Icarus 364 (2021) 114278

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Orbit determination just from historical observations? Test case: The comet of AD 760 is identified as 1P/Halley

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ARTICLE INFO

Keywords:
Comets
Comet Halley
Orbit determination
Data reduction techniques

ABSTRACT

Recent advances in techniques of critical close reading of historical texts can now be applied to records of pre-telescopic celestial observations – allowing significant progress for analyzing and solving orbits of past comets: here, as a blueprint test case, we exemplify our method by solving the orbit of the comet in AD 760 *only* with historical observations and *then* identify it with 1P/Halley. A detailed eyewitness record with drawing of a comet in AD 760 in the Syriac *Chronicle of Zuqnīn* (finished AD 775/6) was not yet included in the study of its orbit – the Chinese reports alone do not yield a sufficient number of dated positions. We analyze the Syriac and Chinese sources with critical methods for quantitative astronomical usage, we also consider a few further records from the Mediterranean and West Asian area. With our conservatively derived dated positions we can determine the best fitting Keplerian orbital solution by least squares fitting yielding the orbital elements ($\chi^2_{\rm red} < 2$ based on 1 million runs); the parameter ranges for non-periodic solutions and highly eccentric periodic solutions are consistent with each other. The allowed parameter ranges for perihelion distance and inclination are sufficiently small to identify the comet with 1P/Halley. Although 1P/Halley is the only comet, where the telescopic orbit is credibly linked to pre-telescopic returns, e.g. to AD 760, our identification confirms claims from extrapolating telescopic observations backward in time – here independently based on historical data. In particular, we obtained a precise perihelion time (760 May 19.1 ± 1.7). The inferior conjunction between comet and Sun as on the previously published orbit (760 May 31.9, Yeomans and Kiang, 1981) is shifted by about one day compared to our new orbit (June 1.8), only the new one is consistent with the last observation (June 1.0) before conjunction as reported in the *Chronicle of Zuqnīn*. Such a precision would be most critical for studying non-gravitational forces on comets. By studying the comet's brightness evolution, we also compute its absolute brightness and activity parameter for AD 760 and found indications that the comet was quite dusty that year. As the last return before a close encounter with Earth in AD 837, the AD 760 perihelion is particularly important for extrapolation further back in time (at AD 837 and AD 800, Yeomans and Kiang, 1981 had to introduce corrections in their standard orbit). Our improved methods developed in a multidisciplinary cooperation offer possibilities also to solve more orbits and to identify more comets from the rich and widespread pre-telescopic transmissions.

1. Introduction

Historical (pre-telescopic) observations were utilized for studying cometary orbits until a few decades ago (e.g. Kiang, 1972, Yeomans and Kiang, 1981, and Stephenson and Yau, 1985 for 1P/Halley, also Marsden et al., 1993 for 109P/Swift-Tuttle). The last years and decades, however, have seen strong advances in both editions of historical sources from various civilizations, and in methods of historical-critical close reading; this enables very literal translation by taking into account that reports, in particular those written by professional court astronomers, are composed by special technical terms. In-depth source- and text-critique led to a much improved understanding of historical observations, which we can use for modern astrophysical applications (see the proceedings of Focus Meeting 5 on this topic during the International Astronomical Union General Assembly 2018, e.g. R. Neuhäuser et al., 2020). Therefore, it is now timely to revisit not only previously

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https://doi.org/10.1016/j.icarus.2020.114278
Received 9 June 2020; Received in revised form 17 December 2020; Accepted 17 December 2020
Available online 8 January 2021

studied texts, but also those which became newly or better available, in order to solve comet orbits from historical observations alone. Here, we apply our methods to the comet of AD 760, to determine its orbit with a sufficient number of dated positions – without assuming which comet it was and without linking it to other perihelia by a period. Previously, only by extrapolating telescopic data backward, it was found that the comet of AD 760 should be 1P/Halley (see Section 1.1 for details). Halley's comet is particularly useful to demonstrate our technique – as independent evaluation of the backward extrapolated orbit. Our methods offer possibilities also to identify other historical comets not yet linked (or with as yet uncertain links) with telescopically observed returns, and also, if not enough historical positions are available, to identify them by linking to backward extrapolated well-known comets.

First, let us briefly exemplify some problems that were encountered in previous attempts, e.g., 109P/Swift-Tuttle: based on the 1862 observations alone, the comet was expected to return around 1981. The possibility of identity with the comet of 1737 was briefly mentioned by Lynn (1902) and fully investigated by Marsden (1973), who wrote that if Swift-Tuttle was not recovered by late 1983, searches should resume for it in 1992 on the assumption that the 1737 comet was Swift-Tuttle (predicted T = 1992 Nov 25.3 ± 2 months). The comet was rediscovered at a ΔT of +17 days. Marsden et al. (1993) considered further historical returns (see also Yau et al., 1994). With the best fit period of ~125 yr (Marsden et al., 1993), the identification with reported sightings in AD 188 and 69 BC remains uncertain for a number of reasons:

(i) for 188 July 28, the Chinese source reports a "guest star as large as a vessel with capacity of 3 pints" (Ho, 1962), the whole report is not typical for comets, no duration is given, it could just be a fireball (Kronk, 1999, p. 44, quoting R. Stothers);

(ii) for BC 69 Aug 20 and 27, the Chinese source gives only two very rough positions for a "guest star", not far from each other, within few days, not sufficient for an independent orbital solution with a period of some 125 yr (Marsden et al., 1993);

(iii) numerically integrating the 1992 orbit back in time shows that the comet had a closer approach to Earth in AD 698, at least for certain values of the non-gravitational parameter A_2, so that orbital parameters may have changed significantly, e.g. by AD 442 about ±1 yr perihelion time – in AD 188 the approach is much closer, "but the -68 (BC 69 return) can be made to fit", (Marsden et al., 1993);

(iv) only the "acceptance of an observed perihelion time during July-Sep 188 essentially restricts" the effect of non-gravitational forces (Marsden et al., 1993);

(v) for 69 BC, the overall orbit yields a minimum separation of 0.62 au, which may be too large for naked-eye detection (Marsden et al., 1993).

Hence, only by *assuming* that the objects of 69 BC and AD 188 were the same comet as the one seen in 1737, 1862, and 1992, one can arrive at an overall orbital solution; this solution surprisingly would not need any non-gravitational forces (Marsden et al., 1993), maybe in contradiction to the strong activity of Swift-Tuttle.

In Hasegawa (2002) orbits for ten comets are determined – except AD 1554, none were derived only from the historical positions, but by other assumptions from the roughly reported comet path. Of those ten, there are three from the first millennium, e.g. AD 839: Hasegawa (2002) does not reflect on the dating problems in the Chinese transmission (see Ho, 1962; Pankenier et al., 2008). While the presumable comet path is shown in his figure 2, he does not distinguish between the various textual specifications of the two comet locations given – and he also does not determine or consider the measurement uncertanties (point coordinates without error bars). He also does not consult other, e.g. European, observations existing for this comet.

When Hasegawa and Nakano (2003) consider to identify comet 153P/Ikeya-Zhang with historical comets, they assume the orbital elements from linking the 2002 and 1661 perihelia and then extrapolate backward to AD 877. The sources from Japan and Europe are brief and contradict each other; the late European source (no comet in contemporaneous texts) is used to fix the duration, but they assume that the "name of the constellation [Libra] would be mistaken". The position of the "guest star" derived from the Japanese source is questionable: it was not considered whether the given "(Dong-)Bi" means the asterism or the lunar mansion. The Japanese text is not included any more in the new compilations of guest stars in Xu et al. (2000) or of comets in Pankenier et al. (2008); e.g., Schove (1984) considered this object as potential nova.

Let us now introduce our approach: a strong radiocarbon variation around AD 775 motivated us to survey celestial observations for some hundred years around this time, in order to find possible sources of its origin. To distinguish between various transient phenomena and to recognize and avoid misidentifications, we developed methods and clear criteria (see, e.g., Neuhäuser and Neuhäuser, 2015a and D.L. Neuhäuser et al., 2018a, 2018b on sunspots and aurorae borealis; more general in R. Neuhäuser et al., 2020, see also www.astro.uni-jena.de/index.php/terra-astronomy.html). We studied in detail not only solar activity proxies (Neuhäuser and Hambaryan, 2014; Neuhäuser and Neuhäuser, 2015; Neuhäuser and Neuhäuser, 2015b), but also comets in the AD 760s and AD 770s, e.g. it was suggested that the ^{14}C and ^{10}Be enhancement observed for around AD 775 could have been delivered by a comet impact on Earth in early AD 773, but we have shown that this claim was based on an incorrect translation of the historical Chinese text (see Chapman et al., 2014, 2015).

As important eyewitness source, we noticed the Syriac *Chronicle of Zuqnīn* (already mentioned by Dall'Olmo, 1978 and Schove, 1984), which features northern lights, comets, and other celestial phenomena in the decades until AD 776 (Harrak, 1999, D.L. Neuhäuser et al., 2018b, 2018c); we discussed its aurorae (text and drawings) and fixed their dating to AD 772 and 773 in Neuhäuser and Neuhäuser (2015a); Hayakawa et al. (2017) considered only observations with drawings, however with questionable identifications and interpretations (see footnotes 10 and 17).

The West Asian *Chronicle of Zuqnīn* (finished AD 775/6) includes an eyewitness report with drawing of a comet for AD 760, now known to be the perihelion passage of comet 1P/Halley; this is complementary to and at least as valuable as the transmitted records from China. By literal technical rendering (new translation) of the historical transmissions from Syriac (West-Aramaic) and Classical Chinese as well as text-critical analysis and close reading, we might obtain more precise and additional observing dates and positions. Such a new set of dated positions with conservative error bars may enable for the first time to solve all orbital elements for AD 760 just from the historical observations. Since the East-Asian observations alone were not sufficient to solve for all elements, previous works had to assume or extrapolate some orbital elements from other perihelia probably belonging to the same comet (e.g. Laugier, 1846); more recent work extrapolated the telescopically observed orbits to the past and then tried to fix the perihelion time with historical observations (e.g. Kiang, 1972, Yeomans and Kiang, 1981, henceforth YK81), Section 1.1. All previous work stressed the importance of historical observations, in particular perihelion times, to determine orbital elements and to study non-gravitational forces (e.g. Sitarski, 1988).

Historical observations of comets are useful to reconstruct their orbital elements, which in turn are needed to study their secular variations, connections between comets and meteor showers, to identify additional sightings in the past, and to predict future appearances. According to the previous orbital reconstruction, the comet had its closest approach to Earth (0.0334 au) on AD 837 Apr 11, the closest for the last few millennia (YK81). The motion of 1P/Halley is highly sensitive to the circumstances of that encounter. Hence, the study of the orbit of AD 760, the next earlier perihelion before AD 837, is also important in this regard.

A comparison of the Syriac with the Chinese observations can also help improving the understanding of the transmitted records, and it is also relevant for various aspects of the history of astronomy, e.g. how the observations were performed, which precision was achieved, whether and which precession constant was applied. Here, we re-determine the AD 760 perihelion orbit only from historical observations. In a future publication, we will then also re-consider the observations in AD 837 (in prep.). With very precise reconstructions of several perihelia, one can

study the influence of non-gravitational effects and cometary activity on the orbit just with historical observations.

First, we introduce comet 1P/Halley and its previous orbital reconstructions (Section 1.1) as well as the historical sources used, mainly the Syriac *Chronicle of Zuqnīn* (1.2) and Chinese compilations about celestial phenomena (1.3). Then, in the context of our improved methods, we present our new technical translations from *Zuqnīn* and China, discuss the sources and the text in detail (Sections 2.1–2.5 and 3.1), and obtain dated positions from the critically evaluated material (Sections 2.6 and 3.2). A few other observations from the East Mediterranean and West Asia are examined more briefly (Section 4). We solve for the orbit just with historical observations of AD 760 with least squares fitting, present the intermediate results – we can confirm that it is comet 1P/Halley (Section 5); we also discuss our results in comparison with previous work. We finish with a consideration about the precession constant as was used implicitly in AD 760 in the *Chronicle of Zuqnīn* (Section 6) as well as a summary and future perspective (Section 7). Some of the results of this work were first presented at the IAU General Assembly 2018 (Focus Meeting 5) by D.L. Neuhäuser et al. (2018c) and Mugrauer et al. (2018).

1.1. Previous orbit reconstructions of comet 1P/Halley

The first periodic (1P) comet, for which an orbital solution was found, is 1P/Halley. Edmund Halley (1705) noticed that three of the comets for which he had computed orbits – namely those in AD 1531, 1607, and 1682 – had similar orbits and had appeared at roughly 75 years. He assumed them to be the same object, made a rough calculation of the planetary perturbations from 1682 onwards and predicted the comet's return in 1758 (Halley, 1749). Mostly by extrapolating the orbital period (and/or elements) from telescopic observations backward, it was noticed that all perihelia of the last two millennia were recorded in East Asia, some only marginally (e.g. Kiang, 1972, YK81, Stephenson and Yau, 1985, see also Kronk, 1999). Observations of perihelion passages also include Babylonian observations in the last two centuries BC (Stephenson et al., 1985, see also Landgraf, 1986).

The orbital elements change from perihelion to perihelion due to perturbations by solar system bodies (e.g. Cowell and Crommelin, 1908 for AD 837 and AD 760) and non-gravitational acceleration (cometary outgasing), e.g. the period changes between 74 and 79 yr for the last 29 returns (YK81). Reconstructions of those osculating orbital elements were done by studying telescopic observations and extrapolating backward – fixed by the perihelion time from historical observations.

