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NEWLY FOUND MAYAN RECORDS OF ASTRONOMICAL PHENOMENA IN DRESDEN CODEX

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SUMMARY: The rich culture of old Maya gave birth to a very complicated and complex calendar; they also recorded important historical events and many significant astronomical phenomena. The main source of information is represented by Dresden Codex (DC), one of the four preserved Mayan hieroglyphic literal legacies. DC roughly covers the interval between 280 and 1325 AD. The old problem of precise Mayan dating with respect to our calendar is traditionally called correlation; it expresses the difference in days between the Long Count of the Mayan calendar and the Julian Date, used in present-day astronomy. There exist more than fifty published correlations that differ one from the other by as much as several centuries. Historians mostly accept the so called Goodman-Martínez-Thompson (GMT) value of 584 283 days, which is based mostly on historical events extracted from the sources of a post-classical period of Mayan history. On the contrary, brothers Böhm used precisely dated astronomical data from classical period to derive the Böhm correlation (BB) of 622 261 days. Unlike the GMT correlation it is in excellent agreement with the astronomical phenomena recorded in DC. Since then we published several papers supporting the validity of BB correlation and its advantage over GMT in the classical period of Mayan history. To this end, we used more records of astronomical phenomena discovered in DC. This study describes six records of planetary conjunctions that we found recently on p. 37 of DC that concern planets Mercury, Venus, Mars, Jupiter, and Saturn. All of these records coincide with the real occurrences of these phenomena within several days, if BB correlation is applied.

Key words. Ephemerides – Planets and satellites: individual: Mercury, Venus, Mars, Jupiter, Saturn – History and philosophy of astronomy

1. INTRODUCTION

Mayan culture, since its very beginnings, was a part of a huge cultural sphere, globally called Mesoamerica (Coe 1972, Haberland 1974). It roughly covers the area reaching from today's Mexican federal states of Durango, Zacatecas, and Tamaulipas in the north, over Guatemala and Belize to west Honduras and north-west Salvador. This vast territory shares many identical cultural and historical features. In the pre-classical period, the culture forming here comes from the same agricultural fundament based on cultivating maize. During centuries ceremonial centers were formed which gradually achieved the character of splendid temple cities, later becoming, in some cases, real cities. Within these, simple bar-

[†] This paper is devoted to the memory of Bohumil Böhm who contributed to this study from the very beginning and deceased in 2015.

rows were build first, later followed by stone pyramids with temples on top. Here, stelae with altars started to be erected. Mutual cultural relations and the exchange of knowledge and ideas at large distances started to be established. Hieroglyphic scripture and calendar were created, in which a 365-day astronomical year (Haab) and a 260-day sacral cycle (Tzolkin) play a dominant role (see Fig. 1 in Section 1.2). First astronomical knowledge appears. Step by step, the original cultural unity of village habitation eroded. During centuries, peculiar cultural manifestations are formed in individual parts of today's Mexico and neighbouring southern countries.

Among these cultures, the Mayan one excels. Its development from simple villages to splendid temple cities was similar to one of other Indian cultures of Mexico. In the time of its heyday, it covered the area of today's federal states of Chiapas, Campeche, Yucatán and territory Quintana Roo in Mexico, Guatemala, Belize, northwest of Salvador, and west of Honduras. Its origin is seen in early agricultural settlements on the Pacific coast of Guatemala and Guatemalan highland between 2200 and 1900 BC – see, e.g., Clark and Pye (2005) or Serrano and Schwarz (2005).

Cultural and economic progress expanded, over several centuries, throughout the whole Mayan territory and culminated by building of temple cities with grandiose pyramids, palaces, temples and playgrounds for ritual ball games (Pérez 2013). Stone stelae and temple walls were covered with numerous carved hieroglyphic texts with calendar dates. Attention was devoted also to astronomical phenomena such as observed motions of the Sun, Moon, visible planets and their conjunctions, and solar eclipses. One of the most elegant temple cities is Palenque in today's Mexican state of Chiapas. Temples are built on step terraces, with large stone panels containing hieroglyphic scripts. All this was possible thanks to the economy that was so efficient that it enabled the non-agricultural class to intensively practice civil engineering, advanced commerce, arts, letters, and also astronomy. After 800 AD came a disaster, the classical period of Maya civilization ended. Due to catastrophic draughts and the invasion of militant groups from central Mexico, Mayan cities are abandoned. At the beginning of the 16th century, after the Spanish invasion, the Maya lived only in simple villages.

