

FIRST LUNAR CRESCENTS FOR BABYLON IN THE 2nd MILLENNIUM B.C.

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Babylon's position in absolute chronology is established via the citations of astronomical phenomena on cuneiform tablets and as astronomical phenomena repeat more or less cyclically it is of vital concern to fit these data optimally to the framework of absolute astronomical chronology.

Astronomical research methods and data applied to ancient Mesopotamia have now been carried out for almost 130 years for ancient observations as well as divination – started by Johann Nepomuk Strassmaier and Joseph Epping.³ A special task is the application of the value of the mean synodic month leading to a forecast of the visibility of the first lunar crescents for each month, especially for the city of Babylon. For modern verifications it is thus of great importance for historians to possess tabulated values for the first lunar crescent phases near the western horizon. As a matter of fact these earliest lunar crescent's visibilities are still an unsettled matter among modern astronomers. Observations of the young crescent depend on astronomical and atmospheric factors as well as human vision. Thus a reconstruction of the actual first lunar crescent observations can yield to uncertainties of at least 1 day.

According to H. Thurston⁴ recorded astronomical data of the Babylonians date back almost 3800 years from now. Further, as Babylonian "Astronomical Diaries" comprise recorded and somehow crudely predicted astronomical events – available in written down form starting from the 8th century B.C. – by advice of H. Hunger⁵ it seemed reasonable to cre-

ate a list of the first lunar visibility from –2000 until 1.⁶ The commercially available astronomical package UraniaStar⁷ and the applied algorithms of J. Meeus⁸ used therein have both already been tested on reliability for astronomical calculations in M. Firneis and M. Rode-Paunzen⁹ using the semi-analytical lunar theory of J. Chapront:¹⁰ ELP 2000.

In this treatise the first lunar crescents for Babylon are only given for the 2nd millennium B.C. while in Anderlič' master's thesis¹¹ values from 2001 B.C. until A.D. 1 were calculated. The complete data set for the 2002 year lunar crescent visibilities may be accessed via http://www.univie.ac.at/EPH/Geschichte/First_Lunar_Crescents/Main.htm. In these tables the date of the crescent phase is given in the Julian calendar – using the astronomical and historical notation. Though the setting time of the sun was calculated for the Eastern European time-zone, the usual day fraction is given in the Julian day fraction starting at 12^h Universal Time; this is an astronomical convention. Further the topocentric apparent geometrical altitude of the moon at the beginning of civil twilight¹² – refraction included – is given as well as the altitude of the moon at the end of civil twilight.¹³ Also the parameters delta azimuth, illuminated fraction of the moon and the so called lunar age are given in the tables of this publication. Because of the uncertainties explained above the list includes all important astronomical data needed to find the first visibility of the lunar crescent with the help of the cuneiform texts where – as the city

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² Austrian Academy of Science, Commission of Astronomy.

³ O. NEUGEBAUER, *A History of Ancient Mathematical Astronomy*, (Berlin 1975), 348.

⁴ H. THURSTON, *Early Astronomy*, (New York 1994), 64.

⁵ H. Hunger personal communication 2001.

⁶ In historical notation 2001 B.C. until A.D. 1 since the year called zero is missing in the historical notation.

⁷ M. PIETSCHNIG and W. VOLLMANN, UraniaStar (version 1.1, November 1995).

⁸ J. MEEUS, *Astronomical Algorithms*, (Richmond 1998).

⁹ M.G. FIRNEIS and M. RODE-PAUNZEN, *The Synchronisation of Civilisation in the Eastern Mediterranean in the Second Millennium B.C. II*, Progress report on Egyptian Astrochronology (Wien 2003), 47.

¹⁰ M. CHAPRONT-TOUZÉ and J. CHAPRONT, *Lunar Tables and Programs from 4000 B.C. to A.D. 8000*, (Richmond 1991).

¹¹ U. ANDERLIČ, *First Lunar Crescents for Babylon (2001 B.C. to A.D. 1) and Nineveh (701 B.C. to 600 B.C.)*, Master's thesis (Vienna University 2003).

¹² The centre of the sun exactly sets on the western horizon.