For the comet of AD 760, Pingré (1783) lists just the Chinese observations and also summarizes the short report by Theophanes (see our Section 4a). With the orbital period of 1P/Halley as 75.3 yr, Laugier (1846) calculated backward from AD 1152, expected its return around AD 775, and identified the comet of AD 760 with 1P/Halley, because some orbital elements were consistent with the presumable observational dates and positions recorded in AD 760 – he did not have sufficient historical data from AD 760 to solve for the orbit. (When Cowell and Crommelin, 1908 wrote that "Laugier identified the apparitions of (AD) 451 and 760 from the observations alone", one could misunderstand that Laugier would have used only historical observations from AD 760 to identify the comet of 760 with 1P/Halley.) Then, Hind (1850), also by assuming a certain orbital period, studied several more perihelia in detail and solved for orbital elements; regarding AD 760, he fully agreed with Laugier (1846) including the perihelion date on AD 760 June 11. This date was also accepted by Cowell and Crommelin (1908), who linked observations from 2 to 3 perihelia into one orbital solution; planetary perturbations from AD 837 Feb 25 calculated backward with the variation-of-elements technique resulted in a perihelion of AD 760 June 15 (period 28,013 days), so that the significant changes in orbital elements over centuries are mainly due to perturbations by planets, while the *"combined effect [of non-gravitational causes] does not amount to more than a week per revolution"* (Cowell and Crommelin, 1908, p. 514).

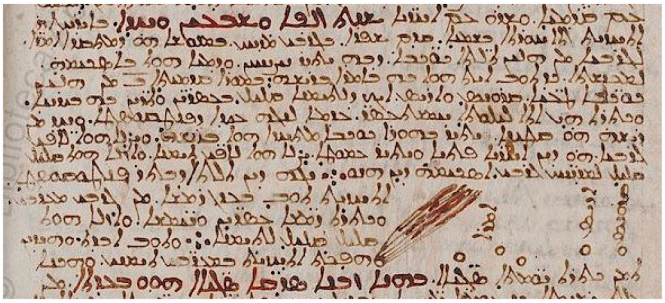

Fig. 1. Syriac text and drawing: The relevant Syriac text from the *Chronicle of Zuqnīn* (finished AD 775/6) on the comet AD 760 (1P/Halley) – from the middle of the first line shown to the middle of the last line – with a drawing embedded in the text (Vatican Library, Vat. Syr. 162, folio 136v): the comet to the left, the three brightest stars of Aries (α, β, and γ Aries) in the center, and the planets Mars and Saturn as *Ares* and *Kronos* to the right, as identified in the Syriac caption. The drawing fits best for around May 25 given the relative position of Ares/Mars east (left) of Kronos/Saturn, both west of Aries. See Fig. 2 for a comparison with a computed position of 1P/Halley for May 25 at 0 h UT.

Kiang (1972) extrapolated backward the orbit again with the variation-of-elements method, rectified his calculated perihelion passage times with revisited Chinese observations, and obtained perihelion passages on 837 Feb 28.27 ± 0.05 (very small error bar due to large motion on sky at close approach to Earth) and 760 May 22.5 (and many others back to 240 BC). Hasegawa (1979) corrected some observing dates in Kiang (1972) by one calendar day, see below; he obtained perihelion times of 760 June 5 ± 4 and 837 Feb 28.15 ± 0.1.

Yeomans (1977) extrapolated backward the orbit by numerical integration, but only back to AD 837, because of a very close approach with a planet, namely Earth (0.04 au) in AD 837. His work was revised and extended back to 1404 BC by YK81, limited again by a close approach to Earth in 1404 BC by 0.03 au; the perihelion times of the two recent millennia were fixed by historical observations with partly revised data from Kiang (1972); for AD 760, they obtained, e.g., a period of 77.00 yr and a perihelion on May 20.67, which is 1.83 days earlier than the May 22.5 date obtained by Kiang (1972); note that YK81 did not revise the Kiang (1972) data on the AD 760 perihelion.

YK81 noticed that the best-fitting orbit found in Yeomans (1977), namely orbit no. 2 in table 3 in YK81, did not work sufficiently well for AD 837, so that they use a different one, orbit no. 3 (table 3 in YK81). This means that one of the non-gravitational parameters (considered to be constant in time) were forced to change instantaneously by YK81 at AD 837, see table 3 in YK81. Furthermore: *"Before the integration of orbit 3 was continued backward, the osculating perihelion passage time was given an empirical correction of* −0.88 *day at epoch 2,026,840.5 (JD)"*, i.e. 837 Mar 14 (YK81, p. 641). YK81 also had to do *"an empirical adjustment of the osculating eccentricity"* at epoch AD 800 (used for technical reasons instead of AD 837), so that orbit no. 3 works for the perihelia before AD 800 (YK81, pp. 641–642).

Sitarski (1988) wrote that YK81 "had to make some subjective changes in orbital elements for AD 837 when the comet closely approached Earth"; he parameterized the non-gravitational forces as a secular change in the semi-major axis (da/dt) and obtained da/dt for 24 orbits from AD 1986 to 87 BC. Twenty five historically observed perihelion times (from YK81) were used to fit a parabolic function $da/dt(t)$; however, without the two data points in the first two centuries AD, the fit would probably be very different (constant or sinusoidal), see his figures 1 & 2; Sitarski (1988) also presents a solution with $da/dt(t)$ being constant (e.g., his table 5). The acceleration parameter da/dt has small error bars back to the 10th century (smaller than $0.52 \cdot 10^{-8}$), but is always larger than $(1.3 - 3.1) \cdot 10^{-8}$ for the 3rd to 9th century AD (Sitarski, 1988). With the parabolic fit to da/dt, Sitarski (1988) obtained as perihelion times, e.g., 837 Feb 28.31 and 760 May 20.53 (our perihelion date is 760 May 19.1 ± 1.7).

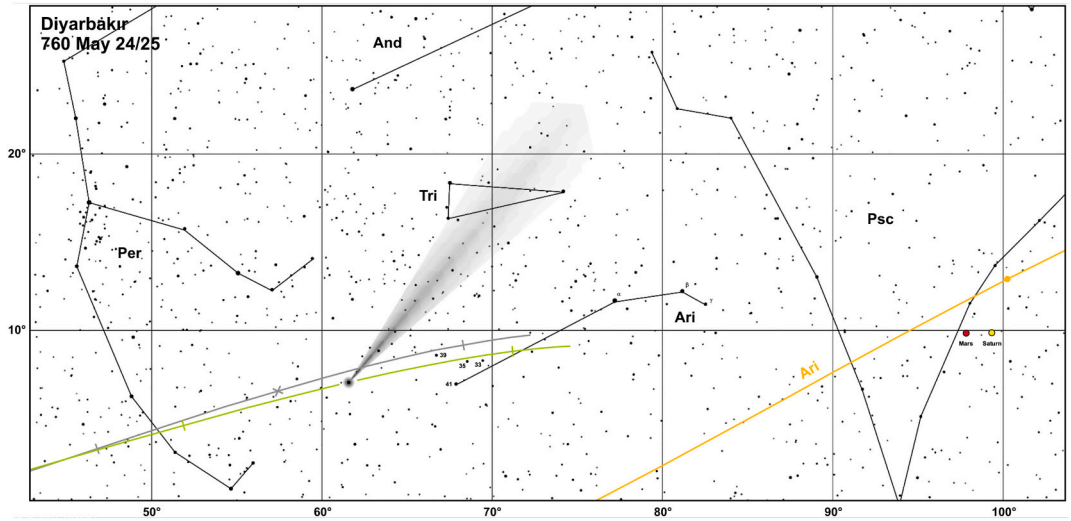

Fig. 2. A comparison withFig. 1shows that the original drawing is for a date around 760 May 25 in the early morning (2:40 h local time, 0 h UT): both Sun (NE) and Moon were under the horizon at that time, 1P/Halley was ~7° above the NE horizon. IAU constellations are indicated in black, the ecliptic in orange with dots at the borders of zodiacal signs. The planets Mars (0.7 mag, red dot) and Saturn (0.5 mag, yellow dot) are still close to each other. The position of the comet is indicated on our own new (green) orbit (and as grey cross on the old orbit, JPL, YK81); both orbits start on May 17. The drawing (Fig. 1) was not used for orbital reconstruction. Here and in all other figures, the comet plasma tail pointing away from the Sun is displayed, while observation and drawing regard the dust tail. This and all other such figures are drawn with Cartes du Ciel (v3.10). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In table 5 in Sitarski (1988), one can see that both the non-gravitational parameters as well as the difference between computed and (presumably) observed perihelion passage time show particular large changes at AD 912, the largest from AD 1986 to 86 BC. For the return in AD 912, it is not even certain whether and which of two short transmissions on a comet from China and Japan pertains to 1P/Halley (Xu et al., 2000), so that extrapolations back in time are also more uncertain due to the problem of identifying the correct report.

YK81 stress that perihelion passage times are best to fix orbital elements in backward extrapolations; for doing so, they use historical observations of one or two more or less accurate dated positions in AD 141, AD 374, and AD 837, when the comet was closest to Earth. In our paper, we can present for the first time a very well observed perihelion time (to within ±1.7 days) for AD 760 observed by the author of the Syriac *Chronicle of Zuqnīn* recorded in his eyewitness report (while the Chinese records give a precise dated position only for their last observation of the comet several weeks after perihelion passage). The passage in AD 760 is of particular importance for further backward extrapolations because of the uncertainties in AD 912, the close approach in AD 837, and also the orbit changes enforced by YK81 for around AD 800 and AD 837.

For more details on the history of orbital solutions of 1P/Halley, see, e.g., YK81 and Yeomans et al. (1986). The most recent orbital elements for many perihelia are published in Marsden and Williams (2008), based on YK81 (and then precessed to J2000.0), which we use below for comparison.

For the next sections, in particular the determination of dated positions and a new orbit, we do not need to assume that the comet of AD 760 is 1P/Halley.

1.2. The 8th century Syriac Chronicle of Zuqnīn as source for a comet in AD 760

For an 8th century manuscript, the Syriac *Chronicle of Zuqnīn* is exceptional: the single manuscript that exists is very likely the autograph, i.e. the original manuscript hand-written by the author (Harrak, 1999); it includes a detailed report with drawing of a comet in AD 760 with stars and planets nearby (Fig. 1).

The *Chronicle of Zuqnīn* offers a world history starting with 'creation' as in the Bible and ending at around the time of writing, AD 775/6. It survived in one manuscript of 173 folios located as Codex Zuqninensis at the Vatican Library (Vat. Syr. 162), and the remaining six folios are found in the British Library (Add. 14.665 folio 2–7); in Codex Zuqninensis, 129 folios are palimpsest, one even a double-palimpsest (Harrak, 1999). Some of the folios in the British Library which cover the last years are partly worm-eaten and very fragmentary. Its first and last folios are lost together with the name of the author (Harrak, 1999). The Chronicle is divided into four parts, all translated to English (Harrak, 1999, 2017) and French (Chabot, 1895).

The author of the chronicle was probably the stylite monk Joshua (Harrak, 1999); a stylite is an early Byzantine or Syrian Christian ascetic living and preaching on a pillar in the open air, so that many celestial observations can be expected in his work. The author of the *Chronicle of Zuqnīn* may have lived on a pillar for some time (Harrak, 1999). During the time of writing of the *Chronicle of Zuqnīn*, the area was outside the border of the Byzantine empire and already under ᶜAbbasid rule.

The *Chronicle of Zuqnīn* is not known to be copied and disseminated; sometime during the 9th century it was transferred to the Monastery of the Syrians in the Egyptian desert; see Section 4b for a possible use by Nuᶜaym ibn Ḥammād. Shortly after the manuscript was found and bought for the Vatican, it was considered to be written by the West Syrian patriarch Dionysius I of Tell-Maḥrē, so that this chronicle was long known as Chronicle of Dionysius of Tell-Maḥrē (Assemani, 1719–1728). Dionysius did write an otherwise lost world chronicle, but lived later (died AD 845). Since this mistake was noticed, the chronicle has been called the Chronicle of Pseudo-Dionysius of Tell-Maḥrē (Chabot, 1895; Abramowski, 1940) or, better, the *Chronicle of Zuqnīn* (Harrak, 1999), because the text mentions the monastery of *Zuqnīn* as the living place of the author; *Zuqnīn* was located near Amida, now Diyarbakır in Turkey near the border to Syria.

The *Chronicle of Zuqnīn* is made of four parts: Part I runs from the creation to Emperor Constantine (AD 272–337), Part II from Constantine to Emperor Theodosius II (AD 401–450) plus a copy of the so-called *Chronicle of Pseudo-Joshua the Stylite* (AD 497 to AD 506/7), Part III from Theodosius to Emperor Justinian (AD 481–565), and Part IV to the time of writing, AD 775/6. The Chronicler used a variety of sources, some of them otherwise lost (Harrak, 1999, 2017). The author knew that some of his sources did not provide a perfect chronology; for him, it is more important to convey his message (to learn from history) than to

give perfect datings.

The events reported in the text are dated using the Seleucid calendar; the Seleucid Era (SE) started on October 7, 312 BC (= Dios 1). There are several versions of the Seleucid calendar, including the Babylonian (Jewish), Macedonian, and West Syrian (Christian) ones. The author of our chronicle systematically used the latter version for reports during his lifetime – a solar calendar, in which the year ran from Tishri/October 1 to Elul/September 30, applied since at least the fifth century AD (Hatch, 1946).

The *Chronicle of Zuqnīn* reports about a variety of celestial phenomena, which can be classified as northern lights, meteor showers, meteorites, a bolide, comets, halo displays, a solar eclipse, and other (atmospheric) darkenings. Observations of auroral (with drawings for AD 502, AD 772, and AD 773) as well as meteoric phenomena (showers, meteorites, bolide) were published before by Neuhäuser and Neuhäuser (2015a) and Neuhäuser et al. (2018b).[1] Eyewitness reports from the author of the Chronicle or sources close to him start around folio 128 in AD 743 and end in AD 775/6, probably shortly before the death of the author (Harrak, 1999). The reports are more extended for the last years of the Chronicle. For his lifetime, he has reported from source material (e.g. letters, Easter tables, etc.) and, even for the very detailed comet report discussed here, probably not only from his own memory as eyewitness (years later), but also from written notes.