1.1. Dresden Codex

Most of Maya inscriptions were destroyed during the Spanish Inquisition; Dresden Codex (DC) is one of the four hieroglyphic codices that survived (the other ones are Madrid, Paris and Grolier). DC was discovered in Dresden (hence its name) and is now deposited in the museum of the Saxon State Library. It is a book consisting of folded 39 sheets (78 pages). Its origin is put on Yucatán Penninsula. It is probably a copy made around 1200 from three different original sources, older by about three to four hundred years (Thompson (1972), Bricker and Bricker (2011), or `https://en.wikipedia.org/wiki/Dresden_Codex`). It covers the interval between 280 and 1325 AD, it is written in Mayan glyphs, and contains calendar data of both historical and astronomical events (often with no indication of which event it is referring to). DC also contains mathematical tables, serving to compute the length of the tropical year and the revolution of planets. The dates in DC are usually expressed in the Long Count of Maya calendar (see Section 1.2), and they are not ranged chronologically. The dates sometimes appear in pairs, sometimes only a date in the 260-day Tzolkin is given, or a difference from the preceding date is recorded.

1.2. Maya calendar, correlation

The Maya developed a very complicated calendar system, described, e.g., by Foster (2002). It consisted of several cycles that can be represented by a simple scheme shown in Fig. 1.

Parallel to these cycles, there is also used the so called Long Count (LC), expressing the number of days elapsed since the origin of Mayan chronology. The whole cycle of LC consists of 1 872 000 days. After its end, a new cycle began. All cycles shown in Fig. 1 and the LC met after 136 656 000 days, i.e., after 374 152 years. LC is similar to Julian Date (JD), used in astronomy. In the preserved texts in Dresden Codex (DC, see below) the dates expressed in LC are usually accompanied by dates in 260-day Tzolkin and 365-day Haab'. Other cycles were not always used. To express the date in LC, the Maya used a modified vigesimal (base-20) positional numeral system of five time intervals and their multiples. These intervals are as follows:

K'in = day

Uinal = 20 K'ins

Tun = 18 Uinals = 360 K'ins

K'atun = 20 Tuns = 7 200 K'ins

B'ak'tun = 20 K'atuns = 144 000 K'ins

Thus the LC date is written in DC as five numerals, usually ranging from top to bottom, or from left to right. If denoted as n_1 through n_5 (corresponding to the number of B'ak'tuns to K'ins), the date is written as $n_1.n_2.n_3.n_4.n_5$. All these numbers go from 0 to 19, with the exceptions of n_1 (0 to 12) and n_4 (0 to 17). The number of LC days is then expressed in our decimal system by a simple formula

$$\mathrm{LC} = 144000 n_1 + 7200 n_2 + 360 n_3 + 20 n_4 + n_5. \quad (1)$$

In today's astronomy, we are similarly using Julian Date (JD), also the number of days counted from

260-day Tzolkin
365-day Haab' } they met after 18 980 days (calendar round)

9-day cycle } they met after 170 820 days

K'atun cycle of 93 600 days was divided to 13 K'atuns, each having 7 200 days. Each K'atun consisted of twenty 360-day Tuns (or „years"), whose were 260 in this cycle. } after 6 832 800 days all these cycles met

Fig. 1: Schematic representation of the Maya calendar.

an arbitrarily chosen origin. The relation between the two counts is given by a difference between the two origins τ = JD − LC, called 'correlation'. The correlation can be determined if we know the date of at least one event in both LC and JD. During the past century, more than fifty different values of correlation were published (for their complete list see, e.g., Böhm et al. (2013)), based on both historical and astronomical events. However, they are mutually highly inconsistent; individual values of τ range from 394 483 to 774 083.

Maya historians mostly accept as a standard the Goodman-Martínez-Thompson (GMT) value of 584 283 days (Thompson 1935). It is based mainly on events from the post-classical period of the Maya civilization. On the other hand, brothers Böhm published their correlation (BB with τ = 622 261days), based purely on numerous astronomical phenomena of the classical period of Maya civilization as recorded in DC, but also carved in stone stelae, altars, and walls of Maya temples (Böhm and Böhm 1991a,b, Böhm and Böhm 1996).

The values of GMT and BB correlations are evidently not consistent – they differ by about 104 years. We believe that the explanation for this difference rests on the fact that the authors of GMT (erroneously) assumed that the Maya calendar was continually used from the oldest phases of Maya history up to the beginning of the 16th century. They reconstructed LC backward from the sources of the post-classical period (16th century) into the classical one (before 900). The continuity between the two, however, does not exist – LC system of dating was interrupted during the 11th century and replaced by the calendar system used in central Mexico (this change was introduced probably under the influence of the important non-Maya city Xochicalco).

