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Eclipse Prediction and the Length of the Lunar Month in Mayan Astronomy

Iwaniszewski, Stanislaw
siwanisz@yahoo.com
Posgrado en Arqueología Escuela Nacional de Antropología e Historia – Instituto Nacional de Antropología e Historia

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Resumen

Uno de los logros más notables de la astronomía calendárica maya fue la invención de la teoría lunar que combinaba un calendario lunar fijo con las predicciones de eclipses. Las predicciones de eclipses se exhiben en la Tabla de Eclipses del Códice de Desde en las páginas 51-58. El calendario lunar se refleja en la Serie Lunar Maya, que se adjuntó a los enunciados cronológicas de los gobernantes mayas dispuestos en los monumentos.

La llamada Tabla de Eclipses tiene la extensión de 405 meses lunares esquemáticos, divididos en 69 grupos de 6 y 5 meses cada uno (D53a-D58b). La propia tabla está precedida por una tabla de múltiplos de 11.960 días (D51a-D52a), la extensión de la tabla. La estructura de la tabla presenta tres módulos con 23 posibilidades de eclipse cada uno, de los cuales veinte ocurren después de seis meses y tres después de cinco meses. Ya que cada módulo contiene 135 meses, la tabla incluye 405 meses (= 3 x 135) o tres series de tritos. Considerando que cada módulo advierte sobre la posibilidad de 23 eclipses, toda la tabla permite advertir sobre la posibilidad de 69 (= 3 x 23) eclipses. Sin embargo, algunos investigadores, argumentaron que la tabla se originó a partir de un *tzolkinex*, un período de eclipse que consta de 88 meses sinódicos. Ambos períodos producen los períodos de medio año de eclipse, que son más precisos que los saros.

A pesar de alternar sistemáticamente los meses lunares de 29 y 30 días, los mayas idearon un método para insertar días intercalares o adicionales a intervalos regulares para seguir las fases lunares con precisión. Este método, conocido por la Tabla Lunar encontrada en la ciudad maya de Xultun, se basa en el registro de 162 meses lunares. La tabla Xultun es compatible con los intervalos de 11960 días utilizados en varias ciudades mayas para realizar los cálculos lunares hacia atrás o hacia el pasado.

El propósito de esta contribución es proporcionar una descripción útil e informativa de la evidencia que se utiliza para inferir los valores medios de la duración de medio año de eclipse y la duración promedia de la lunación en la astronomía maya.

Palabras clave: Teoría Lunar Maya, Tabla de Eclipses del Códice de Dresde, Serie Lunar, tritos, tzolkinex

Abstract

One of the most remarkable achievements of Mayan calendrical astronomy was the invention of a lunar theory that combined a fixed lunar calendar with eclipse predictions. Eclipse predictions are shown in the Dresden Codex on pages 51-58. The lunar calendar is reflected in the Maya Lunar Series, which was attached to the chronological statements of Maya rulers displayed on monuments.

The so-called Eclipse Table covers 405 schematic lunar months, divided into 69 groups of 6 and 5 months each (D53a-D58b). It is preceded by a table of multiples of 11,960 days (D51a-D52a), the period covered by the table. The table structure generally exhibits three units with 23 eclipse possibilities each, of which twenty occur after six months and three after five months. Since each unit contains 135 months, the table includes 405 months (= 3 x 135) or three tritos series. Considering that each units warns about the possibility of 23 eclipses, the entire table allows warning about the possibility of 69 (= 3 x 23) eclipses. Some scholars, however, argued that the table originated from a *tzolkinex*, an eclipse period consisting of 88 synodic months. Both periods produce mean eclipse periods, which are more accurate than the saros.

Despite the Maya systematic alternation of 29- and 30-day lunar months, they devised a method to insert additional or leap days at regular intervals to track the lunar phases accurately. This method, known from the Lunar Table found at the Maya city of Xultun, is based on the record of 162 lunar months. The Xultun table is compatible with the intervals of 11960 days used in several Maya cities to perform lunar computations backwardly. in time.

