Ancient Maya documents concerning the movements of Mars

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A large part of the pre-Columbian Maya book known as the Dresden Codex is concerned with an exploration of commensurate relationships among celestial cycles and their relationship to other, nonastronomical cycles of cultural interest. As has long been known, pages 43b–45b of the Codex are concerned with the synodic cycle of Mars. New work reported here with another part of the Codex, a complex table on pages 69–74, reveals a concern on the part of the ancient Maya astronomers with the sidereal motion of Mars as well as with its synodic cycle. Two kinds of empiric sidereal intervals of Mars were used, a long one (702 days) that included a retrograde loop and a short one that did not. The use of these intervals, which is indicated by the documents in the Dresden Codex, permitted the tracking of Mars across the zodiac and the relating of its movements to the terrestrial seasons and to the 260-day sacred calendar. While Kepler solved the sidereal problem of Mars by proposing an elliptical heliocentric orbit, anonymous but equally ingenious Maya astronomers discovered a pair of time cycles that not only accurately described the planet's motion, but also related it to other cosmic and terrestrial concerns.

The pre-Columbian Maya are well known for their precise calendar and astronomy. The four surviving written documents (which are called the Dresden, Madrid, Paris, and Grolier Codices) that they have left behind include an ephemeris that charts the heliacal risings and settings in the synodic cycle of the planet Venus and an eclipse warning table based on observable lunar and solar cycles. Architectural alignments of specialized assemblages of buildings provide further documentation for a number of Maya astronomical skills. (See refs. 1–3 for general reviews of the literature.) Quite uncharacteristic of Western astronomy, the paramount aim of the Maya astronomers' endeavors seems to have been to discover commensurate relationships both among celestial cycles and between astronomically derived periodicities and nonastronomical cycles. This paper focuses on new research investigating the Maya interest in the planet Mars, which, although already established via the Codices, has recently led to revelations of a number of cycles unknown to Western astronomy. Our examination of these cycles leads to a clearer picture of the practical art of naked eye skywatching as well as to the role of such activity in Maya culture.

Concern with the Synodic Cycle of Mars

The discovery that the 780-day table on pages 43b–45b of the Dresden Codex had something to do with Mars was made nearly a century ago (4). In addition to being the length of three 260-day sacred calendar cycles or *tzolkins*, 780 days is very close to the mean synodic period of Mars; furthermore, 78 days, the length of the table's component modules, is close to the average length of the Martian retrograde period, *ca.* 75 days. Although the Martian association of the table has been disputed (5, 6), recent research has solidified and extended the documentation for this position (3, 7, 8). The astronomical content of the table, which is known from its structure, iconography, and hieroglyphic captions, is concerned with the heliacal rise and retrograde motion of Mars and with eclipse seasons. The importance of heliacal rise is shown indirectly by the relationship between the table's *tzolkin* base date, 3 Lamat, and the very restricted range of the *tzolkin* to which heliacal rise events were limited during the relevant centuries (7). The 3 Lamat base date of the table leads to an entry date 78 days later, in June A.D. 818, within a period of Martian retrograde motion, just before opposition. The iconography of the table—a mythical animal with an everted snout, the so-called Mars beast, that dangles from a celestial band—may refer to Mars dropping well below the ecliptic during this retrograde loop. The retrograde period of A.D. 818 overlapped partially with an eclipse season. A text reference (paired eclipse glyphs) to an eclipse season is part of the hieroglyphic caption to the Mars-beast picture associated with the 19-day interval in which lunar nodal passage, a visible lunar eclipse, and Martian second stationary occurred. A section of the synodic Mars table containing multiples of 780 days suggests that it was intended to be reused after its original run in A.D. 818–820 (although it would have needed periodic correction or adjustment, and the method for this adjustment is not specified). If indeed the table was used over a period of several centuries, as implied by its list of multiples, the astronomical component of its broader astrological function would have been the commensuration of the very variable synodic cycle of Mars with the 260-day sacred cycle and, probably, with the lunar cycle of eclipse seasons.[§]

Concern with the Sidereal Cycle of Mars

Students of Western astronomy often ask whether cultures other than their own might have known (or cared) about the sidereal periods of the planets (i.e., those referred to a heliocentric as opposed to a geocentric frame of reference). For Mars, this period is timed by modern astronomy at 686.98 days, and it is not directly observable. However, a sidereal period, in the sense that it is a cycle that tracks the movement of a planet relative to the stars, that is directly observable would measure the interval between two successive passages of a planet by a given longitude (chosen arbitrarily to be 0° in the present discussion). We discuss here a kind of period that we call the empiric sidereal interval (ESI), which we define as the number of days elapsed between consecutive passages of Mars through a given celestial longitude while in prograde motion.[¶] At first glance, one would imagine that the ESI would fluctuate widely about some mean because of the intervening retrograde loop, which in the case of Mars occupies 75 days on average between first stationary (cessation of) and second stationary (resumption of

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Abbreviations: ESI, empiric sidereal interval; UWT, upper water table.

