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Analyses of the Ancient Chinese Report on the Total Solar Eclipse in 709 BCE: Implications for the Contemporaneous Earth's Rotation Speed and Solar Cycles

Hisashi Hayakawa[1,2,3,4], Mathew J. Owens[5], Meng Jin[6], Mitsuru Sôma[7], and Mike Lockwood[5]
[1] Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, 4648601, Japan; hisashi@nagoya-u.jp
[2] Institute for Advanced Research, Nagoya University, Nagoya, 4648601, Japan
[3] Space Physics and Operations Division, RAL Space, Science and Technology Facilities Council, Rutherford Appleton Laboratory, Harwell Oxford, Didcot, Oxfordshire, OX11 0QX, UK
[4] Nishina Centre, Riken, Wako, 3510198, Japan
[5] Department of Meteorology, University of Reading, Reading RG6 6BB, UK
[6] Lockheed Martin Solar and Astrophysics Laboratory, Palo Alto, CA 94306, USA
[7] National Astronomical Observatory of Japan, Mitaka, 1818588, Japan
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Abstract

Total solar eclipses have occasionally left their footprints on human history for millennia, serving as spot references for the Earth's rotation speed and the solar cycle variations in the past. The earliest datable accounts with explicit mention date back to 709 BCE (hereafter −708) in ancient Chinese records, although the observational site and date were documented differently in previous studies. This study revisits the source reports and confirms the explicit mentions of the eclipse totality and a later addendum concerning the yellowish structure that has been traditionally associated with the K-corona "above and below" the eclipsed Sun. Archeological evidence allows us to revise the coordinate of Qūfù, the observational site, to N35°36′, E116°59′, in contrast to the previous studies. This location contradicts the recent ΔT spline curve, revising the ΔT constraint in −708 to 20,264 s $\leqslant \Delta T \leqslant$ 21,204 s and modifying other ΔT constraints from the eighth and sixth centuries BCE. The later addendum regarding the possible coronal structure requires a philological caveat on the source provenance, although it corroborates well with the recent solar cycle reconstruction. During the total solar eclipse, the solar disk was inclined at ≈58° from the local zenith at Qūfù, locating the possible coronal streamer belts at heliographic latitude ≈+32° ± 45° and −32° ± 45°. Our result broadly agrees with the inclination and width of the streamer belt reconstructed from the recent estimate of open solar flux based on radiocarbon data in the first millennium BCE and offers possible independent support for the recent solar cycle reconstruction in the late eighth century BCE.

Unified Astronomy Thesaurus concepts: Total eclipses (1704); Solar eclipses (1489); Solar corona (1483); Solar cycle (1487); Planetary science (1255); Sunspot number (1652); Celestial mechanics (211); Solar wind (1534)

1. Introduction

Throughout human history, total solar eclipses have been not only astronomical spectacles but also astrophysical laboratories. These events offer unique opportunities for a complete view of the solar atmosphere, from the chromosphere to the solar corona, and for measuring solar coronal activity (J. M. Pasachoff 2009, 2017), the solar diameter (J. P. Rozelot & C. Damiani 2012), and the Earth's rotation speed (F. R. Stephenson 1997, hereafter S97; W. Orchiston et al. 2015; F. R. Stephenson et al. 2016, hereafter SMH16). These eclipses have attracted numerous modern studies and research campaigns to analyze multiple astrophysical topics (M. L. Loucif & S. Koutchmy 1989; Y.-M. Wang et al. 2007; Y. Hanaoka et al. 2012; M. Druckmüller et al. 2014; A. R. Yeates et al. 2018; S. R. Habbal et al. 2021; Z. Q. Qu et al. 2022).

Total solar eclipses have been prominently featured in human history for millennia. These accounts—when their observational sites are well defined—have informed constraints on the variability of the Earth's rotation speed from the eighth century BCE to the early 17th century in terms of ΔT, an offset between the theoretical uniform timescale and the measured time based on Earth's rotation (S97; K. Tanikawa et al. 2010, hereafter TYS10; M. Sôma & K. Tanikawa 2015; SMH16; L. V. Morrison et al. 2021, hereafter M+21; H. Hayakawa et al. 2022). Records of these events that provide indications of the solar corona have been used for spot references of space climatology, occasionally in comparison with modeling, based on their morphological variations over different solar cycle phases (J. Eddy 1976; P. K. Wang & G. L. Siscoe 1980, hereafter WS80; J. M. Vaquero 2003; J. M. Vaquero & M. Vázquez 2009, hereafter VV09; P. Riley et al. 2015; M. J. Owens et al. 2017; H. Hayakawa et al. 2021, 2024).

So far, as is known to the modern scientific community, the earliest record of datable eclipses with an explicit indication of totality dates to the eighth century BCE, based on *Chūnqiū* (春秋), one of the anciet Chinese chronicles (S97; SMH16). The *Chūnqiū*'s eclipse records have attracted discussion concerning ancient chronology and calendars since before the Common Era, as recompiled and reviewed in S. Shinjo (1928) and C. Feng (1929). They have also been subjected to astronomical calculations of local eclipse visibility (T. Watanabe 1958; K. Saito & K. Ozawa 1987, hereafter SO87) and used as the earliest references to constrain the ΔT variability (S97; TYS10; SMH16; M+21).

The earliest of these records in the late eighth century BCE has been of particular interest, since a later source associates a total solar eclipse with what appears to be one of the few allusions to the solar corona in the pretelescopic era (WS80; S97, p. 226; VV09, p. 202; SMH16). Annual solar variability in the first millennium BCE has been reconstructed and resolved by I. G. Usoskin et al. (2025, hereafter U+25) in terms of sunspot number and open solar flux based on precise radiocarbon measurements (N. Brehm et al. 2025, hereafter B+25). Models have been developed for computing the width and inclination of coronal streamer belts from open solar flux and sunspot number (M. Lockwood & M. J. Owens 2014; M. J. Owens et al. 2017). Ephemeris and ΔT data sets have been recently improved for a millennial timescale (R. S. Park et al. 2021, hereafter P+21; M+21), enabling precise computation of solar disk orientation during total solar eclipses and contextualizing solar coronal streamers over heliographic latitudes (H. Hayakawa et al. 2021, 2024).

However, despite its astronomical importance, this eclipse report has been only marginally understood to the international scientific community. There have been complications on the use of inconsistently reported geographical coordinates of the observation in previous studies (N35.°53, E117.°02 in S97, TYS10, and SMH16 versus N35.°65, E117.°05 in SO87) and date (713 BCE, hereafter −712, in WS80 and VV09 versus 709 BCE, hereafter −708, in SO87,S97, TYS10, and SMH16). The reliability of the report should also be critically reevaluated, as this coronal description was written centuries after the eclipse in question. Therefore, this study documents the source records of this total solar eclipse and their philological backgrounds in Section 2. Site and date discrepancies are resolved in Section 3. Section 4 revises the local eclipse visibility and constraints of Earth's contemporaneous rotation speed. Section 5 computes the solar disk orientation and locations of possible coronal streamer belts and compares insights from historical records with the solar coronal streamer belts reconstructed from the radiocarbon-based open solar flux and sunspot number in the eighth century BCE.