¹³ The sun is 6° below the western horizon.

Anderlič-Firneis Criteria	Boundaries		Extreme boundaries	
	Minimum value	Maximum value	Minimum value	Maximum value
Illuminated fraction [%]	0.01	0.03	0.01	0.1
Age [days]	0.6	1.9	0.5	3.1
Altitude (Beginning) [°]	5.79	20.48	5.79	20.48
Altitude (End) [°]	1.90	15.65	1.90	15.65

Table 1 Explanation for the different values used for the first lunar crescent visibilities

of Babylon lies in a very flat plain – the first lunar crescent could have been observed, assuming clear weather, in a very early phase within an accuracy of about 2° ¹⁴ by the Ancients.

Contrary to the lunar crescent visibility boundaries used by Firneis and Rode-Paunzen¹⁵ some of these limits have been exaggerated in cases where the small differences in the criteria can be explained with the smaller number of cases in the data-base used for Egypt as well as the different geographical position of Egypt. This has been proved by comparing the data-set for Nineveh and Babylon with each other, where the dates for the first lunar crescent observation were in accord in more than 93%. The different dates occurred because of the different geographical longitude as well as latitude of both cities.¹⁶ The difference between the criteria used by FIRNEIS *et al.*¹⁷ and the ones used in this treatise is that a visibility of the young moon closer to the horizon has been allowed for. The dates for the first lunar crescents – obtained with the present criteria – give the theoretical possibility of a first lunar crescent observation under optimal conditions where in some cases the possibility of the first lunar crescent sighting lies very close to the boundary of invisibility. Nonetheless at least such a date is a good starting point for a trial correlation (Table 1).¹⁸

Detailed analysis on the actual variation of the synodic month – that is the real time span from the new moon phase to the next one – shows a “Gaussian” distribution as expected (Fig. 1). On the other

side the variation of the time-span from the first lunar crescent to the next one at the beginning of civil twilight shows two primary maxima and a secondary one in its distribution (Fig. 2). The difference between first crescent visibilities shows the typically 24 hour spaced peaks, because either the first crescent can be seen in a low altitude or in a higher one on the next day. Even a small 3rd peak may arise 48 hours later because the illuminated lunar fraction may escape the human vision 24 hours earlier. As the shortest time-span found between two first lunar crescent appearances lies at 28.9736 days the basic value for the graphs was chosen to be 28.9000 days.

When looking at the graphs for the *lunar age* after the conjunction at the beginning and end of civil twilight two rather similar shapes appear (Fig. 3) – only half-day steps are used for this age-parameter since ancient times. At the end of civil twilight the decline of the curve is more pronounced as the lunar age closer to the horizon will increase, but – as a logical conclusion – the histogram area is more or less constant. A similar feature emerges when comparing the two histograms of the *illuminated fraction* of the moon at the beginning and end of civil twilight (Fig. 4). The *altitude* of the moon in crescent phase at the beginning and end of civil twilight as expected shows a nearly equal shape shifted by a mean value of 4.86° for the crescents near the end of civil twilight (Fig. 5 and 6). As a minimal lunar height a value of 1.90° was permitted. Of course a higher number of low-altitude events show

¹⁴ J.M. STEELE, F.R. STEPHENSON and L.V. MORRISON, The accuracy of eclipse times measured by the Babylonians, *Journal for the History of Astronomy* 28, Part 4 (November 1997), 345.

¹⁵ See note 9.

¹⁶ See note 11.

¹⁷ See note 9.

¹⁸ See note 11.