During the past years, we examined how well different values of correlation lead to identification of astronomical events, recorded in DC, with reality given by exact astronomical calculation, with the following results. Klokočník et al. (2008) used astronomical data (solar eclipses, planetary conjunctions, greatest elongations of planets from the Sun, heliacal risings and settings) from DC and stelae to find out which of ten selected correlations yields the best fit with reality. They concluded that only BB correlation is compatible with all astronomical data available. All other considered correlations, including GMT, do not satisfy all of them as they fit only a small subset of them. GMT fits only a part of data from the stelae, but none of astronomical phenomena in the DC. Böhm et al. (2013), considering that short-periodic astronomical events can suffer from some ambiguities, added to long-periodic ones. They used namely the synchrony of the Venus heliacal risings with solar eclipses (period 132 years), Venus and Mars conjunctions with eclipses (period 37 years), conjunctions of Jupiter with Saturn repeated in a rare way (period 80 years), and a synchrony of synodic and sideric periods of Mercury with the tropical year (period 6 years) to test the validity of different correlation again. All these events, as recorded by the Maya, coincide with reality only if BB correlation is used as all others fail. Recently Vondrák et al. (2022) demonstrated that the old Maya observed Mercury and made records of these events. 19 records of Mercury's greatest elongations from the Sun and 9 records of its conjunctions with the Sun were found in DC. Using the BB correlation, all of them coincide with reality on average within two days.

2. PLANETARY CONJUNCTIONS

We found, on p. D37 of DC, two initial dates of Long Count, placed one above the other in the bottom of the utmost right column (9.18.2.2.0 and 9.12.11.11.0), see Fig. 2. From these, the other two time intervals must be subtracted (the symbol of subtraction is shown) to obtain additional dates. These intervals can be seen in the second column from the right. They are overlapped and distinguished by color (1.7.11 in black, 12.11 in red). Thus, we obtain in total six LC dates (in chronological order: 9.12.10.3.9, 9.12.10.16.9, 9.12.11.11.0, 9.18.0.12.9, 9.18.1.7.9, and 9.18.2.2.0) whose close vicinity we inspected and found the corresponding astronomical phenomena.

To this end, we applied BB correlation to convert them to JD and Julian Calendar. To calculate astronomical phenomena, we use the planetary theory VSOP87 by Bretagnon and Francou (1988) within close vicinity (typically several tens of days) of the dates found in DC. All calculations were made for the geographic position of Palenque (17°29′ N,

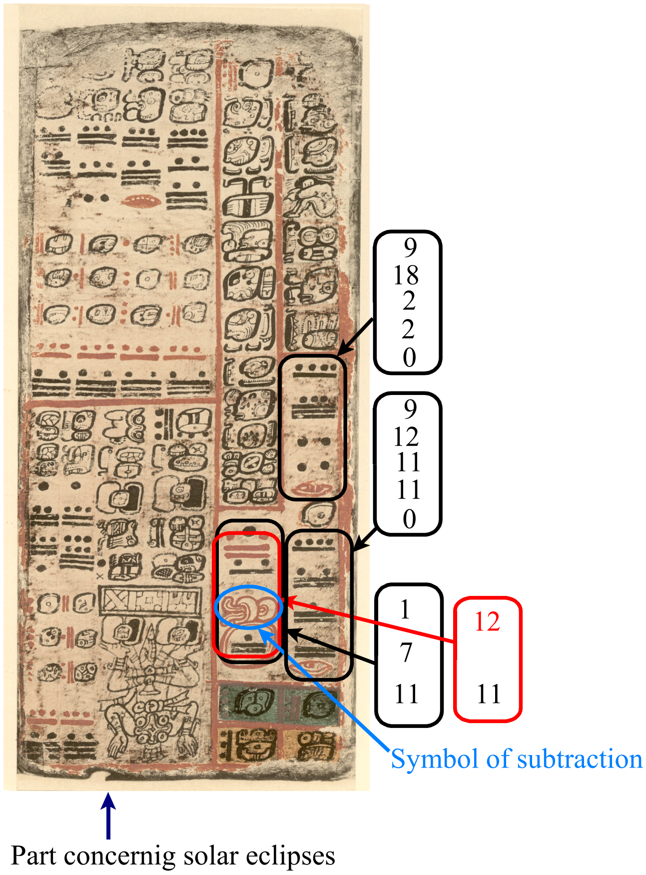

Fig. 2: Page D37 of Dresden Codex with records of planetary conjunctions.

Table 1: Astronomical phenomena identified with dates in page D37 of Dresden Codex.

Date in DC	LC	JD	Jul. cal.	phenomenon
9.12.10.3.9	1 386 069	2 008 330	Jul 5, 786 AD	two stat. p. + two conj. Mars-Jupiter
9.12.10.16.9	1 386 329	2 008 590	Mar 22, 787 AD	conj. Mercury-Venus
9.12.11.11.0	1 386 580	2 008 841	Nov 28, 787 AD	quasi conj. Venus-Mars
9.18.0.12.9	1 425 849	2 048 110	Jun 3, 895 AD	two stat. p. + two conj. Mars-Saturn
9.18.1.7.9	1 426 109	2 048 370	Feb 18, 896 AD	conj. Venus-Mars
9.18.2.2.0	1 426 360	2 048 621	Oct 26, 896 AD	conj. Venus-Mars

92°03′ W), assumed the center of Maya civilization. Namely, we calculate, for the local midnight of each day, the geocentric ecliptic coordinates of both planets. From these we further determine the date of conjunction (when the ecliptic longitudes of both planets are equal) or, alternatively, the date of quasi-conjunction (it occurs when the longitudes of both planets are different, but their angular distance attains minimum). This information is used below for a graphical representation of the phenomenon progression.