This paper aims to provide a helpful and informative description of the records that are utilized to infer the mean values of the length of a half eclipse year and the average length of a lunation in Maya astronomy.

Keywords: Maya Lunar Theory, Dresden Codex Eclipse Table, Lunar Series, tritos, tzolkinex

Introduction

Maya calendrical astronomy invented various quantitative methods to predict celestial phenomena. The most common but by no means the only way was using temporal periods based on the multiples of 260 days. As is known, the cycle of 260 days, known as *tzolk'in*, made up of a combination of 20-day signs and 13 numbers, was one of the essential cultural traits in ancient Mesoamerica. As once Thompson (1972: 27) noticed, one of the functions of this calendar consisted in bringing "all celestial and human activities into a relationship with the sacred almanac by multiplying the span they were interested in until that figure was a multiple of 260"[1]. Without denying its predictive-divinatory essence, the 260 days also became suitable for reckoning time.

Eclipse Periods combined with *tzolk'in* cycles

In Maya lunar theory, the cycles of eclipse possibility and lunar months were equated with multiples of 260 days. Scholars who examined the Eclipse Table of the Dresden Codex identified three major commensurations. They involve:

3 eclipse half-years 3 x 173.31 ≈ 520 days = 2 x 260 days (Teeple 1931),

tzolkinex = 88 lunations = 2598.692 days ≈ 10 x 260 days (Smither 1986; Justeson 2017),

and

3 x tritos = 405 lunations = 11959.888 days ≈ 46 x 260 days[2]

Except for the first case, eclipse period commensuration involves an integer number of lunations (synodic months) and *tzolk'in* cycles. To understand those relationships in modern terms, we add the concepts like the eclipse year (= 346.62 days) or draconic month (= 27.2122 days), with which we today perceive the eclipse periods. But they are known to Western astronomy and are used only here as heuristic tools to explain the periods' meanings to modern audiences. However, Maya left no names but numbers. Therefore, the epistemic criteria with which Maya day keepers observed, understood, and predicted eclipses still need to be discovered.

The Dresden Codex was elaborated sometime during the Late Postclassic period (1200-1530 CE) (Bricker and Bricker 2011: 7) but contains sections whose originals are from previous epochs (between the 5th and 12th centuries), which were copied and reinter-

[1] Among the most well-known and confirmed applications of the 260-day cycle for the commensuration of celestial periods are fifty-two vague years (52 x 365 = 73 x 260), three eclipse half-years (3 x 173.31 = 519.93= 2 x 260), sixty-five mean synodic periods of Venus (65 x 584 = 37,960 = 146 x 260), or a synodic period of Mars (3 x 260 = 780). The reader will find such and other examples in Lounsbury (1978) and Justeson (1989).

[2] - 3 x 173.31 = 519.93 days, or three eclipse half-years;
- 88 x 29.530586 = 2598.69 days, 15 x 173.31 = 2599.65 days, 95.5 x 27.2122 =2598.77 days;
- 135 x 29.530586 = 3986.63 days, 23 x 173.31 = 3986.13 days, 146.5 x 27.2122 = 3986.587 days;.

where the length of the synodic month is 29.530586 days, the length of an eclipse year is 346.62 days, and the length of the draconic month is 27.2122 days.

preted until then (see Bricker and Bricker 2011: 840-845). Since the Table has been described multiple times, I only briefly refer to the elements relevant to the present interpretation.

The table opens with an 8th-century date, starting at 9.16.4.10.8 12 Lamat [1 Muan] (= 6.11.755 Julian). The table is divided into sections or groups by pictures, possibly depicting eclipses. Each section ends with a 148-day interval. The only exception is the last, tenth section which stops up with an eclipse image after running through four 177-day intervals. The six-month intervals display 177 or 178 days, whereas the five-month intervals contain 148 days. Since we are dealing with a schematic lunar count consisting of a regular alternating of 29-day and 30-day months, 177 days denote three months of 29 and three months of 30 days. The number of 178 days indicates four months of 30 days and only two months of 29 days, while the number of 148 days shows three months of 30 and two months of 29 (see Table 1).

