Postprint of a Study on the Yisi Day Eclipse Observation in Yin Oracle Bone Inscriptions Based on JPL Planetary Ephemeris

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Abstract

For the only verifiable record of a solar eclipse existing in the oracle bone inscriptions of the Shang Dynasty, the authors utilized the DE422 planetary ephemeris released by NASA' s Jet Propulsion Laboratory (JPL) to calculate the main parameters of this Yisi solar eclipse as recorded, and to delineate the coverage range of the eclipse path on Earth. The visibility of this solar eclipse at the Shang capital Anyang was further confirmed, thereby verifying the accuracy of the prediction in the Shang oracle bone inscriptions.

Full Text

Research on the Yisi Solar Eclipse Observation in Oracle-Bone Inscriptions of the Yin Dynasty Based on the JPL Planetary Ephemeris

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Abstract

For the only verifiable record of a solar eclipse in the oracle-bone inscriptions of the Yin Dynasty, the authors utilize the DE422 planetary ephemeris released by NASA' s Jet Propulsion Laboratory (JPL) to calculate the main parameters of this Yisi solar eclipse and determine the coverage of the eclipse path on Earth. This work further confirms the visibility of the eclipse at Yin capital Anyang and verifies the accuracy of the Yin oracle-bone inscriptions' prediction of this solar eclipse.

Keywords: Oracle-bone inscriptions; JPL planetary ephemeris; Solar eclipse path

Introduction

China is among the earliest countries to develop astronomy, 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 a primary component of ancient Chinese script and serve as crucial materials for investigating the history of the Shang and Zhou dynasties. One such inscription documents a complete prediction of a Yisi solar eclipse, beginning with divination on a Renzi day and asking whether an eclipse would occur two days later. After numerous inquiries over 54 days —spanning multiple days including Yichou, Guiyou, Gengchen, and Xinsi—the scribe finally recorded a verification statement on the Yisi day: "日有食，夕告于上甲，九牛," meaning "The solar eclipse was observed; that evening, a sacrifice of nine oxen was reported to the ancestral king Shang Jia." This represents the only verifiable solar eclipse prediction in the oracle-bone inscriptions of the Yin Dynasty.

Feng Shi synthesized research from multiple scholars and, based on the ganzhi records and the chronology of Yin kings, identified the eclipse recorded in this inscription as occurring on October 31, 1161 BCE [2]. Zhang Peiyu used Newcomb's fundamental arguments and formulas—upon which modern astronomical almanacs are based—to determine the solar longitude and applied linear interpolation to analyze celestial phenomena between 1500 BCE and 2050 CE, providing visibility conditions for historically famous Chinese cities [3]. Liu Ciyuan and Ma Liping employed Kluepfel' s SunTracker software to calculate eclipse parameters and presented the approximate coverage areas of solar eclipses visible in China between 2300 BCE and 2100 CE [4]. Espenak and Meeus utilized VSOP87 and ELP2000/82 to calculate the positions of the Sun and Moon, publishing ground visibility conditions for solar eclipses from 2000 BCE to 3000 CE [5-6].

This paper employs the DE422 planetary ephemeris released by NASA' s Jet Propulsion Laboratory (JPL) to calculate the positions of the Sun and Moon, investigating the eclipse path distribution for the solar eclipse of October 31, 1161 BCE, with particular focus on examining its visibility at Yin capital Anyang, thereby providing astronomical support for in-depth research on this oracle-bone inscription eclipse record.

1. Overview of Astronomical Planetary Ephemerides

Astronomical planetary ephemerides hold significant practical value for geodesy, astrometry, deep space exploration, spacecraft tracking and control, and other related fields. Based on their compilation principles, solar system planetary and lunar ephemerides are primarily divided into two categories: numerical ephemerides and semi-analytical ephemerides. Numerical ephemerides mainly include the DE series planetary ephemerides released by JPL, the numerical integration series of planetary ephemerides from the Paris Observatory released by the French Institute of Celestial Mechanics and Ephemeris Calculation, and the planetary and lunar series ephemerides released by the Russian Institute of Applied Astronomy. Semi-analytical ephemerides primarily include the Paris Lunar Ephemeris (ELP2000/82) from the French Institute of Celestial Mechanics and Ephemeris Calculation, the series of planetary orbital long-term variation ephemerides (VSOP82/VSOP87/VSOP2000/VSOP2013), and the series of outer planet theoretical ephemerides. Currently, the DE series planetary ephemerides have been widely applied in astrometry, deep space navigation, and interplanetary exploration [7].