The results are summarized in Table 1. All six dates found in DC can be identified with conjunctions, in two cases (July 5, 786 AD and June 3, 895 AD) with two stationary points of both planets (in longitude) and their two conjunctions during six months. In order to find if the corresponding phenomena were really visible at Maya territory, we calculated, for the moments of civil twilight at Palenque (i.e., when the Sun was six degrees below the local horizon) horizontal coordinates of both planets (azimuth A, counted from the south-westward, and altitude h with astronomical refraction applied). These coordinates are further used to demonstrate the visibility of the phenomenon at Palenque.

2.1. Graphical representations

There were two stationary points of Mars and Jupiter in longitude (i.e., the dates when the first derivative of the geocentric ecliptic longitude was zero) and two conjunctions of Mars with Jupiter in April–August 786 AD. The progression of this complicated phenomenon is represented in Fig. 3, where the motion of both planets in the ecliptic system between April 1 and September 30 is displayed. These motions occur dominantly in longitude, latitudes of the planets do not change very much. In order to show also the motion in latitude, its scale is enhanced about ten times.

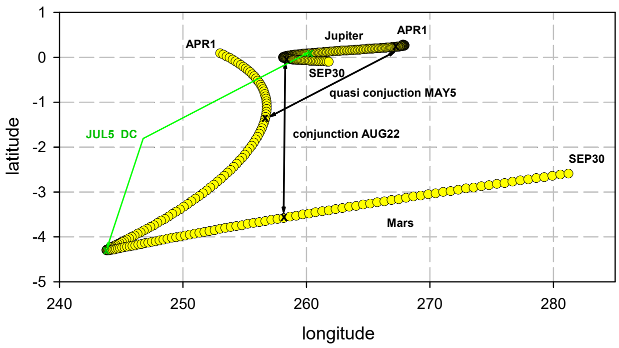

Fig. 3: Two stationary points and two conjunctions of Mars with Jupiter in April–September 786 AD.

The year 786 AD must have provided a spectacular view. In April, both planets were in stationary points (Jupiter on April 11, Mars on April 27) and slightly later they approached their quasi-conjunction (on May 5, with the minimum distance between Mars and Jupiter 10°.76). In July–August there arrived the second stationary points of both planets (Mars on July 3, Jupiter on August 11), and on August 22 another conjunction happened, with the minimum distance between the two planets of 3°.54. The recorded date in DC, July 5, is close to the second stationary point of Mars, and also to the average date of both conjunctions.

Both planets were well visible in the night sky, high above the horizon of Palenque (up to 50°) during both conjunctions. The best visibility was achieved in May (before sunrise in southwest) and in August (after sunset in the south), as demonstrated by Figs. 4 and 5, respectively. The brightness of both planets was sufficiently high; the magnitude of Jupiter was in the range between −2.3 and −2.7 in April–May and between −2.7 and −2.1 in June–September, the magnitude of Mars changed from −0.8 to −2.5 in April–May, and from −2.4 to −0.2 in June–September, respectively.

Next year in March 787 AD, there occurred a conjunction of Mercury with Venus. The record of this event in DC (March 22, 787 AD) is not very far from the real conjunction (March 13). In addition, Mercury was near its greatest elongation from the Sun

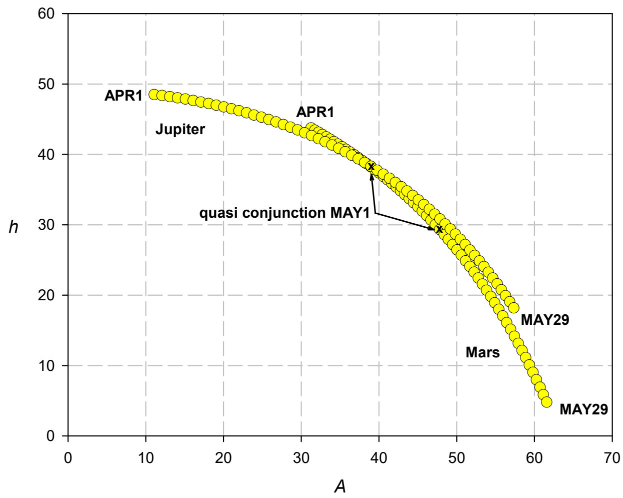

Fig. 4: Visibility of Mars and Jupiter at Palenque, April–May 786 AD.

