Mediterranean Archaeology and Archaeometry, Vol. 16, No 4, (2016), pp. 167-173

10.5281/zenodo.220916

THE BABYLONIAN ASTRONOMICAL DIARIES: A GRAPHICAL ANALYSIS OF THEIR IMPLIED REFERENCE SYSTEM

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Received: 22/02/2016
Accepted: 04/04/2016
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ABSTRACT

The intent of this study is to describe the directional relations employed in the Babylonian Astronomical Diaries and visually demonstrate their function with charts showing positions of the Moon, planets and stars as viewed on dates corresponding with diary entries. The Babylonians observed and recorded celestial events each night for over six centuries during the first millennium BC. A number of cuneiform tablets containing these astronomical diaries have been recovered and were later translated by Abraham Sachs and Hermann Hunger. The majority of diary entries track the position of the Moon with reference to 31 "normal stars," all within 10 degrees of the ecliptic. Entries specify the moon as being "above," "below," "in front of," or "behind" a second body by a specified distance in "cubits." The extant tablets fail to adequately define the reference system used for the topographical relations. Computer-generated star-charts that are specific for the date and location of selected diary entries show a general interdependence between the topographical relations and the celestial course of the Sun, Moon, and planets. John Steele has discussed the Babylonians as having considered the Moon and planets to move through the zodiac within their own individual bands. This is considered with regard to graphical data that represents a distinct correlation between diary descriptions and the path of the general direction of ecliptic travel.

KEYWORDS: Babylonian, astronomical diaries, normal stars, cuneiform tablets, cubit, finger

1. INTRODUCTION

Early Babylonians believed strongly that their gods signaled to them, by way of natural signs, warnings of imminent ill fortune. These portents bode for the city-state and its king, not for the private individual. The principle means of prognostication during the second millennium was the search for divine warnings given in the condition of livers of sheep. Later, as astronomical observations and predictions became more exact, celestial omens grew to become the primary source of divination for the welfare of the nation (Snell, 1997; Barton, 1994; Britton and Walker, 1996; Verderame, 2015).

Babylonian scribes recorded heavenly phenomena nightly for at least six centuries. The compilation of these astronomical diaries may have commenced sometime after the reign of Nabonassar (747-733 BC), preserving data in cuneiform on clay tablets. Abraham Sachs and Hermann Hunger have published the Akkadian transliteration and English translation of these texts. The oldest surviving diary entry is from 652 BC and the most recent from 61 BC (Swerdlow, 1998; Hunger, 1999; Steele, 2015).

Astronomical scribes recorded lunar, planetary, meteorological, economic, and political events. The changing positions of the Moon and planets were often referenced to a set of "normal stars" lying near the ecliptic. The diaries do not define the orientation of these observations or the dimensions of a cubit, nor do they specify the exact time of night that the recordings were made (Graβhoff, 1999).

I approach these questions though graphical analysis with computer software used to generate specific star-charts in order to examine selected diary entries in the search for a frame of reference.

Analytical results for each selected day include comments describing the bodies referenced in the diary entry, examination of the associated topographical relations, and individual angular dimensions of the cubit. Errors in observation or translation brought to light in the graphical analyses are noted. While no effort has been made to isolate the exact time of each entry, certain observations gave significant astronomical clues as to when they might likely have been made. Whenever applicable I have recorded this information.

Data tables have been prepared containing coordinates for the bodies in question, differences in celestial longitude and latitude, cubit distances in relation to these coordinates, and correlations with the topographical relations. Also prepared are computer-generated star-charts corresponding with each selected diary entry. The charts depict the Babylonian skies in a perspective similar to that presumably seen by the scribe recording the observation.

2. ASTRONOMICAL DIARIES

Abraham Sachs began translation of cuneiform tablets containing diary entries of astronomical observations and his work was completed by Hermann Hunger, published in three volumes with plates. Tablets recovered to date range between 652 and 61 BC, mostly from Babylon and Uruk. Only after 400 BC are entries extant in any significant number. The *Diaries* include astronomical entries relating positions of the moon and planets to the normal stars, as well as other lunar data, information concerning solstices and equinoxes, Sirius phenomena, and meteors and comets. Positions are sometimes predicted rather than observed. Certain entries also relate non-astronomical occurrences regarding weather, prices of commodities, river levels, and historical events. Observational methods appear to have remained essentially the same throughout the undertaking. It is estimated that tablets have been recovered for as few as five percent of the months during the period of the *Diaries* (Sachs and Hunger, 1988; Graβhoff, 1999; Evans, 1998; Swerdlow, 1998; Rochberg, 2000; Hunger, 1999; Steele, 2015).

