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# The Variable Earth's Rotation in the 4th–7th Centuries: New $\Delta T$ Constraints from Byzantine Eclipse Records

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## Abstract

As one of the greatest astronomical spectacles, total solar eclipses have long been a subject of scientific interest and have been recorded by numerous civilizations over the millennia. These records are an essential reference for constraining and reconstructing Earth's variable rotation ($\Delta T$) prior to the 17th century. However, $\Delta T$ reconstructions for the 4th–7th centuries have significant uncertainties, mainly owing to a data scarcity. Here, we analyze Byzantine historical sources with reports of total solar eclipses along the Eastern Mediterranean coasts and add probable $\Delta T$ constraints on their basis. We examined five cases of total solar eclipses in 346, 418, 484, 601, and 693 CE, identified times and locations of the observations, and compared them with the existing $\Delta T$ spline curve to derive new $\Delta T$ constraints. Our results probably tighten $\Delta T$ variability in 346 CE, show a larger $\Delta T$ range in 418 CE, and give smaller $\Delta T$ ranges in 484, 601, and 693 CE. Our study tightens the existing $\Delta T$ variations and occasionally support some $\Delta T$ constraints that slightly depart from the $\Delta T$ spline curve in the latest reconstructions. Our results are consistent with contemporary $\Delta T$ constraints from other studies and offer an improved understanding of Earth's variable rotation.

*Unified Astronomy Thesaurus concepts:* Eclipses (442); Solar eclipses (1489); Total eclipses (1704); Earth (planet) (439)

## 1. Introduction

Total solar eclipses have attracted human interest and been noted in the records of numerous civilizations over the millennia (Newton 1972; Schove & Fletcher 1984; De Jong & Van Soldt 1989; Stephenson 1997; Pasachoff & Olson 2014). For any given location, this astronomical spectacle is rare, as it requires the solar disk to coincide exactly with the lunar disk; moreover, total solar eclipses only occur along a narrow totality path. These astronomical spectacles are significant not only for sky watchers but also for scientists. Historical records of total solar eclipses are important for reconstructing the dynamics of solar coronal structures, solar-terrestrial relations, and historical chronologies (Eddy 1976; Hanaoka et al. 2012; Orchiston et al. 2015; Riley et al. 2015; Harrison & Hanna 2016; Pasachoff 2017; Hayakawa et al. 2020, 2021, 2022).

These records are also vital references for reconstructing the variability of Earth's rotation on decadal to centennial timescales (Stephenson et al. 2016, 2018; Morrison et al. 2021), which are essential for understanding long-term variability in sea level, global ice amount, and mantle-core coupling (Lambeck et al. 2014; Mitrovica et al. 2015). The variability of Earth's rotation can be evaluated using $\Delta T$, which is the difference between a theoretically uniform timescale (Terrestrial Time = TT) and a timescale measured with Earth's rotation (Universal Time = UT). This parameter has been derived from timed lunar occultation records from 1623 onward (Morrison et al. 1981; Herald & Gault 2012; Stephenson et al. 2016).

Before 1623, this parameter has been constrained on the basis of analyses of historical eclipse records for their date and probable locations of total/annular solar eclipse records. Philological analyses have especially played major roles to identify probable record provenance and probable observation sites of such eclipse reports (e.g., Stephenson et al. 2018; Morrison et al. 2021). These profiles have been used to

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constrain $\Delta T$ margins, using their relative locations within the narrow bands of totality or annularity based on various historical records from Eurasia (De Jong & Van Soldt 1989; Stephenson & Morrison 1995; Stephenson 1997; Tanikawa & Sôma 2004; Stephenson et al. 2016, 2018; Morrison et al. 2021). On their basis, long-term $\Delta T$ variation has been reconstructed as a spline curve from 720 BCE onward (Stephenson et al. 2016, 2018; Morrison et al. 2021).

However, several caveats must be noted here. The Earth's rotation has a substantial random component, as visualised with phenomenological stochastic modeling (Huber 2006) and occultation records showing variable $\Delta T$ curve from 1623 onward (Figure 10 of Stephenson et al. 2016). Consequently, the previous studies have difficulties in capturing finer $\Delta T$ fluctuations in short-term timescale. Likewise, existing $\Delta T$ reconstructions interpolated their spline curves based on only a small number of records. Inevitably, they accommodate large uncertainties owing in part to the scarcity of actual observational data (Stephenson et al. 2016, 2018; Morrison et al. 2021) and have been subjected to regular updates with historical eclipse records with some occasional aids from historical occultation reports (Sôma & Tanikawa 2015; Martínez Usó et al. 2016; Sôma & Tanikawa 2016; Gonzalez 2017, 2019; Stephenson et al. 2018; Martínez Usó & Marco Castillo 2019; Morrison et al. 2021). It is also important to consider probable record provenance and probable observational sites and admit their geographical uncertainty, as they occasionally leave significant uncertainty in constraining probable $\Delta T$ margins in the historical period.

In this regard, the Earth's rotation reconstructions have hosted significant uncertainty in the 4th–7th centuries CE, owing to the great data scarcity (e.g., Stephenson 2007), as exemplified in Figures 1 and 2 of Morrison et al. (2021). Therefore, this study aims to add new $\Delta T$ constraints utilizing narrative records written in the Byzantine Empire. The Byzantine Empire produced a vast amount of historical records, which in turn offered a rich resource for astronomical and environmental history of the Mediterranean region (Grumel 1958; Schove & Fletcher 1984; Todt & Vest 2017; Murata et al. 2021; Preiser-Kapeller & Izdebski 2022); however, for the $\Delta T$ studies, their eclipse records have been infrequently examined in previous studies (Stephenson 1997; Stephenson et al. 2016). We have analyzed these eclipse records to visualise the observational records and their philological provenances, identify their probable observational sites, and add probable $\Delta T$ constraints to the existing $\Delta T$ data in this period. We have also compared our probable $\Delta T$ constraints with the latest $\Delta T$ spline curve reported by Morrison et al. (2021) and with existing $\Delta T$ constraints from previous studies.

## 2. Materials and Methods

The Byzantine Empire covered the Eastern Mediterranean coasts until Early Islamic Conquest in the 7th century, and the Anatolia and Balkan peninsulas even in its aftermath (Haldon 2005). We selected records of Byzantine eclipse events presented by Schove & Fletcher (1984), along with those of the total solar eclipses cataloged in Espenak & Meeus (2009); in addition, we surveyed other Eastern Mediterranean primary narrative sources.

Here, we examined five total solar eclipse records from the 4th–7th centuries, each of which is considered to be reliable: these records were from 346 June 6, 418 July 9, 484 January 14 , 601 March 10, and 693 October 5. Total solar eclipses are also reported on 393 November 20 and 512 June 29 (Schove & Fletcher 1984), whereas these records suffer from philological and historical uncertainties that require further analyses, beyond the scope of the current study (Janiszewski 2002; Treadgold 2007, pp. 258–264). For each case, we investigated the historical source texts to identify the most reliable reports, and reproduce their original texts and provide their English translations. From these records, we further identified the dates and sites of the reported solar eclipses, confirmed the eclipse totality with the appearance of stars, and computed their observational time following the descriptions and informants' locations. We compared our results with the latest $\Delta T$ model (Morrison et al. 2021 hereafter, M+21) and computed the $\Delta T$ constraints, which we visualized using the Jet Propulsion Lab (JPL) ephemerides DE431 (Folkner et al. 2014).

To identify the dates, times, and sites of these eclipse reports, we needed to understand the philological backgrounds and dating systems of these Byzantine records, which are mainly narrative texts written in Greek, Syriac, and Latin. These records are not necessarily astronomical treatises; in fact, most are chronicles and biographies, as with most medieval eclipse records from Western Europe and the Middle East (Said & Stephenson 1997; Stephenson 1997). During that period, Byzantine secular and ecclesiastical writers, as well as Syriac Christians, prolifically produced a variety of historiographical works (Rapp 2005; Treadgold 2007; Wood 2019) and occasionally reported astronomical phenomena (e.g., solar eclipses) from astrological, astronomical, and apocalyptic viewpoints (Grumel 1958; Schove & Fletcher 1984).

Ideally, the descriptions of a total solar eclipse should provide its year, date, hour, observation sites, and an expression of its totality. Byzantine authors expressed the year and date of an eclipse in terms of various calendar eras used in the Mediterranean region at that time, including: (1) the Year after Creation or Byzantine calendar era, which is based on the Julian calendar and runs from 5509 September 1 BCE (Anno Mundi; hereafter, AM); (2) the Seleucid era dating from 312 October 1 BCE (or Anno Graecorum; hereafter, AG); and (3) regnal years of Roman–Byzantine emperors. Our focus was on the 4th–7th centuries CE; hereafter, we have left out the CE notation, except where needed for clarity.

To determine the exact period in the day, eclipses are recorded according to the division of daytime into 12 equal parts; "the first hour of the day" (i.e., just after the sunrise) or "the sixth hour of the day" (i.e., a seasonal hour until noon), for example (Grumel 1958; Palmer 1993; Bryer 2008). Note that such an hour indication could also mean a point in time, i.e., the end of the given hour. We calculated the reported time ranges to the local apparent time (LAT) by computing the local sunset and sunrise time for each case, and then dividing the daytime durations by 12. We defined local sunrise and sunset as the time when the zenith distance of the atmospherically refracted upper solar limb reached 90°. Based on past conventions, we identified a total solar eclipse by the appearance of stars in the sky, in addition to darkness (Können & Hinz 2008). However, as most actual records lack these details, only a small number of Byzantine records were available for analysis.

For each of these five eclipses, we considered the reliability of the source texts from historical and philological viewpoints. It is occasionally challenging to identify probable observation sites for the historical solar eclipses, unless otherwise the observation sites are explicitly described in the source documents. In this case, we have analyzed the record provenance and identified probable observation sites with original witnesses' residences, as have been commonly performed in the previous $\Delta T$ studies and formed a basis to derive $\Delta T$ spline curves (see e.g., Stephenson 1997; Stephenson et al. 2016, 2018; Morrison et al. 2021). Most eyewitness accounts written in this period have been lost or only remain in fragments through multiple quotations, translations, and interpolations by later generations (Mango & Scott 1997; Németh 2018). Therefore, careful philological and historical case studies are needed to assess the provenance and reliability of these eclipse records with respect to time, place, and other details.