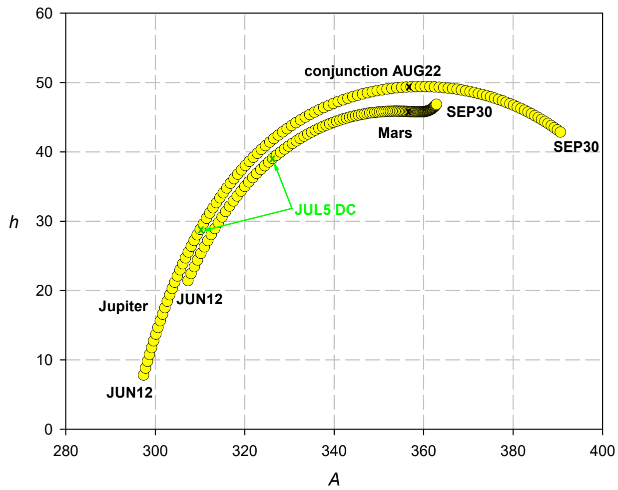

Fig. 5: Visibility of Mars and Jupiter at Palenque, June–September 786 AD.

(March 19). The situation is represented in Fig. 6; both planets move almost parallel to each other, their angular distance changes very slowly, hence it was extremely difficult to estimate the exact date of the conjunction with the naked eye. Fig. 7 shows that the phenomenon was visible at Palenque – the event was observable after sunset in the west, about 11° above the horizon at the moment of local civil twilight. Both planets were sufficiently bright to be observed with the naked eye: the magnitude of Mercury changed between −1.3 and 1.4 and the one of Venus stayed almost constant about −3.8.

The quasi-conjunction of Venus with Mars occurred later the same year, on November 25, 787 AD, with the distance between the two planets equal to 3.19°. The record of this event in DC shows

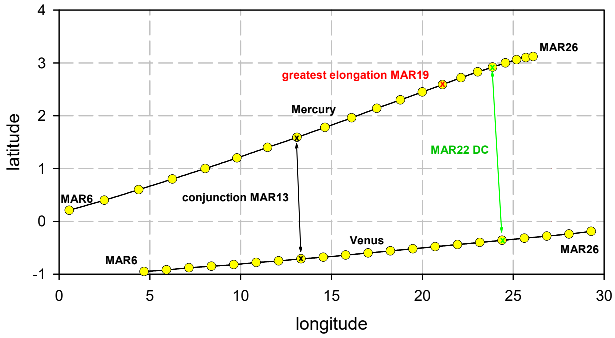

Fig. 6: Conjunction of Mercury with Venus in March 787 AD.

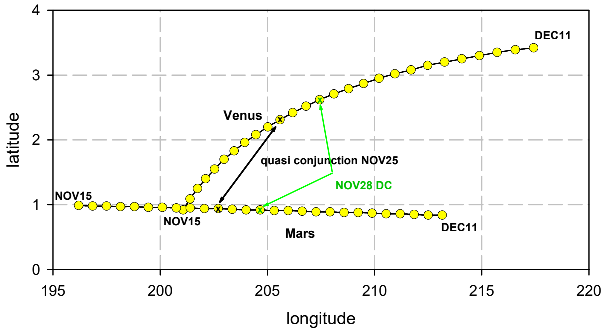

Fig. 8: Conjunction of Venus with Mars in November–December 787 AD.

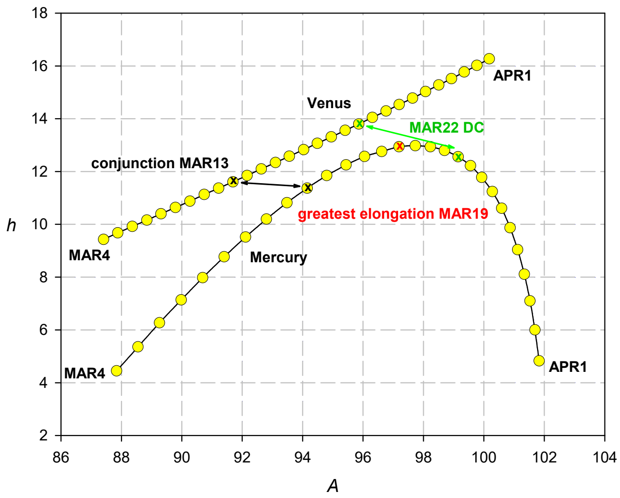

Fig. 7: Visibility of Mercury and Venus at Palenque, March 787 AD.

