namely 340°.

If we were to construct a linear zigzag function fitting the parameters given in the text, we would say: over the period of (360 - 20)° = 340° the lunar latitude has run through its spectrum of latitude (from maximal to minimal latitude and back again to maximal latitude) a variation amounting to two times 6 cubits = 12 cubits.

"Our zigzag function" would have a total variation of 12 cubits in lunar latitude over the period of 340°. Note that 340 = 17 × 20, so that 18 periods of 340° equals 17 periods of 360° which is 17 years; but 17 is an odd and not very practical number. The text, however, has the period of 18 years. Clearly, it does not work in the same way as we who know the period to be 340°. It rather uses a method of successive approximation.

In the first approximation the slow backward movement of the nodes is ignored; the latitude is taken to have the period of 360° with a variation of 2 × 6 cubits = 12 cubits. Then the change in nodal position is taken into account by corrections. The approximation (360° change in longitude corresponding to 12 cubits change in latitude) is used for finding corrections appropriate for different periods of time. Knowing that the node has moved backward by 20° each year, the change in latitude per 20° is found to be 12 cubits × $\frac{20}{360}$ = $\frac{12}{18}$ cubits = $\frac{2}{3}$ cubit. This is the correction for 1 year or for 360°. Hence, the variation in lunar latitude over 360° will amount to 12 cubits + the correction of $\frac{2}{3}$ cubit = $12\frac{2}{3}$ cubits = $12\frac{2}{3}$ × 24 fingers = 12 × 24 fingers + 16 fingers = 304 fingers.

[24]) See L. Brack-Bernsen and H. Hunger 1999, 288.

[25]) This ideal year was since the 3rd millennium B.C. used for administration as a means of easy reckoning.

Correspondingly, the change in latitude over 30° equals 1 cubit (written in line 9 as two discs = 2° = 1 cubit) + a correction. The correction amounts to ($\frac{2}{3}$ cubit) × $\frac{1}{12}$ = $\frac{1}{18}$ cubit = $\frac{1}{9}$ lunar disc. This is just what is written in line 12: "In a month the moon goes up or goes down $\frac{1}{9}$ of its size". Thus we have that the total change in lunar latitude over 30° is 1 cubit + $\frac{1}{18}$ cubit = $2\frac{1}{9}$° = $25\frac{1}{3}$ fingers. These data are situated on a linear zigzag function with the amplitude of 6 cubits = 144 fingers.

Let us determine the period, $P_c$, of this linear zigzag function, *i.e.*, the number of degrees over which the variation of 12 cubits = 288 fingers in lunar latitude takes place. The variation in lunar latitude of 304 fingers takes place over 360°. A variation of 288 fingers will hence take place over $\frac{360°}{304}$ × 288 = $\frac{18}{19}$ × 360° ≈ 341.05°. If we identify 360° with a solar year (according to the schematic year, which is used in our calculation), we get the following relations:

$$19\ P_c = 18 \text{ Solar years} = 18\ P_\odot$$

To recapitulate: Text E stated that the highest lunar latitude after 1 year would occur 20° earlier than to start with. For calculating changes in lunar latitude, the text started out with the approximation 1 year F (corresponds to) 360° = 12 *bēru* F 12 cubits variation in lunar latitude. This approximation is then used for finding the correction ($\frac{2}{3}$ cubit) for the extra 20° = $\frac{2}{3}$ *bēru* (F $\frac{2}{3}$ cubit) which is finally used to correct the first approximation. A similar way of working with approximations can be found in mathematical texts.[26] The height and width of a door is given, its diagonal is to be determined. In a first approximation, the diagonal of the door is found. This first approximation is then utilized for determining a second and better approximation. It is worth mentioning that modern physics also uses this kind of successive approximation in the so-called perturbation theory.

