Postprint: A Re-study of the "Tian Zai Dan" Phenomenon Caused by Solar Eclipse

Authors:

Date: 2024-10-15T09:46:44+00:00

Abstract

The ancient text !!《竹书纪年》!! records that in the first year of King Yi of Zhou, ``the sky dawned twice at Zheng'', which modern scholars believe may have been a solar eclipse occurring at sunrise. The Xia-Shang-Zhou Chronology Project selected the annular solar eclipse of April 21, 899 BCE as the corresponding eclipse for the``sky dawning twice'' phenomenon. More general analysis has found that only solar eclipses with a magnitude above 0.95 can produce the ``sky dawning twice'' phenomenon, and there are also restrictions on the solar altitude at maximum eclipse. Given the determination that``Zheng'' is located in Fengxiang County, Shaanxi Province, the changes in solar illumination during the 899 BCE eclipse and the 1997 eclipse measured by the Chronology Project can be simulated through astronomical software. This confirms the universal existence of the "sky dawning twice'' phenomenon, from which the specific process when the phenomenon occurs can be derived and some details can be reconstructed.

Full Text

Preamble

Vol. 65 No. 5
September 2024

Acta Astronomica Sinica

A Restudy of the "Double Dawn" Phenomenon Caused by Solar Eclipses

WANG Sheng-hao (School of History, Beijing Normal University, Beijing 100091)

Abstract

The ancient text *Bamboo Annals* records that "the day dawned twice in Zheng" during the first year of King Yi of Zhou. Modern scholars interpret this as a solar eclipse occurring at sunrise. The Xia-Shang-Zhou Chronology Project selected the annular eclipse of April 21, 899 BCE as the corresponding event. More general analysis reveals that only eclipses with magnitude above 0.95 can produce a "double dawn" phenomenon, with additional constraints on the Sun's altitude at maximum eclipse. Assuming Zheng is located in Fengxiang County, Shaanxi Province, astronomical software can simulate the sunlight variations for both the 899 BCE eclipse and the 1997 eclipse observed by the Chronology Project. This confirms the general existence of the "double dawn" phenomenon and allows us to reconstruct its specific progression and certain details.

Keywords: solar eclipse, celestial mechanics, history of astronomy, methods: observational

2. Previous Research on "Double Dawn"

The ancient text *Bamboo Annals*, compiled during the Warring States period, records a rare celestial phenomenon: "The day dawned twice in Zheng during the first year of King Yi of Zhou." Modern scholars interpret "double dawn" as the sky brightening twice, suggesting a total solar eclipse at sunrise. To verify this phenomenon, the Xia-Shang-Zhou Chronology Project conducted field observations of the total solar eclipse on March 9, 1997 in northern Xinjiang, confirming the reliability of "double dawn" and ultimately selecting the eclipse of April 21, 899 BCE as the corresponding event. This conclusion served as a crucial anchor for the Western Zhou chronology, though computational limitations at the time left certain issues unresolved.

With the development of electronic computers in the 21st century, numerous astronomical software packages have become available, enabling convenient retrieval of ancient celestial phenomena data and comprehensive reconstruction of their parameters. This provides powerful tools for detailed investigation of the "double dawn" phenomenon. The original *Bamboo Annals* has been lost, but both the *Kaiyuan Zhanjing* and *Taiping Yulan* reproduce this record, lending it credibility. For centuries, this phenomenon received little attention, and ancient scholars never associated it with solar eclipses. With the rise of skepticism about ancient history in modern times, particularly regarding pre-841 BCE history, scholars sought to establish pre-Republic chronologies through ancient astronomical records. In 1944, Liu Chaoyang first proposed that "double dawn" meant the sky brightened twice—a sunrise eclipse. Subsequent scholars including Dong Zuobin, Fang Shanzhi, and Pang et al. supported this view, proposing various candidate years: 966 BCE, 925 BCE, 903 BCE, and 899 BCE. The Chronology Project also used "double dawn" as a key chronological anchor, conducting detailed observations of the March 9, 1997 total eclipse at Altay, Fuyun, Habahe, and Tacheng in western Xinjiang. These observations confirmed the phenomenon's reliability, and after further analysis, the project selected the April 21, 899 BCE annular eclipse as the corresponding event, dating King Yi's first year to 899 BCE and incorporating this into the *Xia-Shang-Zhou Chronology*.