Then, following the JPL ephemerides DE431 (Folkner et al. 2014), we computed the eclipse magnitude for each case based on the existing $\Delta T$ spline curve in M + 21. We defined the magnitude of the eclipses ($M$) as follows:

$$M = (r_s + r_m - d)/(2r_s)... \quad (1)$$

Here, $r_s$, $r_m$, and $d$ represent Sun's apparent angular semidiameter, Moon's apparent angular semidiameter, and apparent angular distance of the centers of the Sun and the Moon, respectively.

Next, we computed the expected $\Delta T$ ranges for each reported total solar eclipse, which accommodates the supposed observational sites of the totality paths. Our method of obtaining the $\Delta T$ constraints from total eclipse observations is the following. First, we assume $\Delta T = 0$ s and calculate the location of the northern and southern limits of the eclipse band following the procedures given in Explanatory Supplement (H. M. Nautical Almanac Office 1961, pp. 224–227). We let the geodetic longitude and latitude of the position where the total or annular eclipse was observed be $\lambda$ and $\varphi$, and calculate the range of longitude $\lambda_1$ to $\lambda_2$, where the total or annular eclipse was seen for the latitude $\varphi$. Then the range of $\Delta T$ can be obtained from the following formula, where $\lambda$, $\lambda_1$, and $\lambda_2$ are expressed in angular degrees.

$$1.0027379 \times 240\ \mathrm{s}(\lambda - \lambda_2) < \Delta T < 1.0027379 \times 240\ \mathrm{s}(\lambda - \lambda_1)... \quad (2)$$

Finally, we compared our new $\Delta T$ constraints with the existing $\Delta T$ spline curve in M + 21 and the existing $\Delta T$ constraints from previous studies. Caveats must be noted here, as we have only identified the probable observation sites of these eclipse records following our analysis of historical sources. These identifications inevitably have some geographical uncertainties and consequently our new $\Delta T$ constraints, as are the cases with the existing $\Delta T$ constraints in the previous studies. These identifications and resultant $\Delta T$ constraints can be easily updated with further philological and historical analyses.

## 3. Total Solar Eclipse of 346 June 6

The Chronicle of Theophanes serves as a primary source for the total solar eclipse on 346 June 6 (Schove & Fletcher 1984, pp. 51–52); this chronicle was written in the early 9th century. In the entry for AM 5838 (345 September 1–346 August 31), Theophanes describes building activities in Syria, a besiege of Nisibis by the Persians, and an eclipse on 346 June 6:

**In the same year, there occurred an eclipse of the Sun on the 6th of the month Daisios [346 June 6] so that the stars were visible in the sky at the third hour of the day.**

Τῷ δ'αὐτῷ ἔτει ἔκλειψις ἡρίου ἐγένετο, ὥστε καὶ ἀστέρας φανῆναι ἐν τῷ οὐρανῷ ἐν ὥρᾳ τρίτῃ τῆς ἡμέρας μηνὶ Δαισίῳ ς′.

(Text: De Boor 1883, p. 38; Translation: Mango & Scott 1997, p. 64)

We also identified similar accounts in the works of Jerome (5th century), George Kedrenos (11th century), and Anonymous' Historia imperatorum (11th century); however, these descriptions were either too simple or dependent on Theophanes' report (Schove & Fletcher 1984, pp. 51–52; besides, Iadevaia 2005, p. 49). Therefore, Theophanes offers a unique and valuable reference for this eclipse.

The appearance of stars in Theophanes's report confirms the visibility of the total solar eclipse. He also offers an approximate hour for when the eclipse was observed. We have identified the observational site as being located either around Antioch (36°12′ N, 36°10′ E) or Nisibis (37°04′ N, 41°13′ E) and computed "the third hour" as 07:07–08:21 LAT at Nisibis and 07:09–08:22 LAT at Antioch, on the basis of the historical context and philological discussions. Theophanes was born in

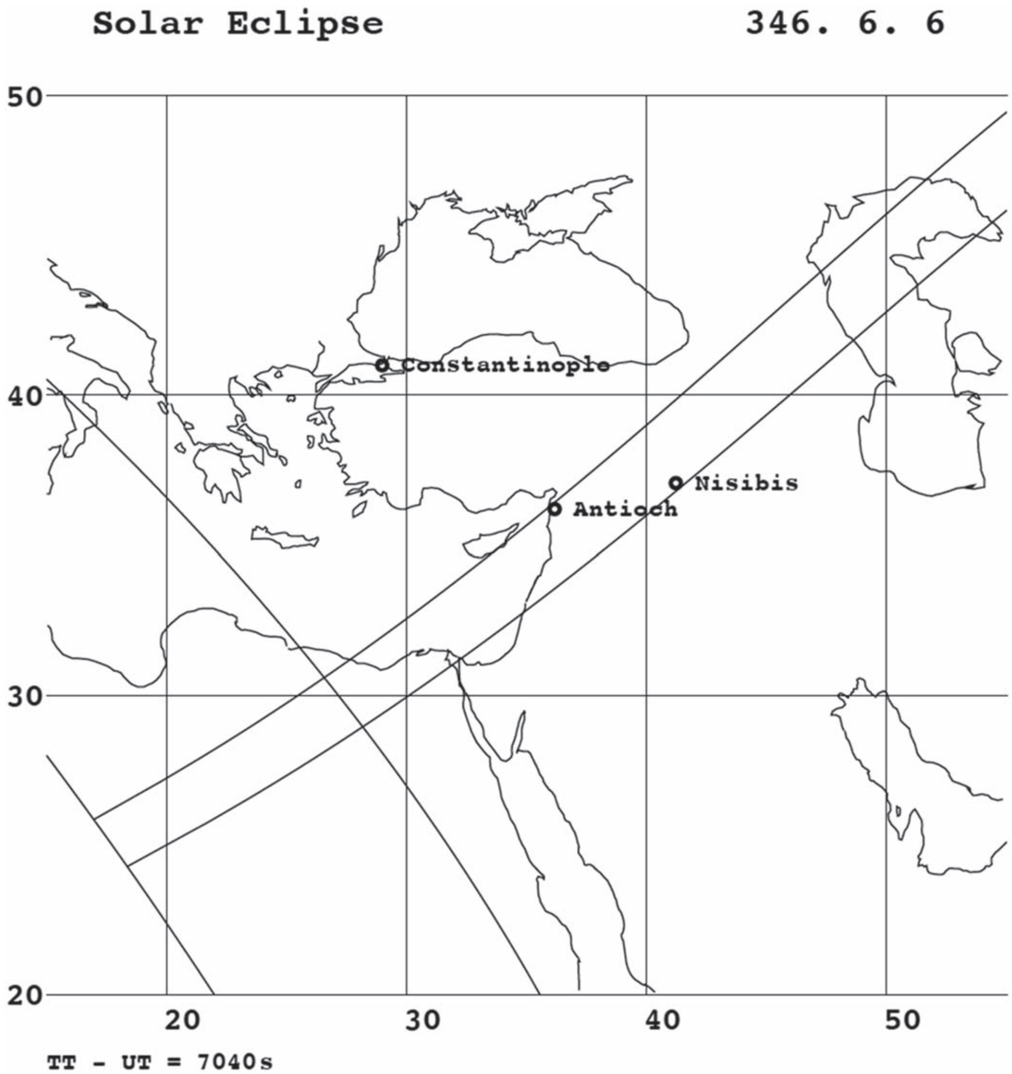


**Figure 1.** Totality path of the total solar eclipse on 346 June 6, following the latest model (M+21) of Earth's variable rotation ($\Delta T$), in which $\Delta T = 7040$ s (Terrestrial Time [TT]—Universal Time [UT]).

Constantinople (ca. 760) and died in Samothrace in 818. He actively served as a bureaucrat in the capital of Byzantium and later took a monastic life in Bithynia. The Chronicle of Theophanes covers secular and ecclesiastical events from 285 to 813. In a strict chronological manner, it describes not only episodes in the Empire, but also includes accounts of Christians and Muslims in the Near East. His sources for the earlier centuries have been subject to scholarly debate. Seemingly, the Chronicle relies mainly on Byzantine ecclesiastical and secular historiographical accounts for his reports of the 4th century to the beginning of the 7th century (Mango & Scott 1997; Jankowiak & Montinaro 2015). It is believed that the descriptions for 345 to 346 were derived from an anonymous Church History. This work has been lost but is thought to have been written by an Arian Christian in the latter half of the 4th century (≈370s), presumably in Antioch (Bidez & Winkelmann 1981, pp. cli–clxiii; Bleckmann & Stein 2015, pp. 56–61). Some scholars have further considered the composition of the lost Arian Church History, according to which the Church History had in turn consisted of two different chronicles: the "first" chronicle includes the 346 eclipse record and was composed shortly after 350 by Eusebius of Emesa, who wrote several accounts in Antioch (Reidy 2015a, 2015b; see Burgess 1999, pp. 113–305, especially p. 273). In any case, the original author who recorded the 346 eclipse was an Antiochene, who was alive at the time of the event and was either an eyewitness or close to the informant. Therefore, we conclude the probable observational site around Antioch, followed by Nisibis.

Applying the M + 21 $\Delta T$ value, we located these sites on the totality path (Figure 1). At these sites, the eclipse reached maximum magnitudes of 1.005 (Nisibis at 07:01 LAT) and 1.004 (Antioch at 06:39 LAT). In each case, our calculation confirmed the visibility of the total eclipse at these sites, but calculated the time of the eclipse maximum phase slightly before the reported time range, particularly with a smaller time lag at Nisibis. These results are consistent with M + 21 and allowed us to further constrain the probable $\Delta T$ range for 346, yielding 6050 s $< \Delta T <$ 7122 s and 6945 s $< \Delta T <$ 8018 s to locate Antioch and Nisibis in the total path, respectively. Allowing for both possibilities, we constrained the $\Delta T$ range of 346 to 6050 s $< \Delta T <$ 8018 s.