2. Historical Eclipse Reports

The various source records used in this study are documented in Appendix A. *Chūnqiū* contains the earliest explicit description of totality in human history (S97, p. 226). Compiled in the Duchy of Lǔ (魯) around the fifth century BCE, the *Chūnqiū* covers the reigns of dukes from −721 to −480 and was later canonized as a Confucian classic. The details surrounding these reports are expanded upon commentary (F. Noma 1991), the liveliest of which is considered the *Chūnqiū Zuǒzhuàn* (春秋左傳; e.g., E. P. Wilkinson 2013, pp. 612–613).

The *Chūnqiū* recorded 37 solar eclipses, 3 of which were noted as "total (既)" (Appendix B). They share the same conventional format. The earliest one reading: "In fall, in the seventh month, on the *rénchén* day, the first day of the month, the Sun was totally eclipsed" (CQ1 in Appendix B). The other two, occurring in −600 and −548 (see CQ2 and CQ3 in Appendix B), likewise noted the totality but provided no further information by way of description.

Centuries later, *Hànshū* (漢書: ca. +96) presents contemporaneous scholarship on the *Chūnqiū* eclipse records, noting that for this total solar eclipse "In Duke Huán's third year, 'in the seventh month, on the *rénchén* day, … Jīng Fáng's *Yìzhuàn* believed that the eclipse in the third year of Duke Huán penetrated the center of the Sun, and it was completely yellow above and below" (HS1 in Appendix C; e.g., S97, p. 226). The physical description is reproduced matter-of-factly in the modern literature (e.g., Beijing Observatory 1988, p. 123). Insofar as it is suggestive of coronal structures, it has been used as evidence of their observation in previous studies (e.g., WS80).

There is reason to exercise caution regarding the reliability of this first century BCE addendum to the eighth century BCE eclipse, which lacks a clear philological provenance (Appendix D). It is clearly not based on direct testimony of Jīng Fáng (−76 to −36). There was no standard vocabulary or discussion of coronal structure in ancient Chinese astronomy (WS80). This is a one-off description. With that caveat in mind, the description is nevertheless consistent with the colorations of solar coronal streamers in naked-eye drawings based on several total solar eclipses during the 20th century, as shown in figures from J. M. Pasachoff & R. J. M. Olson (2014) and Figure 15(a) of H. Hayakawa et al. (2021).

3. Site and Date of the Observation

In order to calculate the local visibility of any given solar eclipses, we need the geographic coordinates of the observational site(s), ephemeris data, and the contemporaneous ΔT value. Since the *Chūnqiū* reports the eclipse of −708 under the reign of Duke Huán of Lǔ, the observational site is commonly considered to be Qūfù, Lǔ's capital. This is a common, plausible assumption, while the geographical location has been debated in previous studies as N35.°53, E117.°02 (S97; TYS10; SMH16) and N35.°65, E117.°05 (SO87). According to archeological reports, the city area of Qūfù during the Lǔ period was located on the northern side of River Xiǎoyí (小沂河) and bordered on the western and northern limits by River Zhūshuǐ (洙水河), as shown in Figure 2 of SAAI (1982) and Figure 2-16 of X. Chen (2021). This places Qūfù at N35° 36′, E116°59′ (using Google Earth Pro), which is ≈8 km from the position used in previous studies.

Previous studies have suggested two dates for the eclipse in question: either −708 (SO87; S97; TYS10; SMH16) or −712 (WS80; VV09, p. 202). It is possible to calculate the local eclipse visibility on the basis of the historical ΔT value and ephemeris data, which have commonly been approximated using M+21's ΔT spline curve and are well defined on the basis of JPL DE 441 (P+21). Among the dates suggested by previous studies, −708 seems robust (S97; TYS10; SMH16), in contrast to −712 (WS80; VV09, p. 202), since a total solar eclipse passed through China on −708 July 17, whereas only one such event occurred in -712 ± 1 (−711 March 24), which only encompassed South America, on the other side of the planet from China.

4. Local Eclipse Visibility and Earth's Rotation Speed

On this basis, we can confidently associate the historical report with a total solar eclipse on −708 July 17, as observed in Qūfù (N35°36′ E116°59′). However, M+21's ΔT (≈20,170 s) does not allow us to locate Qūfù in the totality path and allows a maximum eclipse magnitude of only 0.994 at 07:53:44 UT, while M+21 (see their Table S2) used this eclipse report to constrain their ΔT spline curve. This mismatch likely results from their misidentification of the observational site and usage of slightly different ephemeris data.

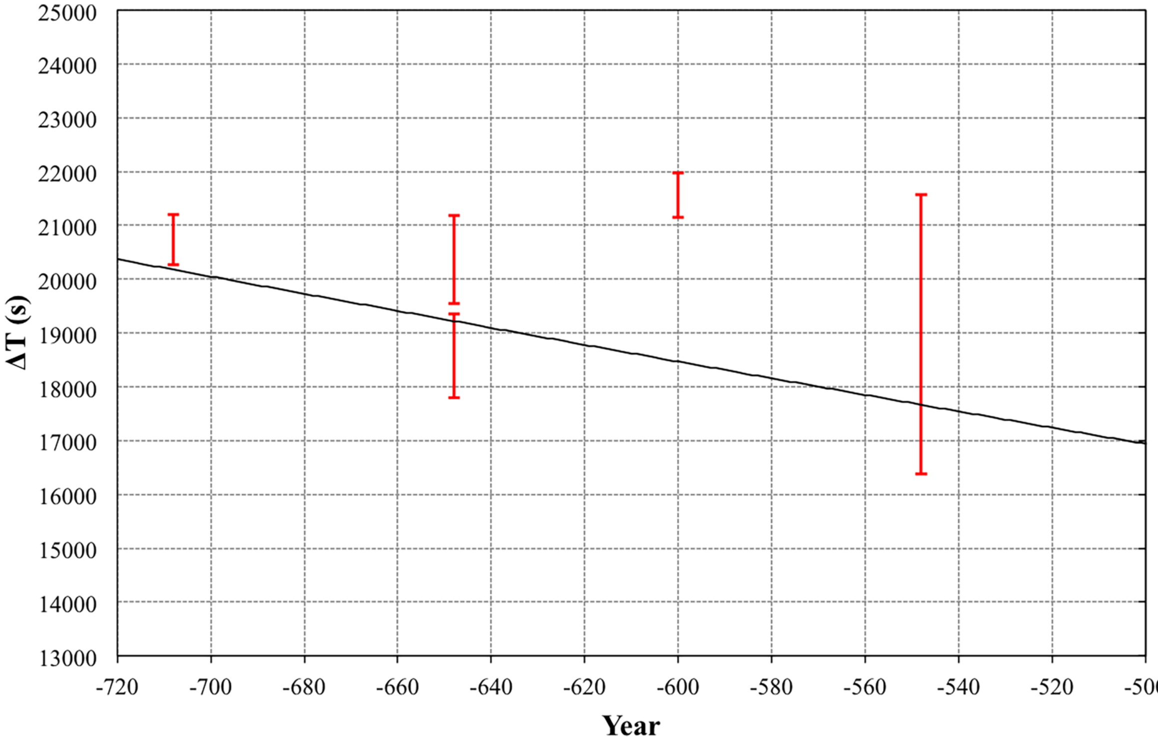

Figure 1. Comparison of M+21's ΔT spline curve (black line) and our ΔT constraints based on total solar eclipses (red bars), as discussed in Appendix E. We show two error margins for the −647 eclipse, owing to two candidate sites for the observation.