Nevertheless, "double dawn" remains controversial. Critics have challenged the Chronology Project's conclusions, arguing that annular eclipses cannot cause significant darkening, that Earth rotation corrections contradict the eclipse occurring at Zheng, or that textual analysis shows no connection between "double dawn" and eclipses. In this context, further investigation using modern astronomical software and more powerful computational tools remains valuable.

3. Sky Brightness Changes from Sunrise and Eclipse

The eclipse hypothesis for "double dawn" proposes that a large-magnitude eclipse at sunrise causes the brightening sky to darken again, creating the visual impression of two dawns. This requires separate examination of how sunrise and eclipses affect sky brightness.

Sunlight reaching Earth must pass through the atmosphere, where scattering makes the sky visible. This scattering also maintains brightness after the Sun drops below the horizon, creating twilight. Standard definitions specify civil twilight when the Sun's center is below 6° (brightest stars visible, no artificial lighting needed), nautical twilight between 6° and 12° (sea horizon visible, most stars visible), and astronomical twilight between 12° and 18° (faintest objects visible, twilight limited to the horizon near sunrise/set). Twilight duration varies significantly with latitude: up to 90 minutes at high latitudes in summer, but only about 20 minutes at the equator. At approximately 35°N in the Central Plains, twilight lasts about 30 minutes.

Sky brightness during sunrise can be measured instrumentally or calculated theoretically. The most influential model is the CIE standard sky model with 15 sky types. The CIE formula for sky brightness is:

1 + c(ed(cid:31) + e (cid:25) [1 + c(edZs (cid:0) e (cid:25) 2 d) + e cos2 (cid:31)](1 + ae b cos Z) 2 d) + e cos2 Zs

where a, b, c, d, e are sky brightness parameters (tabulated for different sky types), Ls is the calculated point brightness, Lz is zenith brightness, Z is the observation point's zenith angle, Zs is the solar zenith angle, and (cid:31) is the angular distance to the Sun. Daytime clear-sky brightness typically ranges 0.5–2.5 cd/m^2. In simplified cases, zenith brightness can represent overall sky brightness, with the empirical formula:

Lz = exp(a0 +a1(cid:13)2 s +a2(cid:13)2 s +a3(cid:13)3 s +a4(cid:13)4 s +a5(cid:13)5 s)

where (cid:13)s is solar elevation in degrees, Lz is in cd/m^2, and a0–a5 are coefficients varying with clear-sky index. provides these coefficients, where K(cid:23) represents the clear-sky index.

Generally, the sky is considered fully dark when solar elevation reaches about -20°. Night sky brightness is approximately 0.1 cd/m^2, making the third dataset in most appropriate. Figure 1 [Figure 1: see original paper] shows zenith brightness versus solar elevation (left) and sky brightness distribution at sunrise (right) for solar elevation 0° (apparent position, accounting for refraction) across different azimuths, including zenith angles of 30°, 60°, and 90° (horizon), using CIE uniform sky parameters (a = 0, b = (cid:0)1, c = 2, d = (cid:0)1, e = 0).

Though idealized, Figure 1 reveals qualitative patterns: brightness growth slows significantly when solar elevation exceeds 10°, while the horizon near sunrise direction is notably brighter than other regions, with opposite directions darker. This contrast diminishes with altitude, becoming minimal by 30° zenith angle.