1.3. Understanding historical observations from China

In imperial China, court astronomers observed the sky all day and night in order to notice changes[2]; owing to this practise – among other transients – comets were recorded in observing logs. While the original night reports for the 8th century are not extant, later compilations or copies thereof are available, which are shortened and may suffer from scribal errors. These include: Jiu Tang shu (JTS) by Liu Xu et al. (945) from AD 945, Tang hui yao (THY) by Wang Pu et al. (961) from AD 961, and Xin Tang shu (XTS) by Ouyang Xiu et al. (1061) et al. from AD 1061, i.e. the astronomical chapters of the *History of the Tang* dynasty (*Tang shu*), as well as the collection Wenxian tongkao (WHTK) by Ma Duanlin from AD 1317. Extracts for comets were published by Pingré (1783) in French as well as by Hsi (1957, only for 1P/Halley AD 837), Ho (1962, see also Hasegawa, 1980 for comments and additions), Kiang (1972), Xu et al. (2000), and Pankenier et al. (2008), all in English.

For general information about astronomy in imperial China, please refer to the detailed monographs by Needham and Wang (1959) and Sun & Kistemaker (1997, henceforth SK97), and short summaries also in Kiang (1972), Clark and Stephenson (1977), Stephenson (1994), Xu et al. (2000), Stephenson and Green (2002), and Pankenier et al. (2008).

Since the *Han* dynasty (206 BC to AD 220), the sky was structured into about 283 asterisms of various sizes with almost 1500 stars in total (down to 6th mag and a few fainter ones, these are of course incomplete); a Chinese asterism[3] can contain one, few or many stars; the stars of an asterism were combined by lines (skeletons). While this system had a strong continuity since the *Han*, some details changed later (not only in Korea and Japan, also in China).

The term *xing*, often rendered as *star(s)*, can be combined to, e.g. *ke xing* as *guest star(s)* or *hui xing* as *broom star(s)*. Classical Chinese word morphology does not distinguish between singular and plural.

The names of 28 asterisms are also used for the 28 lunar mansions (LM), which are right ascension ranges from the determinative (or leading) star of one LM to the next, omitting the south polar region which was not visible from the Chinese mainland, while the north circumpolar region was of special importance known as the enclosure (*yuan*) named *'Ziwei'* or *'Zigong'*, see Stephenson (1994), SK97, and Ho (2003, p. 144). For a list of the 28 LMs and their determinative stars, see, e.g., SK97, Xu et al. (2000), Stephenson and Green (2002), or Pankenier et al. (2008). Given this equatorial system, hour angles of objects can be given as a certain number of *du* (0.9856°) East of the respective determinative star.

There also exist Chinese star charts from the time of the *Tang* dynasty, namely the Dunhuang maps (manuscript Stein 3326 dated AD 649–684 by style of characters, mentioning of an astronomer of that time, style of clothing shown in a figure, and usage of two taboo characters), where more than 1300 stars in 257 asterisms are drawn with skeleton lines, apparently in azimuthal projection (Bonnet-Bidaud et al., 2009).[4]

Separations on sky including comet tail lengths are given in certain old Chinese linear measures, which can be converted to angles such as 1 *chi* being about 1° (Stephenson and Green, 2002; Kiang, 1972 gave 1 chi = 1.50 ± 0.24°), 1 *cun* being 0.1 *chi*, and 1 *zhang* = 10 *chi* (see Ho, 1966; Kiang, 1972; Wilkinson, 2000; Stephenson and Green, 2002).

Sometimes, in addition to or instead of a celestial position given as one coordinate, angle, or separation, the compilations of observing records list the general direction as azimuth, which can be specified in terms of several different compasses; the precision of the compass used (e.g. 4- or 24-point) then defines the uncertainty or azimuth range of such a position.

The observing dates are specified by name of the emperor, year with a multi-year reign period, lunar month, and then usually the day count

[1] Hayakawa et al. (2017) cited some of the celestial observations in this chronicle, including the comet observation in AD 760, but in an unsatisfactory manner: they misinterpreted the Chronicle's text and drawing, they left out the Chinese observations, and they did not attempt to fit a new orbit (for details, see footnotes 10 and 17).

[2] Such observations were performed, because it was thought that they identify dangerous political trajectories (astrology, but also weather rules etc., e.g. from the *Han* dynasty: "320 stars can be named. There are in all 2500 … All have their influence on fate", Needham and Wang, 1959, p. 265), or can indicate misgovernment ("any anomalous happenings in nature … were construed as signs of warnings by heaven toward the misbehaviour or misgovernment of the ruler of man", also from the *Han*, Wang Yüchuan, 1949, Bielenstein, 1984). The dramatic appearance of comet Halley in 12 BC, for example, was interpreted by both Gu Yong and Liu Xiang as a sign that the Western *Han* dynasty was in danger of collapse; the two writers each identified different court factions as responsible for the peril the dynasty faced, and both held that if the right actions were undertaken the sign would vanish and the dynasty would likely survive; neither writer saw the future as fixed or determined, though both associated it with an elevated likelihood of disastrous political events (Chapman, 2015).

[3] Groups of stars (*xing cang*) were given certain names, which do not normally reflect their appearance on sky, even if connected with skeleton lines; this is similar for Babylonian, Western, and Chinese constellations. To discriminate from Western constellations, Chinese star groups are often called *asterism*. However, this term derives from the Greek *asterismos* as was used by Ptolemy in his Almagest for what we now call *constellations* (now defined as fields on sky by IAU mostly based on Ptolemy's Almagest). *Xing qun* is the modern Chinese term for constellation; literally, it means *group of stars*.

[4] Stars and asterisms on the 13 charts are drawn only in a crude way with rough positions and several mistakes, e.g. the asterism name *Lou* in Aries is missing (but the three stars apparently are drawn), the colour-convention for stars is not followed strictly (Chinese charts show the stars and asterisms from three *Han* dynasty schools in different colour: red for those from Shi Shen, black from Gan De, and white/yellow from Wu Xian), twice the Chinese characters for "right" *zuo* and "left" *you*, which are very similar, are mixed up, the asterism *Sangong* near the pole is shown twice (Bonnet-Bidaud et al., 2009). Given that the maps are drawn on expensive pure mulberry fibres (3940 mm by 244 mm scroll), this atlas may be a copy produced by a wealthy but not well-talented student of Li Chunfeng, one of the main astronomers of the 7th century, who is mentioned in the accompanying text and could have done the (now lost) original map based on observations and/or the astronomical chapters of the *Jin shu*, which he had written.

in a 60-day-cycle (*ganzhi*) – a continuous counting was achieved prior to the advent of the imperial period in 221 BC; sometimes, instead of or in addition to the day count (1–60), the age of the Moon is given; the luni-solar calendar had 12 lunar months starting on the second new-moon after winter solstice (i.e. in January or February), plus seven intercalary months in 19 years (called just "x-th intercalary month" located after the "x-th" month), like the Meton cycle; these rules were in use since a calendar reform during the *Han*.

The normal Chinese 24 h-day ran from midnight to midnight, but in astronomical records, for observations after midnight, the former date is given (some late sources may have modified the date to the new civil date). The night was separated into five *watches* of equal lengths per night, which changed during the year.

2. The comet of AD 760 as reported in the Syriac Chronicle of Zuqnīn

2.1. Syriac text and text-critique

In the *Chronicle of Zuqnīn* for SE 1071, i.e. AD 759 Oct 1 to 760 Sep 30 (part IV, folio 136v with drawing and caption, see Fig. 1 with the Syriac hand-writing), we find the following report (brackets from us), here our own literal translation (line breaks by us); the author of the Chronicle used different kinds of punctuation, all marked in the appendix with the transliterated Syriac text – below, his rhombs and colons are given as in the Syriac text, while for his bold points we mostly give full stops and for his weak points we mostly give comma, following English language rules (in the Syriac autograph, it is sometimes difficult to distinguish between a bold and a weak point):

"The year [SE] one thousand seventy one (AD 759/760).
In the month of *iyyōr* (May)[5] a white sign was seen in the sky,
before early twilight (Syriac: *šafrō*), in the north-east [quarter],
in the Zodiac [sign] which is called Aries (*emrō*), to the north from these three stars (*kawkbē*) in it, which are very shining.
And it resembled in its shape a broom, while it was still in the same Aries (*emrō*) at its edge/end/furthest part (*rīšeh*)[6]:
in/at the initial degree (*mūrō*)[7] [of] the second[8] [sign] (i.e. Taurus) from these wandering stars (*kawkbē*), Kronos (Saturn) and Ares (Mars), like somehow a bit to the south, on [day] 22 in the same month.
And the sign itself remained for fifteen nights, until dawn (*nōgah*)[9] of the feast of Pentecost.
And [at] its one end/tip (*rīšōh*), the narrow one, a very bright star (*kawkbō*) was seen at its head/end/tip (*rīšeh*).[10] And it was tilting to the north side, but the other wide and very dark one was tilting to the south side,
and it was going bit by bit to the North-East [direction].
Its shape is as follows [now 4 points forming a rhomb meant as pointing to the drawing, which is embedded in the next lines, Fig. 1].
However, at the beginning (*nōgah*)[11] of [the] third [day] after Pentecost, it was seen again at evening time, from the north-west [quarter].
and it remained for twenty-five evenings.
And it was going bit by bit to the south:: [actually 4 points forming a rhomb meant here as a break].
And it again disappeared.
And then it returned [and] was seen in the south-west[12] [quarter],
and thus there it remained for many days."

Here, our own very literal technical translation ends, we continue with the translation from Harrak (1999, p. 198):

"During this time, many schisms took place in the church because of leadership. The eastern monasteries made John Patriarch, while neither the cities of the *Jazra* nor all the monasteries approved him. The people of the West and Mosul approved George. Because of this the entire Church became troubled."

Several paragraphs later, in year SE 1075, AD 763/4, there is more text on this comet (Harrak, 1999, pp. 200–1):

"A severe plague among horses took place in the whole land. … This disease spread throughout all the nations and kingdoms of the earth, to the point that people were left without horses. The effect of 'the broom' seen a short while before, was clearly seen in reality, as it swept the world like a broom that cleans the house."

2.2. Drawing

A drawing (folio 136v, our Fig. 1) embedded in the text shows the "broom", which was first called "white sign": to the left, we can see it with a small circle ("very bright star") and cone-like lines directed away from it to the upper right, more "narrow" closest to the star-circle; neither the space between these lines nor the star-circle are filled: the

[5] Chabot (1895), Harrak (1999), and Hayakawa et al. (2017) read "ādār/ōdōr" and gave "March" here ("ōdōr" is the correct West-Syrian transliteration here, while "ādār" is East-Syrian); in Syriac, the words for March (*ōdōr*) and May (*iyyōr*) are written very similar: *ʿDR* and *ʿYR*, respectively. We came to the conclusion that *iyyōr* is given here in the MS: (a) epigraphically, the Syriac letter /d/ (as in *ōdōr*) should have a tail, which is not found in the MS, (b) there is no space between /y/ and the following /r/, the two letters are ligatured, but if it were /d/ (as in *ōdōr*) there should be a space (as seen in all occurrences of this letter in the month name *ʿDR* = *ōdōr*), and (c) because of a dot underneath the /y/, the letter was thought to be /d/, i.e. reading *ʿDR* = *ōdōr*, however, in five occurrences of the month name *ʿYR* in the MS, four do not have this diacritical dot, one (folio 150v) has it as a thick one, which should be thin – the chronicler was by no means consistent in using diacritics and symbols. Michael the Syrian also gives *iyyōr* as month of the first sighting (Section 4d).

[6] The Syriac word *rīšeh* mainly means "its head", but "its tip, its edge, its end, its furthest part" etc. and such meanings are also attested in dictionaries (e.g. Sokoloff, 2002). See below for a discussion of position 2.

[7] The Syriac *mūrō* from Greek *moira* for *degree* is also attested in Ptolemy's Almagest for *degree*.

[8] Harrak (1999) gave "in the first degree (of the Zodiacal circle), the second"; Hayakawa et al.: "in the first degree (of the sign), two (degrees)"; see below for a discussion of position 2.

[9] Chabot: "la veille"; respectively "eve" in Harrak (1999); the comet was seen in the morning, as mentioned before; for *nōgah*, see footnote 11.

[10] An alternative translation could be "and its one end/tip, the narrow one, was very bright; a star was seen at its head/end/tip", but it does not work because in the MS there is a punctuation between *qaṭīnō* ("narrow") and *yatīr bahūrō* ("very bright"). Hayakawa et al. (2017) brings a punctuation in their transliteration that is in many places inconsistent with the autograph, in particular they overlooked the punctuation by translating "And one end of it was narrow and duskier, one star was seen in its tip", and they confused the meaning by rendering "duskier" instead of "very bright": the original word *bahūrō* means "dim" in old Syriac, but later also "bright" after Arabic influence; Chabot (1933) emended *bahūrō* into *nōhūrō*, which just means "bright", but this emendation is not necessary; the first letters (/b/ and /n/) are also quite different in Syriac. The translation by Hayakawa et al. (2017) is not satisfactory: "duskier" would be in contrast to the "star" at this end (comet head), and it would not be in contrast to what is later given as "wide and very dark" (the other end); the drawing also clearly shows a "very bright star", the comet head; see below for our discussion of the drawing.

[11] For the Syriac *nōgah*, instead of "beginning", Hayakawa et al. (2017) gave "dusk", which is not attested in Syriac dictionaries; the word *nōgah* does mainly mean "dawn" (see above), but this is not possible here, because the observation was in the "evening time". Harrak (1999) gave "eve". Our translation "at the beginning" follows oriental calendars, where the 24 h-day begins with sunset, e.g. *nōgah d-shaptō* meaning "Sabbath vespers", which happen in the evening after sunset. In the report on a bolide in AD 754, the *Chronicle of Zuqnīn* gave the timing as "on Tuesday, when Wednesday was dawning (*nōgah*) … In the same evening …", i.e. it uses *nōgah* here for the beginning of the oriental 24 h-day (D.L. Neuhäuser et al., 2018b, event 5, p. 77, Harrak, 1999, p. 196).