In order to accommodate Qūfù in the totality path and resolve this contradiction, it is necessary to revise the ΔT margin in −708 as 20,264 s $\leqslant \Delta T \leqslant$ 21,204 s using the JPL DE 441 (P+21) and Sôma methods (M. Sôma & K. Tanikawa 2015). This yields a slightly higher ΔT margin than that of 20,160 s $\leqslant \Delta T \leqslant$ 21,100 s in SMH16 and M+21. This requires us to revise the ΔT spline curve slightly upward compared with that of M+21. Likewise, this required us to revise the ΔT margins in the eighth to sixth centuries BCE to 21,150 s $\leqslant \Delta T \leqslant$ 21,968 s in −600 and 16,379 s $\leqslant \Delta T \leqslant$ 21,574 s in −548 in order to locate Qūfù in each of the totality paths (Appendix E), as shown in Figure 1.

5. Solar Disk Orientation and Coronal Extents

According to Jīng Fáng (−76 to −36), the total solar eclipse in −708 left the eclipsed Sun "completely yellow above and below" (HS1 in Appendix C). Previous studies tentatively associated this "yellow" coloration with the solar corona (WS80; S97; SMH16), specifically the K-corona in WS80. The nonuniform structure rules out the chromosphere or F-corona as candidates for the described feature, since they should instead have been described as a uniform ring. Of course, caution is advised regarding the provenance and reliability of this addendum (Appendix D). However, if we do interpret it as per previous studies (WS80; S97; SMH16), it is reasonable to expect the yellowish K-corona somewhere ±45° around the top and bottom of the solar disk as seen from Qūfù upon totality.

Total solar eclipses last no more than several minutes. Their short duration allows us to compute the orientation of the solar disk in terms of heliographic coordinates. Assuming $\Delta T \approx$ 21,180 s in the ΔT margin of −708, we have computed the beginning, maximum, and end of the total solar eclipse at Qūfù as 07:33:04 UT, 07:33:40 UT, and 07:34:17 UT, respectively. At the maximum, the Sun was located at azimuth 267°.76 and altitude 44°.72. We computed the heliographic coordinates at the eclipse maximum, using the procedure in H. Hayakawa et al. (2021) in combination with the said ΔT value and the ephemeris data of JPL DE 441 (P+21; see Figure 2). Located in the local afternoon (15:21:26 LAT), the solar rotation axis was inclined ≈58° clockwise from the local zenith of Qūfù at the eclipse maximum. This angle is practically unchanged during the total solar eclipse as seen from Qūfù within our ΔT margin (20,264 s $\leqslant \Delta T \leqslant$ 21,204 s), which locates the total solar eclipse between 07:33:04 UT and 07:51:58 UT. This locates the apparent top and bottom of the solar disk with the error margins of ±45°, ruling out their extensions in the right and left directions, and locates the streamer belts within heliographic latitudes ≈+32° ± 45° and −32° ± 45°, respectively.

6. Comparison with Reconstructed Solar Cycles Based on Tree Ring Data

This eclipse is located slightly after the maximum (−710) of U+25's solar cycle No. 28 based on their sunspot number reconstruction from tree ring radiocarbon data sets. Their reconstruction for the open solar flux, with a slight delay from those for the sunspot number, dates the cycle maximum in −709 and locates this total solar eclipse in the immediate aftermath of the solar cycle maximum. Table 1 in U+25 categorises this solar cycle as 4, "a well-defined cycle with a somewhat clear amplitude" (U+25, pp. 6–8). This provides confidence in the cycle phase location of this total solar eclipse, while some uncertainty remains concerning the cycle amplitude in their reconstruction.

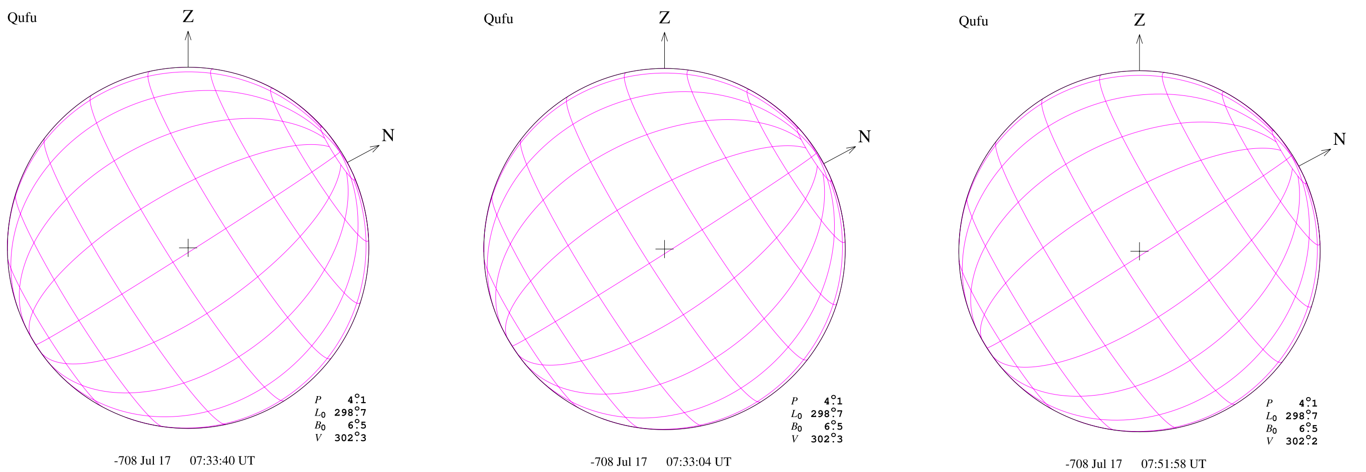

Figure 2. Solar disk orientation at the eclipse maximum on −708 July 17, as seen from Qūfù, with lower-limit, optimal, and upper-limit ΔT values of 20,264 s, 21,180 s, and 21,204 s, respectively.

The description of a possible K-corona contrasts this total solar eclipse with those during the Maunder minimum, a grand solar minimum, where no significant coronal streamers were visible to naked eye (J. Eddy 1976; P. Riley et al. 2015; H. Hayakawa et al. 2021). As such, this eclipse report locates the solar activity in −708 as being outside of the proximate grand solar minimum. Consistently, radiocarbon data indicate this eclipse as taking place during a solar cycle immediately after the Neo-Assyrian Grand Minimum (or the Homer Grand Minimum), which occurred from −807 to −716 (M. A. Van der Sluijs & H. Hayakawa 2023; U+25; cf., S. M. Silverman & H. Hayakawa 2021). Historical reports highlight a similar contrast between the total solar eclipse of 1706 (during the Maunder minimum) without significant coronal streamers and that of 1715 (after the Maunder minimum) with significant coronal streamers (see Figures 11 and 13 of H. Hayakawa et al. 2021). Being outside a grand solar minimum, it is reasonable to expect that solar coronal streamers would be sufficiently bright as to be visible to the naked eye.