This Babylonian way of working with approximations has a great advantage. The relevant numbers are handy: e.g., the change in lunar latitude after 1 month, *i.e.*, over 30° of longitude amounts to $25\frac{1}{3}$ finger. Had we used "our zigzag function" with the period of 340°, the numbers would have been very odd:
If 340° longitude correspond to 12 cubits = 288 fingers latitude, then we get that 30° longitude correspond to $\frac{288}{340}$ finger latitude × 30 = $\frac{144\times3}{17}$ finger = $25\frac{7}{17}$ finger, and this number is very hard to work with within the Babylonian sexagesimal system. "The Babylonian" and "our" linear zigzag function both have the amplitude of 6 cubits. Their slightly different periods result in the different values for the monthly variation on lunar latitude: the nice Babylonian value is $25\frac{1}{3}$ fingers, versus "our" value of $25\frac{7}{17}$ fingers.

We conclude: if the latitude of the moon is found as a function of its longitude according to the numerical advices given in section 1 of Text E, then one will get values situated on the linear "Babylonian" zigzag function described above. This function can then be combined with a numerical scheme describing the displacement of the full moon from month to month. This would lead to a latitude function for consecutive lunations which is, admittedly, more primitive than but still similar to the latitude function found in ACT. How the lunar latitude is worked out in column E of system A, is explained in detail by Aaboe and Henderson 1975, 196-211.

## An alternative interpretation leading to the same results:

We shall briefly mention another way of interpreting the first half of section 1, where for three consecutive years the positions (in longitude) of high, middle, and low lunar latitude were given by means of Normal Stars. The scheme started by indicating positions situated 85° apart. This led to our "rule of thumb" for finding the position of cornerpoints at three-month intervals. We saw the formulations: 5 NU KUR ... 3 *bēru* as a confirmation of the rule of thumb interpretation.

We refer back to the scheme in section 5 of this paper, where we compared the positions given in Section 1 of the Text E to the positions found by means of the rule of thumb. Some of the stars in the scheme could, however, point at another interpretation, so that we perhaps must see the text as a fusion of different but consistent systems. The third position in the second year is 5 UŠ from α Librae = 188°. It is exactly 180° from the starting point of the second year which was located at the longitude of 8° = 20° from η Tauri. This could point at the situation where the moon is observed continually (through all phases) during a single synodic month. If the lunar latitude is surveyed from day to day throughout the synodic month, then the cornerpoints are found to be situated 90° apart. According to this understanding, the scheme gives the position of the cornerpoints for three idealized synodic months, *i.e.*, for the month M of three consecutive years. A few of the positional stars seem

[26]) See J. Høyrup 2002, where he treats VAT 6598 (6-7) on pp. 268-272.

to support this reading, although we must admit that the positions are only given very roughly. Therefore both interpretations are plausible.

The alternative reading delivers the concept of a slowly moving “zigzag curve” on the sky, where the cornerpoints were situated 3 *bēru* = 90° apart. A positional change of 90° corresponds to a variation in latitude of 3 cubits. In this idealized case, the full moon moves by 1 *bēru* = 30° each synodic month, resulting in a 1 cubit variation of the lunar latitude. However, during that period of time the “zigzag curve” has also moved by 1;40 UŠ. As a consequence, the variation in latitude would become larger by the amount of $1\frac{1}{3}$ finger. Note that this interpretation is again based on the schematic month during which the moon has moved (360° +) 30°. And the result of the calculations will, of course, be the same as above. The change in lunar latitude after 1 month is found as the sum of two contributions:

1 synodic month F 1 *bēru* F 1 cubit variation in lunar latitude,

1;40 UŠ shift of cornerpoints F $1\frac{1}{3}$ finger variation in lunar latitude,

total change in lunar latitude = 1 cubit + $1\frac{1}{3}$ finger.

The corrections are here interpreted as a consequence of the slow movement of the cornerpoints. They are, as above, found by linear interpolation within that linear zigzag function with period 360° and amplitude 6 cubits which we above called the first approximation to the lunar latitude.

Shift of cornerpoints after 1 year = 20 UŠ F $\frac{2}{3}$ cubit change in lunar latitude.

Shift of cornerpoints after 1 month = 1;40 UŠ F $\frac{2}{3}$ cubit × $\frac{1}{12}$ = $1\frac{1}{3}$ finger.