Although solar luminosity doesn't appear explicitly in sky brightness formulas, bright skies result directly from solar illumination. The Sun's apparent magnitude is constant, but atmospheric attenuation at sunrise or during cloudy weather reduces visible magnitude below actual magnitude, darkening the sky. Figure 2 [Figure 2: see original paper] shows solar magnitude changes during sunrise and eclipse. The pattern of solar magnitude variation through the atmosphere resembles sky brightness changes. Since specific sky brightness is heavily influenced by clouds, haze, and dust, we use solar apparent magnitude as an indicator of sky brightness.

During eclipses, lunar occultation reduces solar radiation reaching Earth, darkening the sky. However, darkening isn't linear with eclipse magnitude. Figure 2 shows minimal solar luminosity change below 0.8 magnitude, rapid decrease beyond 0.8, and dramatic drop near totality. Sky brightness changes follow solar magnitude trends, though total eclipses remain distinct from true night.

Human eye response approximates logarithmic proportionality to intensity in moderate brightness, but this fails in dim conditions. Moonless night sky brightness is about 0.00021 cd/m^2, while urban lighting can reach 0.1 cd/m^2—a two-order-of-magnitude difference that appears similarly dark to observers. Liu Ciyuan defined a "visual brightness" concept to address this. Using Stellarium simulations, we find bright star visibility serves as a quantitative criterion for human sky brightness perception. lists major stars above 0 magnitude visible at northern mid-latitudes.

Under ideal conditions, Venus can be seen during non-eclipse daytime. When solar magnitude drops below (cid:0)25 (approximately 0.8 magnitude), Venus becomes consistently visible. Jupiter requires solar magnitude around (cid:0)23.5 (0.95 magnitude), while Sirius and Mercury need (cid:0)22.5 (0.975 magnitude). Saturn, Vega, Arcturus, and Capella require solar magnitude below (cid:0)20 (magnitude >0.995), near total eclipse. We classify sky darkness into five levels , using solar magnitude dropping to (cid:0)22.5 (when Sirius, the brightest star, becomes visible) or darker as the darkness threshold.

According to Liu Ciyuan's "visual brightness" definition, a 0.95 magnitude annular eclipse reduces sky brightness to 40% of a total eclipse's effect, similar to our darkness level classification. Clouds and haze affect the Sun and bright stars similarly, preserving their magnitude differences. In clear ideal conditions, bright star visibility during eclipses depends only on eclipse magnitude and the respective altitudes of the Sun and stars.

For sunrise eclipses, observed sky brightness changes represent superimposed effects. Below 0.95 magnitude, solar magnitude decreases by less than 3, insufficient for "double dawn." Below 0.8 magnitude, solar luminosity impact is negligible. For magnitudes above 0.95, detailed analysis is required.

First, we must compare twilight duration with eclipse duration. If the eclipse lasts too long relative to twilight, observers may only perceive persistent darkness until the eclipse ends, not "double dawn." Totality takes about 10–14 minutes from 0.8 magnitude to totality, while a maximum 0.97 annular eclipse requires about 17 minutes from 0.8 magnitude to annularity. At 35°N in the Central Plains, twilight lasts about 30 minutes, making the brightening-darkening-brightening sequence of "double dawn" entirely possible for sunrise eclipses.

Second, the eclipse timing cannot be too early. If maximum eclipse occurs when solar elevation is below (cid:0)3° (see Section 5), it only delays brightening without producing "double dawn."

For magnitudes above 0.98, solar magnitude drops dramatically, relaxing requirements on solar elevation at maximum eclipse. At 6° solar elevation (achievable by high mountain horizons), atmospheric extinction alone reduces solar magnitude by over 1 magnitude, and combined with eclipse effects, the total reduction exceeds 5 magnitudes, creating obvious "double dawn." For such total or near-total eclipses, maximum eclipse occurring between (cid:0)3° and 6° can produce the phenomenon.