The top two panels of Figure 3 show U+25's recent reconstruction of the open solar flux and sunspot number (black lines) with a $\pm 1\sigma$ uncertainty (red and blue, indicating the resulting upper and lower limits). Negative sunspot numbers and open solar flux values were deemed unphysical and set to zero (M. J. Owens et al. 2024). Using these data as input, we further estimated the width and inclination of the streamer belts, using the continuity modeling methods of M. Lockwood & M. J. Owens (2014) and M. J. Owens et al. (2017), with the loss rate coefficient determined from the SILSO International Sunspot Number (SSN) version 2 (F. Clette et al. 2023). This method has been validated by comparison with drawings of eclipses in the 19th–20th century CE within the coverage of SILSO SSN version 2, as shown in Figure 1 of M. J. Owens et al. (2017) and Figures 4 and 5 of Hayakawa et al. (2024). The streamer belt width is shown in the third panel of Figure 3. Here, we show the best and upper/lower limits by black, red, and blue lines on the basis of $\pm 1\sigma$ uncertainty, respectively. The bottom panel shows the streamer belt inclination, which is only a function of the estimated solar cycle start and end dates. These results are also broadly consistent with the −708 eclipse report, which indicated the possible presence of a K-corona at heliographic latitude $\approx +32° \pm 45°$ and $-32° \pm 45°$. For the −708 eclipse, the estimated streamer belt width and inclination are not sensitive to uncertainty in sunspot number and open solar flux. The modeled streamer belt for −708 has a half-width of 39° and an inclination of up to 23° with respect to the solar rotational axis. The schematics at the bottom of Figure 3 show how this would look from Qūfù; as the Sun rotates, streamers could span anywhere within $0° \pm 62°$. Thus, they are roughly located "above and below" the eclipsed Sun, adjusting the orientation of the solar rotation axis by ≈58° clockwise following Figure 2. Of course, caveats must be noted here. The comparison is valid, if we take this addendum at face value. Our reconstruction is directly affected by the chronological uncertainty of U+25's reconstruction, while U+25 assigned a quality flag of 4 and regarded the cycle phase as "well-defined." As this eclipse report is independent of U+25's data set, this report in turn provides a spot reference for space climatology in the eighth century BCE and independently validates U+25's reconstruction around −708.

7. Conclusion

This study analyzes ancient Chinese reports of a total solar eclipse occurring at Qūfù. The eclipse report explicitly mentioned the visibility of the eclipse and potentially alluded to a yellowish coronal structure "at the top and bottom" of the eclipsed Sun. Archeological evidence allows us to revise the coordinates of Lǔ Palace in Qūfù to N35°36′, E116°59′, in contrast with those used in previous studies: N35.°53, E117.°02 (S97; TYS10; SMH16) and N35.°65, E117.°05 (SO87). Our calculation shows no total solar eclipses visible from China and neighboring regions in −712 ± 1, in contrast to WS80 and VV09, and one promising candidate on −708 July 17, in agreement with SO87, S97, TYS10, and SMH16.

The ΔT spline curve used by M+21 would place Qūfù (N35°36′, E116°59′) beyond the totality path of this eclipse, yet that report was used as one of the ΔT constraints for their spline curve. As such, adopting the actual geographical coordinates of Lǔ Palace in Qūfù inevitably required us to revise the ΔT margins in the eighth to sixth centuries BCE to 20,264 s $\leqslant \Delta T \leqslant$ 21,204 s in −708, 21,150 s $\leqslant \Delta T \leqslant$ 21,968 s in −600, and 16,379 s $\leqslant \Delta T \leqslant$ 21,574 s in −548 in order to locate Qūfù in each of the totality paths (Figure 1).

In contrast with *Chūnqiū*, *Hànshū* specifically includes an addendum that has been interpreted as an indication of the