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[§] Page M.2a of the Madrid Codex contains a remaining portion of what may have been another version of a 780-day synodic Mars table, but too little has survived to be sure of its structure (8).

[¶] We exclude cycles in which any portion of the retrograde loop occurs at the starting longitude from which a given ESI is reckoned. For example, if Mars passed 0° longitude just before reaching first stationary, it would pass it a second time while in retrograde motion and a third time after having resumed prograde motion following second stationary. However, the two passages through 0° longitude in prograde motion would be separated by a relatively short interval, fewer than 200 days, which would not constitute an ESI; the passage of longitude 0° shortly after second stationary would be included in the new ESI.

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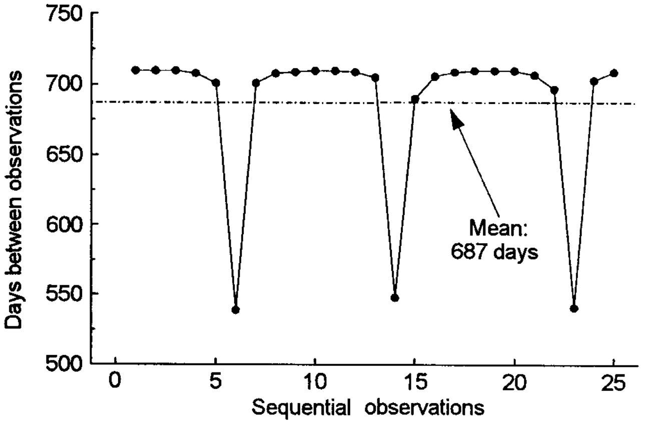

Fig. 1. Empiric sidereal intervals of Mars in the early 8th century A.D., based on 25 sequential observations of Mars at longitude 0°.

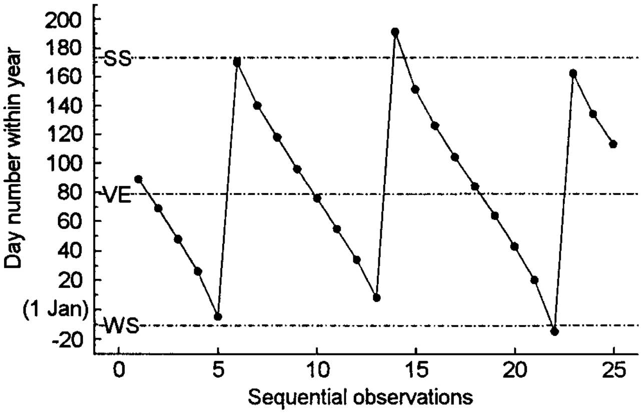

Fig. 2. Seasonal distribution of beginning/ending points of ESIs of Mars (same data set as in Fig. 1).

normal west-to-east motion). However, a closer look at modern astronomical ephemerides reveals that for a practical observer there are really two ESIs, a lengthier one that includes the retrograde loop (we call it the long ESI) and a shorter one that does not (the short ESI). It turns out that these periods alternate rhythmically in an easily discoverable manner, with one short ESI following seven or eight consecutive long ESIs (i.e., about every 14 years), and each is remarkably constant in duration over long epochs.‖ Fig. 1, which graphs the lengths of 25 ESIs of Mars between A.D. 700 and A.D. 747, shows this pattern of variation between long ESIs of 700 or more days and short ESIs of *ca.* 540 days. The actual sidereal mean of *ca.* 687 days occurs or is closely approximated only very rarely (only once in Fig. 1).