[12] Lit. west southern

impression is that the sign is here brighter than at its wider end ("wide"), where the space between the lines are mostly filled with ink ("very dark"). The objects drawn are the observed comet with tail (left part), the three brightest stars of Aries (α, β, γ Aries, shown in position relative to each other as on sky) in the centre, shown as three empty circles (labelled *emrō* for Aries), and the planets Mars and Saturn to the right (labelled *Ares* and *Kronos*, respectively), also drawn as empty circles (apparently to indicate them as sources of light) – all roughly aligned, probably meant to be at about the same altitude above horizon. In the text, the Syriac word *kawkbō* is used for each of the six empty circles, i.e. for the three different kinds of objects (comet head, three fixed stars, and two planets), so that *kawkbō* stands here in general for "celestial object" appearing round (similar to the Arabic *kawkab*), all these different objects were considered as some kind of *star*. This drawing is also shown on the front cover of the English translation (Harrak, 1999), and it is the only figure that was also mentioned and redrawn in the French translation (Chabot, 1895), see also footnote 17.

The record in our Chronicle is probably the author's eyewitness report, because the drawing is embedded in the text, labelled by the same hand, philological arguments (same terms), and because other sources are not mentioned (otherwise, it often gives the source). Since the drawing compares well with the real situation on sky in particular regarding Saturn and Mars relative to each other and relative to the stars of Aries (see Fig. 2), we can date the drawing to about 760 May 25 (early morning). Saturn and Mars had a close conjunction in the night of 760 May 22/23 with a separation of only ~40′. Our new orbit (Fig. 2) shows the position of the comet for May 25, where the angular separation between the comet and α, β, γ Ari is quite similar to the angular separation between α, β, γ Ari and the planets Mars and Saturn – similar as drawn in the Chronicle. While the text has for the first detection "a white sign" (May 18), it is stated for May 22 "it resembled in its shape a broom". Regarding the depiction it is said: "Its shape is as follows". Indeed, we clearly see "a broom" "tilting to the south side" (while "going … to the north-east"). Thus, the scenario is fitting well, but we did not use this drawing for the orbit reconstruction. The text information is more precise.

2.3. Dating

The text reports the "white sign" to be seen "for fifteen nights, until dawn of the feast of Pentecost", i.e. on Pentecost Sunday. For the year given (SE 1071, i.e. AD 760/761), most Christian churches (including churches under the Byzantine Patriarchate) celebrated Pentecost on 760 May 25, but some eastern churches celebrated Pentecost one week later on June 1. Hence, 15 nights earlier is definitely May, so that in any case, it is obvious that the *Chronicle of Zuqnīn* meant May here (Syriac *iyyōr*), see footnote 5.

The reason for the two different Pentecost (and Easter) dates in AD 760 is the difference between two ecclesiastical Easter calendars: in AD 760, the first computed (cyclic) full moon after the start of spring (defined for March 21 at the AD 325 Council of Nicaea) was on Saturday Apr 5 according to the 532-year cycle[13] constructed by Irion in AD 562 for the Byzantine Patriarchate (based on a previous 200-year cycle by Andreas of Byzantium for AD 353–552), so that the Byzantines celebrated Easter on Apr 6 (like also the Roman church following the 532-year Easter calendar by Dionysius Exiguus starting in AD 532), while the Armenian, Jacobite, and Nestorian churches followed a different 532-year Easter table, namely the Armenian scholar Anania Sirakaci's (AD 610–685) reform (early AD 660ies) of Andreas' Easter table, according to which the paschal full moon in AD 760 would be on Sunday Apr 6, so that Easter has to be dated Apr 13 (see Sanjian, 1966, Mosshammer, 2008, pp. 257–277). This dispute is also reflected in the *Chronicle of Zuqnīn* (Harrak, 1999):

"The year (SE) 1070: Lent was confused. Some of the Easterners introduced Lent on the 18th of *Šebāṭ* (Feb) and ended it on the 6th of *Nīsān* (Apr). Others introduced Lent on the 25th of *Šebāṭ* (Feb) and ended it on the 13th of *Nīsān* (Apr). All of the Christians were confused, when in one place they celebrated Easter, in another place Palm Sunday; in one place it was Passion week, in another place Easter."

(With the above expression "some of the Easterners" for the other churches, our author probably refereed to the Byzantine Patriarchate or other churches west of the Euphrates.) Our Chronicle reported the Easter dating problem for SE 1070, i.e. AD 758/9; in AD 759, Easter Sunday was on April 22, in AD 760 on April 6 or 13 (see above); hence, the above given end date of lent (Apr 6 or 13) points to AD 760; the given introduction of lent on Feb 18 or 25 would be a Monday in 760, i.e. the correct weekday for the start of lent in the Syriac churches (where there is no Ash Wednesday). There is also a brief mention of this problem by Theophanes, who dates it to AD 760. Hence, all the evidence points to AD 760 for the report on the Easter dating problem misdated to AD 759 in the Chronicle of *Zuqnīn*. The same problem also happened in AD 570 and 665 (Mosshammer, 2008, pp. 276–277).[14]

The monastery of *Zuqnīn* belonged to the Syriac Orthodox church, informally known as the Jacobite Church; this is known, because our chronicler listed bishops and patriarchs, which were also listed by the 12th century Michael the Syrian (e.g. Chabot, 1899–1910), who clearly identified them as to belong to the Syriac Orthodox patriarchate (Jacobite). Hence, it is clear that Easter was on Apr 13 and Pentecost on June 1 at the monastery of *Zuqnīn*: since it is reported that the comet was seen "for fifteen nights, until dawn of the feast of Pentecost", it was first detected on May 18 "before early twilight". This is well consistent with the fact that the Chinese sources give May 17 for the first detection (Section 3.1).

2.4. The "white sign" as comet: Criteria

In transmitted texts on celestial transients, using a pheno-typical description, it is often uncertain which kind of celestial phenomenon is meant: in our text the phenomenon is not called "comet", and even if it would be called that way, it may still be uncertain whether a comet in today's sense is meant. Five criteria are developed (timing, position/direction, colour/form, motion/dynamics, and duration/repetition) for various kinds of celestial phenomena, see, e.g., Neuhäuser and Neuhäuser (2015a) and D.L. Neuhäuser et al. (2018a) for criteria for aurora borealis and D.L. Neuhäuser et al. (2018b) for meteor showers (and aurorae).

The "white sign" or "broom" reported in the Chronicle of *Zuqnīn* fulfils all five criteria for comets:

(i) timing, observed at night-time or twilight: "before early twilight", "fifteen nights", "at evening time", "twenty-five evenings", and stars and planets are mentioned (and shown in the drawing);

(ii) Position of first and/or last sighting: often close to Sun, in or near the ecliptic: "before early twilight, in the north-east" "seen again at evening time, from the north-west", and "in the Zodiac [sign] which is called Aries (*emrō*)"; also tail direction away from the Sun: "[at] its one end/tip, the narrow one, a very bright star (*kawkbō*) was seen at its

[13] 19 years Meton cycle × 4 years leap year cycle × 7 days per week are 532 years, with the number of days in 532 Julian solar years being identical to 235 average synodic months within less than one day, so that Easter falls onto the same date and weekday after 532 years.

[14] The *Chronicle of Zuqnīn* does not report any Easter dating problems for AD 570 nor 665; this problem, called "crazatik" or "Erroneous Easter", was resolved only in AD 1824 (Mosshammer, 2008, p. 277). Our Chronicle narrates one other Easter confusion for SE 857 (i.e. Easter AD 546, but correct year is AD 547, see Mosshammer, 2008, p. 256), when three different dates for lent and Easter are mentioned to have been followed by different parts of the population. For a discussion of the Easter problem and Easter tables, see McCluskey (1998, pp. 84–87) and for the Eastern churches also Sanjian (1966) and Mosshammer (2008).

Table 1
Dated positions of the comet in AD 760 from historical observations (coordinates for epoch of date).

Loc.	Date 760	Text regarding position and date (1)	Coordinates / Obs. time (UT)	
Chin.	May 16/17	C1: east direction … located/situated in *Lou* (LM 16)	α=00:48–01:33	azi=90 ± 45°
(2)	Fig. 7	*Tang* Emperor Suzong … *Qianyuan* [reign-period] …	(α in hh:mm)	alt ≥0°
		… 3[rd] year, 4[th] month, *dingsi* (54) night, 5[th] watch	(3) May 16.86 (± 1 h)	
Zuq.	May 17/18	Z1: Aries, to the north from these three stars in it … very shining	azi=65.3–73.1°	alt=2–7°
(4)	Fig. 3	[SE] 1071 iyyōr … before early twilight … 15 nights, until dawn … Pentecost	(5) May 18.0 (± 1 h)	
Zuq.	May 21/22	Z2: in/at the initial degree [of] the second [sign] (i.e. Taurus) …	λ=28.5–31.5°	β=10.4–12.4°
	Fig. 4	… still in the same Aries at its edge/end/furthest part		
		[SE] 1071 iyyōr (May) … on [day] 22 in the same month	(6) May 22.0 (± 1 h)	
Chin.	after May 17	C2: moved toward east north corner	azi=22.5–67.5°	
Zuq.	May 31/Jun 1	Z3: it was going bit by bit to the North-East [direction]	azi=45 ± 22.5°	alt=0–15°
	Fig. 5	sign itself remained for 15 nights, until dawn of the feast of Pentecost	(7) June 1.0 (± 0.7 h)	
Zuq.	Z4: June 1/2, probably also 2/3 (possibly also 3/4): not seen, i.e. close to the Sun		close to the Sun	
Michael of Syria: below the rays of the Sun for three days, i.e. not seen at least June 1/2 and 2/3				
Zuq.	June 2/3,	Z5: seen … from the north-west [quarter]	azi=270–360°	alt=0–15°
	3/4, or 4/5	at the beginning of [the] 3rd [day] after Pentecost … at evening time	(8) June 3.74 (± 1d)	
	Fig. 6	(June 2/3 excluded from Michael of Syria)		
Chin.	(9) Fig. 8	C4: … *Xuanyuan* (but not in LM 24 nor 26)	α=8h39±13m (9) δ=31.9 ± 3.1°	
Zuq.		June 3 or 4 to 28 or 29: seen … from the north-west [quarter] … for 25 evenings (see Z5)		
		June 2/3 excluded from Michael of Syria (see Z4 and Z5)		
Chin.	June 9/10	C4: THY: ominous star seen at west direction	azi=270–315°	alt=0–90°
	THY: intercalary 4[th] month, 21[st] day		(10) June 9.58 (± 1 h)	
Chin.	July 5/6	C5: reaching *Taiwei Youzhifa* 7 *cun* position (=0.7° off β Vir)	α=10h46±4m	δ=8°38′ ± 1°
	Fig. 8	[since May 17] in all more than 50 days, only then [it] disappeared	(11) July 5.6 (± 2d)	

Remarks:
(1) Section, where we explain this dated position, is indicated by, e.g., Z1 or C1 meaning first *Zuqnīn* or first Chinese dated position, respectively.
(2) *Tang* dynasty capital (now Xi'an, China, $l = 108°57'$, $b = 34°16'$), JTS text unless otherwise stated.
(3) Right ascension (α) range for LM 16; azimuth (azi) for *east direction*; altitude (alt) above horizon.
(4) Monastery of *Zuqnīn* near Amida (now Diyarbakır, Turkey, $l = 40°13'$, $b = 37°55'$).
(5) Azimuth from α to 33 Ari and altitude from 41 to β Ari.
(6) Ecliptic longitude *initial degree [of] the 2nd [sign]* (Taurus) would be $\lambda \simeq 30°$, with an error of ±1.5°; ecliptic latitude range for 41 to 39 Ari.
(7) Altitude above *Zuqnīn* 's horizon at azimuth NE during astronomical morning twilight or earlier.
(8) Altitude above *Zuqnīn* 's horizon at azimuth NW during astronomical or nautical evening twilight on June 3 or 4.
(9) Most likely June 9 (see C4), but date not used for orbital fit; right ascension (α) range for LM 25, declination (δ) range for the stars of *Xuanyuan*, which are also in LM 25, i.e. 15, μ, and ε Leo.
(10) Western azimuth for June 9 from China and NW azimuth from *Zuqnīn* "for 25 evenings" since "third [day] after Pentecost" (including June 9) together.
(11) Conservatively, 1° around *Youzhifa* (β Vir).

head/end/tip. And it was tilting to the north side, but the other wide and very dark one was tilting to the south side";

(iii) colour and form (extension): "white sign", "resembled in its shape a broom", the *white broom* points to the comet dust tail appearing white due to reflection of sunlight (while the plasma tail would appear bluish and much fainter);

(iv) dynamics, i.e. moving on sky relative to the stars: first "north from these three stars", "it was going bit by bit to the North-East", seen until Pentecost (June 1 morning), then again soon later after conjunction with the Sun, "it was seen again from the north-west", "it was going bit by bit to the south", etc.; and.

(v) duration: "remained for fifteen nights", "remained for twenty-five evenings", etc.

Furthermore, our Chronicler connects the sighting of this transient object as negative portent with unfortunate events (e.g. "many schisms"), as was not unusual at this time.

2.5. Nomenclature of transient celestial objects

The *Chronicle of Zuqnīn* describes the object of AD 760 as "white sign" and as *kawkbō* ("star") with or in the shape of a "broom" (for *kawkbō*, see Section 2.2), but it did not use the Syriac term *nayzkō* – usually translated with "comet", literally meaning "short spear" or "lance"; maybe, the term used here by our Chronicler is motivated by the real form of the phenomenon on sky resembling more a *broom* than a *lance*.