Many of the astronomical entries describe topographical relations between celestial bodies. In each case the first body is denoted as being "above," "below," "in front of," or "behind" the second. A distance in cubits (KÙŠ) and/or fingers (SI) is normally included. The larger percentage of observations are closer to sunset or sunrise, perhaps allowing a scribe to sleep during the middle of the night (Graβhoff, 1999; Swerdlow, 1998; Sachs and Hunger, 1988). The *Diaries* never define exact time of observation, units of measure, or the system used to reference these topographical relations. My study approached these questions graphically with the thought that visual analysis could provide further insight.

When a relation states that a planet is "above" a star it is north of the star, and if "below" it is south (Jones, 2004). "In front of" is west and "behind" is east. Swerdlow (1998) has argued the irrelevance of the actual ecliptic to the Babylonians, and that instead the Sun, Moon, and planets for them moved within a band sectioned into regions by the zodiacal signs. Steele (2007a) describes the Babylonians as considering the Sun, Moon and five planets to travel in bands approximately parallel to the ecliptic, with their movement described by topographical relations in regard to those bands. He states that the relations of "above" and "below" were not distances perpendicular to the ecliptic. These measurements instead were distances within the band of travel while the body advanced through the signs of the zodiac (Steel, 2007a; Steele, 2007b). Following examination of Normal Star Catalog BM 36609+, Roughton, Steele, and Walker (2004) found the two extremes of the Moon's latitude band to have been six cubits wide, an important discovery that defined a band of travel. The graphical depictions of this study examine such movement.

3. METHODOLOGY

My evaluation of the reference system utilized by Babylonian scribes necessitated examining diary entries pictorially, as well as quantitatively, using graphical astronomical software. For this I selected Chris Marriott's SkyMap Pro (Marriott, 2012). It generates charts accurate to plus or minus 6000 years from the present, easily encompassing the first millennium BC time-frame of the *Diaries*.

I verified the accuracy of SkyMap by comparing its positions with those generated by NASA's Jet Propulsion Laboratory on their *Horizons* non-graphical ephemeris-calculating site. The entering arguments for SkyMap begin with the location of the observer. For that I chose 33° 19′ 42″ north latitude and 44° 25′ 47″ east longitude, the coordinates for Baghdad, which can be pre-selected within the software. There are forty-eight minutes difference in latitude between Babylon and Baghdad, and one minute difference in longitude, depending on the precise point of geographic measurement. Thus Baghdad is approximately 89 kilometers north of Babylon, giving the same relative sky perspective for these purposes in either location. Testing done with positions for both Babylon and Baghdad revealed no perceptible visual difference for the stars and planets and an insignificant mathematical difference for the Moon only. Final results were normally unaffected and, at worst, made a difference in angular degrees per cubit that varied by no more than one one-hundredth of a decimal degree. SkyMap automatically adjusts the time zone for Baghdad to be 180 minutes ahead of UTC. Baghdad is approximately 177 minutes, 40 seconds and Babylon 177 minutes, 36 seconds of time-difference ahead of UTC. Through comparative analysis I found this variation also to be imperceptible for observational purposes.

SkyMap uses Terrestrial Dynamic Time (TDT) internally for its computations. The user specifies time in local time converted to UTC that then is internally converted to TDT. The difference, or *delta T*, between TDT and UTC is about 1 minute and increases at less than 1 second per year (Marriott, 2012). Star positions are computed with corrections for proper motion, precession, nutation, and aberration. The program's primary star catalog is the Tycho 2 Catalog.