## 4. Total Solar Eclipse on 418 July 19

Philostorgius' Church History (written in the 5th century) provides the most detailed account of the total solar eclipse on 418 July 19 (Schove & Fletcher 1984, pp. 72–73). While several late antique authors over the Mediterranean coasts also reported the eclipse, they mostly made observations from Western Europe and did not explicitly describe the totality (Schove & Fletcher 1984, pp. 72–73). Philostorgius stated the following:

**When Theodosius [i.e., Emperor Theodosius II] had reached adolescence, on the nineteenth of July at about the eighth hour, the Sun was so completely eclipsed that stars appeared. And such a drought followed this event that there was everywhere an unusually high number of deaths of human beings and animals.**

ὅτι Θεοδοσίου τῆς τῶν μειρακίων ἡλικίας ἐπιβεβηκότος καὶ τοῦ μηνὸς Ἰουλίου είς ἐννέα ἐπὶ δεκάτη διαβαίνοντος περὶ ὀγδόην τῆς ἡμέρας ὥραν ὁ ἥλιος οὕτως βαθέως ἐκλείπει, ὡς καὶ ἀστέρας ἀναλάμψαι. καὶ αὐχμὸς οὕτω τῷ πάθει συνείπετο, ὡς πολλῶν ἀνθρώπων καὶ τῶν ἄλλων ζῴων ἀσυνήθη φθορὰν πανταχοῦ φέρεσθαι.

(Text: Bleckmann & Stein 2015, p. 430; Translation: Amidon 2007, p. 159; see Bidez & Winkelmann 1981, p. 145; Des Places et al. 2013, pp. 544–545).

The Church History covers the period 315–425 and was published in around 430. Unfortunately, the text is extant only in Photios' summary, the patriarch of Constantinople in the 9th century, and in some fragments (Treadgold 2007, pp. 126–134; Meyer 2011). In Book 12, after narrating an event in Rome from 408 onward, Philostorgius focuses on the situation in the Eastern Roman Empire. Here, the narrative, including the above eclipse record, seems to be his own eyewitness account. He also demonstrates his profound knowledge of various astronomical phenomena and their astrological interpretations (see Meyer 2011; Des Places et al. 2013, pp. 90–92).

The report describes a complete eclipse with the appearance of stars, indicating visibility of the total solar eclipse on this date. Although Philostorgius does not specify the exact year, we can confidently associate this report with the total eclipse of 418 July 19. According to him, when the emperor Theodosius II (401–450) reached adolescence, there appeared portents of "divine anger" including earthquakes, a fire from the sky, a comet, a drought, and a total eclipse (see Bleckmann 2008; Meyer 2011). Based on the period of Theodosius II's adolescence and his birth in 401, the day and hour of the eclipse, and its totality, are consistent with the event of 418.

From the report, we identified the observational site as Constantinople (41°00′ N, 28°59′ E) and computed the "eighth hour" as 13:14–14:28. Philostorgius was born in Borissus, Cappadocia between 366 and 368. When he was 20 years old, he traveled to Constantinople, Alexandria, and Syria to pursue his studies, including astronomy. He lived in Constantinople from 394/5 until his death sometime after 430 (Treadgold 2007, pp. 126–134). Relying on the information of his birthplace only, Martínez & Marco (2019) raised Borissus as a possible observational site of Philostorgius' eclipse record. However, this is historically unlikely, as he had moved to Constantinople more than 20 yr before the eclipse. The chronology of Philostorgius' biography establishes that the eclipse was observed in Constantinople (see Treadgold 2007, p. 132; Amidon 2007, pp. 159–160; Meyer 2011, pp. 27–29).

Applying the M + 21 $\Delta T$ value, Constantinople did not fall within the totality path (Figure 2(a)); the maximum eclipse magnitude reached only 0.987 at 13:05 LAT, while the time of the eclipse maximum phase was slightly off the reported time range. However, Philostorgius' report strongly indicates the visibility of the total solar eclipse. We constrained the $\Delta T$ range to 6825 s $< \Delta T <$ 8997 s for 418 to confirm the data in Philostorgius' report (Figure 2(b)). This is slightly higher than the M + 21 $\Delta T$ value, which inevitably suffers from significant uncertainty owing to the lack of parallel references of contemporary eclipse reports (Figures 1 and 2 of Morrison et al. 2021).

## 5. Total Solar Eclipse on 484 January 14

Marinus of Neapolis (early 5th century to ∼490) reported a great eclipse shortly before the death of his master, a famous Neoplatonic philosopher Proclus (412–485), in a biographical work entitled Proclus, or on Happiness, ch. 37, which Marinus dedicated to his late master (Figure 3). This eclipse is consistent with that which occurred on 484 January 14 , with a parallel record from Persia (Schove & Fletcher 1984, pp. 81–82; Stephenson 2007, p. 212). Here, Marinus described the eclipse as follows:

**Before the year of his [i.e., Proclus's] death, there were portents, such as an eclipse of the Sun, so conspicuous that it became night by day. In fact, a deep darkness descended and stars appeared. This occurred in Capricorn at the eastern cardinal point.**

Ἐγένοντο δὲ καὶ διοσημεῖαι πρὸ ἐνιαυτοῦ τῆς τελευτῆς, ὡς ἡ ἔκλειψις ἡ ἡλιακὴ οὕτως ἐναργὴς ὥστε καὶ νύκτα μεθ' ἡμέραν γενέσθαι. Σκότος γὰρ ἐγένετο βαθὺ καὶ

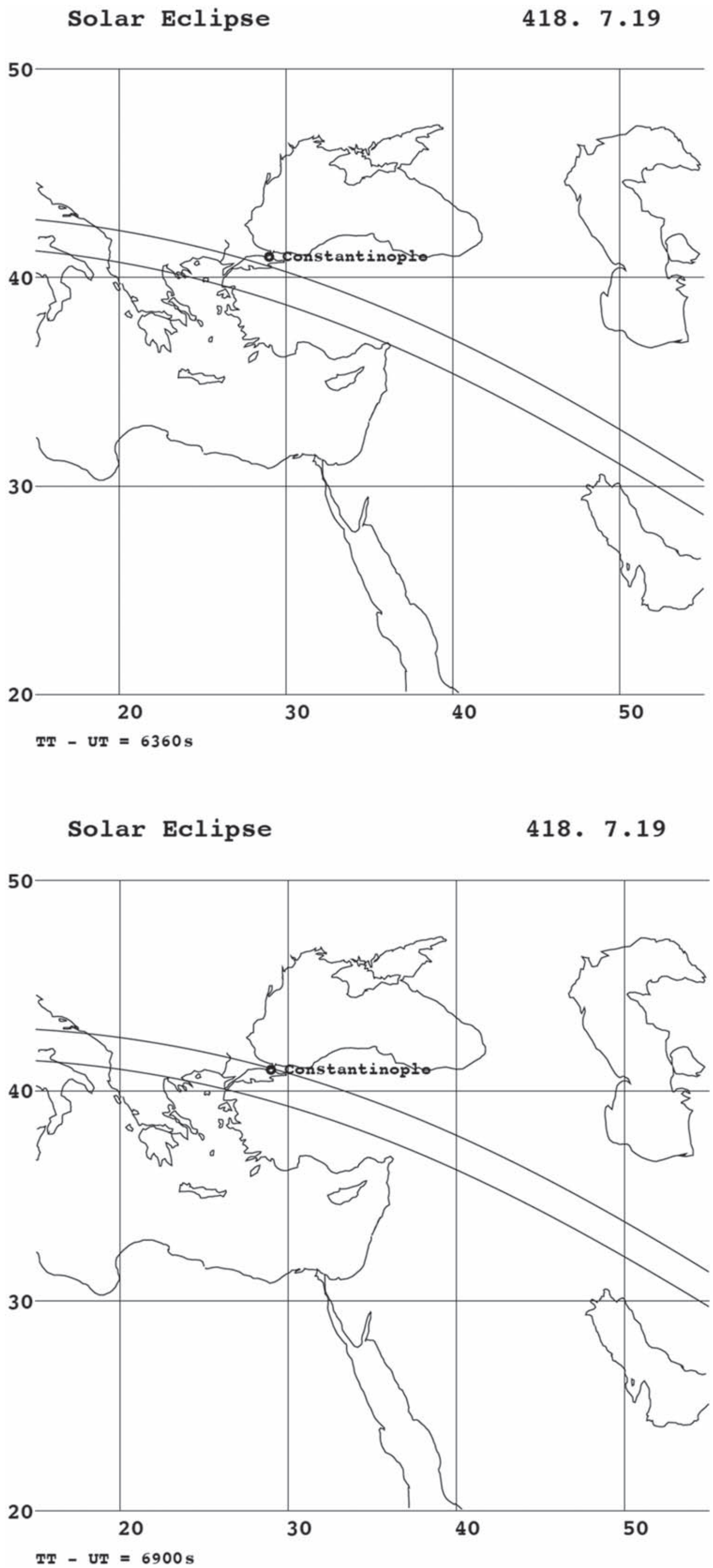


**Figure 2.** Totality path of the total solar eclipse on 418 July 19, following (a) M + 21's Earth's variable rotation ($\Delta T$), in which $\Delta T = 6360$ s, and (b) our revision ($\Delta T \approx 6900$ s).