The table covers a period of 405 schematic lunar months or a period of 11,960 days, but contains also the period of 11,959 days (Bricker and Bricker 2011: 260-261).

The triple tritos period (3 x 135 lunations)

The general layout of the table originates from the scheme of three similar groups containing 135 months each, or the three tritos series[3]. Tritos is a period of 135 lunations during which the pattern of 23 eclipse possibilities repeats. By converting the intervals of multiples of 177/178 days into 6-month groups and 148 days into 5-month groups, we see that each tritos group includes twenty 6-month intervals and three 3-month ones (see Table 1). The Eclipse Table accumulates up to sixty-nine 5- and 6-month intervals[4]. Following the idea proposed by Britton (1989), the argument develops as follows. Because lunar eclipses are visible from every place where the moon is above the horizon, there are observed more often than solar eclipses. The cyclical recurrence of lunar eclipses creates a framework on which one can also predict eclipse possibilities. The fundamental idea is that the next eclipse can occur six or sometimes five months after the last observed eclipse. In other words, eclipse possibilities occur with 6-month gaps, followed by a 5-month interval, and again 6-month gaps reappear. Eclipses separated by five months are much less frequent.

[3] According to Meeus (1997:53), the name tritos was proposed by George van der Bergh in his *Periodicity and Variation of Solar (and Lunar) Eclipses* (1955). 135 mean synodic months = 3986.7655 days, and 146.5 mean draconic months = 3986.590 days. Thus one tritos after the eclipse, the sun and moon will stay again in syzygy, but with respect to the opposite node. The reader will find more information on the tritos series in Hartner (1969) and Querejeta (2011).

[4] The term tritos referring to the structure of the Dresden Codex Eclipse Table, was first introduced by Smiley (1973). However, most scholars usually refer to three 135-month groups, three 23 eclipse half-years, or three groups of about 3986 days.

Knowing that tritos consist of 135 months, we can compute how many 6-month and 5-month intervals are within those 135 months. Thus within a tritos, there are *m* eclipses at six-month intervals and *n* eclipses at five months.

m x 6 + n x 5 = 135

since m and n must be integer numbers and m is bigger than n, then m = 20 and n = 3

20 x 6 + 3 x 5 = 135

Group and Codex pages	Number of days	6-month and 5-month series	Ratio of 6-month to 5-month intervals	Number of months	Ratio of 6-month to a 5-month intervals
Group I (53a)	177, 177, 148, picture	6-6-5-	2:1	17	2:1
Group II (53a-55a)	177, 177, 177, 178, 177, 177, 177, 177, 177, 148, picture	6-6-6-6-6-6-6-6-6-5-	9:1	59	20:3
Group III (55a-56a)	178, 177, 177, 177, 177, 148, picture	6-6-6-6-6-5-	5:1	35	
Group IV (56a-57a)	177, 177, 177, 178, 177, 177, 148, picture	6-6-6-6-6-6-5-	6:1	41	
Group V (58a-52b)	177, 177, 178, 177, 177, 177, 177, 177, 177, 148, picture	6-6-6-6-6-6-6-6-6-5-	9:1	59	20:3
Group VI (52b-53b)	178, 177, 177, 177, 177, 148, picture	6-6-6-6-6-5-	5:1	35	
Group VII (53b-54b)	177, 177, 177, 177, 177, 177, 148, picture	6-6-6-6-6-6-5-	6:1	41	
Group VIII (54b-56b)	177, 177, 178, 177, 177, 177, 177, 177, 148, picture	6-6-6-6-6-6-6-6-5-	8:1	53	18:2
Group IX (56b-57b)	177, 178, 177, 177, 177, 177, 148, picture	6-6-6-6-6-6-5-	6:1	41	
Group X (57b -58b)	177, 177, 177, 177, picture	6-6-6-6-	4:0	24	
	Total	60:9	60:9	405	60:9

Table 1. Schematic rendition of the structure of the Dresden Codex Eclipse Table. The 177, 178, and 148 days denote a series of 6 or 5 schematic months of 29 and 30 days. The table contains 405 months arranged in 69 groups. The pictures with eclipse imagery divide the groups into ten bigger units however, Groups I and X can be joined. In this way, each third of the table contains twenty 6-month intervals or multiples and three 5-month intervals (20 x 6 +3 x 5 = 135 months, 3 x 135 = 405 months). Each group ends with a 5-month multiple. Each hyphen denotes an Eclipse Possibility. Source: self made.