Positions for the Sun and planets during the first millennium BC are computed by SkyMap using the Bretagnon and Francou "VSOP87" (Variations Seculaires des Orbites Planetaires) planetary theory. VSOP87 claims precision to within 1″ +/- 4000 years from J2000 for Mercury through Mars and somewhat less for Jupiter and Saturn. All planetary position computations in SkyMap begin heliocentrically and are then reduced to geocentric coordinates with corrections made for light time, gravitational deflection, and aberration. Finally the result is converted to topocentric coordinates. Moon positions are computed from the ELP 2000-82B lunar theory. Accuracy is to within 0.01″ (Marriott, 2012). SkyMap proved very capable in accurately plotting ancient celestial positions.

I selected representative entries from throughout the 591-year span of the *Diaries* according to the following criteria: first I attempted to find months that were very complete in their entries, that is months in which entries for most days have been preserved and translated. Next I tried to find the first such month closest to the beginning of the extant *Diaries*. No suitable entries were found until 568 BC and then they still did not yet reflect months that were complete. Wherever possible I avoided those months missing numerous daily entries or with entries appearing subject to excess interpretation in translation. Months fully satisfying my criteria were not found regularly until 309 BC. Having established a starting point in 568 BC, I attempted to find an acceptable month every 20 – 30 years throughout the span of the *Diaries*. Analyzing entries for entire months had the additional benefit of facilitating the evaluation of monthly patterns of observation by the Babylonians as each lunation progressed.

The *Diaries* are recorded in regnal years, but entry into SkyMap is with Julian dates, thus necessitating a conversion. Sachs and Hunger provided a key for most months to facilitate this calculation. Because the Babylonian year begins with the vernal equinox, care must be taken with months X through XII. While in the same Babylonian year, parts of month X and all of months XI and XII fall in the next Julian year.

I next selected a suitable local hour within the proper context of the specified Babylonian watch of the night. I first examined the "beginning of the night" as 1 seasonal hour after sunset and "first part of the night" as two seasonal hours after sunset. "Middle of the night" I maintained as the midpoint between sunrise and sunset and for "last part of the night" I used 2 seasonal hours before sunrise. Ultimately I came to use 1 seasonal hour after sunset for both the beginning and the first parts of the night and 1 seasonal hour before sunrise for the last part of the night as these times seemed best to fit the descriptions recorded in the diary entries. Evans (1998) was used in my estimation of the seasonal hour each month in Babylon. The Babylonian day begins and ends with the sunset. As a result the entries for "middle of the night" and "last part of the night" fall on the following Julian day.

4. CHARTS

Perhaps the most immediate and telling data is that found in the software-generated star charts drawn of the Babylonian sky. A chart was generated for every position selected for the study and was captioned with the reference date given that day by Sachs and Hunger (1988):

-372 I 12

The text of the diary entry, beginning with the reference line from the diary page, is included as well.

8 [Night of the 12th], first part of the night, the moon was 2 cubits behind alpha Virginis.

The first specified body is centered in the middle of each chart. The second body is normally found near the first. The zero-degree horizontal grid line represents the horizon, below which any body is no longer in the observer's field of view. Also depicted is the celestial equator with its associated right ascension. Additional gridlines represent the ecliptic coordinate system, in reference to the apparent path of the Sun. The bottom of the chart lists time and day in both local time and UTC.

The ecliptic is represented on the charts as a heavier line across the same part of the sky as the first and second bodies. It is labeled with degrees of celestial longitude that increase from west to east, normally in 30-degree increments. The ecliptic grid system also includes lines of celestial latitude, with zero degrees at the ecliptic and +/- 15 degrees as the next lines above and below in the standard size depiction. The horizon grid system runs from top to bottom on the charts. The celestial North Pole is at 90 degrees and the horizon is a slightly heavier black line at zero degrees. Intermediate lines of altitude are given every 15 degrees in the normal depiction. Azimuth is measured from north and is given in 30-degree increments, increasing from left to right. The celestial equator is shown as a heavier black line labeled with hours of right ascension. These increase from west to east and are denoted with a cross and the corresponding hour. I chose not to include grids for declination so as to reduce clutter on the charts. If not otherwise stated, chart references in the analyses are made with respect to the ecliptic.

It was necessary to examine entries from the *Diaries* in relation to the ecliptic. SkyMap did not give apparent topocentric ecliptic coordinates and gave heliocentric ecliptic coordinates only for the planets. As my requirements were for topocentric ecliptic coordinates of all bodies, it was necessary to use spherical trigonometry for transformations to the proper format.