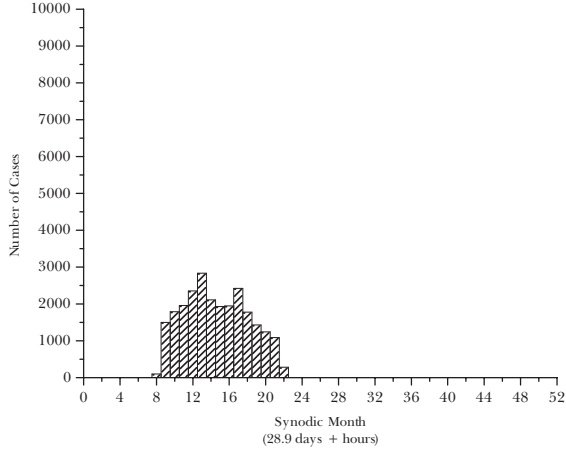


Fig. 1 The length of the synodic month shown in hours with a start-off value of 28.9 days

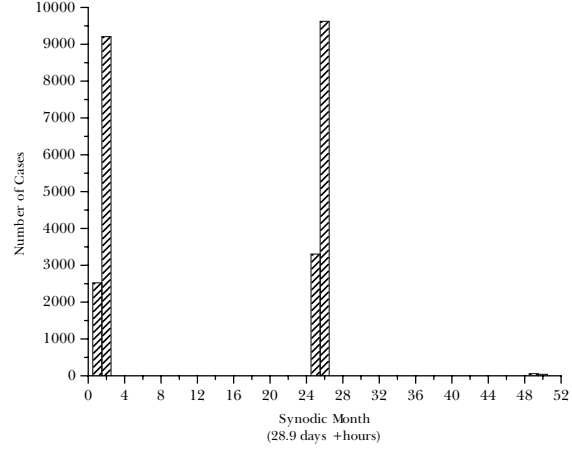


Fig. 2 Time-interval between two successive first lunar crescents at the beginning of civil twilight shown in hours with a start-off value of 28.9 days for the city of Babylon (44.42° E; 32.53° N)

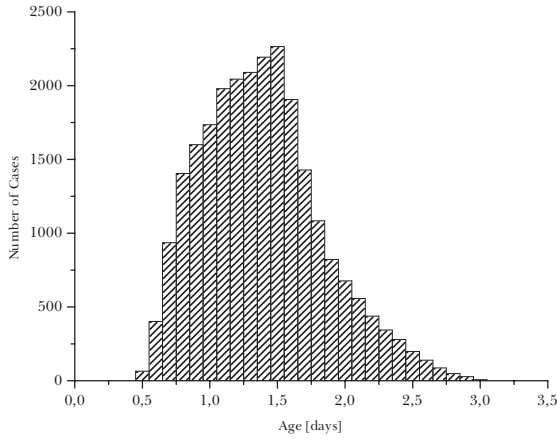


Fig. 3 The age of the moon at the time of first lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

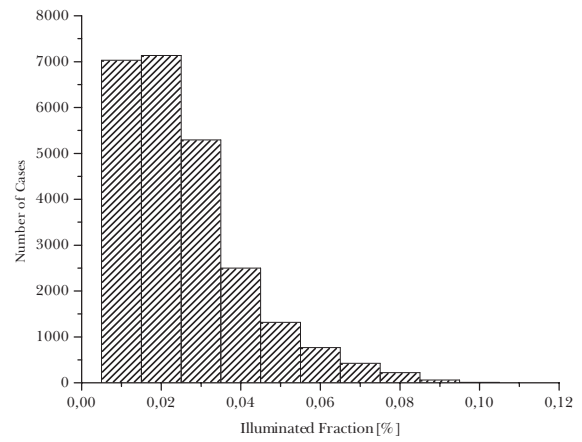


Fig. 4 The illuminated fraction of the moon at the moment of first lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

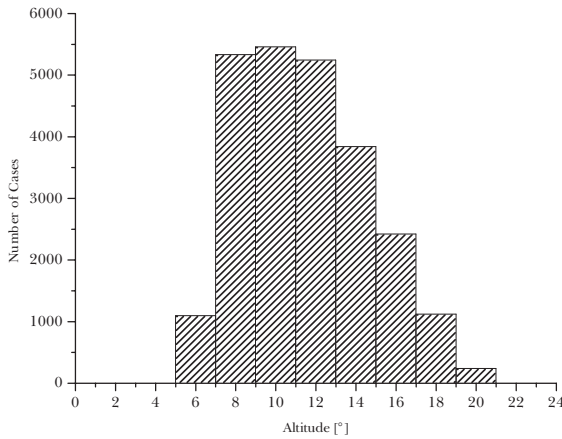


Fig. 5 The altitude of the moon at the time of first lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