For magnitudes between 0.95 and 0.98, timing requirements become stricter. These eclipses have limited intrinsic brightness reduction and require atmospheric scattering losses to create noticeable darkening. At 2° solar elevation, extinction reduces about 2.6 magnitudes, yielding 5–6 magnitudes total reduction—barely dark. For such large partial eclipses, "double dawn" generally requires solar elevation between (cid:0)1° and 2°, with specific feasibility requiring further analysis.

Tidal effects gradually slow Earth's rotation, lengthening the day. Over millennia, this becomes substantial. For the Western Zhou period around 900 BCE, Earth's rotation slowdown reached about 6 hours (22,000 seconds), shifting eclipse paths 90° westward and completely changing observation locations. Thus, Earth rotation correction is essential for ancient astronomical calculations, especially for phenomena like "double dawn." Traditionally, this correction uses a parabolic function of years since present:

cT^2

where T is centuries since 1800, coefficient c is in seconds/century^2, typically around c = 30.

4. Verification of the 1997 Eclipse

The Xia-Shang-Zhou Chronology Project selected the March 9, 1997 total solar eclipse to verify "double dawn." The eclipse's western limit lay at the border between Xinjiang and Russia/Kazakhstan. The project organized observations across Xinjiang, recording varying degrees of "double dawn" at Altay, Habahe, Fuyun, and Tacheng.

shows these cities' maximum eclipse magnitudes, mid-eclipse times, coordinates, and sunrise times (Beijing time) during the 1997 eclipse. The Tacheng observation is most notable: despite theoretical predictions of minimal brightness change, the comet's disappearance and reappearance created a profound impression of sky darkening, providing crucial evidence for "double dawn." The observation is described in Literature [5] p. 63:

"The weather was exceptionally clear (heavy snow had fallen previously, clearing only after midnight). The comet was bright. At 8:00, the east showed faint light. At 8:10, clouds appeared in the east, showing red color that gradually spread upward. Stars gradually disappeared; people became distinguishable. At 8:20, the comet vanished. At 8:30, light shot from below the horizon, but the dawn glow seemed unusual, lacking its typical warmth and brilliance. At 8:35, obvious darkening occurred—the dawn glow transformed into evening sunset colors. Sunlight contracted from bright orange to dark red and iron gray. The faint red at the zenith faded, and the whitish western sky also darkened. At 8:38, the vanished Hale-Bopp comet suddenly reappeared in the northeast, piercing the sky like a dagger for over two minutes. From 8:45, the sky and clouds gradually turned from red to yellow, from dark to bright, and all stars finally disappeared."

At Altay and Fuyun, larger magnitudes and closer timing to sunrise, combined with eastern mountains blocking the Sun even above the horizon, produced more dramatic "double dawn" effects, recorded in Literature [5] pp. 61–63.

Using Stellarium to simulate this eclipse and compare with eyewitness accounts yields . At Tacheng, the simulated "double dawn" was extremely weak: minimal sky brightness change after 8:30, with the Hale-Bopp comet showing slight brightening from 8:36–8:37, consistent with observations. At Fuyun and Altay, simulations matched observations well, showing pronounced "double dawn." Tacheng's smaller magnitude and sub-horizon maximum eclipse placed it at the phenomenon's threshold, serving as a criterion for "double dawn" occurrence.

5. Testing the 899 BCE Eclipse

Usable chronological phenomena are periodic, making their recurrence intervals crucial. Phenomena recurring every ~10 years have little value for dating; those requiring >10^3 years may have no suitable candidates. Generally, phenomena with 60–300 year cycles are most valuable. We must therefore determine "double dawn" recurrence intervals.

First, considering only central eclipses (total or annular) whose western limits lie within China: given China's large east-west span, such eclipses occur about every 30 years, but many occur in remote regions (Xinjiang, Tibet, Northeast, South China) invisible from the Central Plains. Restricting to the Central Plains civilization area reduces frequency to roughly once per 200 years, making it valuable for chronology.

lists potential "double dawn" events observable in the Central Plains from 2000 BCE to 2000 CE. The data show "double dawn" eclipses occur roughly every 200 years. Around the 899 BCE eclipse, the previous possible event was 1093 BCE and the next was 727 BCE, both far outside King Yi's plausible reign, demonstrating the phenomenon's chronological value.