In other words, within a tritos of 135 months, there are 23 eclipse possibilities, of which twenty are at 6-month intervals, and three are at 5-month gaps (consult Table 1). The distribution of eclipse possibilities in the manuscript is uneven. It shows two equal groups of 10-6-7 (=59-35-41 months) and another group that can be displayed as 9-7-7 (=53-41-41 months). Each tritos consists of 3987, 3986, and 3986 days, respectively. A single tritos period is not very efficient to define the length of a half eclipse year (= 173.3100379 days): a 3986-day period produces the value of 173.3043 days, while that of 3987 – 173.3478 days. However, a triple tritos period of 11959 days is much more precise since it yields 173.3188 days.

The tenfold *tzolk'in* periods

The idea of associating 260 days (*tzolk'in*) with eclipse cycles is also expressed using tzolkinex (Verbelen 2001). This name describes the cycle of 88 synodic months during which a pattern of 15 eclipses is supposed to repeat. This period of 2598.69 days is equal to 10 *tzolk'in* cycles (2600 days), with a difference of 1 day. The existence of this eclipse period in the Eclipse Table was first suggested by Smither (1986); later, Justeson (2017) developed arguments for the identification of the shifting 88-month intervals observable in Mesoamerica between 100 BCE and 1500 CE. He concluded that tzolkinex was probably well-known from a very early date. Based on the same formula as shown in the case of tritos, we have:

$m \times 6 + n \times 5 = 88,$

for $m = 13$ and $n = 2$

$13 \times 6 + 2 \times 5 = 88$

There are 15 possible eclipses within a tzolkinex of 88 lunar months. Out of these, thirteen occur at 6-month intervals and two at 5-month intervals. Table 2 displays all the intervals within the Eclipse Table, but we cannot determine the starting point of the tzolkinex series due to its structure. However, if there is an interval of 5 or 6 lunar months between any two sequential pairs separated by 88 lunar months, we can identify up to 16 different tzolkinex series. Some of these series occur once, while others occur three or four times, forming longer-term chains. They produce eclipse half-year periods of 173.253, 173.239, and 173.3243 days, respectively. The number of days varies between 2598 (37.8 %), 2599 days (60%), and 2600 days (2.2 %). From Table 2, we can see that the average value of the eclipse half-year period is approximately 173.243 days.

Reasoning from the Eclipse Table, the tzolkinex does not preclude the occurrence of the tritos. Even one might suggest that one cycle derives from another. It is enough to add 47 synodic months to 88 months to obtain 135 months. Likewise, 223 (Saros) contains 88 + 135 months. Britton (1989: 8) showed that extending the number of eclipse possibilities is possible simply by adding the parameters of the last two cycles (as in the Fibonacci series). So, there is no reason to deny the existence of the 135-month structure in the Eclipse Table. In light of the above, the hypothetical shift from tzolkinex to triple tritos eclipse predictive cycle may be motivated by the search for a more precise "rule of thumb" used to herald eclipses. Ultimately, both cycles share the Maya need to combine eclipse periods with the use of *tzolk'in*.

Hartner (1969: 62-63) states that the 88-month and 135-month cycles (tzolkinex and tritos) can predict over 50% of the observed lunar eclipses. We can now define the average eclipse periods (the average number of months between successive eclipse possibilities). In the case of the tzolkinex, it is 88:15 =5.8667; in the case of the tritos and triple tritos, it is 135:23=5.8696. By the way, a saros cycle yields 5.8684 and is less accurate than tzolkinex and tritos.