The patterning in the variation in length of the ESI of Mars—seven long periods plus a short one (7L + S) or eight longs and a short (8L + S)—has a *seasonal* element for the terrestrial observer. The seasonality of the Martian cycle is shown in Fig. 2 for the same early 8th-century temporal span shown in Fig. 1. As before, the beginning/ending point for the ESI is set arbitrarily at celestial longitude 0°. The date of this day in a proleptic Gregorian year is graphed, with days numbered sequentially from 1 January (for graphic clarity, December dates are shown as negative numbers). The first ESI plotted ended in late March of A.D. 702, a few days after the vernal equinox. This period had a length of 710 days (compare Fig. 2 with Fig. 1). The next four ESIs, with lengths of 710, 710, 708, and 701 days, ended in early March, mid-February, late January, and late December (27 December A.D. 709), respectively.** The next ESI (the sixth one graphed) ended on 19 June A.D. 711, after a duration of only 539 days. The same seasonal pattern is repeated in the rest of the graph (Fig. 2): the last of the seven or eight long ESIs in a given pattern ends very close to the winter solstice. The subsequent short ESI ends near the summer solstice, and the recession through the tropical year starts anew from this near-summer-solstice date, continuing for the next seven or eight (long) ESIs. Because the ESI groups commensurate very well with the tropical year (7L + S is a few days over 15 years, and 8L + S is a few days short of 17 years), the seasonal patterning shown here for the early 8th century is sufficiently stable through time that it holds true for the entire span of centuries relevant to pre-Columbian Maya astronomical computations. Our use of 0° celestial longitude as the beginning/end point of an ESI was an arbitrary choice, but the reality of the seasonal patterning would remain unchanged if some other definition of beginning/end point were chosen. The shape of the seasonality distribution shown in Fig. 2 would be exactly the same, but the calibration of the *y* axis would be different.

The cultural implication of the commensuration of one kind of Martian sidereal cycle and the tropical year is that it made it very easy for the ancient Maya to make a certain kind of prediction about the apparently erratic behavior of Mars that had both direct meaning and practical function for them; thus, if the celestial beginning point for a Martian cycle had been defined as the movement of Mars into a certain part of the sky—a certain region of a given constellation, for example—then as subsequent occurrences of this same Martian position recessed through the tropical year, the careful observer would know when the succession of normal (long) periods was about to be interrupted by a short one. When the movement into the appropriate constellation occurred in a particular season (near winter solstice in our arbitrary model), the observer would know with certainty that the next Martian cycle, lacking a retrograde period, would be a short one—closer to 7 × 78 days than 9 × 78 days. The ability to predict with ease and certainty when an ESI of Mars would be long (containing retrograde) and when it would be short (lacking retrograde) could well have constituted valuable knowledge for the ancient Maya specialists concerned with relating celestial periodicities to the everyday world of the agrarian population.

Is there, however, any evidence that such knowledge was used or even that what we have called long and short ESIs were recognized? A table of 702-day intervals in the Dresden Codex, which has recently been recognized as having to do with a sidereal cycle of Mars (9), provides clear evidence in favor of an affirmative answer to this question. Fig. 1 shows unambiguously that a 702-day value is much more relevant than the Western value of *ca.* 687 days for a terrestrial observer keeping track of Mars' position against the background of the stars (and, as discussed below, it permits easy commensuration with the other cycles of interest to the Maya). The table in the Dresden Codex, which we have called the "upper water table" (UWT), is part of a more complex instrument occupying pages 69–74 of the Dresden Codex, which contains frequent iconographic and glyphic references to rainfall (a so-called "lower water table" appears just below the UWT on the relevant pages). The

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‖A sample of 88 long ESIs from the 2nd, 8th, and 11th centuries A.D. has a length mean and standard deviation of 706.67 ± 4.86 days. The 12 short ESIs associated with these series have a mean length of 543.17 ± 6.79 days, producing a difference between long and short means in this sample of 163.50 days. There are no significant differences among the samples from the three different centuries.

**All Western-calendar dates in this communication are expressed in the Gregorian calendar.

Table 1. Base dates of tables in the Dresden Codex concerned with movements of Mars