Equally important is locating "Zheng." Ancient texts show "Zheng" was a significant place in mid-Western Zhou closely associated with the king. The current *Bamboo Annals* records: "King Mu built the Zhi Palace at West Zheng; kings after Mu resided at West Zheng." Mid-Western Zhou bronze inscriptions also mention the king residing at "Zheng," such as the 1976 excavated three-year (疒兴) hu vessel: "The king was at Zheng, feasting, and called upon Guo Shu to summon (疒兴)." Traditionally, Western Zhou "Zheng" was placed at modern Hua County, Shaanxi, based on *Shiji・Zheng Shijia* commentary: "Zheng is a county under Jingzhao, established by Duke Wu of Qin in his 11th year." According to *Shiji*, Zheng was the fief of Prince You (later Duke Huan of Zheng), King Xuan's younger brother. Some sources also link "Zheng" with "Yulin" and "Shi," placing them near Hua County.

Since Chen Mengjia, new views emerged: Chen argued Western Zhou "Zheng" meant "established well" and was located in Fengxiang, a view supported by Tang Lan, Yin Shengping, and Lu Liancheng. Du Yong argued *Zuozhuan*'s "Yulin" was in Fufeng, Shaanxi, not Fengxiang. Others like Li Xueqin and Liu Ciyuan maintained Hua County location.

Western Zhou mid-period "Zheng" should be determined through combined historical, epigraphic, and archaeological evidence. Pang Xiaoxia noted "Zheng" originally meant "established," possibly referring to multiple locations, and mid-Western Zhou "Zheng" might differ from Duke Huan's Zheng. Over-reliance on isolated evidence linking "Yulin" and "Shi" with "Zheng" is risky. Conversely, bronze inscriptions and limited historical records identify "Zheng" as a royal residence. Fengxiang-Fufeng area contains major Western Zhou sites with high-status artifacts, while Hua County lacks such finds, making it unlikely as "Zheng."

Shang Zhiru's view deserves attention: using extensive archaeological data, he identified the Xiquandu site in Fengxiang as likely King Mu's Zhi Palace at Zheng, featuring palace-scale rammed earth foundations and column bases indicating high-status architecture. Inscriptions provide corroboration: when the king resided at "Zheng," he frequently worked with Guo Shu (Guo of Western Guo, modern Baoji, undisputed), suggesting "Zheng" was near Guo, likely in Fengxiang. This paper concurs that "Zheng" is at the Xiquandu site in Fengxiang, Shaanxi.

With "Zheng" provisionally located at Xiquandu (107°31 42 E, 34°31 6 N), we can examine sunrise time, direction, and topography to assess whether the 899 BCE eclipse could create "double dawn" at Zheng. On April 21, sunrise azimuth is approximately 79°25 , and at 5° elevation, about 83°15 —both east-northeast. Stellarium shows sunrise at 5:32 local time (6:23 Beijing time) with 26-minute twilight duration.

Zheng lies on the Loess Plateau below Qishan. Mountains extend from northwest through north to northeast, dropping sharply eastward with slight rises southeast. Detailed topographic data from GIS creates the skyline shown in [Figure 3: see original paper]. The sunrise direction (east-northeast) has reduced but still >4° skyline, suggesting prolonged solar occlusion after sunrise, similar to Fuyun and Altay.

The April 21, 899 BCE eclipse was annular with maximum magnitude 0.976, though Fengxiang's visible magnitude was about 0.962, reducing apparent magnitude by only 2.63—near the "double dawn" threshold. The eclipse lasted approximately 2 hours 10 minutes, with 12 minutes from 0.8 magnitude to maximum. Twilight lasted about 26 minutes, and solar ascent from horizon to mountain emergence required about 24 minutes—both longer than large-magnitude eclipse phases. Figure 4 [Figure 4: see original paper] shows solar apparent magnitude curves for different maximum eclipse elevations.