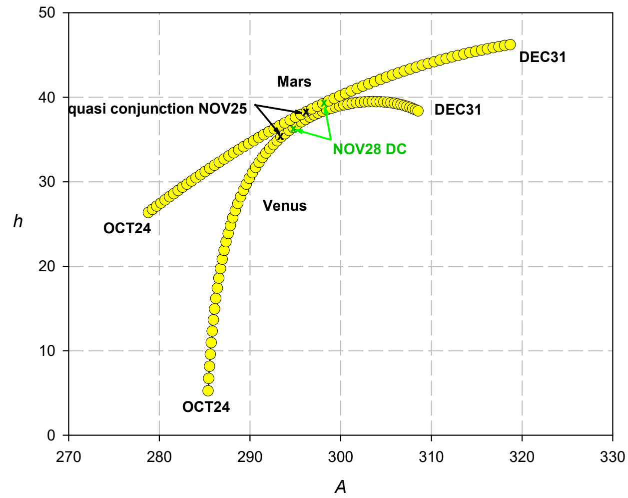

Fig. 9: Visibility of Venus and Mars at Palenque, November–December 787 AD.

November 28, only three days away. The motion of both planets in geocentric ecliptic coordinates is depicted in Fig. 8, their visibility above the horizon of Palenque in Fig. 9. Venus and Mars were visible near their quasi-conjunction before sunrise very well, high above the southeast horizon, their magnitudes ranging from −4.9 to −4.7 for Venus and 1.7 to 1.5 for Mars.

The year 895 AD brings a situation very similar to the one of 786 AD. Around the date recorded in DC (June 3, 895 AD) we found two stationary points of Mars and Saturn in geocentric ecliptic longitude (Saturn on February 14, Mars on March 14, Mars on May 28, and Saturn on July 4), and two conjunctions of both planets (quasi conjunction on March 15, with their minimum mutual distance between the planets equal to $0\overset{\circ}{.}81$, and conjunction on July 11, with their minimum distance of $4\overset{\circ}{.}28$). The progression of this complicated phenomenon is displayed in Fig. 10. The recorded date in DC, June 3, is near the average date of the second stationary points, and also the average date of both conjunctions.

Both planets were well visible at Palenque around the dates of their conjunctions in March (after sunset above the west horizon) and July (before sunrise above the south horizon), as demonstrated in Figs. 11 and 12, respectively. The magnitude of Mars changed from 0.2 to −1.9 in February–April and from −1.6 to −0.2 in May–July. During the same periods the magnitude of Saturn progressed from 1.3 to 0.9 and from 1.0 to 1.4, respectively.

Conjunction of Venus with Mars happened on February 16, 896 AD, very close to the Maya record in DC (February 18). The situation is depicted in Fig. 13. Both planets were very close to each other - only $0\overset{\circ}{.}09$, and they moved almost mutually parallel. As seen in Fig. 14, the visibility at Palenque was very good, the conjunction occurred about 30° above the west horizon at the moment of civil twilight, and the brightness of both planets was also favorable. Their magnitudes stayed almost constant in the range −4.0 – −4.1 and 1.3 – 1.4 for Venus and Mars, respectively.

The last conjunction that we detected occurred in October 896 AD. Being recorded in DC on October

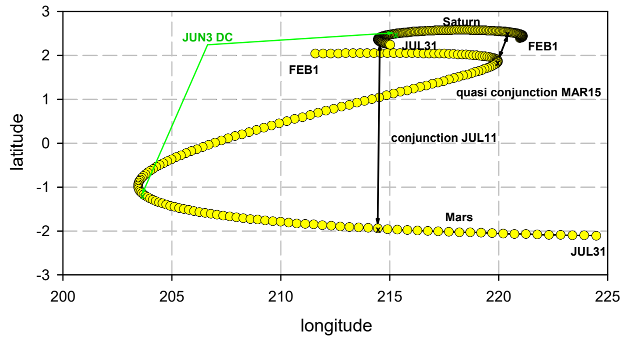

Fig. 10: Two stationary points and two conjunctions of Mars with Saturn in February–July 895 AD.

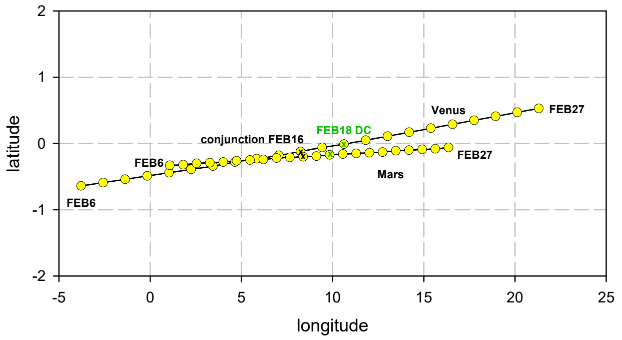

Fig. 13: Conjunction of Venus with Mars in February 896 AD.