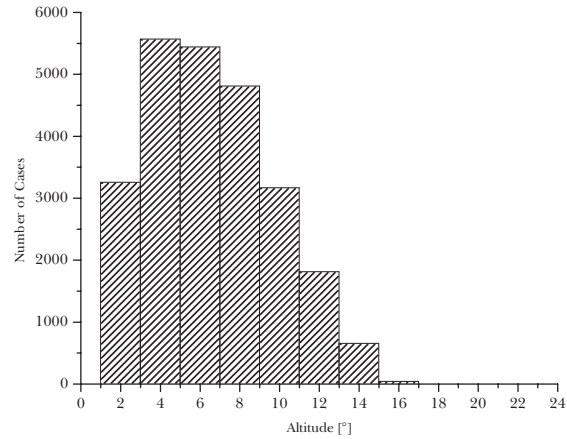


Fig. 6 The altitude of the moon at the time of first lunar crescent visibility at the end of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

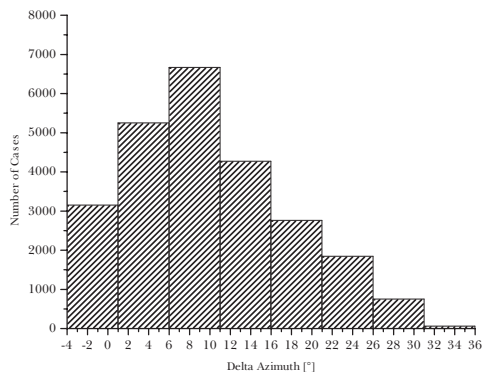


Fig. 7 Delta azimuth at the time of first lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

up at the end of civil twilight. Actual *azimuthal differences* (always reckoned in the sense sun-centre minus moon-centre) may range from -3.99° to $+36^\circ$ with a maximum between 6° and 11° (Fig. 7). By plotting the lunar age against the altitude of the moon or the altitude of the moon against the illuminated fraction of the moon no random distribution can be found (Figs. 8 and 9). Further, for a better master screen of the number of cases' distribution a 3-dimensional plot has been generated for the lunar age against the altitude of the moon and

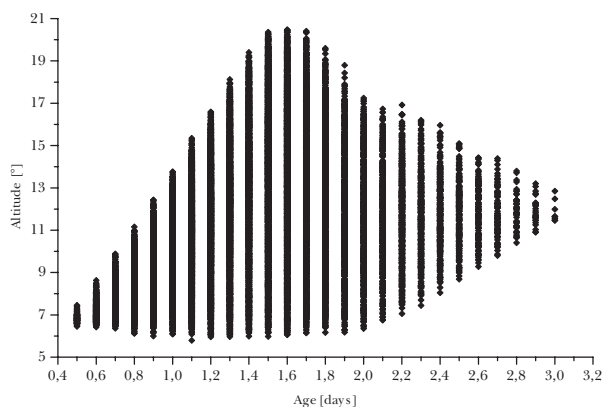


Fig. 8 First lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

another 3-dimensional plot for the altitude of the moon against the illuminated fraction of the moon (Figs. 10 and 11).

Dates given for the first lunar crescent occurrences require optimal observing conditions in the evening of the first lunar crescent. Under non optimal conditions – for instance like dust, which greatly effects observability due to the low altitude of the moon – the next day should be taken as the day of the first lunar crescent observation. Sometimes the first lunar crescent can be seen one day earlier – even below our chosen altitude of 1.90° – because for instance hot air may cause extraordinary refraction. As L. FATOOGHI *et al.*¹⁹ has provided 209 first crescent visibilities for Babylon for the time-interval between 568 B.C. and 74 B.C., our values were counter-checked against his data-base. Nearly 80% of identical dates resulted. The rest of his first lunar crescents occurred one day later or earlier – mostly later. Details on this and further facts may be found in Anderlič' master's thesis²⁰ yielding an explanation that in some cases Fatoohi allowed for a lunar height above the horizon of less than 1.90° when using our calculation algorithm. Anyway agreement was well achieved within the error bars.