Tabulated date, in Maya and Gregorian calendars	Long. of Mars 23:30 LT	Length in days of ESIs bracketing tabulated date (position shown by *)
1. 1.4.3.6.10 9 Oc 13 Mac 13 Jan. 2637 B.C.	213.02°	.. 697 **541** * 702 709 ..
2. 8.6.16.7.14 9 Ix 7 Mac 24 Feb. A.D. 176	55.81°	.. 709 703 * **528** 704 ..
3. 9.11.11.15.14 9 Ix 2 Yaxkin 25 Jun. A.D. 664	9.11°	.. 701 **538** * 702 708 ..
4. 9.13.10.15.14 9 Ix 12 Muan 4 Dec. A.D. 702	156.64°	.. 708 **528** * 697 708 ..
5. 9.15.9.15.14 9 Ix 17 Zec 13 May A.D. 741	314.51°	.. 703 **545** * 696 706 ..
6. 9.17.15.6.14 9 Ix 12 Zip 18 Mar. A.D. 786	247.40°	.. 706 **546** * 688 706 ..
7. 9.19.7.2.14 9 Ix 17 Ch'en 13 Jul. A.D. 817	105.38°	.. **526** 707 711 711 * 712 ..
8. 10.9.5.1.14 3 Ix 2 Kankin 20 Aug. A.D. 1012	53.85°	.. 706 **535** * 697 708 ..
9. 10.11.4.0.14 9 Ix 7 Zip 8 Jan. A.D. 1051	181.39°	.. 708 **536** * 690 707 ..
10. 9.19.7.15.8 3 Lamat 6 Zodz 24 Mar. A.D. 818	257.37°	.. **545** * 691 ..

Dates 1–9, UWT (pp. 69–74); date 10, synodic Mars table (pp. 43b–45b). Martian longitude data, for north-central Yucatan, are from ref. 10.

evidence for the kind of knowledge discussed here is to be found in the multiple base dates of this table.

The UWT contains nine base dates (Table 1, dates 1–9) written in several different Maya calendrical notations that can all be related to the Maya Long Count and therefore correlated with the Gregorian calendar.[††] If each of these base dates is considered, hypothetically, to begin an ESI of the sort discussed above, most of them (seven of nine, with only dates 2 and 7 not fitting the pattern) would begin a long ESI that immediately follows a short ESI. For example, on the fourth date in Table 1, 4 December A.D. 702, Mars was located near midnight local time at *ca.* 157° of celestial longitude. The immediately previous time Mars was at that longitude was 528 days earlier, on 24 June A.D. 701, but the time before that when Mars was at that location was 16 July A.D. 699, 708 days before the date in A.D. 701. The next time after the A.D. 702 base date when the celestial longitude of Mars was *ca.* 157° was 697 days later, on 31 October A.D. 704. The frequency of occurrence of long and short ESIs follows a pattern of $7L + S + 7L + S + 8L + S + \dots$ (repetition of this sequence). Every sequence of 25 ESIs includes 3 short ones; the empiric probability of a short period is, therefore, 0.12. That being the case, the probability of seven or more dates in a sample of nine immediately following a short period rather than a long one by chance alone is on the order of 10^{-5}. It seems, therefore, highly likely that the variation in ESIs of Mars was known to and used by the authors of the UWT. This conclusion receives additional support from the fact that the (only) base date of the synodic Mars table on pages 43b–45b of the Dresden Codex (as discussed above) fits exactly the same pattern (date 10 of Table 1). If it is considered, hypothetically, to begin an ESI, the one it begins (on 24 March A.D. 818) is a long one immediately following a short one.

Implications Concerning Commensuration

What useful function might a knowledge of the ESI serve? In Western astronomy, the general utility comes from the commensurative relationships among the synodic and heliocentric sidereal periods of Mars (and other planets) and the sidereal and tropical years of Earth. Some of these relationships, which are well known to modern astronomy (2, 12), may be summarized as follows:

7 SYNMARS $\sim$ 8 SIDMARS $\sim$ 15 YEARS
15 SYNMARS $\sim$ 17 SIDMARS $\sim$ 32 YEARS
22 SYNMARS $\sim$ 25 SIDMARS $\sim$ 47 YEARS
37 SYNMARS $\sim$ 42 SIDMARS $\sim$ 79 YEARS
133 SYNMARS $\sim$ 151 SIDMARS $\sim$ 284 YEARS