Our Chronicler also called an object reported for AD 768/9 (probably 770 May) "sign in the likeness of a broom", also a comet in today's sense (Harrak, 1999, pp. 226/7). For the 6th century, the *Chronicle of Zuqnīn* describes three objects as both *kawkbō* and *nayzkō* (Harrak, 1999, p. 136, n. 5), for the first two it is explicitly mentioned that they are called "kometes" by the Greek (e.g. Harrak, 1999, p. 93) – the term "kometes" is taken from its source, the otherwise mostly lost Chronicle of John of Ephesus (based on John Malalas).

The author of the *Chronicle of Zuqnīn* should have noticed that all these objects are of the same class (comet in our sense) given similar drawings. Greek terms like "kometes" may have been outmoded in the ^{c}Abbasid caliphate, but acceptable when used in quotation. The terms *nayzkō* in Syriac, *nayzak* in Arabic, and "kometes" in Greek formerly all meant the same – not only a comet in today's sense, but more generally a transient, extended celestial object; bright supernovae were sometimes also called "kometes" or *nayzak*, as they appeared to be extended due to strong scintilation, see R. Neuhäuser et al. (2016).

2.6. Dated positions from the Chronicle of Zuqnīn

The observations of the *Chronicle of Zuqnīn* were made near Amida, now Diyarbakır (Turkey) at longitude 40°13′ East and latitude 37°55′ North. The Syriac record gives details regarding the comet path on sky.

(Z1) On 760 May 18 in the morning, "a white sign was seen in the sky, before early twilight, in the north-east [quarter], in the Zodiac [sign] which is called Aries, to the north from these three stars in it, which are very shining". The Chronicler specifies that the "white sign" is

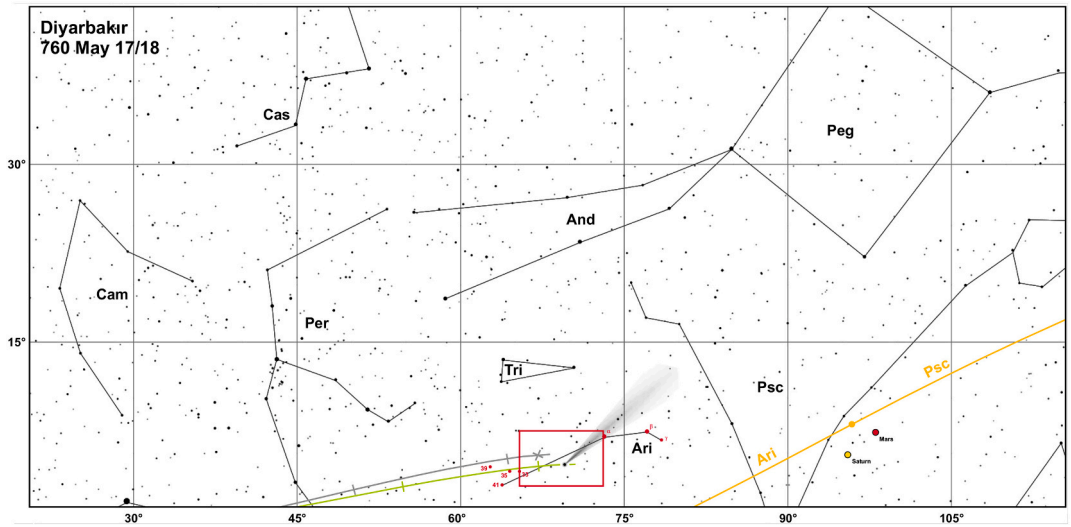

Fig. 3. Horizon plot for Amida for 760 May 18 at 2:40 h local time: The Chronicle of *Zuqnīn* reported a *white sign … in … Aries, to the north from these three stars in it, which are very shining … before early twilight*, the first dated position in Section 2 (Z1), to the north of α, β, γ Ari on the horizontal system. The comet with tail directed away from the Sun (in the NE below horizon) is indicated for May 18 at 0 h UT on the new (green) orbit (as grey cross on the old orbit). The expected positions on May 20.0 and 26.0 (UT) are indicated with green (and grey) tick marks. Our positional error box is shown in red, the relevant stars in Aries as red dots with their names, Mars as labelled red dot, Saturn yellow, and the ecliptic in orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

seen "in the Zodiac [sign] called Aries", which is either the constellation figure of Aries or the ecliptic longitude range; this does not need to be decided here, because there is a more stringent constraint next: the "three" "very shining" "stars" in "Aries" are obviously α, β, and γ Ari (2.0 to 4.5 mag), which are also depicted in the drawing (Fig. 1). Regarding the drawing, our Chronicler's description is here clearly in the horizontal system, "to the north" means from α, β, and γ Ari toward the azimuth north at about the same altitude above horizon, being "in the Zodiac [sign] … called Aries". To specify that the comet appeared "in the north-east" is correct, since the Chronicler here means the whole NE quadrant ($0-90^\circ$) – later he specified that the comet "was going bit by bit to the North-East", which is more strictly the direction toward azimuth NE, $\sim 45^\circ$ (see Z3).

We can obtain the coordinate error box as follows: "to the north from these three stars" in Aries means, in the Chronicler's horizontal system, an azimuth range from α Ari (the horizontally northernmost star among α, β, γ Ari) to 33 Ari (the horizontally southernmost star among the set of stars mentioned next: 33, 35, 39, 41 Ari, see below position 2); this gives an azimuth range of $65.3-73.1^\circ$. As altitude, we use the full range from the lowest star of these two sets (41 Ari) to the highest (β Ari), $2-7^\circ$, see Fig. 3. This converts then in certain ranges in right ascension and declination, used for our orbit fit.

The first detection of the comet was around the beginning of astronomical twilight or slightly earlier ("before early twilight"), i.e. Sun $\sim 18^\circ$ below horizon; as uncertainty, we assume the time from astronomical to nautical twilight (± 0.75h centered around the beginning of

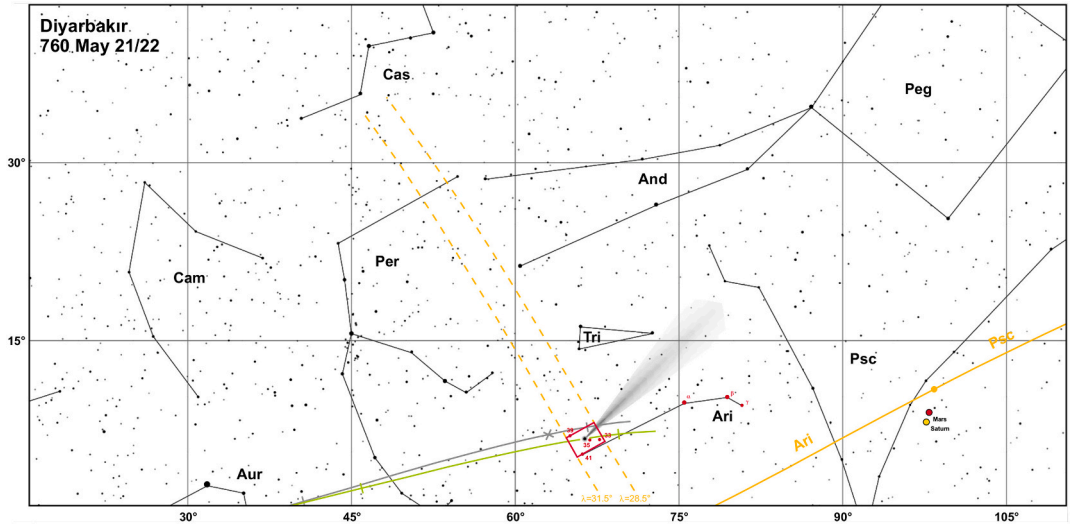

Fig. 4. Horizon plot for Amida for 760 May 22 at 2:40 h local time: The Chronicle of *Zuqnīn* reported the comet to be *in/at the initial degree of* [the] *second* [sign] (i.e. Taurus) … *still in the same Aries at its edge/end/furthest part*, the second dated position in Section 2 (Z2). This record constraints the comet position to be close to 30° ecliptic longitude (Taurus 0°) $\pm$ some uncertainty, estimated to be $\pm 1.5^\circ$ (from some other observations of the same author, see Section 2) – indicated here by orange dashed lines with ecliptic longitude λ given (ecliptic in orange). The comet was at this longitude range and also still in Aries (at its end); the end of Aries was built by 33, 35, 39, and 41 Ari, indicated as red error box, while the head of Aries and its surrounding is made up by α, β, and γ Ari. The comet is indicated for May 22.0 (UT) on the new (green) orbit (grey cross on the old orbit). The expected positions on May 20.0 and 29.0 (UT) are indicated with green (and grey) tick marks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

astronomical twilight); at this time, the positional error box is rising above horizon. We obtain as observing time May 18 at around 2:50 h local time (0:10 h UT), rounded to UT May 18.0 (±1h).

(Z2) Later, on May 22, "it was still in the same Aries at its edge/end/furthest part". Some translations give "head", the main meaning of the respective Syriac word, but this is not the intended meaning here, because the comet was first near its three most shining stars, which are clearly α, β, and γ Ari (see drawing and position Z1), usually considered the area where the head of Aries is depicted. However, since the Chronicler reported that the comet "was going bit by bit to the North-East" (i.e. toward azimuth ~45°, Fig. 4) during the 15 nights since the first detection, and for May 22 that "it was still in the same Aries", the observer must now mean the other end of Aries, namely 33, 35, 39, and 41 Ari[15] (3.6–5.3 mag) – the *other* end compared to α, β, γ Ari.[16]

The meaning of the next wording may appear to be difficult: "in/at the initial degree [of] the second [sign] (i.e. Taurus) from these wandering stars, Kronos and Ares, like somehow a bit to the south". The "wandering stars, Kronos and Ares" are Saturn and Mars, respectively, which had a close conjunction in the night of 760 May 22/23 (a separation of only 40′ in ecliptic latitude when at the same ecliptic longitude), when Mars overtook Saturn moving faster (from night to night) from the west to the east. Given the Babylonian-Greek tradition, in which our Chronicler may be standing, moment and azimuth of rising are highly significant – and, indeed, "somehow a bit to the south" is already fulfilled just at their rising: the azimuths of Mars and Saturn were just 1.5° "south" of East on the horizontal system at their rising (so that we may conclude that the Chronicler could obtain such a high positional precision); the two planets remained in the SE quadrant until sunrise.

The wording "still in the same Aries at its edge/end/furthest part" is descriptive meaning still in the constellation figure of Aries. The Syriac text then gives a colon indicating a more precise specification of the position: "in/at the initial degree [of] the second [sign]" points to the initial degree of the ecliptic longitude range of the second zodiacal sign (or unit); given that the number zero was not yet available at that time, "in/at the initial degree" of Taurus can be a longitude of around 0° Taurus, i.e. an ecliptic longitude of about 30°; the uncertainty range would be ±1.5°, as obtained above for the positional precision of the Chronicler; we use an ecliptic longitude range of $\lambda = 28.5 - 31.5°$ (epoch of date). (If the "initial degree" would instead be the longitude range Taurus $0 - 1°$, this would be covered in our uncertainty range.) The stars 33, 35, 39, and 41 Ari ("still in the same Aries at its edge/end/furthest part") are located at about this ecliptic longitude for a correct precession constant at around AD 760 (see Section 5 for a discussion of precession).

The wording "in/at the initial degree [of] the 2nd [sign] from these wandering stars, Kronos and Ares" might mean that this position is in the 2nd sign *after* the one with "these wandering stars, Kronos and Ares"; indeed, Saturn (ecliptic longitude 2°) and Mars (1°24′) were in the first zodiacal sign/unit, namely Aries, on May 22 (again showing the high positional precision of our Chronicler, supporting the uncertainty assumed above); in the sequence of the Zodiac, the comet was now in the 2nd sign "from" the planets, i.e. in Taurus (Fig. 4). It might be surprising that different systems (ecliptic, horizontal, and descriptive) are used for specifying the position, but we find this also in the East Asian tradition, where positions are given descriptive and/or with azimuth and/or with hour angles (equatorial), see Section 3. The positions of 39 and 41 Ari (including 33 and 35 Ari) define the ecliptic latitude range $\beta = 10.4 - 12.4°$ (epoch of date).

This morning observation was on May 22 at around the start of astronomical twilight, when the relevant objects were all visible at more than 5° altitude; this is at 2:50 h local time (±0.75h as in position Z1, at the beginning of this time window, our positional error box is rising), rounded to UT May 22.0 (±1h).

The drawing, embedded into the text after the report on the morning sightings (before reappearance in the evening) fits best for around May 25 given the relative position of Mars slightly east (left) of Saturn (Figs. 1 and 2). Since the different separations between the objects shown in the drawing are not to scale, we cannot derive exact coordinates of the comet from the drawing alone – and we also cannot measure a realistic angular tail length from the drawing. Hence, the drawing was not used for orbital reconstruction. In Figs. 2-8, a tail is shown by Cartes du Ciel directed away from the Sun like the plasma-tail, while the drawing shows the ("white") dust tail.

The mentioned "tilting" of the comet head toward the north and of the tail toward the south, again meant in the horizontal system ("And [at] its one end/tip, the narrow one, a very bright star was seen at its head/end/tip. And it was tilting to the north side, but the other wide and very dark one was tilting to the south side") is consistent with the comet path for those first 15 nights.[17] Indeed, as seen in Fig. 2, the comet head points toward the northern half ("side"). That the tail is drawn and said to point toward the "south side" would than mean that the tail is not strongly curved.