As mentioned before the main parameters of the first lunar crescent are: the lunar age, the illuminated fraction and the altitude. To find the main peri-

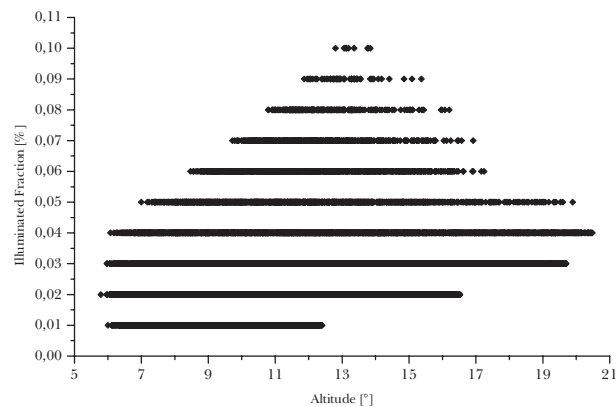


Fig. 9 First lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

¹⁹ L.J. FATOOGHI, F.R. STEPHENSON and S.S. AL-DARGAZELLI, Babylonian First Visibility of the Lunar Crescent, *Journal for the History of Astronomy* 30, Part 1 (February 1999), 51.

²⁰ See note 11.

²¹ Wolfram Research Inc. Mathematica, Version 5.0, Champaign II (2003).