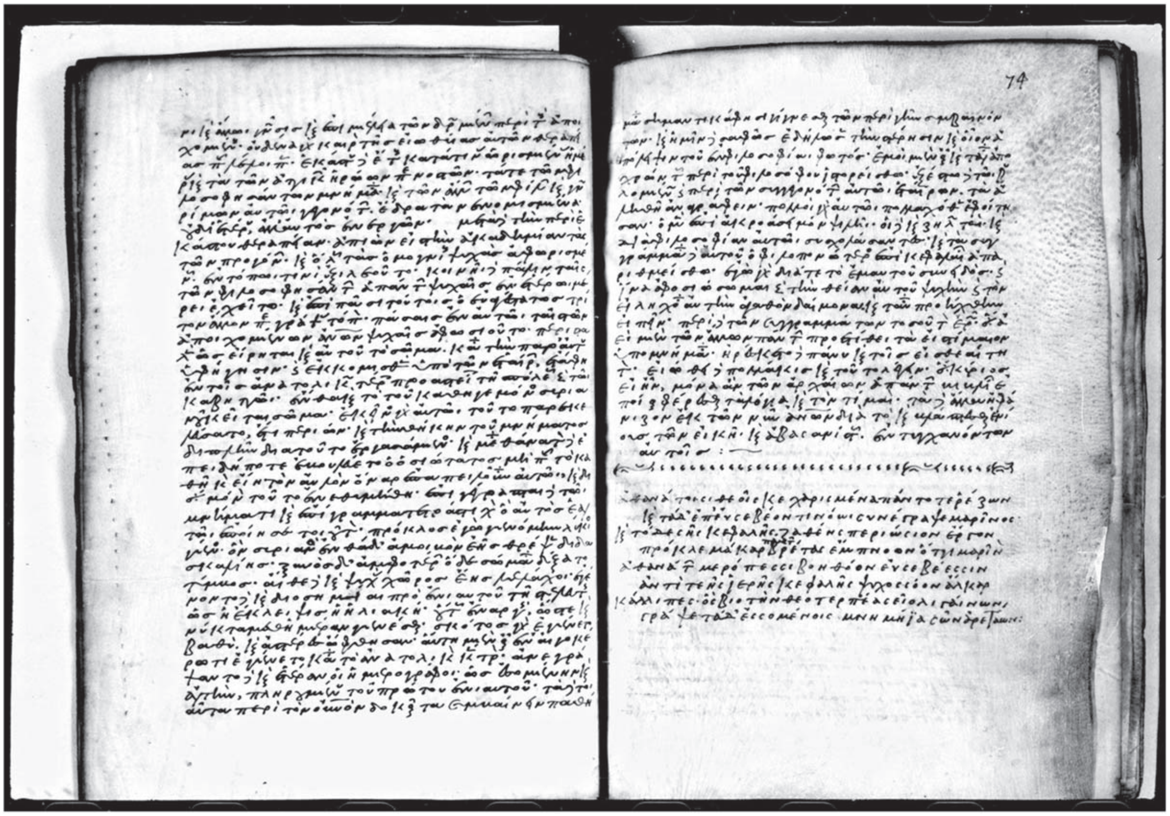

**Figure 3.** An image of one of the oldest manuscripts of Marinus: Proclus, or on Happiness, ch. 37 (Original Source: Bibliothèque nationale de France, Coislin 249 [10th c.], fols. 73v–74r).

ἀστέρες ὤφθησαν. Αὕτη μὲν οὖν ἐν Αἰγοκέρωτι ἐγένετο κατὰ τὸ ἀνατολικὸν κέντρον.

(Text: Saffrey et al. 2001, p. 43; Translation: Edwards 2000, pp. 113–114, with modifications; see Masullo 1985, pp. 92–93).

The report confirms the visibility of a total solar eclipse, including a description of deep darkness and the appearance of stars; however, the date and hour are not indicated. The observational site has been identified as Athens (37°58′ N, 23° 44′ E). Marinus was born in Neapolis (Nabulus of modern Palestine), but moved to Athens in ~460s, where he became Proclus's disciple and successor at his school; Marinus stayed in Athens until his death in ~490. His work, Proclus, or on Happiness, seems to have been completed within a year after the death of Proclus in 485 April (Blumenthal 1984; Masullo 1985 pp. 15–20; Saffrey et al. 2001, pp. ix–xxxix). Marinus describes the date of the eclipse as being 1 yr before the death of Proclus (i.e., 484). Therefore, we can safely conclude that Marinus's eclipse is that of 484 January 14. Marinus seemingly witnessed this eclipse, and his report suggests considerable knowledge and interest in astronomy. For example, his description of the location of the eclipse uses technical terms such as "the eastern cardinal point" ('τὸ ἀνατολικὸν κέντρον'); moreover, he explains that his contemporaries made a prediction for when the next eclipse will occur (a partial eclipse on 486 May 19; Neugebauer & Van Hoesen 1959, pp. 135–136).

Applying the M + 21 $\Delta T$ value, Athens was outside the totality path (Figure 4(a)); the maximum eclipse magnitude reached 0.991 at 07:07 LAT, immediately after local sunrise (at 07:06 LAT), where local sunrise is defined as the contact between the upper solar limb and terrestrial horizon. To locate Athens in the totality path, we needed to constrain the probable $\Delta T$ margin for 484 as $4479\ \mathrm{s} < \Delta T < 5455\ \mathrm{s}$, yielding a slightly lower $\Delta T$ value than that of M + 21 (see also Stephenson 2007). For example, adopting $\Delta T = 5000$ s, the total eclipse (maximum magnitude 1.014) occurred at 07:21 LAT, well after local sunrise (07:06 LAT). Moreover, the revised $\Delta T$ value allowed us to locate the solar disk of this total eclipse in the Capricorn constellation in the eastern sky, which was consistent with Marinus' report and provided support for our revised $\Delta T$ value (Figure 5).

## 6. Total Solar Eclipse on 601 March 10[9]

The solar eclipse of 601 March 10 has been associated with an inscription on a contemporary Coptic ostracon found at

9 Section 6 has been partially cited as "H. Hayakawa 2021 private communication" in Tanikawa et al. (2022).

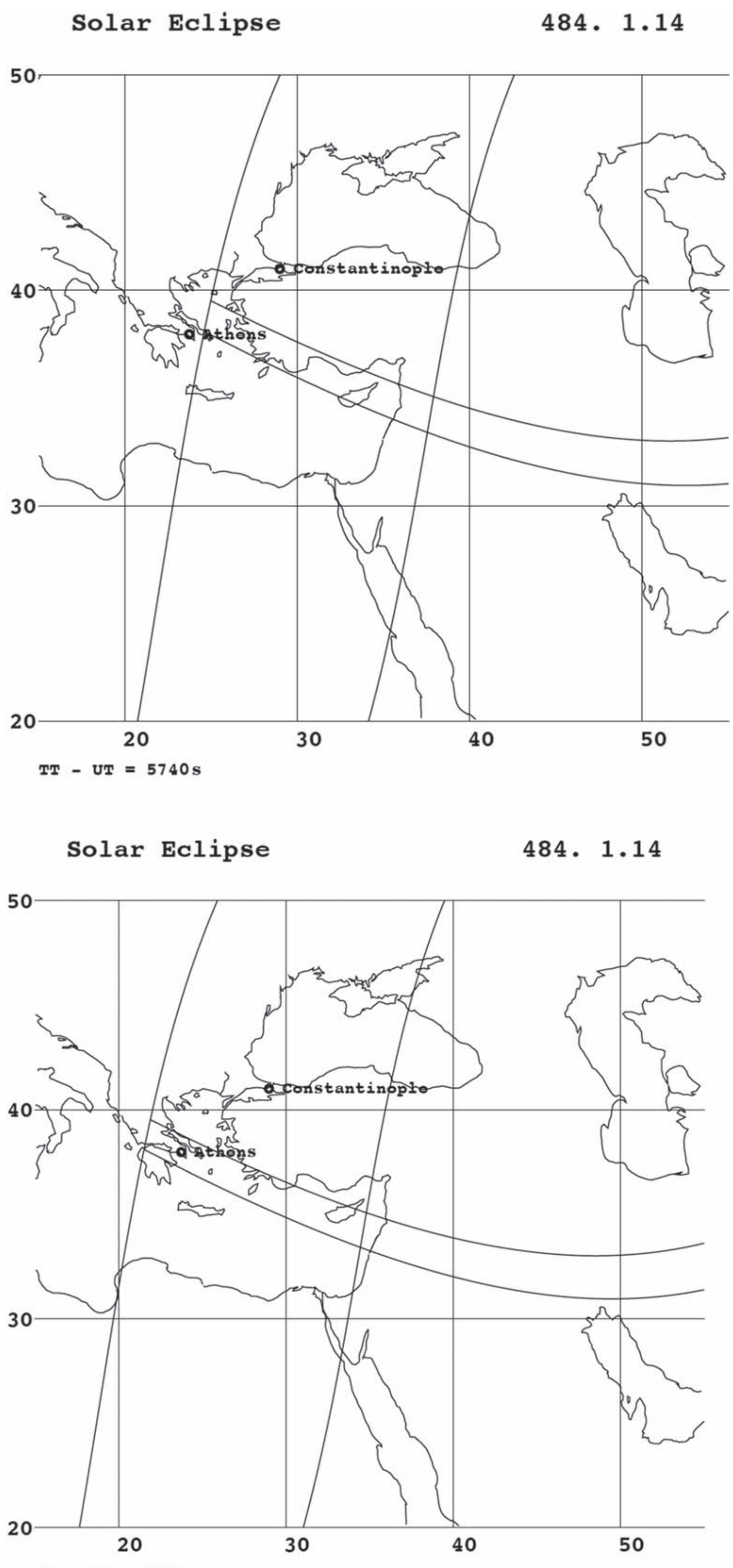


**Figure 4.** Totality path of the total solar eclipse on 484 January 14 , following (a) the latest model M + 21's Earth's variable rotation ($\Delta T$), in which $\Delta T = 5740$ s, and (b) our revision ($\Delta T \approx 5000$ s).