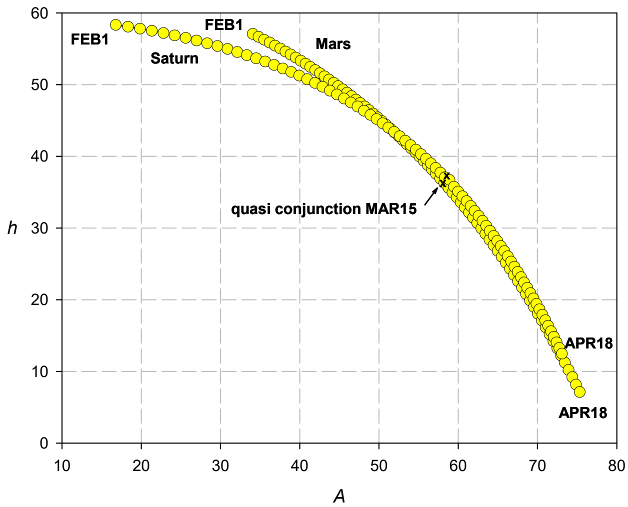

Fig. 11: Visibility of Mars and Saturn at Palenque, February–April 895 AD.

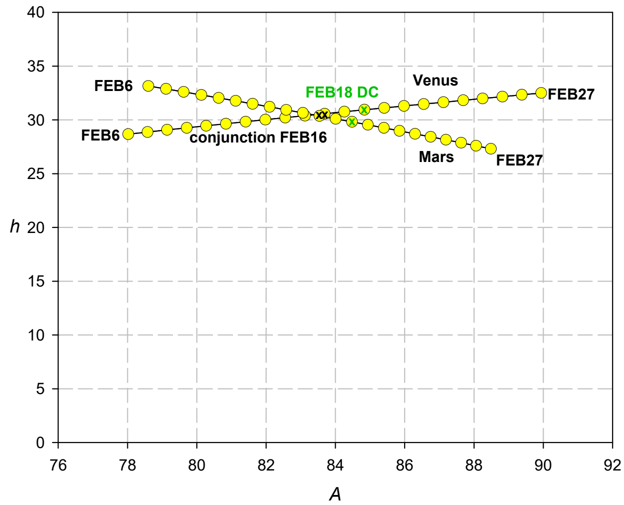

Fig. 14: Visibility of Venus and Mars at Palenque, February 896 AD.

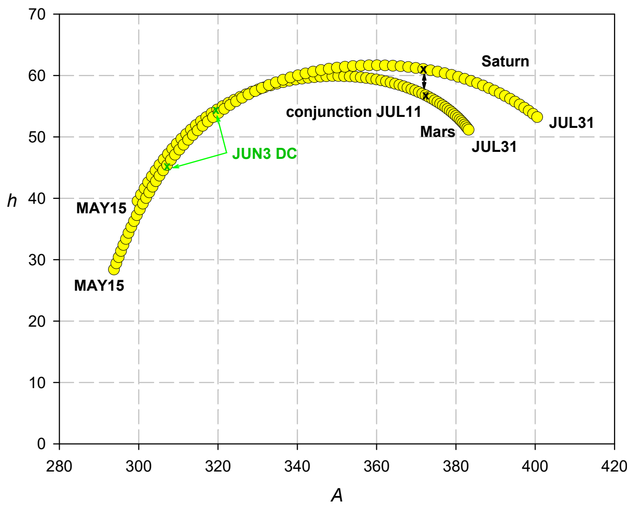

Fig. 12: Visibility of Mars and Saturn at Palenque, May–July 895 AD.

26, it happened in reality on October 24, only two days earlier. The situation is to be seen in Fig. 15. Very similarly to the preceding case, they stayed very close to each other for a long time, the smallest angular distance between them being only $0\overset{\circ}{.}27$. Both planets were well visible before sunrise, high above the east horizon, as shown in Fig. 16. The magnitudes of both planets remained almost constant, for Venus between −4.2 and −4.1, for Mars between 1.8 and 1.7.

3. DISCUSSION AND CONCLUSIONS

The ability of the old Maya to observe with high accuracy different astronomical phenomena, and their skill to utilize their natural patterns for predictions is admirable. They recorded the results of their observations and predictions in the Maya calendar, and preserved to us in Dresden Codex.

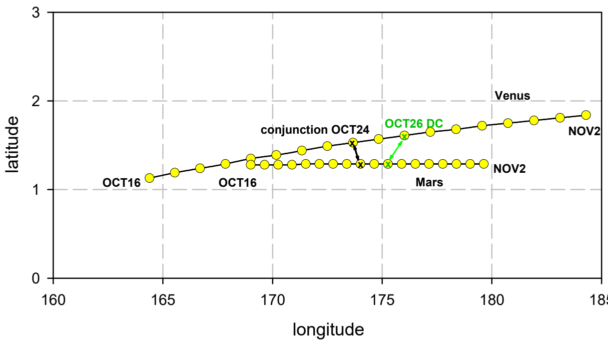

Fig. 15: Conjunction of Venus with Mars in October 896 AD.