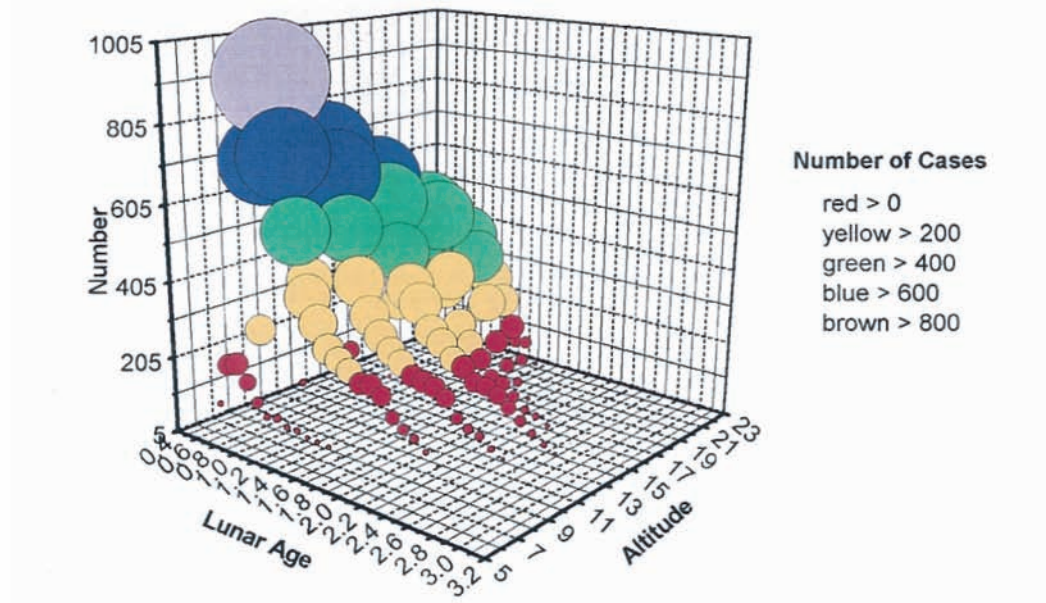


Fig. 10: First lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

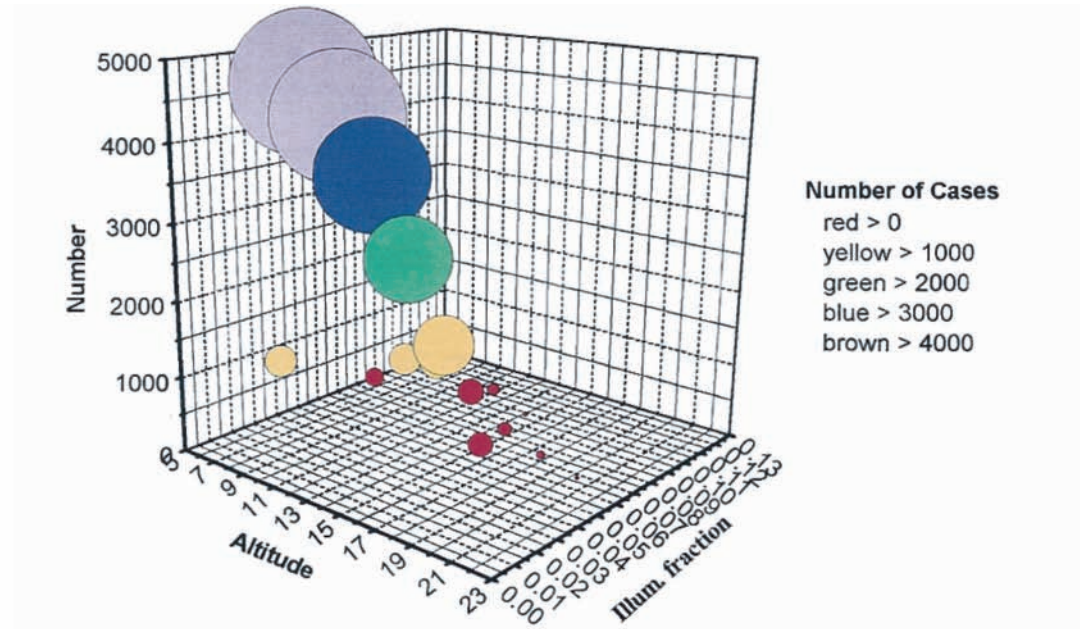


Fig. 11: First lunar crescent visibility at the beginning of civil twilight for the city of Babylon (44.42° E; 32.53° N) for the years 2001 B.C. until A.D. 1

od of these characteristic values of the first lunar crescents a Fourier analysis has been executed using the program Mathematica²¹ (Fig. 12). The x-axis represents the synodic months of the whole calculation time-span (only the first half of the whole graph was plotted because of aliased frequencies at higher values on the x-axis) and the y-axis gives the magnitude of the parameter, respectively. The peak

with the highest magnitude was found at a value of 2003 on the x-axis which represents the 2003rd part of the whole calculation time-span for these 2002 years. Dividing the peak value of this point on the x-axis through the whole calculation time-span yields the frequency. Taking the reciprocal of the frequency for all three parameters a period of 12.36 synodic months has been achieved. This is clear as

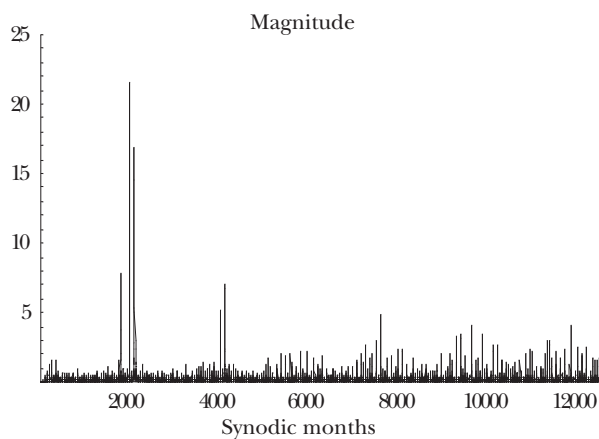


Fig. 12 Fourier analysis of the lunar age

one year later the positions of the sun and moon relative to the earth are nearly the same.

A general look at the lunar age-components – concerning first crescent visibility for Babylon over 2000 years – shows the typical 18.6-year peaks well known since ancient times as the Metonic cycle.

The various criteria for first crescent visibility, for instance the Anderlič-Firneis criteria, thus seem reasonable. However, the problem with $\Delta T = TD - UT$ (Delta T = Terrestrial Dynamical Time minus Universal Time) still resides and is immanent in all calculations dating back actual ancient lunar observations and this is a problem still not perfectly solved in modern astronomy.