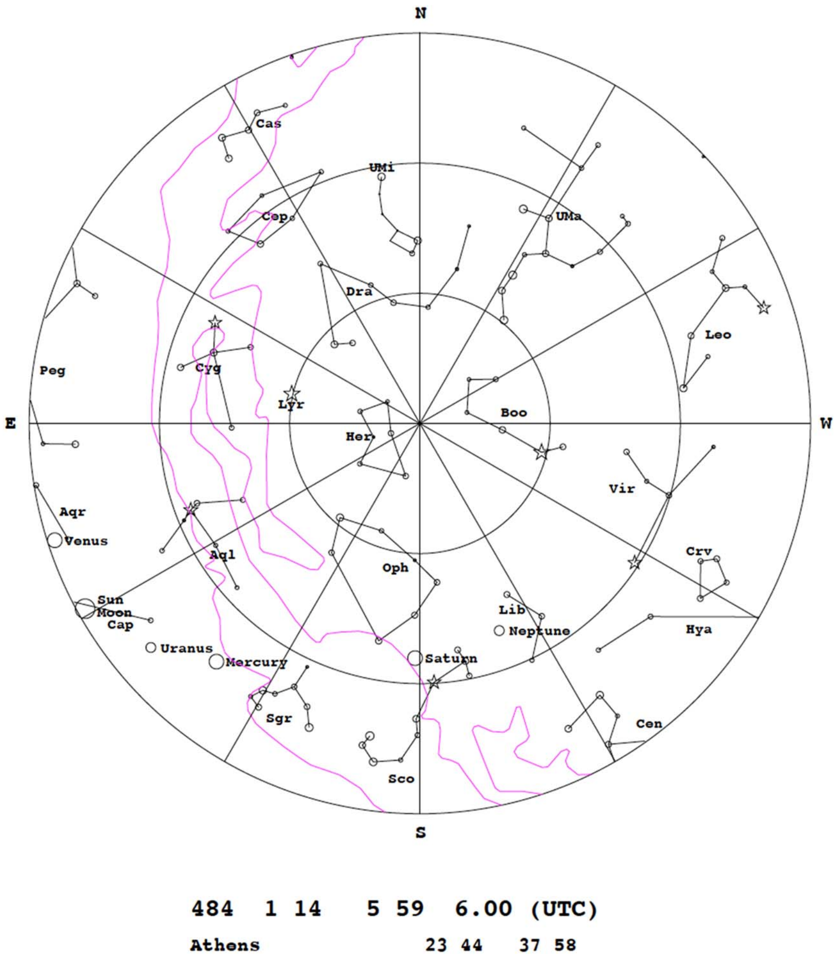


**Figure 5.** Relative locations of the Sun, Moon, and Capricorn during the total solar eclipse of 484 January 14 based on our revised $\Delta T$ (Earth's variable rotation) value ($\Delta T = 5000$ s).

Djême, the Chronicle of John of Nikiû composed in the late 7th century, and several Syriac chronicles edited in the 8th century onward (Schove & Fletcher 1984, pp. 111–112; Gilmore & Ray 2006). The Coptic ostracon simply describes the Sun's darkening, which does not guarantee the visibility of the total solar eclipse (Gilmore & Ray 2006). In contrast, the Chronicle of John of Nikiû provides important details (Figure 6) as follows:

**And likewise, during the reign of Maurice [i.e., 582–602], the city of Antioch was troubled by a great earthquake and laid low. Now it had been laid down seven times. Many roads (?) in the east were destroyed, and islands, and an innumerable multitude of men through the earthquake. And likewise at that time, the Sun was eclipsed at the fifth hour of the day, and the light of the stars appeared. And there was a widespread alarm, and men believed that the end of the world was at hand. And all men wept and implored and prayed to Christ our God to have mercy and compassion upon them. Thereupon, the light reappeared, and the Sun rose out of the darkness.**

ክፍል ፡ ፻፭ ፡፡ ወዓዲ ፡ በመዋዕሊሁ ፡ ለዝንቱ ፡ ሞሪቅ፡ ሐመት፡ ሀገረ ፡ አንጾኪያ ፡ በድልቅልቅ ፡ ዐቢይ ፡ ወወድቀት ፤ ወዝኮነ ፡ ስብዐ ፡ ጊዜያተ ፡ ለወዲቆታ ፡፡ ወንሕሉ ፡ ብዙኀ ፡ ፍናዋት ፡ ዘምሥራቅ ፡ ወደሰያት ፡ ወሞቱ ፡ ብዙኃን ፡ ሰብእ ፡ ዘኢይትኌለቁ ፡ እምነ ፡ ድልቅልቅ ፡፡ ወዓዲ ፡ በውእቱ ፡ ዘመን ፡ ጸልመት ፡ ፀሓይ ፡ በ፭ ሰዓተ ፡ መዓልት ፡ ወኣስተርኣየ ፡ ብርሃነ ፡ ከዋክብት ፡፡ ወኮነ ፡ ሐከከ ፡ ዐቢየ ፡ ወኀለዩ ፡ ከመ ፡ ቀርበት ፡ ኅልፈተ ፡ ምድር ፡፡ ወኮኑ ፡ ኵሎሙ ፡ ሰብእ ፡ ይበክዩ ፡ ወየኀሥሡ ፡ ወይስእሉ ፡ ኀበ ፡ ክርስቶስ ፡ አምላክነ ፡ ከመ ፡ ይምሐሮሙ ፡ ወይሣህሎሙ ፡፡ ወእምዝ ፡ አስተርአየ ፡ ብርሃን ፡ ወሠረቀ ፡ ፀሓይ ፡ እምነ ፡ ጽልመት ፡፡

(Text: Zotenberg 1883, pp. 181–182; Translation: Charles 1916, p. 163, with slight modifications).

The Chronicle of John of Nikiû consists of 123 chapters, covering from the Creation of the world to the Muslim conquest of Byzantine Egypt during the early 640s. John was an Egyptian Coptic Bishop of Nikiû (modern Zawyat Razin:

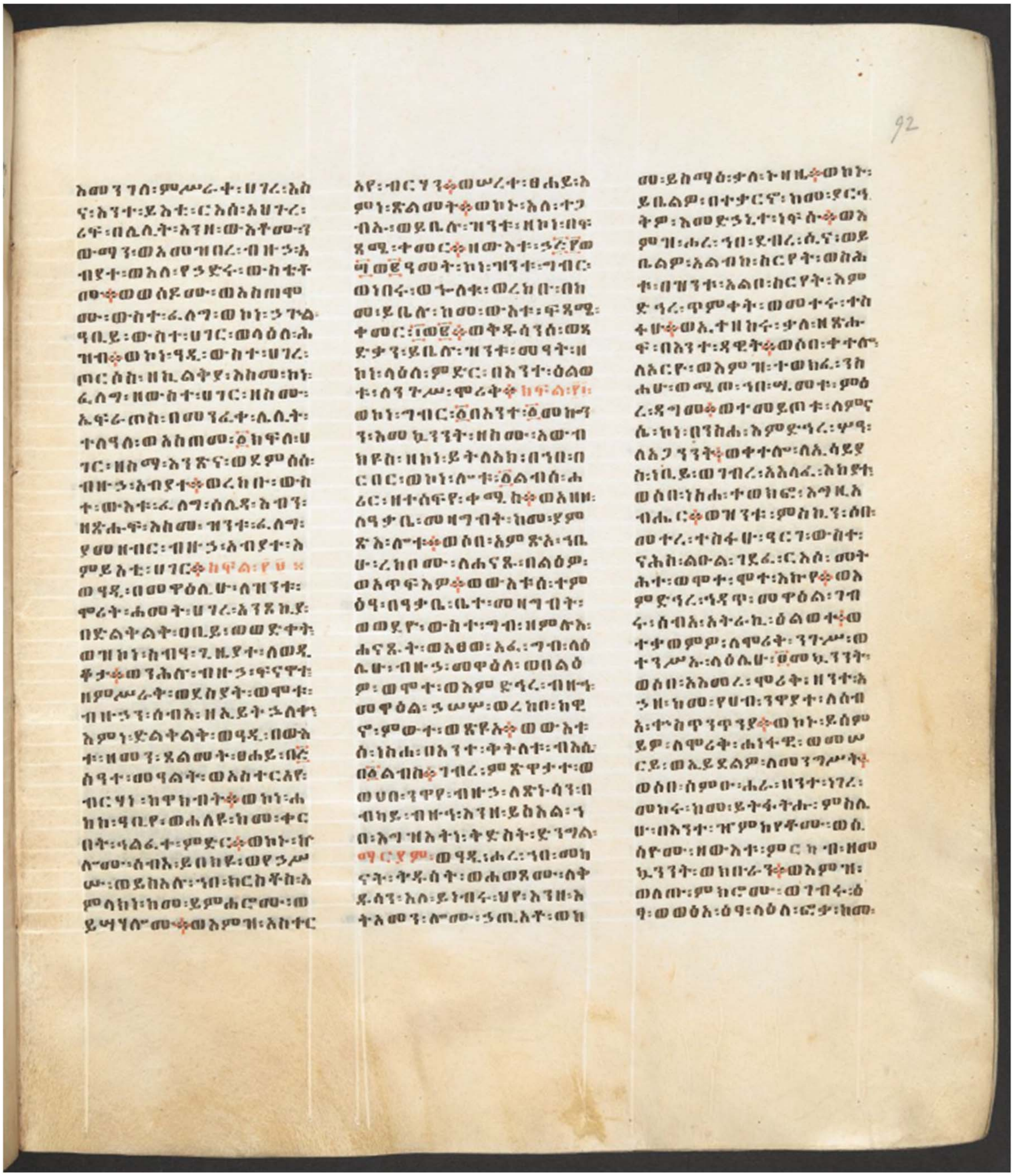

**Figure 6.** An image of one of the oldest manuscripts containing the eclipse account by John of Nikiû (Original Source: British Library, Or 818, f. 92r).

30°25′ N, 30°51′ E) during the late 7th century and wrote his chronicle, probably in Coptic (or Greek) as early as ∼ 650 (Hoyland 1997, pp. 152–156; Witakowski 2012, pp. 140–141). The original version has been lost, and what survives is a 17th century Ge'ez translation of an Arabic paraphrase of the original (Booth 2011; Brown & Elagina 2018; Elagina 2018).

John offered neither the exact date nor the observation site of this eclipse; however, the report is commonly identified with the total solar eclipse of 601 March 10, following his descriptions of the observation hour ("fifth hour of the day") and context of his narrative. It is challenging to robustly identify the observation site, as current literature has not identified John's source of information for the eclipse (Zotenberg 1877, 1878, 1879; Carile 1986; Howard-Johnston 2010, pp. 181–189). However, modern astronomical authorities have commonly identified it as Antioch (Neugebauer 1979, pp. 101–102; Schove & Fletcher 1984, pp. 111–112). It is unlikely that John was an eyewitness to this eclipse, as he was alive in the 680s and the eclipse took place almost eight decades before this. Examining the philological and historical aspects of the text, we concur that the observation site was probably Antioch (see Appendix A). However, while improbable, we are open to the possibility that the observation site was Nikiû. On the other hand, several later Syriac chronicles also mention this eclipse and its totality (Schove & Fletcher 1984, p. 112); however, philological uncertainties prevented us from identifying their observation sites, and hence from using them as $\Delta T$ references (see Appendix B).