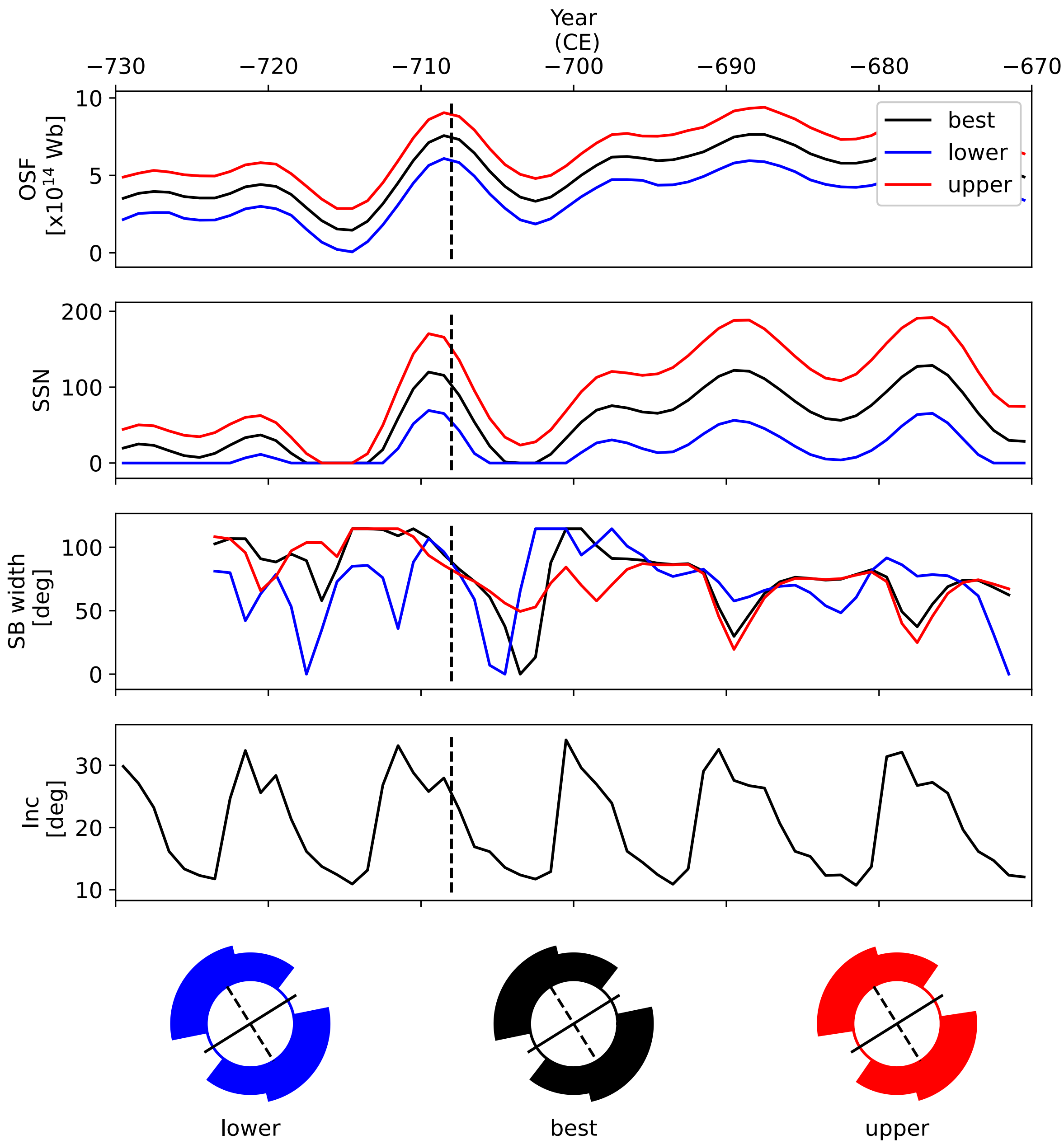

Figure 3. Contextualization of the total solar eclipse in −708 (dashed vertical black line) upon contemporaneous solar cycles on the basis of radiocarbon data sets (U+25). The first and second panels show U+25's open solar flux (OSF) and SSN. The third and fourth panels show the full streamer belt width (SB width) and inclination (Inc.) using the methods and coefficients of M. Lockwood & M. J. Owens (2014), while their loss rate coefficient is adjusted according to SILSO SSN version 2 (F. Clette et al. 2023). On their basis, the bottom panel schematically shows how streamer belts look from Qūfù upon the said total solar eclipse in these three scenarios.

solar corona. There is good reason to be cautious of this claim, since the author credited with this addendum lived some seven centuries after the eclipse itself, and earlier provenance cannot be ascertained. However, as long as we follow the traditional interpretation, this report may provide valuable information on contemporaneous solar magnetic activity. The revised ΔT margin allows us to compute the orientation of the solar disk within the total solar eclipse as being inclined ≈58° clockwise from the local zenith. This value remains practically the same within the local visibility of the total solar eclipse within the said ΔT margin in −708 (Figure 2). This locates the possible solar corona "at the (apparent) top and bottom" of the eclipsed solar disk (within error margins of ±45°) as heliographic latitude ≈+32° ± 45° and −32° ± 45°.

This study has contextualized this total solar eclipse using U+25's reconstruction of the open solar flux and sunspot number in the first millennium BCE. This eclipse took place after the end of the Neo-Assyrian Grand Minimum (or the Homer Grand Minimum) of −807 to −716. On that basis, we computed the width and inclination of the streamer belts as spanning anywhere within 0° ± 62° (Figure 3). This is broadly consistent with what we learn from the Chinese source report and our eclipse calculation. As such, our analysis of the earliest datable report of a solar eclipse with an explicit allusion to possible coronal streamer belts offers possible independent support for the robustness of recent annual solar cycle reconstructions from the eighth century BCE (B+25; U+25). This report potentially allows us to verify two aspects of the model—streamer belt tilt and width back in the eighth century BCE—although caution is still advised concerning the report's reliability. This study is of potential benefit to investigations and analyses of historical solar eclipses, informing long-term assessments of Earth's rotation speed and also space climatology.

Acknowledgments

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Data Availability

The historical source records that we used in this study are listed in Appendices A–C. The ephemeris data are acquired from NASA JPL DE 441 (P+21). The radiocarbon-based reconstructions of the sunspot number and open solar flux are derived from U+25.

Appendix A
Bibliography for Historical Documents

Arkhílokhos: Edmonds, J. M. 1931, *Elegy and Iambus II*, London, William Heinemann Ltd.

Chūnqiū Zuǒzhuàn: 春秋左傳 *in:* 『斷句十三經經文』臺北, 臺灣開明書店, 1955.

CQ-NAJ: 春秋左氏伝校本, MS 274-0113-0001 of the National Archives of Japan.[8]

Hànshū: 班固(撰)顔師古(注)『漢書』第五册, 北京, 中華書局, 1962.

Hēródotos: Godley, A. D. 1946, *Herodotus. With an English translation by A.D. Godley: Books I and II*, London, William Heinemann Ltd.

HS-NAJ: 前漢書, MS 史001-0002-0011 of the National Archives of Japan.[9]

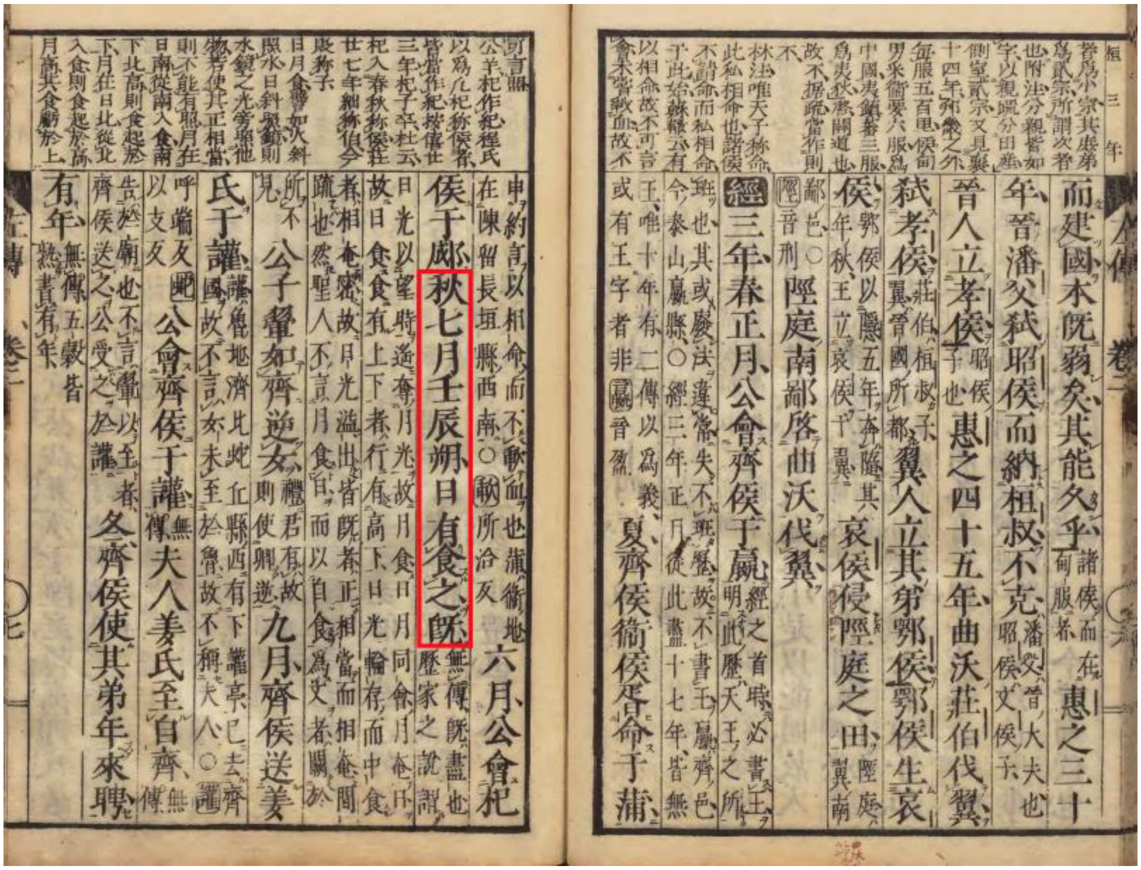
Appendix B
Reports for Total Solar Eclipses in *Chūnqiū*

The *Chūnqiū* records three total solar eclipses. The reports are as reproduced from *Chūnqiū Zuǒzhuàn* in Appendix A and should be conferred to the recent scholarly translation (S. Durrant et al. 2016).