5. ANALYSIS

The year and month are listed first and are then followed by the reference date and its Julian equivalent. The text of the scribal entry is given first in Akkadian, is followed in English in italics. Each section concludes with a brief analysis below the chart. The analyses may include such as the introduction of the Akkadian and modern names of the normal stars, the position of the first body in relation to the second body in angular degrees of longitude or latitude, the associated angular equivalent of a cubit in degrees of longitude or latitude, and analytical observations and comments. When an estimate of the time of observation can be made, that information is included. The following four representative examples, taken from hundreds in the greater study, demonstrate the insight gained with these graphical depictions:

VOLUME I – DIARIES FROM 652 BC TO 262 BC (Sachs and Hunger, 1988)

NEBUKADNEZAR II YEAR 37, *Simānu* (SIG)
-567 III 8
(27 – 28 June 568 BC)

GE$_6$ 8 USAN 2 ½ KÙŠ *sin šap* RÍN *ša* SI GUB

Night of the 8th, first part of the night, the Moon stood 2 ½ cubits below β Librae.

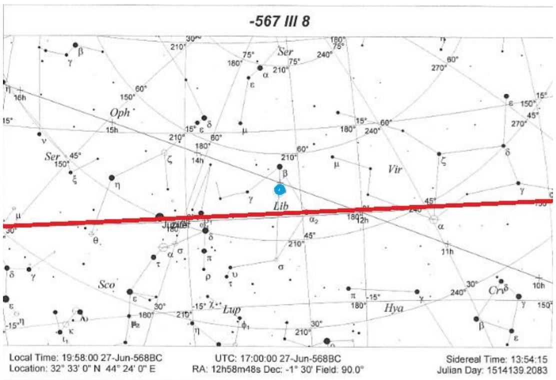

Figure 1. -567 III 8

Zubeneschamali is the common name for β Librae (β Lib). The Babylonians knew it as RÍN *šá* SI, or "The northern part of the Scales." *Zubenelgenubi*, or α Librae, is RÍN *šá* ULÙ, "The southern part of the Scales." The orientation of "north" and "south" is shown here as being perpendicular to the ecliptic, as the two stars are separated by a difference in celestial latitude. At 20:00 the Moon was 4.27 degrees of latitude below β Lib at 1.71 degrees per cubit. Oriented with the ecliptic the Moon was nearly directly below β Lib.

DARIUS II YEAR 5, *Ajjaru* (GU$_4$)
-418 II 7
(1 – 2 May 419 BC)

GE$_6$ 7 *sin ina* IGI AN 2/3 KÙŠ *i sin ana* SI NIM

…night of the 7th, the Moon was 2/3 cubit in front of Mars, the Moon being a little high to the north.

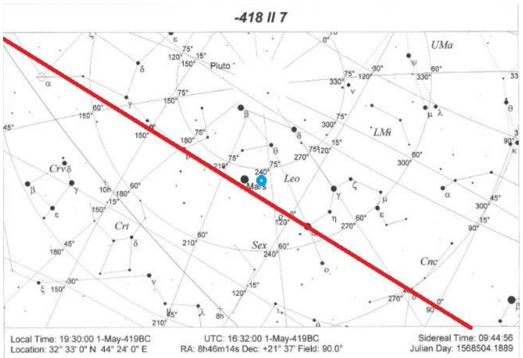

Figure 2. -418 II 7

At 20:00 the Moon was 2.40 angular degrees of longitude in front of Mars at 3.61 degrees per cubit. When viewed in relation to the ecliptic, it was also "a little high to the north." The given rate of 3.61 degrees per cubit is a little high. An observation taken 1 seasonal hour later puts degrees per cubit into a more acceptable range and still fits the diary description. The discrepancy in this example may be due simply to the selected time of entry.

ARTAXERXES II YEAR 32, *Nisannu* (BAR)
-372 I 18
(13 – 14 April 373 BC)

GE$_6$ 18 USAN *dele-bat* SIG ŠUR GIGIR *šá* SI 1 ½ K[ÙŠ]

Night of the 18th, first part of the night, Venus was 1 ½ cubits below β Tauri.