John of Nikiû reported the appearance of stars in the fifth hour, calculated to be 10:02–11:01 LAT at Antioch. However, this appears to be slightly problematic when we reconstruct the totality path with the M + 21 $\Delta T$ value. This path runs from Lower Egypt to Azerbaijan along the southeastern frontier of Syria (Figure 7(a)). The eclipse magnitude at Antioch reached only 0.925 at 10:25 LAT. Our calculation chronologically supports the reported time of the appearance of stars, but does not sufficiently reduce the sky brightness for such appearances. To locate Antioch in the totality path, we need to constrain the probable $\Delta T$ margin to 2319 s $< \Delta T <$ 3005 s (Figure 7(b)), yielding a significantly lower $\Delta T$ value than that of M + 21. Alternatively, if we assume an observational site at Nikiû the $\Delta T$ margin becomes 3612 s $< \Delta T <$ 4386 s, which is closer to the M + 21 $\Delta T$ spline curve.

## 7. Total Solar Eclipse on 693 October 5

The Chronicle of Theophanes serves as a primary reference source for the total solar eclipse on 693 October 5. Theophanes reported the following:

**In this year [AM 6186 = 693 September 1—694 August 31], there occurred an eclipse of the Sun on the fifth of the month Hyperberetaios [i.e., 693 October 5], a Sunday, in the third hour, so that some of the brighter stars became visible.**

Τούτῳ τῷ ἔτει ἔκλειψις γέγονεν ἡλίου μηνὶ Ὑπερβερεταίῳ ε′ ἡμέρᾳ α′ ὥρᾳ γ′, ὥστε φανῆναί τινας λαμπροὺς ἀστέρας.

(Text: De Boor 1883, p. 367; Translation: Mango & Scott 1997, p. 513).

Philological and historical analyses have traced his source to an eyewitness account of Jacob of Edessa (d. 708), who lived at the Monastery of Eusebona near Teleda (36°15′ N, 36°48′ E) in the 690s (Salvesen 2008; Debié 2010, p. 144; Todt & Vest 2014, pp. 1150–1151). For events from the 630s to the late 8th century including the eclipse report, the Chronicle of Theophanes relies heavily on Near Eastern Syriac writings, including the lost chronicle of Theophilus of Edessa (695–755 +; Hoyland 2011, pp. 1–34 and 189). Nevertheless, Theophilus must have relied on another source, as the date of the eclipse was before his birth in 695. Jankowiak (2015, p. 69) has associated his report in this period with Jacob of Edessa's lost chronological accounts. In fact, this eclipse was also reported in a Syriac chronicle of Elias of Nisibis (975–1046), who indicated his source as Jacob of Edessa: "Year 75 [AH = 694–695 CE], which began from the Saturday, 2 Ijar [i.e., May 2] of the year 1005 of the Greeks [AG = 693 October 1–694 September 30 CE]: from Khuwarizmi and Jacob of Edessa. [...citation from Khuwarizmi is omitted here...] and there was a total eclipse of the Sun on Sunday, 5 Tešrīn [i.e., 693 October 5], at the fifth hour of the day" (Brooks 1910, p. 152; Delaporte 1910, pp. 94–95). This report has been compared with Theophanes's report, and both their sources have been identified as Jacob of Edessa's eyewitness account. Although Jankowiak (2015, p. 69) identified specifically that the source was Jacob's Chronicle, there is still the possibility that the eclipse was reported in another work of this prolific ecclesiastic man (see Brooks 1907, p. 257; Delaporte 1910, pp. vii–viii; Witakowski 2008).

While several later Byzantine and Western European authors also noted the eclipse of 693 with mention of the appearance of stars, all relied on the Chronicle of Theophanes (Schove & Fletcher 1984, pp. 137–142; Wahlgren 2006, p. 171). As for later Syriac writers, Michael the Syrian records this eclipse in his chronicle, written in the 12th century (Chabot 1910, pp. 446–447). Like Theophanes and Elias, Michael's record also relies on Jacob of Edessa through the chronicle of Theophilus of Edessa, but offers slightly different hours for the eclipse; i.e., "during the third and fourth hours" (Chabot 1910, pp. 446–447; Hoyland 2011, p. 189).

In summary, these reports all indicate that Jacob witnessed a total solar eclipse at Teleda, emphasizing the appearance of stars and eclipse totality.

The totality was reported either in the third hour (Theophanes), the fifth hour (Elias), or the third to fourth hour (Michael), calculated to be 08:09–09:07 LAT, 10:05–11:02 LAT, and 08:09–10:05 LAT, respectively. However, applying the M + 21 $\Delta T$ value places Teleda slightly off the total path (Figure 8(a)). Here, the maximum eclipse magnitude reached only 0.996 at 09:30 LAT, which cannot explain the appearance of stars. To establish Teleda in the totality path, we needed to constrain the probable $\Delta T$ margin for 693 as 2726 s $< \Delta T <$ 3740 s (Figure 8(b)), yielding a slightly lower $\Delta T$ value than that of M + 21.

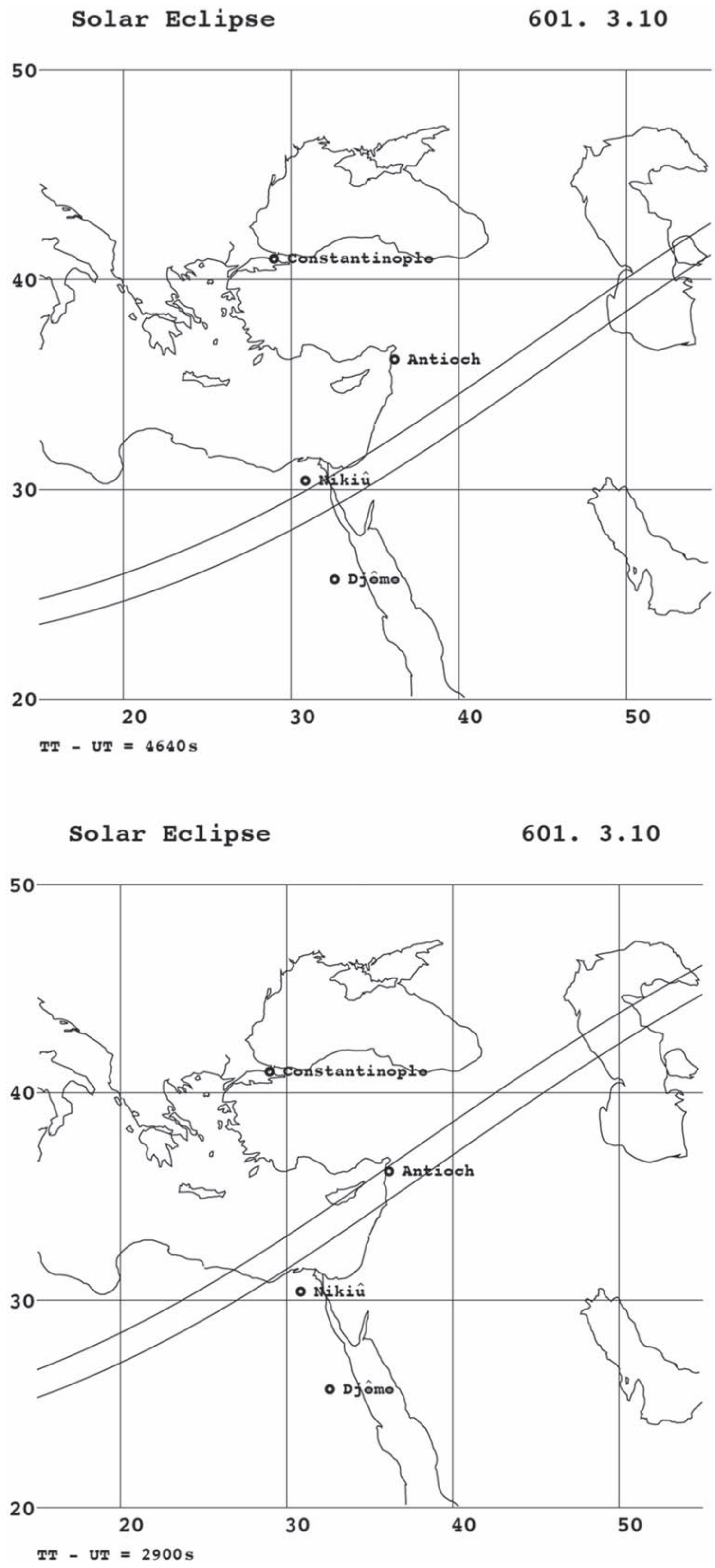


**Figure 7.** Totality path of the total solar eclipse on 601 March 10, following (a) M + 21's Earth's variable rotation ($\Delta T$), in which $\Delta T = 4640$ s, and (b) our revision ($\Delta T \approx 2900$ s).