Report CQ1, *Chūnqiū Zuǒzhuàn*, p. 10 (Figure B1):

Transcription: [桓公三年…] 秋七月壬辰朔，日有食之，既。

8 https://www.digital.archives.go.jp/item/3959246
9 https://www.digital.archives.go.jp/item/2317710



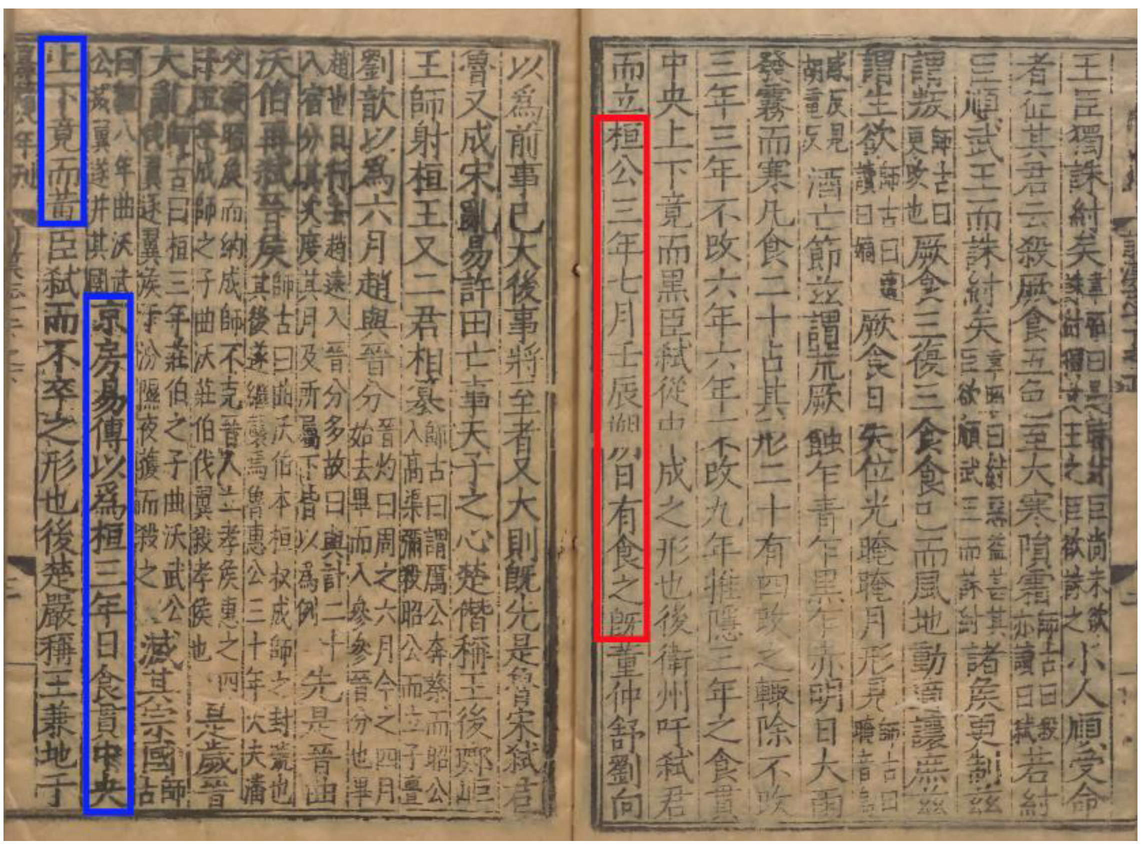


Figure B1. Excerpts of records of the −708 total solar eclipse in CQ-NAJ (v. 2, ff. 6b–7a) and HS-NAJ (v. 27, ff. 2b–3a), reproduced courtesy of the National Archives of Japan (see Appendix A). The red and blue squares show records of the total solar eclipse and mentions of the possible coronal structure.

Our translation: [In Duke Huán's third year…] In fall, in the seventh month, on the *rénchén* day, the first day of the month, the Sun was totally eclipsed.

Report CQ2, *Chūnqiū Zuǒzhuàn*, p. 79:

Transcription: [宣公八年…] 秋七月甲子, 日有食之, 既。

Our translation: [In Duke Xuān's eighth year…] In fall, in the seventh (*sic*.) month, on the *jiǎzǐ* day, the Sun was totally eclipsed.

Report CQ3, *Chūnqiū Zuǒzhuàn*, p. 144:

Transcription: [襄公二十有四年…] 秋七月甲子朔, 日有食之, 既。

Our translation: [In Duke Xiāng's 24th year] In fall, in the seventh month, on the *jiǎzǐ* day, the first day of the month, the Sun was totally eclipsed.

The date of CQ1 aligns with the total eclipse of −708 July 17 (e.g., S97, pp. 226–227). Some studies date it to −712 (WS80; VV09, p. 202), but we concur with the majority opinion that the date is as written, −708 July 17 (see Section 3). In CQ2, the year and sexagenary day (*jiǎzǐ*) align with the total eclipse on –600 September 20, when we accept a text criticism of the scribal error of "seventh month (七月)" and "tenth month (十月)" that are frequently confused in ancient sources (C. Feng 1929, pp. 91–102; S97, p. 226). Lastly, CQ3 is an unambiguous match with the total eclipse on −548 June 19 (S97, pp. 225–227).

Appendix C
Reports for Total Solar Eclipses in *Hànshū*

Written by Bān Gù (班固: 32–92), Treatises on Five Elements (五行志) of *Hànshū* (漢書) summarizes contemporary omenological studies of the total eclipses recorded in the *Chūnqiū*, providing context, (misinformed) precision on the dates, and, in one case, additional physical descriptions. From the Zhōnghuá Shūjú edition (*Hànshū* in Appendix A), the related passages are as follows.