Starting day	Interval	Sum of days	Interval	Sum of days	Interval	Sum of days	Interval	Sum of days	Average half-year eclipse period (days)
0	2599	2599	2599	5198	2598	7796	2599	10395	173.25
177	2599	2776	2599	5375	2598	7973	2599	10572	173.25
354	2599	2953	2599	5552	2598	8150	2599	10749	173.25
679	2599	3278							173.267
856	2599	3455							173.267
1033	2599	3632	2599	6231	2598	8829			173.244
1211	2598	3809	2600	6409	2598	9007	2598	11605	173.233
1388	2599	3987	2599	6586	2598	9184	2598	11782	173.233
1565	2599	4164	2599	6763	2598	9361	2598	11959	173.233
1742	2599	4341	2599	6940	2598	9538			173.244
2244	2599	4843	2599	7442	2598	10040			173.244
2422	2599	5021	2598	7619	2598	10217			173.222
3130	2599	5729	2598	8327	2599	10926			173.244
4666	2599	7265							
7117	2598	9715							
8652	2599	11251							

Table 2. Tzolkinex intervals identified in the Eclipse Table. Source: self made.

The length of a lunar month

Among the Maya, a fundamental requirement for a lunar theory was to enable those who used it to predict when the lunar month should begin. A month was always a whole number of days; it could be either 29 or 30 days long. Ideally, the 1st day of a lunar month was expected to begin when the lunar crescent was first sighted, or in Maya terminology, "arrived" (*huli*) in the sky. But since the lunar month was regularly alternating between 29 and 30 days, it was necessary from time to time to insert an extra "intercalary" day to one of the 29-day months. Various scholars have discussed this topic, but the final Mayan solution became known when archaeologists discovered what has been called a Lunar Table from Xultun.

Painted in the first half of the 9th century in the Maya city of Xultun, the Lunar Table tells us that intercalation occurred every 956-957 days, implying that the mean lunar month was 29.5308642 days long. This result works well, especially compared to astronomical computations, which tell us that the leap day should be added every 964.4 days. The table contains twenty-seven intervals of 177 or 178 days, each group under the influence of one of three patron gods known from Glyphs C of the Lunar Series. There are twenty-two groups of 177 days and five groups of 178 days, totaling 4,784 days. The structure of the table stems from the computation of 9 x 531 plus 5 days, showing five leap days within nine cycles of 531 days. Each cycle of 531 days contains three series of 177 days, and each cycle of 177 days contains three series of 59 days. In other words, 3 x 177 = 531 = 9 x 59. Therefore, 9 x 531 = 4,779 = 81 x 59. These occurrences conclude that the Maya derived the lunar count from the 59-day cycle (30 + 29 days). The structure of the Xultun Lunar Table makes it helpful in constructing a lunar theory attached to the multiples of 260-day cycles. The number of 4784 days equals 18 x 260 plus 104 days. 104 days = 2/5 of 260 days, so after recycling 2.5 times the 4784-day interval, we reach the whole number of 260-day cycles:

4784 x 2.5 = 11960 = 46 x 260.

The length of the lunar month is 4784: 162 = 29.5308642 days.

Conclusions: A new look at 11960-day cycles

In conclusion, the Eclipse Table reveals that the half-eclipse year's duration fluctuates between 173.243 days (if we apply the tzolkinex cycle) and 173.3188 days (if we count the triple tritos cycle). Furthermore, from the Xultun Table and other evidence we have deduced the average length of a synodic month to be 29.5308642 days. This information can be helpful for researchers who conduct comparative studies.

If the 12 Lamat date were used as a standard eclipse table base for a formal table of 11.960 days uncorrected, it would serve to compute the Lunar Series as the Xultun table suggests. The intervals composed of integer multiples of 11.960 days found in so-called Distance Numbers in Mayan hieroglyphic texts did not correspond to eclipse cycles, but instead, they acted as the tools to quickly find the correct Lunar Series back in time (e.g., Iwaniszewski 2020). The eclipse tracking table would have used the intervals of 11.959 and 11.958 days (Bricker and Bricker 2011: 291-303)[5].

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[5] Observe that 260 x 46 = 11,960 days and 405 x 29.53056 = 11,959.887 days but 69 x 173.31 = 11,958.39 days.