Study of Lunar Eclipse Records in Yin Oracle Bone Inscriptions Based on Modern Astronomical Planetary Ephemerides: Postprint

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Abstract

The five records of solar and lunar eclipses in the Yin oracle bone inscriptions constitute the most conclusive evidence currently known for astronomical dating of the Yin-Shang period. The Xia-Shang-Zhou Chronology Project has determined the occurrence dates of these five lunar eclipses recorded in the Yin oracle bone inscriptions. The authors of this paper employ the modern astronomical planetary ephemeris DE422, released by NASA's Jet Propulsion Laboratory (JPL), to compute the primary parameters of these five eclipses, investigate their observability across the Earth's surface, and further confirm their visibility at the Yin capital Anyang. The research results support the occurrence dates provided by the Xia-Shang-Zhou Chronology Project for the five eclipses and can serve as a reference for in-depth study of the Yin oracle bone inscription eclipses.

Full Text

Research on Lunar Eclipse Records in Yin Oracle Bone Inscriptions Based on Modern Astronomical Planetary Ephemeris

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Abstract

There are five lunar eclipses with heavenly stems-earthly branches dating recorded in the Yin period oracle bone inscriptions, which represent the most conclusive materials known for astronomical dating during the Shang dynasty. The Xia-Shang-Zhou Chronology Project has previously determined the dates of these five lunar eclipses. In this study, we utilize the DE422 modern astronomical planetary ephemeris released by NASA's Jet Propulsion Laboratory (JPL) to calculate the main parameters of these five lunar eclipses and investigate their observability across the Earth's surface, with particular focus on confirming their visibility at Anyang, the capital of the Yin dynasty. Our results support the eclipse dates provided by the Xia-Shang-Zhou Chronology Project and offer valuable reference for further research on lunar eclipses recorded in Yin oracle bone inscriptions.

Keywords: Yin oracle bone inscriptions; modern astronomical planetary ephemeris; lunar eclipse
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China has one of the earliest developed astronomical traditions in the world, with verifiable written records of celestial phenomena dating back over three thousand years. These ancient astronomical records hold significant value not only for historical and ancient astronomical research but also for modern astronomical studies [1]. Oracle bone inscriptions constitute the primary content of Shang dynasty oracle bones and serve as crucial materials for studying the social history of the Yin-Shang period. Through nearly a century of effort by several generations of scholars, five lunar eclipse records with sexagenary cycle dates have been identified in the Yin oracle bone inscriptions. Chinese and foreign scholars have calculated and verified the occurrence dates of these eclipses, yielding more than thirty different conclusions [2]. Based on new chronological classifications of Yin oracle bones, historians and archaeologists have determined that these five lunar eclipses occurred within a thirty-year timeframe from the latter half of King Wuding's middle reign to the end of his rule, possibly extending into his successor Zu Geng's reign. Zhang Peiyu [3] identified five lunar eclipses visible at Anyang, the Yin capital, that satisfy both the sexagenary cycle dates and sequential order recorded in the oracle bone inscriptions. These occurred on July 12, 1201 BCE (Guiwei evening eclipse), November 4, 1198 BCE (Jiawu evening eclipse), December 27, 1192 BCE (Jiwei evening to Gengshen eclipse), October 25, 1189 BCE (Renshen evening eclipse), and November 25, 1181 BCE (Yiyou evening eclipse). This research has been recognized as a significant achievement of the Xia-Shang-Zhou Chronology Project [4].

Astronomical planetary ephemerides hold substantial practical value for astronomy, Earth sciences, and related disciplines. The DE series modern astronomical planetary ephemerides released by NASA's Jet Propulsion Laboratory (JPL) have been widely applied in astrometry, deep space navigation, and interplanetary exploration. In September 2009, JPL released the DE422 planetary ephemeris [5], with a data span from December 7, 3001 BCE to January 30, 3000 CE. This ephemeris can satisfy the fundamental requirements of researchers studying ancient astronomical records. This paper employs the

DE422 ephemeris to calculate these five Yin period lunar eclipses, examining their observability across the Earth's surface and specifically investigating their visibility at Anyang, the Yin capital.