Report HS1: *Hànshū*, v. 27, p. 1482 (Figure B1):

Transcription: 桓公三年「七月壬辰朔, 日有食之, 既」。董仲舒、劉向以為前事已大, 後事將至者又大, 則既。先是魯, 宋弒君, 魯又成宋亂, 易許田, 亡事天子之心; 楚僭稱王。後鄭岠王師, 射桓王, 又二君相篡。劉歆以為六月, 趙與晉分。先是, 晉曲沃伯再弒晉侯, 是歲晉大亂, 滅其宗國。京房易傳以為桓三年日食貫中央, 上下竟而黃, 臣弒而不卒之形也。後楚嚴稱王, 兼地千里。

Our translation: In Duke Huán's third year, "in the seventh month, on the *rénchén* day, the first day of the month, the Sun was totally eclipsed". Dǒng Zhòngshū (董仲舒) and Liú Xiàng (劉向) believed that [when] major events had already taken place, and greater ones were yet to come, then [the resulting eclipse] would be total. Before, the rulers of Lǔ and Sòng had been murdered. Lǔ had abetted the turmoil in Sòng, exchanged the field of Xǔ (NB a disputed territory), and abandoned its loyalty to the Son of Heaven (NB the Zhōu King). Meanwhile, Chǔ had usurped [the royal title], declaring [its ruler] "king." After, Zhèng resisted the king's army, King Huán was shot, and two ministers overthrew their lords. Liú Xīn believed that [this] was in the sixth month, which [omenologically] corresponds with [the states of] Zhào and Jìn: prior to this, Earl Qǔwò of Jìn had twice assassinated the marquis of Jìn, and, in said year, Jìn fell into great disorder and its ruling house was extinguished. Jīng Fáng's *Yìzhuàn* believed that the eclipse in the third year of Duke Huán penetrated the center of the Sun, and it was completely yellow above and below—a form [suggestive of] vassals' failed attempt at assassinating his lord. Afterward, Yán of Chǔ declared himself king and seized territory spanning a thousand Chinese leagues.

Report HS2, *Hànshū*, v. 27, p. 1488:

Transcription: 宣公八年「七月甲子, 日有食之, 既」。董仲舒, 劉向以為先是楚商臣弒父而立, 至于嚴王遂彊。諸夏大國唯有齊, 晉, 齊, 晉新有篡弒之禍, 內皆未安, 故楚乘弱橫行, 八年之間六侵伐而一滅國; 伐陸渾戎, 觀兵周室; 後又入鄭, 鄭伯肉袒謝罪; 北敗晉師于邲, 流血色水; 圍宋九月, 析骸而炊之。劉歆以為十月二日楚, 鄭分。

Our translation: In Duke Xuān's eighth year, "in the seventh (*sic*.) month, on the *jiǎzǐ* day, the Sun was totally eclipsed." Dǒng Zhòngshū and Liú Xiàng held that, earlier, [King] Shāngchén of Chǔ had killed his father to take the throne, and by the time of King Yán, Chǔ had become powerful. Among the major states of the Central Plains, only Qí and Jìn remained prominent, but both were in the thralls of usurpation and regicide, and their internal affairs were unstable. Thus, Chǔ took advantage of their weakness to act aggressively. Within eight years, Chǔ launched six invasions and destroyed one state. They attacked the Lùhún Róng, displayed their military [might] to the [royal] house of Zhōu. Later, they also invaded Zhèng, the Earl of Zhèng baring his shoulders to apologize; they defeated the Jìn army at Bì, unleashing a river of blood; and they besieged Sòng for nine months, dismembering corpses to use as fuel. Liú Xīn believed that the second day of the tenth month corresponds with [the states of] Chǔ and Zhèng.

Report HS3, *Hànshū*, v. 27, pp. 1491–1493:

Transcription: 二十四年「七月甲子朔, 日有食之, 既」。劉歆以為五月魯、趙分。「八月癸巳朔, 日有食之」。董仲舒以為比食又既, 象陽將絕, 夷狄主上國之象也。後六君弒, 楚子果從諸侯伐鄭, 滅舒鳩, 魯往朝之, 卒主中國, 伐吳討慶封。劉歆以為六月晉、趙分。

Our translation: In [Duke Xiāng's] 24th yr, "in the seventh month, on the *jiazi* day, the first day of the month, the Sun was totally eclipsed." Liú Xīn believed that the fifth month corresponds [omenologically] to [the states of] Lǔ and Zhào. [Then], "in the eighth month, on the *guǐsì* day, the first day of the month, the Sun was eclipsed." Dǒng Zhòngshū believed that the eclipses on subsequent months were both total, symbolizing that yáng was to be extinguished and that barbarians would dominate the Central States. After, six lords were assassinated, and the Prince of Chǔ indeed led the feudal lords to attack Zhèng, destroying Shūjiū and forcing Lǔ to pay homage to Chǔ. Ultimately, Chǔ dominated the Central States, attacked Wú, and punished Qìng Fēng. Liú Xīn believed that the sixth month corresponds [omenologically] to [the states of] Jìn and Zhào.

Appendix D
Caveats on Jīng Fáng's *Yìzhuàn*

Beijing Observatory (1988, p. 123) reduces Jīng Fáng's description in HS1 to an unqualified addendum to CQ1 (Figure B1). Likewise, WS80 treats Jīng Fáng as a reliable source, interpreting his addendum as implying a K-corona. While the description would seem to correspond in every way to the expected presence and orientation of coronal streamer belts in our analysis, caution is advised regarding the origin and nature of Jīng Fáng's remarks.

First, the authenticity of Jīng Fáng's *Yìzhuàn* is a subject of debate. The work is only partially extant; contents relating to astral-omenology survive only as quoted in other sources, and mismatches in quotations, titles, and volume numbers have led some philologists to doubt the authenticity of these quotations (P. Qin 2021). More to the point, most of these quotations are "theoretical" in nature, based not on observation but on ancient wisdom, numerology, and schematic and analogical reasoning. The two exceptions involving historical eclipses both occur in the Treatises on Five Elements of *Hànshū* (ca. +96), where it is unclear to what degree the *Hànshū* is quoting, paraphrasing, or developing upon the *Yìzhuàn*. However, this is not critical, since the *Hànshū* was finished in +96, and its contents are not in question. The report in question predates that, even if not authored by Jīng Fáng.

Second, since Jīng Fáng (−76 to −36) did not witness the eclipse in –708, we must ask how he arrived at this description. There are two possibilities: either he worked backward using omenological theory, deducing what "must have happened" in –708, or he worked from some undocumented source. The former was a frequent practice of omenology, which was intertwined with historical hermeneutics in historiography and Confucian exegesis. For example, one might point to the retrospective insertion of astral omens and other divinatory contents into *Chūnqiū* as a narrative device to make sense of the relationship between disjointed events (M. Kalinowski 1999). In fact, *Hànshū* cited a parallel quote for a partial solar eclipse in −719 and guessed (推) the eclipse in the third year of Duke Yǐn having penetrated the center of the Sun, being completely black above and below the eclipsed Sun, in association with the shape of vassals' assassination of their lord from inside (*Hànshū*, v. 27, p. 1480). Our calculation indicates this eclipse as a partial solar eclipse that reached the maximum magnitude of 0.437, following M+21's ΔT value (20,353 s). These results might indicate this eclipse penetrating the black cloud above and below. Alternatively, the descriptive similarity might indicate a back-projection of the political events to the reported solar eclipses in the past, including the addendum of the −708 eclipse, while *Hànshū* contrasts the description as guessing (推) and considering (以為) for the addendum of the −719 eclipse and the −708 eclipse.