(Z3) For the time until the morning of June 1 ("the sign itself remained for fifteen nights, until dawn of the feast of Pentecost", June 1), we are informed that the sign "was going bit by bit to the North-East". This wording ("to the North-East") now implies a direction, while earlier the comet's appearance was described as seen "in the north-east" [quarter], see position 1. Hence, the comet was last detected in the NE shortly after rising and shortly before sunrise, i.e. low on the horizon. We conclude on an altitude of up to 15° (Fig. 5). Regarding the azimuth,

[15] The relevant stars in Aries are all listed in Ptolemy's Almagest, where only the ecliptic system for measurements and decriptions were used: γ Ari as "the more advanced of the two stars on the horn" (Ptolemy: faint 3rd mag) and β Ari as "the rearmost of them" (3rd mag), the two first stars listed for Aries, while α Ari is listed among the stars "around Aries", but still for the same zodiacal sign, α Ari as "the star over the head, which Hipparch (calls) *the one on the muzzle*" (bright 3rd mag); then also "the four stars over the rump", namely 41 Ari as "the rearmost, which is brighter (than the others)" (4th mag), 39 Ari as "the northernmost of the other three, fainter stars" (5th mag), 35 Ari as "the middle one of these three" (5th mag), and 33 Ari as "the southernmost of them" (5th mag) (Toomer and Ptolemy, 1984, pp. 339–340).

[16] Since the drawing (for a date around May 25) may imply that the comet head is roughly aligned with α, β, and γ Ari and the two planets Mars and Saturn, all at about the same altitude, the star δ Ari cannot be meant, as it is at much lower altitude and even fainter than even 33 Ari.

[17] Hayakawa et al. (2017) interpret this description as two tails, the plasma tail and the dust tail (in Hayakawa et al.'s section on their Drawing 6), but that is clearly wrong: at the "end/tip" that is given as "the narrow one", where "a very bright star was seen", is obviously the comet head, and it "was tilting to the north side", correct for the head (not for any tail): Aries was in the east (early morning around AD 760 May 25, Figs. 1 and 2), the comet head was pointing toward the north side, while the tail was pointing (and drawn) toward the opposite direction (south side); the tail is drawn roughly away from the Sun, which is about to rise at NE azimuth 61° (observation *before early twilight in the north-east*), as it should be both for a plasma ion tail and a dust tail blown by solar wind (possibly with slightly different misalignments); given that the tail is described as "white", we deal here with the dust tail; Hayakawa et al. stated "that 'one end of it … was turning to the north' sounds like the ion tail", again wrong, because this observation was in the morning in the East with the Sun about to rise from azimuth 61° (NE), so that the ion tail must point away from it to the south. Also, the drawing clearly shows one tail only, exactly as described in the text: at the head it is narrow, and the opposite end (of the tail) is larger and wider (see Section 2.2). Furthermore, a comet with head and two tails has three ends, while text and drawing show only two ends (head and one tail). The Hayakawa et al. interpretation is wrong in respect of astronomy and philology as well as regarding the drawing. While Hayakawa et al. otherwise stress the importance of drawings (and do not even consider those celestial observations in the Chronicle which come without drawings), here they disregard and neglect the clear and fully realistic drawing and misinterpret the text. The misinterpretation as *two-tailed comet* is even featured in the title of the Hayakawa et al. paper as their main result.

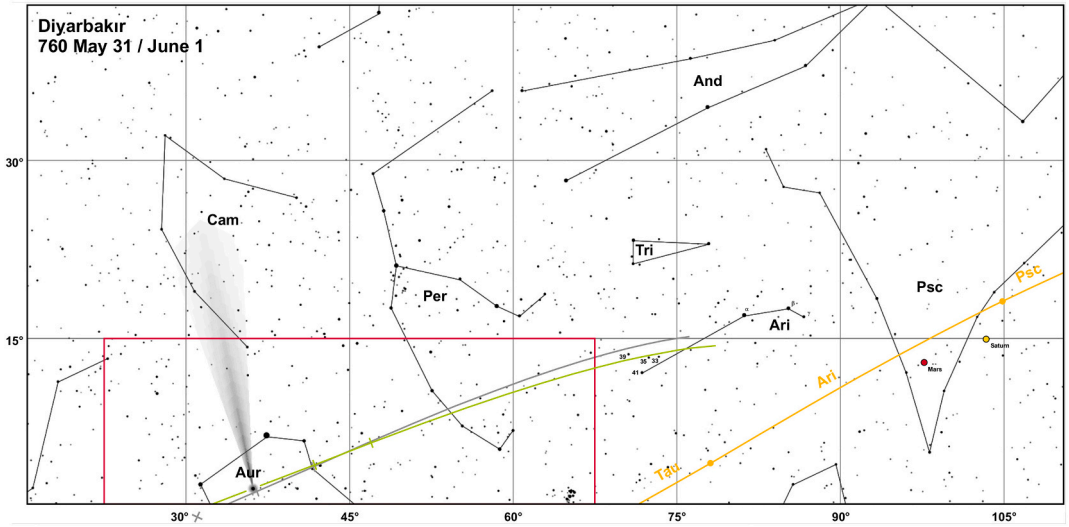

Fig. 5. Horizon plot for Amida for 760 June 1 at 2:40 h local time: The Chronicle of *Zuqnīn* reported that the comet *was going bit by bit to the North-East* direction until dawn of Pentecost in the night May 31 to June 1, the third dated position in Section 2 (Z3), the red error box. The NE direction is taken to be azimuth 45 ± 22.5°. The comet is indicated with tail directed away from the Sun for June 1 at 0 h UT on the new (green) orbit (as grey cross on the old orbit slightly below the horizon). On our new orbital solution, the comet was in conjunction with the Sun on June 1.8 (UT) with minimal elongation being 19.1° (according to the standard JPL orbit, it was on May 31.9 with 18.5° minimum elongation); the last observation before comet-sun-conjunction as reported in the *Chronicle of Zuqnīn* for *early morning* of June 1 is consistent only with our new orbit regarding this inferior conjunction. The expected positions on May 30.0 and 31.0 (UT) are indicated with green (and grey) tick marks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

NE is 45° (east of north), and since the Chronicler here uses an 8-point compass, the azimuth range is 45 ± 22.5°. Since this is the last detection before it *"became under the rays of the Sun"* (Michael of Syria, Section 4d), the comet is in the early morning of June 1 already quite close to the Sun: therefore, we restrict the observing time to the end of astronomical twilight at around 3:20 h local time at the latest, while the beginning of astronomical twilight at 2:40 h is taken as the middle of the observing window, so that we get June 1.0 (± 0.7 h) UT.

(Z4) Then, after conjunction with the Sun, our Chronicler sighted it again "at the beginning of [the] third [day] after Pentecost at evening time" (Pentecost Sunday was on June 1): (a) our term *Tuesday* in Syriac language is called *third day* (as third day of the week), the oriental *beginning* of it would be our Monday evening (June 2 evening) – but then the Syriac wording would be slightly different; (b) the most likely meaning of "at the beginning of [the] third [day] after Pentecost" is that the Chronicler counted the days since after the last detection: 1st day after the last sighting is Monday, 2nd is Tuesday, 3rd is Wednesday, which begins on our Tuesday after sunset (June 3 evening); (c) if the "beginning" is related to the start of a new 24 h-day after three full days, then he would mean our Wednesday (June 4) evening.

With an additional text from Michael the Syrian (Section 4d), we can constrain the invisibility of the comet to "three days" (i.e. 2.5–3.5 days), namely from June 1 in the early morning (last sighting) to June 3 or 4 in the evening.

Since the comet was last seen in the morning of June 1 in the NE and then again first in the evening of June 3 or 4 in the NW, we can conclude

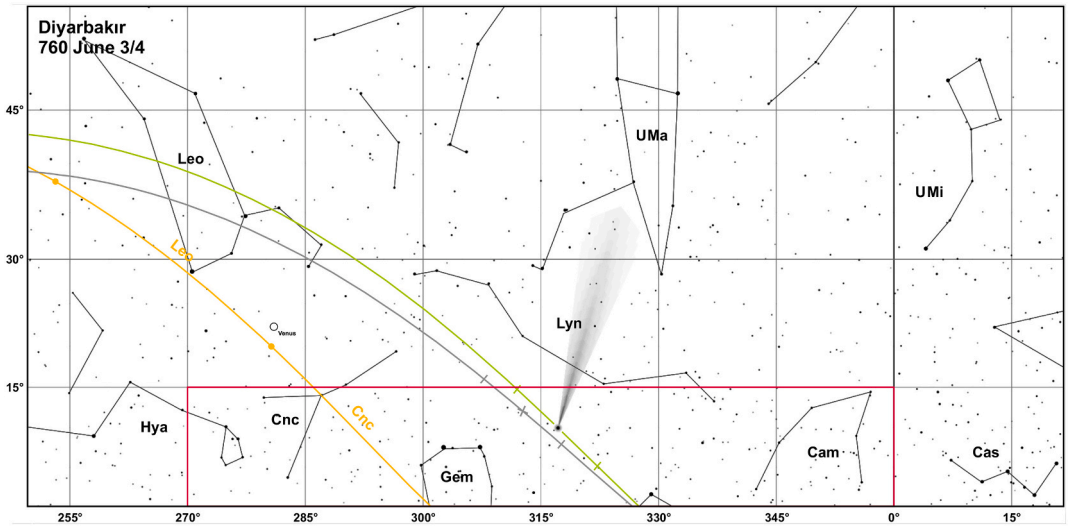

Fig. 6. Horizon plot for Amida for 760 June 3 at 20:30 h local time: The Chronicle of *Zuqnīn* reported that the comet was seen *from the north-west* [quarter] *at the beginning of* [the] *third* [day] *after Pentecost … at evening time* (Z4 and Z5, Section 2), the red error box. The comet is indicated with tail directed away from the Sun on the new orbit (cross on the old orbit). Along our best fitting orbit of 1P/Halley the closest encounter of the comet with the Earth occurred on 760 June 3.6 (UT) with 0.37 au (according to the JPL standard orbit, closest approach was on June 2.7 with 0.41 au). The expected positions on June 2.74 and 4.74 (UT) are indicated with green (and grey) tick marks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

that it was close to the Sun around June 2 (conjunction), i.e. not seen due to the much brighter nearby Sun. Since we cannot independently derive the brightness of the comet around perihelion with sufficient precision due to possible cometary activity (Section 5), we refrain from estimating the area, where the comet was invisible due to the much brighter Sun.

(Z5) After conjunction with the Sun, the comet "was seen again at evening time, from the north-west [quarter] for twenty-five evenings", i.e. shortly after sunset and shortly before setting of the comet, i.e. at low altitude of again up to 15° (for first detectability) and an azimuth for the whole north-western quarter (270 − 360°), with an uncertainty for the full azimuth range of the whole NW quarter (Fig. 6). The date of the observation was concluded above (Z4) to June 3 or 4, possibly already June 2. The Chronicler here says that this observation was performed "at evening time", i.e. at between the start of nautical twilight and the end of astronomical twilight, i.e. on June 3 (±1d) between 19:50 h and 21:10 h local time (UT 17:10 h-18:30 h), i.e. on June 3.74 (±1d) UT.

With an additional observation from China for June 9, we can constrain the azimuth even further for that date, see below: the *Chronicler of Zuqnīn* has seen the comet in the NW quarter since June 3 ± 1 "for 25 evenings", so that it was in the NW on June 9. With an additional text from Michael the Syrian (Section 4d), we can constrain the first detection after conjunction to June 3 or 4 in the evening.

The comet "was seen again at evening time, from the north-west [quarter] and it remained for twenty-five evenings" – until June 27 or 28 (constrained with Michael the Syrian), moving "bit by bit to the south" (horizontal system) and "again disappeared". When the author afterwards mentioned a reappearance in the SW quarter ("then it returned [and] was seen in the south-west [quarter], and thus there it remained for many days"), he could indeed mean the fading comet (about 4th mag or fainter, Fig. 14), which was difficult to be detected for a few nights due to the moon becoming too bright (or, e.g., some obscuration along the horizon); the given position, in the SW quarter, would be reliable for a detection around July 5 when the moon exited the evening sky. However, the last position transmitted in the Chinese sources (near β Vir around July 5, see C5 below) would be 'in the SW quarter' only at the beginning of astronomical twilight; it may still be credible, because the Chronicler is otherwise quite precise, and the comet's brightness (Fig. 14) does allow such a detection.

We cannot exclude that the Chronicler meant a different object,[18] but it is not very likely – the context (see Section 2.1) supports the former. If the last object was again our comet, it must have been seen since at the earliest from June 29 on, and then for "many days", i.e. more than about three days, but less than a month. These considerations do not yield a sufficiently precise dated position for the orbit determination – we can compare it below with the Chinese observations in July and our new orbital solution. Furthermore, the credible source Michael the Syrian specified that the comet was seen for 40 days after conjunction with the Sun, which may be somewhat rounded, but would be fully consistent with the Chinese and *Zuqnīn* records, yielding until about or up to July 12 or 13 for the last sighting.