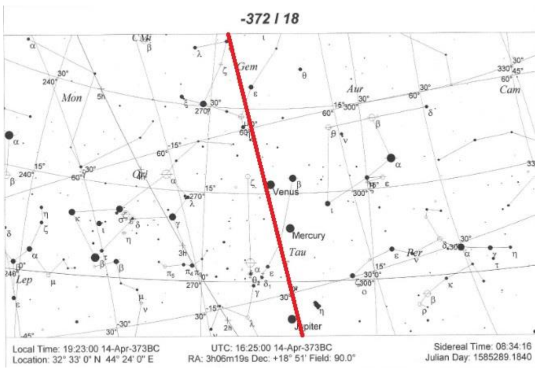

Figure 3. -372 I 18

In the Julian calendar this observation was made in the evening of the same day as the previous morning entry. At 19:00 Venus was 4.10 degrees of latitude below β Tau at 2.73 degrees per cubit. It was positioned both below and slightly in front of β Tau.

VOLUME II – DIARIES FROM 261 BC TO 165 BC (Sachs and Hunger, 1989)

SELEUCID ERA YEAR 93, *Araḫ-samnu* (APIN)
-218 VIII 4
(31 October – 1 November 219 BC)

GE$_6$ 4 SAG GE$_6$ *sin ár* SI MÁŠ 1 KÙŠ *ár* GENNA 2 KÙŠ *ana* NIM GUB

Night of the 4th, beginning of the night, the Moon was 1 cubit behind β Capricorni, it stood 2 cubits behind Saturn to the east.

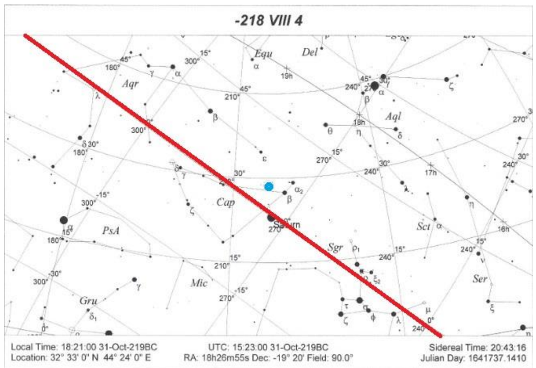

Figure 4. -218 VIII 4

At 18:22 the Moon was 3.14 degrees behind β Cap at 3.14 degrees per cubit – a value that is slightly too large. The Moon also was 3.76 degrees of longitude behind Saturn at 1.88 degrees per cubit. If the observation had been taken earlier then Saturn's degrees per cubit would be too small. If it would have been taken at a later time then β Cap's degrees per cubit would grow too large.

6. DISCUSSION

In the search for an orientation system for the Babylonian astronomical diaries one must first ask "why?" Indeed, what did inspire Mesopotamian celestial interest? An answer is that of practical value – value in devising and regulating a lunar calendar and, more importantly, in developing and refining the ability to detect omens foretelling the future of the king and the nation.

Nearly as early as written records exist we find references to stars in proximity to the Sun, Moon, and planets. As interest in celestial omens grew, so did the attention paid to these heavenly bodies. The planets' relative positions were thought to relate messages from the gods, messages warning the king of impending danger. Close attention was paid to their exact location, the stars they were near, their proximity to one another, and the courses they followed across the sky. It is this interest that taught the Babylonians of the celestial path travelled by the planets and inspired their invention of the zodiac as a system of reference for omen observations. While the Babylonians may not have perceived the ecliptic as we do today, they were most definitely aware of the direction of travel taken by the bodies they called "interpreters" (Swerdlow, 1999).

This "ecliptic region" appears to have been a primary focus of Babylonian astronomy and astrology. All 31 "normal stars" selected for reference in the *Diaries* lie within ten degrees of the Sun's path. Passages in MUL.APIN and *Enūma Anu Enlil* highlight celestial bodies within this same vicinity. Divining the future focused attention on the Moon and the planets and this, in turn, gave the Babylonians a frame of reference related to movement in this portion of the night sky.