The latter's main difficulty is the absence of Jīng Fáng's source documentation for this addendum. While ancient Chinese authors frequently documented their sources, Jīng Fáng's *Yìzhuàn* did not survive, at least for the astro-omenological section; the excerpt in question survived in *Hànshū*, which annotated the source for this addendum only as Jīng Fáng's *Yìzhuàn*, without mentioning their further provenances. Unfortunately, without additional evidence, we cannot determine whether this addendum derives from an unknown source that has since been lost or from Jīng Fáng's own invention on the basis of the subsequent political event. For now, we must therefore include a caveat on the reliability of this addendum.

Appendix E
Contextualization to Contemporaneous ΔT Constraints

In order to determine the stability of our ΔT, we analyzed the two other total solar eclipses recorded in the *Chūnqiū* chronicle, in −600 and −548. Among them, we need to correct the date used by CQ2, as discussed in Appendix C. Following our procedure, we arrive at 21,150 s $\leqslant \Delta T \leqslant$ 21,968 s in −600 and 16,379 s $\leqslant \Delta T \leqslant$ 21,574 s in −548 to locate Qūfù in the totality paths.

Our results indicate that the ΔT margins of −708 and −600 are slightly higher than M+21's ΔT spline curve. Previously, SMH16 rejected the reliability of the −600 eclipse report because their ΔT margin of −600 (21,120 s $\leqslant \Delta T \leqslant$ 21,900 s) did not overlap with that of −708 (20,160 s $\leqslant \Delta T \leqslant$ 21,100), and it was slightly unnatural to expect an increase rather than a decrease in the ΔT value in this interval. These ΔT margins were taken over to M+21 as they were. In contrast, our results indicate an overlap of these ΔT margins (21,150 s $\leqslant \Delta T \leqslant$ 21,204 s).

We also explored other eclipse records that have been used for ΔT constraints. In contrast with SMH16, TYS10 used Chinese records for partial solar eclipses and Greek records for total solar eclipses. Where reports lacked explicit mention of totality, TYS10 assumed these to be partial solar eclipses. This assumption is too ambitious, given that we know some eclipse accounts in the totality path did not explicitly mention the totality (S97). TYS10 also assumed eclipse reports lacking an annotation of *shuò* (朔) to be eclipses on the horizon, but this assumption does not allow us to constrain the ΔT error margins to the extent that TYS10 did.

TYS10 used two eclipse accounts: those from Arkhílokhos (Ἀρχίλοχος) and Hēródotos (Ἡρόδοτος). Arkhílokhos's Fragment 74 (*Arkhílokhos*, pp. 134–135) has been associated with a total solar eclipse that he witnessed at Páros or Thásos on −647 April 6 (J. K. Fotheringham 1920, pp. 107–108; S97, pp. 338–342; F. R. Stephenson et al. 2020, pp. 48–49). In order to locate Páros (Πάρος: N37°05′, E025°09′) or Thásos (Θάσος: N40°47′, E024°43′) in the totality path, we need to set ΔT margins of 19,544 s $\leqslant \Delta T \leqslant$ 21,184 s for Páros and 17,798 s $\leqslant \Delta T \leqslant$ 19,362 s for Thásos. Both scenarios are possible. In previous studies, neither SMH16 nor M+21 used this account for their ΔT constraints, whereas TYS10 used it to derive ΔT margins as 19,409 s $\leqslant \Delta T \leqslant$ 20,402 s and 18,353 s $\leqslant \Delta T \leqslant$ 19,235 s. Our ΔT ranges are constrained by other eclipses from different years and are therefore considerably wider than those of TYS10.

The other Greek account describes the total solar eclipse in −584 that has been associated with Hēródotos's account of the battle between Lydia and Media. In contrast with S97 (pp. 342–344), M. E. Özel & Y. Kaçar (2007) located the observational site for this total solar eclipse at Pteria (Πτερία), and TYS10 derived their ΔT margin for this event on their basis. However, Pteria was the battlefield not between Lydia and Media but that between Lydia and the Achaemenid Empire (*Hēródotos*, 1, 74–76). Therefore, the observational site is not Pteria but remains undefined in this description. Our interpretation is consistent with J. K. Fotheringham (1920, pp. 108–109) and F. R. Stephenson et al. (2020, pp. 49–51), who stated caveats on the site identification for the battlefield in Asia Minor. Hence, we cannot use Hēródotos's account to constrain the ΔT margin for the total solar eclipse of −584.

Our result is summarized in Figure 1 and Table E1. It is difficult to derive a precise ΔT spline curve, since the data are scarce. However, in contrast to previous studies (e.g., TYS10; SMH16), our results do not require selective omission of CQ2 in −600. In this case, ΔT might have remained around 21,150 s $\leqslant \Delta T \leqslant$ 21,184 s in −708 and −548, rather than showing a steady decline as in SMH16 and M+21. Our revision indicates that we do not need to selectively omit the

Table E1
The ΔT Constraints in the Eighth to Sixth Centuries BCE on the Basis of Historical Reports for the Total Solar Eclipses that Are Discussed in Appendix E

	Our Study			M+21		TYS10	
Year	LL (s)	UL (s)	Site	LL (s)	UL (s)	LL (s)	UL (s)
−708	20,264	21,204	Qūfù	20,160	21,100	20,153	21,094
−647	19,544	21,184	Páros	⋯	⋯	19,409	20,402
−647	17,798	19,362	Thásos	⋯	⋯	18,353	19,235
−600	21,150	21,968	Qūfù	21,120	21,900	21,059	21,878
−584	⋯	⋯	⋯	⋯	⋯	19,172	21,008
−548	16,379	21,574	Qūfù	16,160	21,640	16,134	21,634

Note. This table shows lower limits (LL) and upper limits (UL) of the ΔT constraints in our study, M+21, and TYS10. M+21 and TYS10 rejected the record in −600. Our study rejected the site identification of the −584 record that TYS10 used owing to their misidentification.

−600 eclipse report in order to reconstruct ΔT and also shows better consistency within *Chūnqiū*. On this basis, we locate ΔT values within the overlap of the ΔT margins dating from −600 and −548 ($21{,}150\,\mathrm{s} \leqslant \Delta T \leqslant 21{,}204\,\mathrm{s}$). Of course, CQ2 has a dating problem in the source report (confusion of the seventh and tenth months; see Appendix B). This problem reduces the reliability of the −600 eclipse report and the resultant ΔT margin in this year. Further careful assessments are required for the ΔT variability around here. Here, we need to be extra cautious on usage of the horizon events, as they are highly sensitive to the altitude of and horizontal profile around observational sites.

ORCID iDs

Hisashi Hayakawa https://orcid.org/0000-0001-5370-3365
Mathew J. Owens https://orcid.org/0000-0003-2061-2453
Meng Jin https://orcid.org/0000-0002-9672-3873
Mike Lockwood https://orcid.org/0000-0002-7397-2172

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