Shift of cornerpoints after 9 years = 180 UŠ F 6 cubits.

Shift of cornerpoints after 18 years = 360 UŠ F 12 cubits.

For both interpretations of section 1, we end up with the same numerical values for the lunar latitude. They represent a linear zigzag function moving slowly with time, so that it will be back to the starting situation after 18 years.

## 7. *Short notes on numbers*

### 18 years or 19 years?

As shown above, a “Babylonian” zigzag function for lunar latitude, constructed according to instructions given in the text, is based on the following period relation:

$$19\ P_c = 18 \text{ solar years} = 18\ P_\odot$$

This may revive the discussion on the 19 years, mentioned in the beginning of section 4, which again takes up the subject of lunar latitude. We read Section 4 as referring back to section 1.

> “(18) In 19 [Periods = 18] years the moon will come close to the place of the Normal Stars where it came close (before). Where the moon made an eclipse, it will make (one again). (19) When it took a highest (position) (or) when it took a lowest (position), it will repeat(?) it in your year. You determine the full (months) and the hollow (ones).”

This part of the text has caused a lot of discussion: Neugebauer (1967, 205) writes that “The mention of the 19-year cycle is surely a mistake for the 18-year eclipse cycle” while Moesgaard (1980) and later Koch (2001) strongly argue for the reading 19 years = 235 synodic months also called Meton’s cycle.

Earlier, we tended to agree to Moesgaard’s and Koch’s arguments; but now we have found support for Neugebauer’s proposal to correct the number 19 years to 18 years. Section 4 mentions eclipses and full and hollow months - but clearly also lunar latitude, which, according to Section 1, will repeat after 18 and not after 19 years. But 18 years equals 19 periods (19 $P_c$). It is possible that the much discussed passage in Text E section 4, referring to the latitude function in section 1, was meant to say something like 19 periods of latitude equals 18 years. Hence after 19 periods which equals 18 years, all lunar phenomena which are connected to the latitude will take place (again) at the same place of the sky, according to that model.

Be that as it may, we can even give further support for the reading 18 years: in line (19) the text tells the scribe to determine the length of the month. In the procedure text TU 11, six different methods are collected for predicting the length of a lunar month.[27] Two of these methods use data from lunations taking place 18 years (= 223 synodic months) earlier, but none of the methods mention some 19 years or 235 months. The only really good and elegant Babylonian method for the prediction of the length of lunar months utilizes the Goal-Year method (which is heavily based on the 18 year cycle = 223 months) and it will give the

[27]) See L. Brack-Bernsen 2002.

correct month length in 97 per cent of all cases.[28] This method was well known at the time when Text E was written and it is to assume that its scribe knew and referred to that method.

## 8. *Conclusions*

Section 1 of Text E is concerned with the latitude movement of the moon. The movement of lunar nodes and extrema is followed over three years according to a simple rule of thumb. In steps of three months, the positions (in longitude) of the cornerpoints are found: go 3 *bēru* minus 5 UŠ forward in order to get from one cornerpoint to the next, *i.e.*, to get from extrema to node and from node to extrema. Normal Stars are used as reference points. Then the amplitude in latitude is said to be 6 cubits, and indications are given how to calculate the lunar latitude according to a simple mean value scheme. Between the lines of section 1 we see a heavy use of the schematic year of 12 months à 30 days and the often occurring identification of times and positions. It is used as a convenient approximation to nature. We try to illustrate how the schematic year and the corresponding schematic movement of the moon may have been utilized as a practical tool for the construction of a linear zigzag latitude function.

Therefore, if our understanding is correct, we have here a text which shows us some of the steps taken by the Babylonians on their way towards a mathematical description of lunar latitude: starting from observation - a simple rule of thumb is found - which serves as a basis for the construction of a linear zigzag function for lunar latitude. Hereby the ideal year and its connection to changing positions of the ideal "full moon" is used as an easy approximation.

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[28]) See Brack-Bernsen and Hunger 2002, 53.

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