The 899 BCE annular eclipse offered two "double dawn" opportunities. With maximum eclipse at ~1° solar elevation, a brief brightening-darkening sequence occurs ~10 minutes before sunrise, followed by sharp magnitude increase. This coincides with Vega and Arcturus disappearing; if ancients observed a reappearing star (as in 1997 Tacheng), the darkening impression would intensify. Eastern mountains blocking the Sun and dawn light would prevent association with eclipse. After annularity ended, solar magnitude would surge, brightening the sky again—creating "double dawn." By 5° elevation, magnitude decreased to ~0.5 with intense sunlight, likely unnoticed as eclipse-related.

With maximum eclipse at 2°–4° elevation, another brightening-darkening sequence occurs while the Sun remains below the skyline. Bright stars like Jupiter might reappear, though darkness would be less profound than the former case. According to NADC eclipse software, this eclipse's $\Delta T = 22{,}125$ s, placing maximum eclipse well before sunrise and preventing "double dawn." Only when $\Delta T < 20{,}500$ s could "double dawn" occur. [Figure 5: see original paper] shows Earth rotation corrections from Han Yanben et al. [20].

Given the large dispersion in Earth rotation corrections from ancient eclipses [20], a ΔT of ~20,500 s for the 899 BCE eclipse is plausible. Conversely, the

Spring and Autumn period near Western Zhou contains many eclipse records, including total eclipses that constrain Earth rotation. The earliest occurred in 709 BCE, with NADC giving $\Delta T = 19{,}434.76$ s when the totality path passed Luoyang—still below 20,500 s without contradiction. However, if maximum eclipse at Zheng occurred at 2°–4° elevation (requiring $\Delta T < 20{,}000$ s), contradictions might arise.

shows five potential "double dawn" eclipses in less than 200 years between 727 BCE and 546 BCE—likely impressing Eastern Zhou historians. Another large-magnitude sunrise eclipse occurred in 314 BCE, with its central path's western end in southern Shanxi, the main Wei state area—possibly why *Bamboo Annals* authors highlighted "double dawn."

Some scholars proposed 925 BCE and 871 BCE eclipses as candidates [5]70−73. Brief analysis: NADC places the 925 BCE eclipse's western limit west of Pamir, requiring extreme ΔT adjustment to reach Shaanxi—far beyond acceptable ranges. The 871 BCE eclipse's western limit lies in Qinghai; adjusting ΔT from NADC's default 21,690.72 s to ~24,500 s (c 34 in equation (3)) could bring it near Zheng. However, this annular eclipse had only 0.957 maximum magnitude, allowing less error margin, and 871 BCE is only 30 years from 841 BCE—making it difficult to accommodate Kings Yi, Xiao, Yi, and Li within 30 years.

Within acceptable parameters, the April 21, 899 BCE eclipse corresponds to King Yi's "double dawn at Zheng." The "double dawn" phenomenon is fully explainable by sunrise eclipses. For magnitudes >0.98, solar elevation at maximum eclipse of (cid:0)3°–6° can produce "double dawn." For 0.95–0.98 magnitudes, conditions are much stricter; below 0.95, "double dawn" is impossible. The 1997 eclipse simulation confirms observational reliability, with Tacheng data providing a lower threshold. The 899 BCE eclipse simulation reveals two possible "double dawn" timings at solar elevations of (cid:0)1° and 2°–4°, with the former more plausible given Earth rotation constraints. Although the 899 BCE eclipse remains imperfect in Earth rotation correction and magnitude, it is currently the optimal solution.

Acknowledgments

Thanks to reviewers for suggestions, to Professor Wu Jiabi of Beijing Normal University for advice, and to Wu Yang of the Strategic Support Force for providing geographic data on the Xiquandu site.