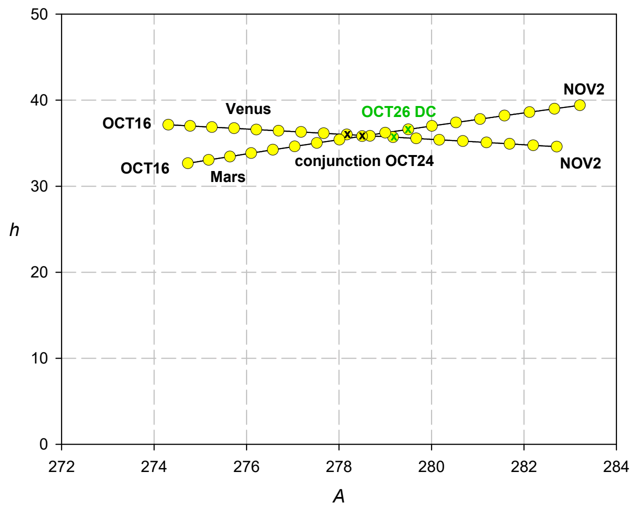

Fig. 16: Visibility of Venus and Mars at Palenque, October 896 AD.

In this study, we succeeded in finding six new records of astronomical phenomena in DC – conjunctions of all known planets of the epoch. All of them correspond to real events, well visible from the Maya territory, when the correlation of brothers Böhm is used to convert Maya Long Count to Julian Date. The differences between the two dates (Maya record in Dresden Codex and reality) are only several days, which is quite acceptable when considering that the Maya did not have any observational technique than the naked eye.

We also made an experiment using the GMT correlation. When this value was used, the six dates in Julian Calendar changed (about 104 years earlier) to July 13, 682 AD, March 30, 683 AD, December 6, 683 AD, June 11, 791 AD, February 26, 792 AD, and November 3, 792 AD. We tried to find possible planetary phenomena close to these dates and found only two candidates, visible from Palenque: the best visibility of Mercury near its greatest elongation from the Sun on July 8, 682 AD, and conjunction Mercury–Venus on December 3, 683 AD. For the remaining four dates, no corresponding phenomenon was found.

The difference between BB and the GMT correlation, 37 978 days, is almost exactly equal to 104 Haabs and also to 146 Tzolkins. This is probably not a mere random coincidence, as we already stated (Böhm et al. 2013).

We propose the explanation that the GMT correlation is based on the (erroneous) assumption that the Maya calendar was continually used from the beginning of the Maya history up to the 16th century. The continuity between the classical and post-classical period however does not exist – the LC system of dating was interrupted during the 11th century. The reconstruction of LC backward from the sources of the post-classical period (16th century) into the classical one was therefore wrong. Evidently, the BB correlation yields a much better fit with astronomical phenomena than GMT.

Thus, the present study provides another independent confirmation of the BB correlation, valid in the classical period of Maya civilization. The GMT correlation can probably be used for the events in the post-classical period only.

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НОВООТКРИВЕНИ МАЈАНСКИ ЗАПИСИ О АСТРОНОМСКИМ ПОЈАВАМА У ДРЕЗДЕНСКОМ КОДЕКСУ

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Оригинални научни рад

Богата култура древних Маја изнедрила је врло сложен и комплексан календар; мајанска култура такође је забележила важне историјске догађаје и многе значајне астрономске појаве. Главни извор информација представља Дрезденски кодекс (ДК), један од четири сачувана мајанска хијероглифска писана наслеђа. ДК отприлике обухвата интервал између 280. и 1325. године н.е. Стари проблем прецизног мајанског датирања у односу на наш календар традиционално се назива корелацијом; изражава разлику у данима између мајанског Дугог рачуна и Јулијанског датума, који се користи у данашњој астрономији. Постоји више од педесет објављених корелација које се међусобно разликују чак и за неколико векова. Историчари углавном прихватају такозвану GMT вредност (Gudman-Martinez-Tompson) од 584283 дана, која се углавном темељи на историјским догађајима из извора који припадају посткласичном периоду мајанске историје. Напротив, браћа Бем су користила прецизно датиране астрономске податке из класичног периода да би извели Бемову корелацију (BB*) од 622261 дана. За разлику од GMT корелације, она се одлично поклапа са астрономским појавама забележеним у ДК. Од тада смо објавили неколико радова који подржавају валидност BB корелације и њену предност над GMT у класичном периоду мајанске историје. У ту сврху, користили смо више записа о астрономским појавама откривеним у ДК. Ова студија описује шест записа о планетским конјункцијама које смо недавно пронашли на стр. 37 ДК, који се односе на планете Меркур, Венеру, Марс, Јупитер и Сатурн. Сви ови записи се поклапају са стварним појавама ових феномена у размаку од неколико дана, ако се примени BB корелација.