3. The comet of AD 760 as reported in classical Chinese sources

3.1. Chinese texts and text-critique

Extant Chinese sources for this comet include Jiu Tang shu (JTS, Xu et al., 945; in Ho, 1962: CTS, using the older Wades-Gilles romanization), Tang hui yao (THY, Wang Pu et al., 961), and Xin Tang shu (XTS, Ouyang Xiu et al., 1061; in Ho: HTS) – also, Wenxian tongkao (WHTK 286/23a, Ma Duanlin, 1317) provides a copy of XTS 32.838 with one insignificant variant. We prefer here JTS as the basic text, because – as will be shown – it is the intrinsically most consistent and detailed text (it is also the oldest one), but also consider the variants in XTS and THY; XTS omits certain details, e.g. the exact observing time ("5th watch") for the comet of AD 760.[19]

We present here our own new, technical, very literal translations, which aim to preserve the detail and word order of the original Chinese, but have been slightly smoothed to present correct English sentences (see appendix for the Chinese texts); significant variants in Ho (1962, no. 273 and 274), Xu et al. (2000), and Pankenier et al. (2008) are mentioned in footnotes. First, we translate the oldest text from JTS (36.1324, and much shorter in 10.258), counted as object no. 273 in Ho (1962), with some Chinese terms, explanations, and significant variants from THY (43.767) and XTS (32.838, unless otherwise specified) in round brackets, our additions in square brackets (e.g. the day/night number in the 60-day-cycle), starting with the night 760 May 16/17, line breaks by us:

> "Tang Emperor Suzong (literal: Tang['s] Solem Ancestor) *Qianyuan* [reign-period][20] 3[rd] year, 4[th] month, *dingsi* (54) night (THY gives the lunar date: "27[th] day", XTS omitted "night"), 5[th] watch ("5[th] watch" omitted in THY and XTS),
> [a] broom (*hui*) [star] (XTS: " *hui xing"* for "broom star") emerged (THY: "seen at (*yu*)", XTS: "there was … at (*yu*)") east (*dong*) direction, colour being white,
> length (JTS 10.258 adds: about) 4 *chi* (THY and XTS have color and length after the next phrase),
> it was located/situated in (*zai*) *Lou*, [in] *Wei*[21] for-a-while/space (*jian*),
> it rapidly moved toward east (*dong*) north (*bei*) corner (THY omitted "corner"; XTS has instead: "east direction rapidly moved"),
> passing through *Mao, Bi, Zui* (XTS: "*Zuixi*"), *Shen,*[22] *Jing* (XTS: "*Dongjing*"), *Gui* (XTS: "*Yugui*"), *Liu*[23] [and] *Xuanyuan* (THY added "*xiu*" for "lodge"[24]),
> reaching *Taiwei Youzhifa*[25] 7 *cun* position (THY: "reaching *Taiwei* west (*xi*), *Youzhifa* west (*xi*) 7 *chi*"; XTS omitted "*Taiwei*" and has only "reaching *Youzhifa* west (*xi*)"),

[18] Chinese sources did report several more *guest stars* after the perihelion of 1P/Halley in AD 837, see e.g. Xu et al. (2000).

[19] Kiang (1972) uses only JTS and XTS (after Ho no. 273); Stephenson and Yau (1985) prefer the THY text.

[20] Xu et al. (2000) added here "i.e. 1st year of the Shangyuan reign period" – in fact the *Shangyuan* reign period started only at the beginning of the 4th intercalary month, after the *Qianyuan* reign period had ended with the 4th month.

[21] *Lou* ("Hillok" or "Lasso") and *Wei* ("Belly" or "Stomach", see SK97 and Ho, 1966) could be the asterisms of that name (both in "our" Aries, i.e. the constellation as defined by the International Astronomical Union) or the lunar mansions (right ascension ranges) named after these asterisms (LM 16 and LM 17, respectively) starting in the west with the determinative star β Ari for *Lou* and with 41 Ari for *Wei*. See below for position C1.

[22] Xu et al. (2000) give "Can" here, which is a more common pronunciation of the Chinese character; however, in this context, the correct pronunciation is "Shen", LM 21 and an asterism in Orion.

[23] This list could point to either asterisms or LMs: *Mao* ("Mane", LM 18), *Bi* ("Hunting net", LM 19), *Zui* or *Zuixi* ("Beak", LM 20), *Shen* ("Triaster" or "Hunter", LM 21), *Jing* or *Dongjing* ("Eastern Well", LM 22), *Gui* or *Yugui* ("Spectral Carriage", LM 23), and *Liu* ("Willow", LM 24); translations of asterisms here are the *Han* time interpretation, some have changed later (SK97).

[24] *Xuanyuan* ("Yellow Emperor") is usually only an asterism, which does not have the additional function as LM asterism; given that it seems to be listed here as *xiu*, it may have some 'lodge'-like function; *Xuanyuan* is meant as skeleton of 17 stars in Leo and Lynx starting with α Leo close to the ecliptic.

[25] *Taiwei* ("Great Tenuity Enclosure" or "Supreme Subtlety Palace" or "Privy Council") is one of three asterisms, which are so-called "enclosures" (*yuan*) with two "walls" each, *Taiwei* being a large area with 10 stars in Virgo and eastern parts of Leo (12 stars in *Tianguan shu*, but then only 10 in the official *Shi Shi*, SK97); the determinative star of *Taiwei* is *Youzhifa* (β Vir) at the southern end of *Taiwei's* western wall (SK97).

in all more than 50 days, only then (*fang*) [it] disappeared (THY very similar; XTS has "in all more than 50 days, [it was] not seen")" (continued below).

We will discuss this transmission in detail below to obtain dated positions.

Next, we present additional relevant texts, not given in Xu et al. (2000) and Pankenier et al. (2008). Ho (1962) cited under his no. 274 a record from JTS 36.1324 (Ho: CTS 36/8a), and gives two more texts, HTS 32/6b (=XTS 32.838) and, almost identical, WHTK 286/23a (286/29b-30a in the Siku quanshu huiyao edition). Here our own new literal translation of the JTS text (with variants from XTS and also from THY 43.767), which follows immediately after the previous comet report:

"Intercalary 4[th] (XTS omitted "4[th]") month, *xinyou* (58=May 20 with night 20/21), new-moon (THY: " *Shangyuan* reign-period, [initial] year, intercalary 4[th] month, 21[st] day" (=June 9)),
[an] ominous star (*yao xing*) seen at (*yu*) south (*nan*) (THY: "west (*xi*)"; XTS: "there was [a] broom star (*hui xing*) at (*yu*) west (*xi*)") direction, length several *zhang*.
This time, since [the] beginning [of the] 4[th] month, heavy fog [and] heavy rain, reaching [the] end [of the] 4[th] intercalary month (i.e. the last 10 days), only then (*fang*) [it, i.e. bad weather] stopped (instead of this whole sentence, THY and XTS have "Reaching 5[th] month, [ominous star] disappeared", XTS adds: "Only [when] reaching …").
This month, rebel bandit Shi Siming again captured [the] Eastern Capital (i.e. Luoyang). Grain prices leapt [up] in expense, *dou* (i.e. about 6 liters of rice) reaching eight hundred *wen*. People ate each-other [and] corpses covered [the] ground."

After reporting the disappearance of the comet, "Only [when] reaching 5[th] month …", XTS (32.838) adds:

"*Lou* corresponds to [the pre-imperial state of] *Lu*, *Wei* [and] *Mao* [and] *Bi* correspond to *Zhao*, *Zuixi* [and] *Shen* correspond to *Tang*, *Dongjing* [and] *Yugui* correspond to [the] capital city (*jingshi*) (meaning probably the historical capital of the Zhou dynasty) allotment, [as for] *Liu*, its half corresponds to [the] *Zhou* allotment. As-for-cases-in-which (*zhe*) two brooms seen in-succession, amassing disaster. Moreover, *Lou*, *Wei* space (*jian*) [corresponds to] *Tiancang* ('Celestial Granary')."

The whole last paragraph is an astro-omenological interpretation of the comet report. In Chinese astro-omenology, *Wei* (LM 17) governs granaries and warehouses, as found in the *Jin shu* (Ho, 1966, p. 100, Ho, 2003, p. 147) – and indeed, the term *Tiancang* means 'Celestial Granary/ies'. There is also an asterism *Tiancang*, which is however located mostly in LM *Kui* and only partly in LM *Lou*; there are further asterisms meaning *'Celestial Granaries'* in LMs *Lou* and *Wei*, e.g. *Tianjun* (SK97), written *Tianqun* in Pankenier et al. (2008). (*Lou* governs cattle rearing and animal sacrifices, see Ho, 1966, p. 100.)

In the past, it was considered that there were two comets in spring AD 760, e.g. Yeomans et al. (1986). All sources for Ho no. 274 give "several *zhang*" as length, so that one could consider that they mean the same object: the "ominous star" (*yao xing*) in the west in THY (June 9 evening) would fit with the comet path given in the previous text; the object(s) in JTS, XTS, and WHTK for May 20/21 (morning) in the south or west are not consistent with the path of comet no. 273, which was then still in the NE. If the previously cited JTS text refers to the same object, a date correction would be needed – it should be June 9 (as in THY) instead of May 20. One explanation could be: May 20 corresponds to the 58th day, *xin-you* in the 60-day-cycle, while June 9 is the 18th, *xin-si*, so that only the 2nd part would have been mistaken in JTS, XTS, and WHTK by a copying scribe (*you* for *si*); THY conserves the correct date as date in the lunar calendar (day 21 = June 9), converted from the 60-day-cycle as found in its source. Note that the two dates (May 20 and June 9) pertain to the same Chinese lunar month (4th intercalary month), just the day within the month is different. More reasonably, since "new moon", i.e. the first day of the lunar month, is given in JTS and XTS in addition to *xin-you* (58), which is correct for May 20, a confusion between date and event might be just due to a false concatenation in the compilation process; furthermore, it is plausible that the second comet report, preserved correctly in the THY text, originates from another source and observing site, where, e.g., weather conditions did not allow a detection earlier than June 9.

To sum up, among the three texts for Ho object no. 274, the THY transmission appears to be the least corrupt: sighting on June 9 (JTS and XTS: May 20/21), THY has west direction (XTS also west, but JTS has south). That the information in THY is most reliable here, relies on the assumption that the "two" objects Ho no. 273 and 274 are one and the same comet; this is supported by the fact that the duration in the first comet report (about 50 days after May 17/18) corresponds well with the disappearance in THY and XTS ("Reaching 5[th] month, [it] disappeared"). This assumption is also supported by the following astro-omenological interpretation in XTS 32.838: "As-for-cases-in-which (*zhe*) two brooms seen in-succession, amassing disaster". In the translation "two separate broom stars appearing simultaneously" (Stephenson and Yau, 1985), the word "separate" is added (but not given in the Chinese text); the sense of the adverb in Classical Chinese (*reng*) suggests repetition with close or immediate proximity in time ("appear one after the other" or "in quick succession" or "repeatedly").[26] That it is only one comet is justified by further independent reports, where the conjunction with the Sun is explicitly reported, e.g. the *Chronicle of Zuqnīn* (see above) and several further East Mediterranean and West Asian reports (Section 4).

There is one more extant source, XTS 6.162–3, but the variant transmission gives only very short information:

"4[th] month … *dingsi* (54), there was [a] broom star, emerged at (*yu*) *Lou, Wei*, *Jiwei* (56), Lai Zhen (died ca. AD 763) became *Shannan* Eastern Circuit's Military Commissioner charged to overcome [the rebellion of] Zhang Weijin. Intercalary month (4[th] omitted) *xinyou* (58), there was [a] broom star, emerged at (*yu*) west (*xi*) direction. … Jimao (16), [there was a] large amnesty, change [of] reign-period [title], grant [of] civil [and] military office [and] rank. … This month [was a] large famine. Zhang Weijin surrendered."

This late source shows how compilers work: XTS 6.162–3 concatenated input from XTS 32.838, a source which is already shortened – as one consequence, the comet's position at the beginning is a bit corrupt. This source, which belongs to the "Basic Annals" (*Benji*) section of the history (a general chronicle of events during the reign of each emperor), rather than the technical treatise, is only interested in the first appearance of the comet (first sightings at the very beginning and after conjunction with the Sun) – the main point is the connection to historical events on Earth.

The year 760 fell midway through the An Lushan rebellion (AD 755–763). The early years of the rebellion had witnessed the abdication of an emperor who had reigned for more than forty years, the fall and subsequent recapture of the main capital at Chang'an, and casualties reportedly numbering in the millions. In both JTS and XTS 6.162–3, close chronological proximity associates the comet's appearance with politics, the rebellion and the famine that accompanied it; XTS 32.838 reflects these in an astro-omenological interpretation.

As quoted above, JTS reports the weather: "This time, since [the] beginning [of the] 4[th] month (new-moon on Apr 19/20), heavy fog [and] heavy rain, reaching [the] end [of the] 4[th] intercalary month (i.e. the last 10 days, new-moon on June 17/18), only then [it, i.e. bad weather] stopped." Monsoon typically arrives in May and may well end in June. In addition to shortenings and omissions in the compilation process, problems with weather and the rebellion may also have influenced the observations and the data record (and might be partially

[26] Stephenson and Yau (1985) and Yeomans et al. (1986) thought that, in addition to the comet seen since AD 760 May 16/17, there would have been another comet seen in the south or west since May 20/21.