The DE422 planetary ephemeris, released by JPL in September 2009, spans from December 7, 3001 BCE to January 30, 3000 CE and includes nutation and libration information. This ephemeris can satisfy researchers' basic requirements for studying ancient astronomical records [8,9].

2. Calculation of the Yisi Solar Eclipse

2.1 Apparent Positions and Conjunction Time

To calculate the relevant parameters of a solar eclipse, precise positions of the Sun and Moon as observed from the Earth' s center must be known. Since the 1990s, the DE series planetary ephemerides released by JPL have adopted the International Celestial Reference System (ICRS) recommended by the International Astronomical Union (IAU). The corresponding International Celestial Reference Frame (ICRF) is realized through a set of extragalactic radio source positions. Its coordinate origin is the solar system barycenter, and its coordinate axes have fixed orientations in space. The DE422 planetary ephemeris also employs the ICRF frame. Using this ephemeris, one can directly interpolate to obtain three-dimensional rectangular coordinates and velocity information for planets at any moment within its data span. Furthermore, utilizing the NOVAS software provided by the U.S. Naval Observatory, the apparent right ascension and declination of the Sun and Moon can be determined.

This paper examines the solar eclipse that occurred on October 31, 1161 BCE. Interpolation first yields the moment when the apparent right ascension of the Sun and Moon are identical as 07:30:24 Terrestrial Dynamical Time (TDT), which represents the time of solar-lunar conjunction. Further analysis indicates that this eclipse was an annular solar eclipse. Table 1 provides the TDT times for various eclipse phases including first contact, second contact, maximum eclipse, third contact, and fourth contact.

Table 1 TDT times of solar eclipse phases on October 31, 1161 BCE

Partial eclipse begins	Total eclipse begins	Maximum eclipse	Total eclipse ends	Partial eclipse ends
04:30:32	05:39:02	07:36:59	09:35:01	10:43:31

2.2 Eclipse Path and Visibility

Considering the long-term variation of Earth' s rotation, a time correction ΔT exists between Terrestrial Dynamical Time (TDT) and Universal Time (UT), with its value changing over time. Ancient astronomical records can be used to deduce ΔT values for antiquity, and conversely, known ΔT values for a particular period can be used to determine observational conditions for astronomical events at that time. Stephenson synthesized various ancient astronomical records, adopting a lunar tidal acceleration of -26.0 arcseconds/(century)^2, and provided piecewise fitting formulas for ΔT [11]. The DE422 planetary ephemeris employed in this paper uses a lunar tidal acceleration of -25.85" /(century)^2 [12]; after applying corrections for this difference, the ΔT value for October 31, 1161 BCE is obtained as 27,361 seconds. Based on the geometric relationship of the eclipse formed by the positions of the Sun and Moon [13], the distribution of this solar eclipse can be determined (see Figure 1 [Figure 1: see original paper]).

Figure 1 The solar eclipse path on October 31, 1161 BCE (azimuthal projection)

In Figure 1, "Mag" represents eclipse magnitude and "Wide" represents the width of the central eclipse path. Figure 2 [Figure 2: see original paper] presents the eclipse path distribution using cylindrical projection.

Figure 2 The solar eclipse path on October 31, 1161 BCE (cylindrical projection)

To intuitively demonstrate the observational conditions for this eclipse in the ancient Central Plains region of China, a partial enlargement of Figure 2 is provided as Figure 3 [Figure 3: see original paper]. In the figure, Yin capital Anyang (longitude: 114º.38, latitude: 36º.1) is marked with a black five-pointed star.

Figure 3 Partial enlargement of Figure 2

Conclusion

This paper utilizes the DE422 planetary ephemeris released by NASA' s Jet Propulsion Laboratory to calculate the Yisi solar eclipse on October 31, 1161 BCE—the only verifiable solar eclipse recorded in the oracle-bone inscriptions of the Yin Dynasty. The eclipse path distribution is presented, confirming the visibility of this eclipse at Yin capital Anyang. This eclipse was observed as a sunrise eclipse throughout central and eastern China. The results demonstrate that Yin capital Anyang had favorable conditions for actually observing this eclipse, thereby corroborating the accuracy of the Yin oracle-bone inscriptions' prediction of this solar eclipse.

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