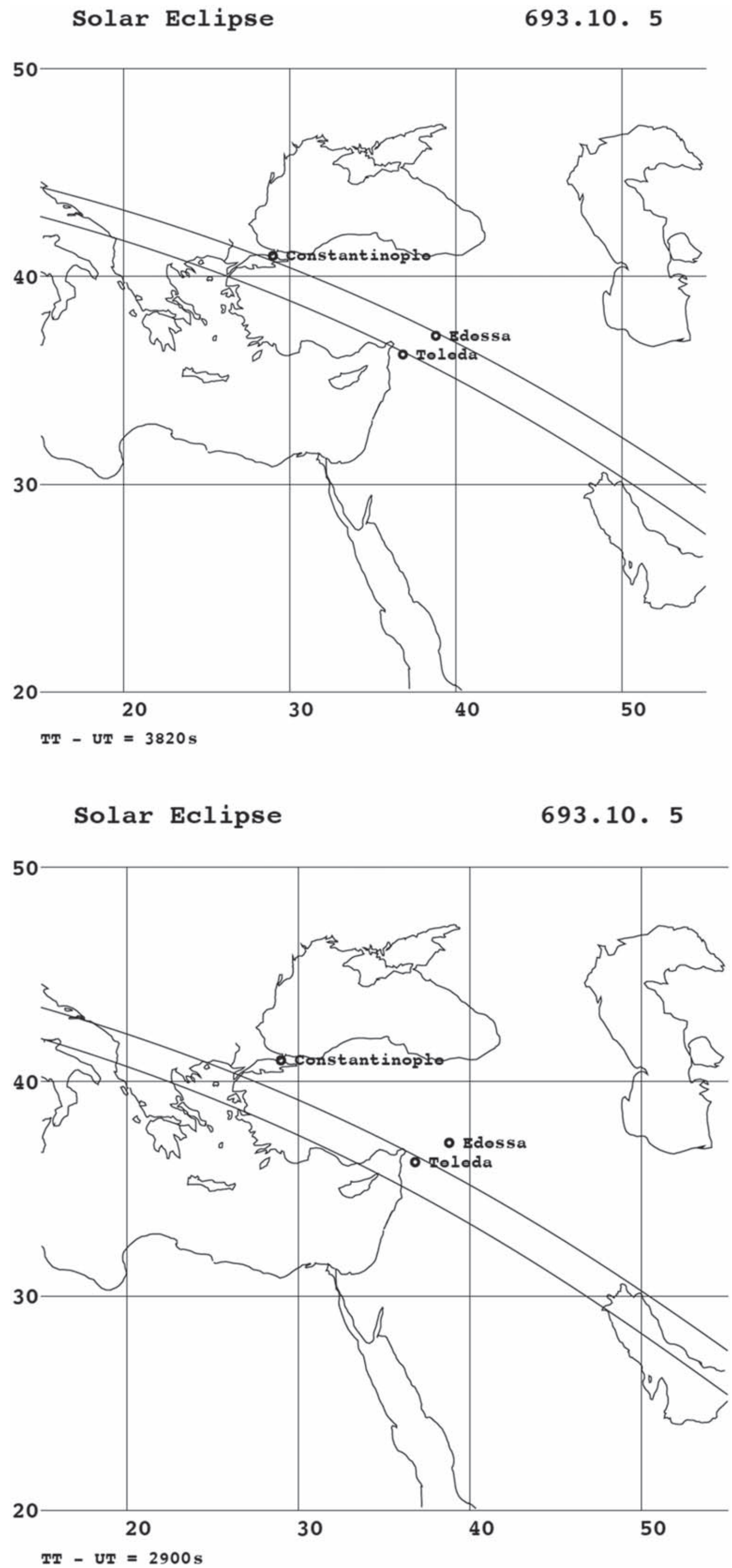


**Figure 8.** Totality path of the total solar eclipse on 418 July 19, following (a) M + 21's Earth's variable rotation ($\Delta T$), in which $\Delta T = 3820$ s, and (b) our revision ($\Delta T \approx 2900$ s), which is consistent with probable $\Delta T$ constraints in 601, 616, and 628.

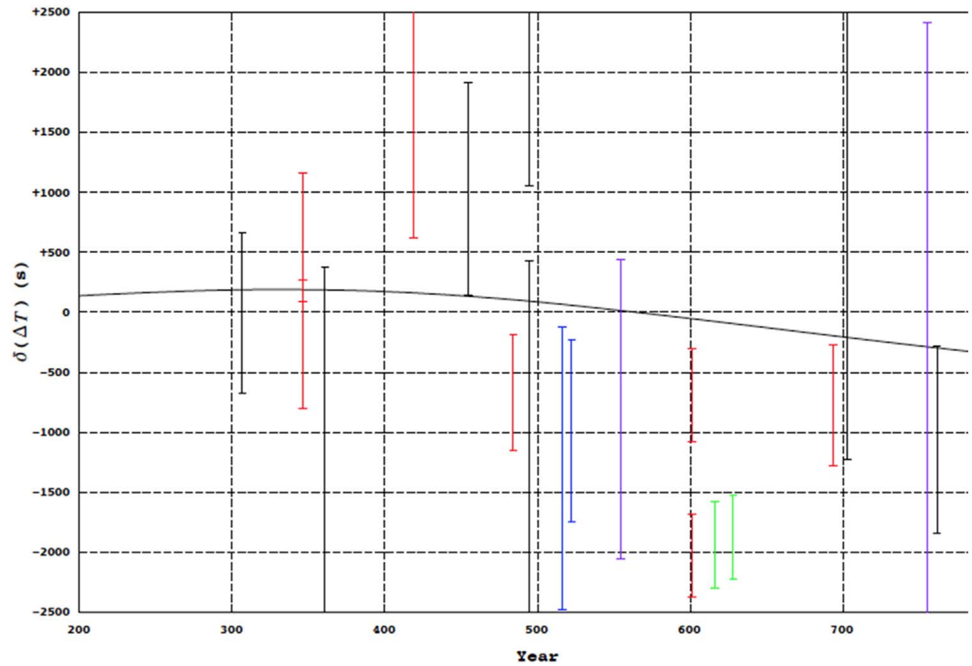


**Figure 9.** Time series of Earth's variable rotation ($\Delta T$) constraint for the 4th–7th centuries from this study (red bars), from the current $\Delta T$ spline curve (black bars; Morrison et al. 2021), and from other previous studies, including Sôma & Tanikawa (2016) [blue bars], Martínez Usó & Marco Castillo (2019) [purple bars], and Sôma et al. (2003) and Tanikawa et al. (2022) [green bars]. We have shown two error margins for the same eclipse, if we have two candidates for the probable observational sites (e.g., those of 346 and 601) or if we have a reference from a partial-eclipse record. In this graph a quadratic function of time is subtracted from $\Delta T$ by the equation of $\delta(\Delta T) = \Delta T - (31.4\ [s]\ ((\text{year} - 1825)/100)^2 - 10\ [s])$, where the quadratic function showing the long-term trend in $\Delta T$ is taken from M + 21.

**Table 1**
Summary of Great Eclipses Recorded in Byzantine Narrative Texts, Including Dates, Site of Observations, and our Probable $\Delta T$ Constraints

| Date | Site | Latitude | Longitude | M + 21's $\Delta T$ (s) | Our $\Delta T$ constraints (s) | Reference |
|---|---|---|---|---|---|---|
| 346 Jun 6 | Antioch | 36°12′ N | 36°10′ E | 7040 | $6050 < \Delta T < 7122$ | Section 3 |
| 346 Jun 6 | Nisibis | 37°04′ N | 41°13′ E | 7040 | $6945 < \Delta T < 8018$ | Section 3 |
| 418 Jul 19 | Constantinople | 41°00′ N | 28°59′ E | 6360 | $6825 < \Delta T < 8997$ | Section 4 |
| 484 Jan 14 | Athens | 37°58′ N | 23°44′ E | 5740 | $4479 < \Delta T < 5455$ | Section 5 |
| 601 Mar 10 | Antioch | 36°12′ N | 36°10′ E | 4640 | $2319 < \Delta T < 3005$ | Section 6 |
| 601 Mar 10 | Nikiû | 30°25′ N | 30°51′ E | 4640 | $3612 < \Delta T < 4386$ | Section 6 |
| 693 Oct 5 | Teleda | 36°15′ N | 36°48′ E | 3820 | $2726 < \Delta T < 3740$ | Section 7 |

## 8. Summary and Discussion

Overall, we have added five probable $\Delta T$ constraints from the Byzantine historical records to further improve the M + 21 $\Delta T$ curve, as summarized in Table 1. These new constraints fill a considerable $\Delta T$ data gap in the 4th–7th centuries, for which M + 21 hosted only three total solar eclipses and two partial solar eclipses as valid $\Delta T$ constraints.

Figure 9 compares $\Delta T$ constraints for the 4th–7th centuries, including those derived in this study, those in the existing $\Delta T$ spline curve (M+21), and those from previous studies. In this graph a quadratic function of time is subtracted from $\Delta T$ by the equation of $\delta(\Delta T) = \Delta T - (31.4\ [s]\ ((\text{year}-1825)/100)^2 - 10\ [s])$, where the quadratic function showing the long-term trend in $\Delta T$ is taken from M + 21. Our probable $\Delta T$ constraints in 346 are comparable to M + 21's $\Delta T$ constraints in 306 ($6550\ s < \Delta T < 7890\ s$) and 360 ($\Delta T < 7100\ s$, $9420\ s < \Delta T$), and are able to refine the probable $\Delta T$ margin during this period. Moreover, M + 21's $\Delta T$ constraint for this period is slightly higher than that of the spline curve, which is consistent with our probable $\Delta T$ constraints for 346 and supports our upward $\Delta T$ modification.

Our probable $\Delta T$ constraint for 418 has a somewhat higher $\Delta T$ margin than the M + 21 $\Delta T$ spline curve (Figure 9 and Table 1). Instead, it is comparable to M + 21's $\Delta T$ constraint in 454 ($6030\ s < \Delta T < 7800\ s$), which accommodates M + 21's $\Delta T$ spline curve only at the lower end. These $\Delta T$ constraints show similar margin ranges. This $\Delta T$ variation is possible if $\Delta T$ remains similar and/or slightly decreases between 360 and 454. On this basis, we revised the $\Delta T$ margin upward in 418 compared to that of M + 21.

In contrast, our probable $\Delta T$ constraint in 484 requires a lower $\Delta T$ margin than the M + 21 $\Delta T$ spline curve (Table 1). This record is mostly consistent with the multiple $\Delta T$ constraints over 454–554 in previous studies, as shown in Figure 9. Generally, these $\Delta T$ constraints are located below the M + 21 $\Delta T$ spline curve, as shown in the Chinese occultation records of 516 (2893 s $< \Delta T <$ 5246 s) and 522 (3568 s $< \Delta T <$ 5090 s) in Sôma & Tanikawa (2016) and the Merovingian occultation record of 554 (3000 s $< \Delta T <$ 5500 s) in Martínez Usó & Marco Castillo (2019). Our $\Delta T$ constraint is also consistent with that of a Chinese report on a partial solar eclipse in 494, which identified a $\Delta T$ margin of $\Delta T <$ 5980 s and 6600 s $< \Delta T$. Nevertheless, caveats must be noted for this record, as Stephenson (1997, pp. 243–244) explicitly confirmed that no possible $\Delta T$ managed to realize this eclipse magnitude (≈0.33), and that the eclipse magnitude reached ⩾ 0.56. Overall, these records indicate lower $\Delta T$ margins than those of M + 21 and a steeper $\Delta T$ decrease over 418–554, in combination with our $\Delta T$ constraint at 418.