1. Universal Time Correction

The DE422 modern astronomical planetary ephemeris adopts Terrestrial Dynamical Time (TDT) as its time system. Due to long-term variations in Earth's rotation, a difference exists between Universal Time (UT), which is based on Earth's rotation, and TDT. This difference is known as the Universal Time correction (ΔT). Ancient astronomical records can be used to derive historical ΔT values, and conversely, known ΔT values for a particular period can be used to calculate the observability of celestial phenomena at that time [6-8]. Morrison and Stephenson synthesized various ancient astronomical records and, assuming a lunar orbital acceleration of -26.0 arcseconds/(century)^2, derived a ΔT fitting formula for dates before 501 BCE: [-20+32$\times$(year-1820)^2/100^2] seconds [7]. We calculated the ΔT values corresponding to the five eclipse dates: July 12, 1201 BCE; November 4, 1198 BCE; December 27, 1192 BCE; October 25, 1189 BCE; and November 25, 1181 BCE. Since the DE422 ephemeris employs a lunar orbital acceleration of -25.85 arcseconds/(century)^2 [9], we applied a correction to the ΔT values in this study. The corrected ΔT values are listed in Table 1 . As ΔT determinations depend on ancient astronomical records, the formula-derived ΔT values contain uncertainties [10]. Table 1 also presents the error ranges for ΔT and the resulting longitude variations caused by these errors.

2.1 Overview of the Yin Period Lunar Eclipses

A lunar eclipse is a special astronomical phenomenon that occurs when the Earth moves between the Sun and the Moon, causing the Moon to pass through Earth's shadow. When the entire lunar disk enters Earth's umbra, it is called a total lunar eclipse; when only a portion enters, it is a partial lunar eclipse. Additionally, when the Moon passes through Earth's penumbra, it is called a penumbral lunar eclipse. Researchers typically focus on total lunar eclipses and partial lunar eclipses with large magnitudes. Total lunar eclipses have seven contact phases: penumbral eclipse beginning, first umbral contact, second umbral contact (total eclipse beginning), greatest eclipse, third umbral contact (total eclipse ending), fourth umbral contact, and penumbral eclipse ending. Partial lunar eclipses have five phases: penumbral eclipse beginning, first umbral contact, greatest eclipse, fourth umbral contact, and penumbral eclipse ending. Based on the geometric positions of the Sun, Moon, and Earth, the times of these contact phases can be calculated [11], and these phases can be illustrated through lunar eclipse overview diagrams. Figure 1 [Figure 1: see original paper] presents overview diagrams for the five lunar eclipses occurring on July 12, 1201 BCE; November 4, 1198 BCE; December 27, 1192 BCE; October 25, 1189 BCE; and November 25, 1181 BCE. In these diagrams, P1 and P4 mark the Moon's center at penumbral eclipse beginning and ending, while U1, U2, G, U3, and U4 mark the Moon's center at first umbral contact, second umbral contact, greatest eclipse, third umbral contact, and fourth umbral contact, respectively. Clearly, the eclipses on July 12, 1201 BCE, November 4, 1198 BCE, and October 25, 1189 BCE were partial lunar eclipses, while those on December 27, 1192 BCE and November 25, 1181 BCE were total lunar eclipses.

2.2 Observability of the Yin Period Lunar Eclipses

After accounting for the Universal Time correction ΔT, we calculated the altitude angles of the Moon at each contact phase as observed from Earth's surface to determine the visibility of each phase. The observability of these five Yin period lunar eclipses was calculated and plotted using cylindrical projection in the five sub-panels of Figure 2 [Figure 2: see original paper]. In these maps, the red curves represent contours where the Moon's altitude angle is zero at each contact phase, corresponding to the boundaries of moonrise and moonset. The red circles indicate the ground projection points of the Moon at greatest eclipse, while the solid red vertical lines mark the terrestrial meridians where greatest eclipse is observable. The dashed red vertical lines represent longitude variations in the greatest eclipse meridian caused by ΔT errors. The opposite side of Earth from the red vertical lines is the region where the lunar eclipse is not visible.