Twenty-two of the "normal stars" have names that specify "front," "rear," "northern," "southern," or, in the instance of Scorpius, "upper," "middle," and "lower." The orientation of "front" and "rear" appears to be in direct relation to the diurnal travel of celestial bodies. The object rising and setting first is "front," while the trailing body is "rear." This correlation also holds true in the *Diaries* where topographical relations of "in front of" and "behind" follow the same convention. Northern, southern, upper, middle, and lower all circumstantially correlate with celestial latitude and are for practical purposes perpendicular to the path of planetary travel. The same holds true in the *Diaries* for topographical relations of "above" and "below."

This dependence becomes much clearer when viewed graphically with the star-charts. These pictorial representations, more than any other evidence, demonstrate direct correlation between the topographical relations and the direction of travel of the Moon and planets. It is important to note, however, that these relations are only of a general nature.

This study also examined the dimension of a cubit in angular degrees. Computations were strictly an arithmetic calculation of the difference in either celestial longitude or celestial latitude. The average of all values in the study gives a cubit as being 2.39 angular degrees, very close to the number that was originally suggested by Graβhoff (1999). This, however, includes values for the Moon that are by nature somewhat less precise due to the speed of the Moon's travel and the uncertainty of the exact time of observation. When Moon-related values are extracted, leaving only those taken with the much slower planets, the average becomes 2.22 angular degrees. Alexander Jones (2004) found a cubit to be approximately 2.27 degrees.

My effort to isolate the actual time of observation for suitable scribal entries was purely speculative, but proved to be most interesting. "Selected time of entry" was the point I chose to begin each analysis. In a number of cases the proximity of the body to the horizon at rising or setting and the time of sunrise or sunset narrowly defined the possible window in which the observation could have occurred. Such an example is that of –77 IV 28 where at 04:11 Venus was still below the eastern horizon. While there certainly are exceptions, the great majority of entries seem to imply that data was recorded during the first two hours after sunset or the last two hours before sunrise. This practice could be logical in keeping with an observational program designed to produce dependable long-term results as it allowed scribes to get a reasonable amount of rest. Some entries do occur during the middle of the night, but they are by far in the minority.

Also of interest are errata discovered in diary entries by the graphical analysis. Visual display on the star-charts proved to be a most valuable tool. Some diary entries by the scribes were so far off that no time adjustment could make them right. In the entries chosen for this study were found six cases where the positions given were entirely wrong, either as recorded by the scribes or in later translation. The entry for –567 I 9 was one day off and is so noted by Sachs and Hunger. On –288 VII 27 the entry describes Jupiter when Mercury actually was located nearest the specified position. A relation of 10 fingers above is given on –246 I 10 when the body is really 10 fingers below. The entry for –190 III 18 is also one day off but, in this instance, was not described as being so in the diary notes. In –140 XI 20 the Moon is above, not below, and in –77 IV 3 it is east and not west.

The *Astronomical Diaries* appear to have been compiled in part to refine celestial divination and its search for omens with keys to the future. Priests and scribes closely observed the positions of the Moon and planets. This gave rise to an orientation regarding the direction that these bodies travelled, and stars were named accordingly. This data shows that "in front of" and "behind" loosely relate to differences in what we know to be celestial longitude and "above" and "below" to that of celestial latitude. The corresponding star-charts clearly depict these relationships. There is no known direct correlation, however. While early Babylonians could have perceived the path of the Sun across the stars of the zodiac, they would not have had to for these purposes. One need only observe nightly celestial travel to imagine relations of "in front of" or "behind." "Above" and "below" are then easy extensions describing relations perpendicular to this path. Based upon the findings of this study, it is probable that the topographical relations utilized by Babylonian scribes in the *Astronomical Diaries* were in correlation to the general path of ecliptic travel, the direction of movement for the Sun, Moon, and planets. There is no evidence of a specific relationship to the exact ecliptic, however, and no evidence was found of any specific coordinate reference system. These findings show a general relationship with the direction of travel around the ecliptic, but they do not discount the assertions of Steele (2007a; 2007b) regarding movement of these bodies in bands that only parallel ecliptic travel.

The many date/location-specific star-chart depictions created for this study proved to be most useful tools for confirmations, perspective, and insight.

ACKNOWLEDGEMENTS

I wish to thank Jamil Ragep, Daniel Snell, Rufus Fears, Tibor Herczeg, and James Evans for their comments and support.

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