Our probable $\Delta T$ constraints for 601 show two possibilities depending on observation sites: Antioch (2319 s $< \Delta T <$ 3005 s) and Nikiû (3612 s $< \Delta T <$ 4386 s). Historical studies support the former hypothesis, in which case, the $\Delta T$ constraint is significantly lower than that of the M + 21 $\Delta T$ spline curve and requires us to revise the $\Delta T$ margin at least ⩾ 1635 s, as shown in Figure 9 and Table 1. In fact, $\Delta T$ values around this region remain controversial. Figure 9 shows a significant discrepancy between M + 21's $\Delta T$ spline curve ($\Delta T \approx$ 4600 s) and M + 21's $\Delta T$ constraint in 616 (2270 s $< \Delta T <$ 2990 s). Furthermore, Sôma et al. (2003) and Tanikawa et al. (2022) obtained a significantly lower $\Delta T$ margin of 2267s $< \Delta T <$ 2959s (in contrast with the M+21 spline curve [$\Delta T \approx$ 4400 s]), based on a Japanese report on a total solar eclipse at Asuka in 628. Our probable $\Delta T$ constraint in 601 offers an independent, and hence robust, contribution to the $\Delta T$ constraint. We found that we needed to revise the $\Delta T$ range of the early 7th century significantly downward compared to that of M + 21. This indicates a steep decrease in $\Delta T$ from 418 to 601 and relative $\Delta T$ stability over 601–628. The probable 601 $\Delta T$ margin can be alternatively—less likely—constrained as 3612 s $< \Delta T <$ 4386 s by assuming Nikiû as the observation site. This is closer to M + 21's $\Delta T$ spline curve, but contradicts M + 21's $\Delta T$ constraint in 616.

Our probable $\Delta T$ constraint in 693 requires a slightly lower $\Delta T$ margin compared to M + 21's $\Delta T$ spline curve (Table 1). This margin is consistent with the existing $\Delta T$ constraints for 702 ($\Delta T <$ 1440 s and 2720 s $< \Delta T$) and 755 ($\Delta T <$ 6000 s), but slightly higher than the existing $\Delta T$ constraint for 761 (1700 s $< \Delta T <$ 3260 s). This $\Delta T$ variation is fairly well explained if the $\Delta T$ margins remain stable over 601–702 (≈2900 s), followed by a slight decrease over 702–761.

In summary, our results refine probable $\Delta T$ margins for the 4th–7th century, but also significantly modify the $\Delta T$ variation compared to those of M + 21, which helps to resolve several controversial $\Delta T$ margins in this interval. Our analyses have revised the $\Delta T$ margin for the 5th century upward, but those for the 6th–7th centuries have gone downward. These new data improve our understanding of Earth's variable rotation on a centennial timescale and ultimately contribute to further geophysical discussions, such as the long-term variability of sea level, global ice volumes, and core-mantle coupling (Lambeck et al. 2014; Mitrovica et al. 2015).

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*Data Availability:* We consulted Morrison et al. (2021) for the $\Delta T$ spline curve and Folkner et al. (2014) for the Jet Propulsion Lab (JPL) ephemerides DE431. We have accessed the Bibliothèque nationale de France and the British Library to consult MS Coislin 249 and MS Or 818.

## Appendix A
## Source of John of Nikiû's Eclipse Account

Chapter 101 of the Chronicle of John of Nikiû in which the eclipse on 601 March 10 is reported, narrates an earthquake that occurred in Antioch (dated to 588: Guidoboni et al. 1994, pp. 348–349) followed by the eclipse, indicating that both occurred during the reign of Byzantine Emperor Maurice (reigned 582–602), as the wrath of God for the heresy of the Emperor.

The chapter structure indicates that the eclipse was also observed in Antioch, similar to the preceding earthquake, and that both records are from Antiochene reports. The record of the 588 earthquake certainly originated from Antioch, as attested by other contemporary Antiochene reports (Guidoboni et al. 1994, pp. 348–349; Debié 2000, p. 411). However, since no earlier records than that of John of Nikiû attest to the eclipse of 601, we must consider the possibility that John may have gotten this eclipse record from another (possibly non-Antiochene) source. Significantly, later in the same chapter, John describes that people who saw the eclipse suspected that it occurred at an "end of the cycle of 532 yr," and when they calculated, it was at "the end of the 12th cycle" (Zotenberg 1883, p. 182 and 416; Charles 1916, p. 163). The 532 yr cycle was developed in late antique Alexandria to calculate the day of Easter in a given year, and consists of a combination of a 19 yr lunar cycle and a 28 yr solar cycle ($19 \times 28 = 532$). It is estimated that the Coptic Church of the period had the year 5493 BCE as the Creation of the world and that the reign of Maurice was under the 12th 532 yr cycle, which began in 360/361 CE (Grumel 1958, pp. 136–139; Mosshammer 2008, pp. 198–203; Emmel 2019). In this case, if one interprets "the end of the 12th cycle" simply as that of the 12th 532 yr cycle, the result would correspond to 891/892 CE, which is incomprehensible (see Zotenberg 1879, pp. 318–319). Neugebauer (1979, pp. 101–102) considered that a record of an eclipse that occurred on 891 August 8 was inserted into the chapter by a later scribe or translator of the Chronicle. However, Neugebauer's interpretation seems inappropriate because the eclipse of 891 was annular at the most. On the other hand, our analysis of John's Chronicle has revealed that when he uses the word "cycle" without an adjective, he always means a 19 yr lunar cycle (see Zotenberg 1883, pp. 203–208, 219–220, 441–449 and 464; Charles 1916, pp. 183–188 and 200). Applying this principle to "the end of the 12th cycle" in Chapter 101, the year meant here is $19 \times 12 = 228$th yr from the beginning of the (12th) 532 yr cycle, i.e., 587/588 CE. This date does not match any known eclipse, but perfectly matches the date of the Antiochene earthquake that John mentions at the beginning of the chapter. Therefore, it is likely that the architype of the text in the chapter used by John contained only the Antiochene earthquake of 588 with the calculation of its year and that the eclipse record of 601 was inserted at some point during the transmission of earthquake's report.

It is quite probable that the eclipse record had already been inserted when John of Nikiû referred to the Antiochene material. In Chapter 101, the Antiochene earthquake and the eclipse are described as the divine punishment for the heresy of Maurice, and the Chronicle of John of Nikiû is consistently critical of the Emperor (Whitby 1988, pp. 7, 19, 131, 195 and 299). However, John of Nikiû lived a century later than Maurice and had little incentive to compose such a narrative, and so it is more likely that the source text he used had already been edited to stress the Emperor's faults by adding the sign of an eclipse to the disasters caused by the punishment of God. Indeed, the Chronicle of John of Antioch, which was completed in around 610 and has been transmitted only through fragments and excerpts, expresses a hostile attitude toward Maurice. As a contemporary of Maurice, the author was active in Antioch and moved to Constantinople shortly before 610, where he completed his Chronicle (Roberto 2005; Treadgold 2007, pp. 311–329; for other explanations, see Mariev 2008; Booth 2019, pp. 815–816). Fragments of his Chronicle reveal a favorable attitude toward the Emperor at the time of his arrival in Constantinople, Phocas (reigned 602–610), who took the imperial throne by killing Maurice and his sons. In contrast, John of Antioch apparently expressed a harsh attitude toward the preceding emperor Maurice, perhaps aiming to gain Phocas' favor (Whitby 1988, pp. 122–124; Roberto 2005, pp. 546–551; Treadgold 2007, p. 312; for other similarities between John of Antioch and John of Nikiû see Roberto 2010, p. 57; Booth 2011). When he edited the section on Maurice's reign, he could have used Antiochene records and his own experience in Antioch. Moreover, it is clear that John of Nikiû's Chronicle made use of John of Antioch's Chronicle, at least in chapters 29 and 103 (Zotenberg 1877, p. 480; 1879, pp. 318–319; Carile 1986, pp. 362–363 and 383; Roberto 2005, 52–53 and 548–549). These arguments allow us to infer that the eclipse record in the Chronicle of John of Nikiû most likely came from a lost part of the Chronicle of John of Antioch, who witnessed the eclipse of 601 in Antioch.

## Appendix B
## Philological Discussions on Syriac Chronicles Addressing the 601 Total Solar Eclipse

The Chronicle of Zūqnīn (second half of the 8th century) narrates that "The year 912 [AG = 600/601 CE]: Great darkness occurred at midday. The stars came out and were visible as if it were night; they remained for about three hours" (Chabot 1933, p. 148; Palmer 1993, pp. 54–55; Harrak 1999, p. 140). Some decades later, the Chronicle of 819 and Chronicle of 846 (both 9th century) reported the same eclipse in an abstracted form (Brooks 1904, p. 230; Chabot 1920, p. 10; Palmer 1993, pp. 76 and 81). Both reports seem to be dependent on the Chronicle of Zūqnīn, or all three works have a common source for the eclipse record (see Palmer 1990, pp. 8–13; Palmer 1993, pp. 75 and 83–84). The ultimate source of the reports has not yet been identified, and it is impossible to say where the eclipse was observed with certainty (perhaps Antioch or Edessa, where most late antique Syriac writings were produced; for the current literature on this problem, see Palmer 1993, pp. 69–70; Harrak 1999, pp. 28–32; Debié 2000; Palmer 2009; Hayakawa et al. 2017). On the other hand, an 11th century Syriac chronicle of Elias of Nisibis (975–1046) reports similar information on this eclipse but correctly adds the weekday as "Friday" and moreover informs us of his source, "the Ecclesiastical History of Allaha-Zekha" (Brooks 1910, p. 124; Delaporte 1910, pp. 77–78). However, again, we cannot identify when and where Allaha-Zekha wrote his History, as his name and work are otherwise unknown to us (see Vandenhoff 1920; Witakowski 2007; Borrut 2009). They could possibly go back to the same source as that of John of Nikiû; however, further textual evidence is needed for such analyses.

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