Here the Martian synodic period (SYNMARS) is taken to be 779.94 days, its sidereal period (SIDMARS) is 686.98 days, and YEARS stands for either the tropical year (365.2422 days) or the sidereal year (365.2564 days). The point of this is that a synodic station of Mars (first stationary, for example) would reoccur at about the same place in the sky at about the same time in the year of the seasons every 15, 32, etc., years. (The error of the commensuration decreases as the length of the commensurative period increases, from about 17 days in 15 years to about 1 day in 284 years.) It must be emphasized, of course, that these useful relationships are based on the heliocentric sidereal period of Mars, *ca.* 687 days, which, so far as we are aware, was not known to or used by the pre-Columbian Maya. However, the use of ESIs, which we certainly can attribute to them, accomplishes the same function. We noted above that the repeating pattern of long and short ESIs is $7L + S + 7L + S + 8L + S + \dots$. This pattern of 25 periods contains very nearly the same number of days as do 25 multiples of the heliocentric sidereal period of 686.98 days, *ca.* 17,174 days; the last 17 ESIs in the pattern ($7L + S + 8L + S$) are essentially equal in length to 17 heliocentric sidereal periods, *ca.* 11,679 days.[‡‡] There is then, using cycles that can be attributed to the ancient Maya, excellent commensuration of Mars' position in the sky with its synodic stations and with the tropical year. We note, finally, that the *ca.* 11,679 days contained in $7L + S + 8L + S$ ESIs is equivalent to 20 synodic periods of Venus with an error of only about 1 day ($583.9 \times 20 = 11{,}678$); the appearance of the glyph for Venus in the captions to the UWT is good presumptive evidence of a concern with the relationship between the cycles of Venus and Mars.

Conclusions

One of the great benefits of studying the astronomies of other cultures lies in the possibility of appreciating alternative ways of understanding the cosmos. The pages of the Dresden Codex dealing with Mars provide specific examples of such alternative views. The pre-Columbian Maya had an interest in the synodic

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[††] The dates, which appear on pages 69, 70, and 73, are written in *pictun*, serpent-number, ring-number-plus-long-round, initial-series, and truncated initial-series notations (9, 11). All can be expressed in terms of the number of days elapsed since the start of the current Maya era, a day designated 13.0.0.0.0 4 Ahau 8 Cumku. This beginning day of the era fell on Julian Day Number 584,283, corresponding to 11 August 3114 B.C. in a back-reckoned Gregorian calendar (5).

[‡‡] Pooled samples from three $7L + S + 7L + S + 8L + S$ sequences, one each from the 2nd, 8th, and 11th centuries, have means and standard deviations of 17,171.67 ± 0.58 and 11,679.00 ± 1.00 days, respectively.

cycle of Mars, as has long been known. However, they divided the 780 days of the cycle into not just a few long subdivisions (for example, visibility and invisibility), but rather into 10 units of 78 days each, with each 78-day unit being further subdivided. One such 78-day span fits well, as we have seen, with the Martian retrograde period; but also, and perhaps of equal importance, a module of 78 days has relevance for other aspects of Mars that were of interest to the Maya. The case study of Mars elaborated in the present paper suggests that the Maya were interested in the sidereal motion of that planet as well as its synodic cycle, but they expressed this interest in a highly unorthodox, yet practical manner. They discovered and elaborated in the UWT of the Dresden Codex formulations for tracking Mars across the zodiac and for relating such movement to the terrestrial seasons. Seasonal Mars predictions achieved in a manner similar to that already argued for Venus (13) seem to have been a major goal. The methods chosen for keeping track of the cycles of Mars also satisfied the Maya propensity for interrelating celestial and noncelestial motions via commensurate numbers. We summarize the outcome of these investigations by highlighting the Martian numbers and their interrelations brought to light in the present study of Maya documents.

The UWT deals with the troublesome Martian sidereal period in an ingenious way by establishing two directly observable Martian cycles hitherto unrecognized in western astronomy: a more frequently occurring long cycle (702 days) that incorporates the retrograde loop and a less frequently occurring short cycle that excludes it. The choice of 702 days as the canonical length of the long ESI and the stated length of the sidereal Mars table (rather than 707, which would have been more accurate) was surely based on the commensurability of this value with the 780-day synodic period and the 260-day sacred calendar or *tzolkin*: $(702 \times 10) = 7{,}020 = (780 \times 9) = (260 \times 27)$. Furthermore, the use of 702 days made it possible to regard both the synodic and sidereal Martian cycles as being composed of modular units of the same size: the synodic period of 780 days = 10 × 78, the long ESI of 702 days = 9 × 78, and the short ESI of *ca.* 543 days is close to 7 × 78.

Close examination of ancient Maya documents concerning the movements of Mars provides a fuller picture of Maya planetary knowledge by offering an example from a pre-Columbian American civilization of alternative approaches to very familiar astronomical phenomena. While Kepler solved the sidereal problem of Mars by proposing an elliptical heliocentric orbit, a daring leap for its time, equally ingenious Maya astronomers, operating in a less abstract, earthbound frame of reference, managed to discover a pair of time cycles that not only accurately described the planet's motion but also married it to other cosmic and terrestrial concerns.

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