References

[1] Liu Chaoyang. *Chinese Cultural Studies*, 1944, 2: 39
[2] Dong Zuobin. *Western Zhou Calendar*. Taiwan: Institute of History and Philology, Academia Sinica
[3] Fang Shanzhi. In: Peng Lin, ed. *Studies on the Year of King Wu's Conquest*

of Shang. Beijing: Beijing Normal University Press, 1997: 554
[4] Pang K D, Yau K, Chou H, et al. *Vistas in Astronomy*, 1988, 31: 833
[5] Liu Ciyuan. *From Double Dawn to King Wu's Campaign against Shang*. Beijing: World Book Publishing Company, 2006
[6] Xia-Shang-Zhou Chronology Project Expert Group. *Report on the Xia-Shang-Zhou Chronology Project 1996–2000*. Beijing: World Book Publishing Company, 2000: 24-25
[7] Stephenson R F. *ApJ*, 1992, 33: 91
[8] Keenan D J. *East Asian History*, 2002, 23: 61
[9] Wang Xuejun. *Studies in Dialectics of Nature*, 2015, 6: 78
[10] Wu Yuxiang, Liu Chunyan, Wen Sheng. *Acta Optica Sinica*, 2014, 11: 1101004-1
[11] Liu Ming, Ma Jian, Zhang Baogang. *China Illuminating Engineering Journal*, 2009, 20: 29
[12] Chen Mengjia. *Acta Archaeologica Sinica*, 1956, 4: 85
[13] Tang Lan. *Cultural Relics*, 1976, 6: 39
[14] Yin Shengping. In: *Archaeology and Cultural Relics* Editorial Office. *Archaeology and Cultural Relics Supplement No. 3*. Xi'an: Archaeology and Cultural Relics Editorial Office, 1983, 3: 33
[15] Lu Liancheng. In: *Archaeology and Cultural Relics* Editorial Office. *Archaeology and Cultural Relics Supplement No. 2*. Xi'an: Archaeology and Cultural Relics Editorial Office, 1983, 2: 8
[16] Du Yong, Wang Yuliang. *Journal of Langfang Normal University (Social Sciences Edition)*, 2017, 4: 75
[17] Li Xueqin. *Notes on Xia-Shang-Zhou Chronology*. Shenyang: Liaoning University Press, 1999: 40
[18] Pang Xiaoxia. *Archaeology and Cultural Relics*, 2014, 3: 66
[19] Shang Zhiru. In: Ancient Characters Research Office, Sichuan University History Department. *Ancient Characters Research Vol. 13*. Beijing: Zhonghua Book Company, 1986, 13: 438
[20] Han Yanben, Li Zhisen, Lin Baisen, et al. *Acta Astrophysica Sinica*, 1984, 2: 107

Restudy of the "Double Dawn" Phenomenon Caused by Solar Eclipse

WANG Sheng-hao (School of History, Beijing Normal University, Beijing 100091)

ABSTRACT: According to the ancient document *Bamboo Annals*, the day dawned twice ("double dawn") in Zheng (郑) during the first year of King Yi of Zhou, which modern scholars regard as a solar eclipse occurring around sunrise. The Xia-Shang-Zhou Chronology Project selected the annular eclipse of April 21, 899 BCE as the candidate for this "double dawn" eclipse. More general research confirms that only eclipses with magnitude exceeding 0.95 can produce the "double dawn" phenomenon, with constraints also applying to the Sun's altitude during maximum eclipse. After locating "Zheng" in Fengxiang County, Shaanxi, we used astronomical software to simulate the solar brightness changes during both the 899 BCE eclipse and the 1997 eclipse observed by the Chronology Project. This confirms that "double dawn" is a general phenomenon and enables us to derive its specific process and reconstruct certain details.

Key words: eclipse, celestial mechanics, history of astronomy, methods: observational

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