2.3 Observation Conditions at Anyang

Yin Ruins is the site of the late Shang dynasty capital and represents the first confirmed capital city in Chinese history with both documentary and archaeological evidence from oracle bone inscriptions, located in present-day Xiaotun Village, Yindu District, Anyang City, Henan Province. We calculated the observation conditions for these five lunar eclipses at this location (36°.13 N, 114°.33 E), with results presented in Table 2 . In the table, "local time" is obtained by adding the local longitude divided by 15 to Universal Time; times preceded by "-1" indicate the previous day, while "+1" indicates the following day.

The results show that all five lunar eclipses occurred during nighttime hours at Anyang, with each contact phase appearing between sunset and sunrise. The earliest first contact occurred at 18:18 local time for the November 25, 1181 BCE eclipse (local sunset at 16:58), while the latest fourth contact occurred at 01:13 for the July 12, 1201 BCE eclipse (local sunrise at 04:38). The eclipse magnitudes ranged from 0.49 to 1.74 (magnitudes greater than 1 indicate the Moon's disk penetrated deep within Earth's umbra). Barring cloudy or rainy conditions, the changes in sky brightness and the illuminated portion of the Moon during these eclipses would have been quite conspicuous, suggesting that ancient observers likely would have noticed these phenomena, potentially causing considerable attention or even alarm. It should be noted that the times listed in Table 2 were calculated using the ΔT values from Table 1; therefore, the Anyang observation times also contain uncertainties due to ΔT errors.

This study utilizes the DE422 modern astronomical planetary ephemeris released by NASA's JPL to calculate relevant parameters for the five dated lunar eclipses recorded in Yin oracle bone inscriptions, presenting the ground visibility of each contact phase and observation conditions at Anyang, the Yin capital. The results demonstrate that Anyang had the astronomical conditions to practically observe these eclipses, supporting the preliminary findings of the Xia-Shang-Zhou Chronology Project regarding Yin period lunar eclipses. Chronological research naturally requires interdisciplinary collaboration among astronomy, history, archaeology, and isotopic dating, necessitating more in-depth investigation and comprehensive analysis. The results of this paper provide a valuable reference for further research on lunar eclipses recorded in Yin oracle bone inscriptions.

References

1. Feng S. Astroarchaeology in China (3rd Ed)[M]. Beijing: China Social Sciences Press, 2017.
2. Feng S. Review and study on the lunar eclipse data recorded in the Yin period oracle bone inscription[J]. Journal of Ancient Books Collation and Studies, 2002, 6: 8-19.
3. Zhang P Y. The identification of oracle bone inscriptions related to solar and lunar eclipses and the Shang dynasty dating[J]. Social Sciences in China, 1999, 5: 172-198.
4. Expert group of the Xia-Shang-Zhou Chronology Project. 1996-2000 Achievement Report of the Xia-Shang-Zhou Chronology Project (simplified version)[M]. Beijing: World Book Publishing Company, 2000.
5. Konopliv S, Asmar S W, Folkner W M, et al. Mars high resolution gravity fields from MRO, Mars seasonal gravity, and other dynamical parameters[J]. Icarus, 2011, 211: 401–428.
6. Han Y B. Two interesting phenomena in variation of the Earth's rotation derived from studies of records of ancient astronomical observations[J]. Progress in Geophysics, 1996, 11(4): 116-118.
7. Morrison L V, Stephenson F R. Historical values of the Earth's clock error ΔT and the calculation of eclipses[J]. Journal for the History of Astronomy, 2004, 120: 327-336.
8. Ma L H, Han Y B, Yin Z Q, Qiao Q Y. Research on Zhongkang solar eclipse based on modern astronomical planetary ephemeris[J]. Astronomical Research & Technology. 2020, https://doi.org/10.14005/j.cnki.issn1672-7673.20201021.001
9. Williams J G, Boggs D H, Folkner W M. DE421 lunar orbit, physical librations, and surface coordinates, 2008, http://naif.jpl.nasa.gov/pub/naif/generic_{kernels}/spk/planets/de
10. Huber P J. Modeling the length of day and extrapolating the rotation of the Earth[J]. Journal of Geodesy, 2006, 80(6): 283-303.

11. Tang H L, Yu Z K, Shen C J. Calculation of Solar and Lunar Eclipses[M]. Nanjing: Jiangsu Science and Technology Press, 1980.

Note: Figure translations are in progress. See original paper for figures.