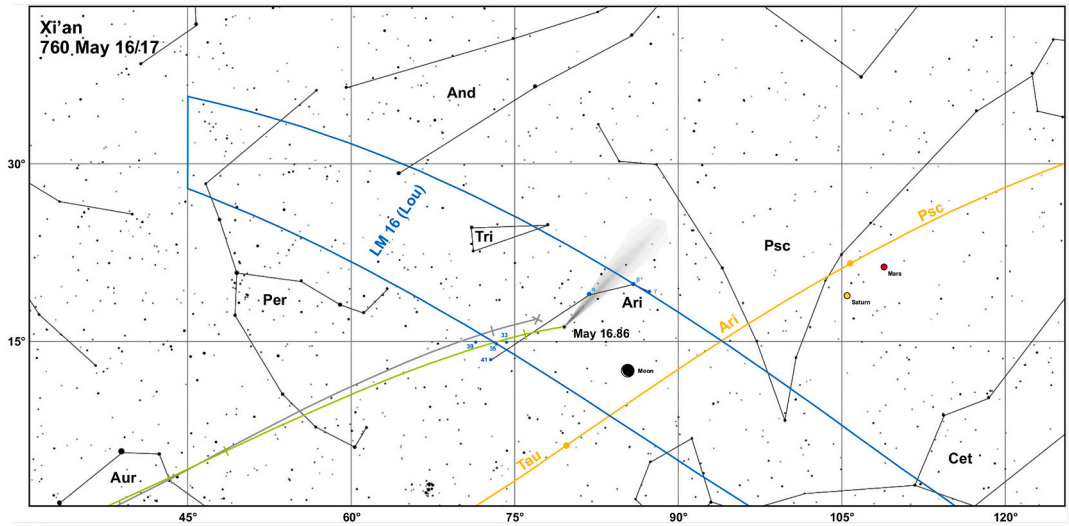

Fig. 7. Horizon plot for Chang'an (now Xi'an, China), the*Tang*capital, for the night 760 May 16/17 at 4 h local time: The waning crescent moon is seen in Aries. The Chinese reported a *broom* [star] *emerged east direction … it was located in Lou*, the first dated position in Section 3 (C1). *Lou* is here Lunar Mansion 16 (LM 16), the right ascension range from β Ari to 35 Ari (*Wei* is LM 17). The given *East direction* can be considered as azimuth 90 ± 45°, so that the given right ascension range (LM 16) is constrained in the NE by azimuth 45°, but in the SE by the local horizon. The positional error box is indicated by blue lines. The star α, β, and γ Ari and 35, 39, and 41 Ari, which make up the asterisms *Lou* and *Wei*, respectively, are indicated as blue dots, but the asterisms are not meant here. Our new and the previous (JPL/YK81) orbits are shown as green and grey lines, respectively, from May 16/17 midnight onward to the east. We draw a comet with plasma tail directed away from the Sun (in the NE below horizon) for its position on May 16.86 (UT) on the new (green) orbit – and for the same date as cross on the old (grey) orbit. In order to illustrate the motion of the comet along both paths the expected positions on May 20.0 and 30.0 (UT) are indicated with green and grey tick marks, respectively; the ecliptic in orange. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

responsible for the famine). Still, since the beginning of the *Tang* dynasty (AD 618), there are no better transmitted records for any comet before AD 760 (see Pankenier et al., 2008 for the texts).

The Korean "Chronicle of the Three Kingdoms" (Samguk sagi) briefly reported a " *hui* comet" sometime during the lunar month 761 May 9 to June 7 (Ho, 1962, no. 275); this work, compiled AD 1142–1145 (Shultz, 2004), is often off by a few years – probably, our comet is meant. The Kingdom of Silla is traditionally dated 58 BC to AD 935. However, the Silla dynasty, which united the whole of peninsula, ran from AD 668 to 935.

From the Chinese observations also all five comet criteria mentioned above (Section 2) are fulfilled. A "broom colour being white" also points to a comet with dust tail.

3.2. *Dated positions from Chinese sources*

The observing times below are calculated for Chang'an (today: Xi'an, China, longitude 108°57′ East, latitude 34°16′ North), the capital during the *Tang*; however, during the An Lushan rebellion AD 755–763, observations could have been obtained from the Eastern capital Luoyang (longitude 112°27′, latitude 34°40′). We can deduce the following dates and positions:

(C1) When the Chinese give May 16 as date for an observation at the end of the night (JTS: " *dingsi* [54] night, 5[th] watch"), they refer for the whole night (as usual) to the date at the start of that observing night, so that the observation was in the morning of what we date May 17; the 5th watch is the last fifth of the night, see below. The discovery of the comet by the Chinese and the *Zuqnīn* Chronicler at the end of the nights of May 16/17 and 17/18, respectively, may have been facilitated by the nearby waning crescent moon at that time: the comet and Moon (2 days before conjunction) were in Aries (Fig. 7).

The text then says "[a] broom (*hui*) [star] emerged east (*dong*) direction". The term "east" clearly marks a direction, it does not mean "morning" – the time of observation is given otherwise as "5[th] watch".

The "east direction" given with the characters " *dong fang*" is from a compass with at least four points. (NB: the Chinese record from XTS 32.839 on Halley in AD 837 mentioned for the pointing of the tail, in turn, the directions "west" (xi), "south" (*nan*), "north" (*bei*), and then "east" (*dong*), always in combination with the character for "pointing" (*zhi*) (Pankenier et al., 2008) – the pointing direction of the tail is not given in the record for AD 760.) If the wording *dong fang* for "east direction" is from the 4-point-compass, it then yields an azimuth of 90° (east of north) with an error bar of ±45°; while it could even be from an 8-point-compass (see below, C2), then with a smaller error bar, we conservatively choose here the larger ±45° error bar from the 4-point-compass.

The position is then given in JTS as " *zai Lou*" translated by us as "it was located/situated in *Lou*". The term *Lou* could in principle refer to LM 16 or the asterism *Lou* with α, β, and γ Ari. In almost all Chinese texts on comets (at least until AD 900), e.g. Halley in AD 837, as well as solar and lunar eclipses (as quoted in Xu et al., 2000 and Pankenier et al., 2008),[27] the character "*zai*" is related to a Lunar Mansion (or to one of the three "enclosures"), and it often comes with a "*du*" measurement or some other positional specification.[28] In sum, the wording "*zai Lou*" translated as "it was located/situated in *Lou*" meant here Lunar Mansion *Lou* (LM 16).

[27] also noticed by J. Steele, priv. Comm., as he told us during the Leiden workshop on historical observations in Oct. 2019

[28] However, compilers have also concatenated the texts, so that "*zai*" can appear to be connected to a non-LM asterism, e.g. comet Halley in AD 837: in the older JTS, there is a descriptive position related to *Xuanyuan* ("emerged *Xuanyuan* of/from right") without *zai* plus an equatorial hour angle ("*zai Zhang* (LM 26) 7 *du*"), which was then concatenated by XTS to "*zai Xuanyuan* right", i. e. *zai* with a non-LM asterism. NB: "right" could be a scribal error for"left", "*zai Zhang* (LM 26) 7 *du*" is not consistent with "*Xuanyuan* of/from right" – the Chinese characters for right and left are almost similar, such a mistake happens often.

The text continues with "*Wei jian*". One of the principle meanings of the term *jian* is "space" by referring to a period of time.[29] The information of our record could then be that the comet was first in LM *Lou* and then in the *Wei* space; because shortly later, more LMs follow, the context and also the astro-omenological interpretation point to the fact that LM *Wei* is referred to here.[30] If we would interpret it as "located/situated in LM *Lou*, asterism-space *Wei*", i.e. around the asterism *Wei*, then the LM *Wei* would not have been mentioned as LM at all, even though the comet did pass through this wide LM, and the following LMs are all given. Although the rendering of *jian* as "between" (preposition) would be acceptable from a linguistic perspective, it should be avoided, because it creates a false impression that we are dealing with asterisms rather than lunar mansions.[31]

One can also read *jian* as a verbal complement as "for-a-while" (see Wang Li, 2000),[32] especially the best transmitted text, JTS, allows such a rendering in a grammatically plausible way: "It was located/situated in (*zai*) [LM] *Lou*, [in LM] *Wei* for-a-while, [then] it rapidly moved toward east north corner, passing through *Mao*, *Bi*, …". The general motion of this comet is consistent with being first moving slowly in/through *Lou* (LM 16) and for a while through *Wei* (LM 17), but then more rapidly through Mao (LM 18) and Bi (LM 19), where the "north east corner" (45 ± 22.5°) is situated (see below, Fig. 8).

In sum, the position statement "*zai Lou Wei jian*", both *Lou* and *Wei* are most certainly Lunar Mansions (i.e. right ascension ranges). For obtaining positions (and uncertainties) on sky, our interpretation of *Lou* as LM is also more conservative than as asterism, because we use large measurement uncertainties (the whole LM *Lou*, constrained to azimuth *east*).[33]

A position in LM *Lou* means that the right ascension is somewhere between the right ascension of the determinative star of LM 16 *Lou*, namely β Ari with $\alpha = 0$ h 48 m 4 s, and the right ascension of the determinative star of LM 17 *Wei*, namely 35 Ari with $\alpha = 1$ h 33 m 18 s (epoch of date).

The position of the comet is then constrained by the LM *Lou* (right ascension range) and the azimuthal range "*dong*" for East (90 ± 45°), see Fig. 7. Such a position is fully consistent with the *Chronicle of Zuqnīn*. While the more professional Chinese court astronomers detected the comet only one day before the *Zuqnīn* chronicler, we have for the beginning (Z1) and for May 22 (Z2) two precise dated positions from the latter. The compilations of the original Chinese sources transmitted mostly reduced information: for astro-omenological purposes – the addition of the XTS text (32.838) is a good example – it was very important to record the motion through the lunar mansions.

Finally, we have to estimate the observing time: the "5[th] watch" specified by the Chinese corresponds to the last fifth of the night.[34] On 760 May 17, the "5th watch" corresponds to 2h54m to 4h54m local time (Chang'an, now Xi'an, being 7:15 h east of Greenwich) or UT May 16.86 (± 1 h).[35]

Note that for these first few statements about the comet, the records from China and *Zuqnīn* are quite similar: (a) China "night, 5[th] watch" (May 16/17) / *Zuqnīn*: "before early twilight" (May 17/18) (b) China "east direction" / *Zuqnīn* "north-east [quarter]", (c) China: in (LM) *Lou* / *Zuqnīn*: in Aries, (d) China: "colour being white" / *Zuqnīn*: "white sign", (e) China: "broom star" (*hui xing*) / *Zuqnīn*: "resembled in its shape a broom".

(C2) After the comet discovery in the LM *Lou*, then LM *Wei*, the comet is next given to have "rapidly moved toward east (*dong*) north (*bei*) corner", without date; only the oldest source, JTS, has "corner", while this detail was lost in the later THY and XTS; XTS also omitted "north". The phrase "toward east north corner" is a clear direction on sky. The azimuth is given here with the two terms "east (*dong*)" and "north (*bei*)" from the 4-point-compass (see above), but in combination (and together with the term "corner"), it is then a direction like from an 8-point-compass, i.e. an azimuth of 45° (east of north); the error bar would then be ±22.5°. We cannot use this position for the orbit.

Next, our text provides a list of LMs through which the comet has passed, which goes beyond azimuth NE, so that the motion toward the explicitly given azimuthal direction "toward east north" (JTS, THY) may have some significance here – the compilation may point to the disappearance of the comet due to conjunction with the Sun (LM 19, *Bi*). The *Chronicle of Zuqnīn* gives the same or a similar position ("it was going bit by bit to the North-East"), but with a date for the last sighting before conjunction with the Sun (June 1, see above).

(C3) Next, it is said that the comet is "passing through" the lunar

[29] Needham & Wang (1959, p. 256, note g) pointed out that the character transcribed *jian* originally showed the moon in a gate, later the Sun in a gate; thus, it seems that *jian* is a fitting character for the space of a lunar mansion.

[30] *Wei* ("Belly") can in principle be either the Lunar Mansion (LM) 17 or the asterism of the same name, both have 35 Ari as determinative star. There are three LMs, which are written in Chinese characters all transcribed as "*Wei*"; and the same characters also refer to asterisms of the same names, in which the determinative star of the respective LM lies. In this paper, we deal only with that asterism and LM *Wei*, whose determinative star is 35 Ari. The situation is similar for *Bi*: there are two LMs whose Chinese characters are transcribed as "*Bi*", LM 14 and 19 (and also two asterisms of the same names); in this paper, we deal only with the *Bi* that is LM 19 ("Hunting Net"), whose determinative star is ε Tau (SK97).

[31] The phrase "*zai Lou Wei jian*" was translated as "between *Lou* and *Wei*" by Ho (1962), Stephenson and Yau (1985), Xu et al. (2000), and Pankenier et al. (2008). However, this translation neglects *zai* (as a technical term here, it is related to *du* measurements, see above), but focusses purely on *jian*, translated with the preposition "between". The term 'between' is ambiguous, e.g. 'between A and B' may include or exclude A and B themselves, meaning something like either 'among A and B' or 'in between A and B'; see also note 33 (in between two asterisms instead of between/among two LMs). Hence, we prefer the more literal "space".

[32] Wang Li (2000) gives a typical example; usually when used in this sense, *jian* is preceded by the existential *you* (*you jian* – lit. "there was a while").

[33] Kiang (1972) used as position "between *Lou*-16 and *Wei*-17", where the numbers point to LMs, but then gave the positions of the two stars in the asterisms *Lou* and *Wei*, namely right ascension 15° and declination 17° for *Lou* (which is almost exactly the 760.5 position of α Ari, the easternmost star of *Lou*, also according to Kiang, 1972) and right ascension 23° and declination 22° for *Wei* (the position of 35 Ari, the westernmost star of *Wei*). The orbital fit by Kiang (1972) indeed resulted in a position almost exactly in the middle between α Ari and 35 Ari.

[34] "A night (sunset to sunrise …) divided into five night-watches" (Needham et al., 1986, p. 199); this was the general rule for dividing the night into five watches with equal lengths per night, but varying during the year. However, for cultural reasons and other applications, it seems that sometimes a certain amount of time (e.g. 2.5 *ke* being 36 min, or different periods) were inserted between sunset and the beginning of the 1st watch (analogously in the morning); the system changed over time and varied from location to location (Needham et al., 1986, pp. 199–205). Since the habit at around AD 760 is uncertain, we used the general rule as default. If we would subtract the 2.5 *ke* at dawn and dusk, the determination stars of *Lou* (β Ari) and *Wei* (41 Ari) would not yet be visible at the start of the (earlier) time window.

[35] For morning observations, Kiang (1972) changed the date given in the Chinese source at midnight, but overlooked that practically, the reports do not give a new date for the second half of the night (see introduction); for AD 760 May 16/17, he argued: "The date correspondence to May 16, and in this case it seems more reasonable to reckon the beginning of a day, not at midnight, but at daybreak, 6 a.m., say, hence the presumed time of observation is around May 16.95 local time, or May 16.65 UT", both incorrect, but the offset happens to be small; Kiang (1980) and YK81 already noticed that astronomical night reports use the date pertaining to sunset for the whole night; the observing time for AD 760 May was not corrected by YK81, apparently because it happened to be almost correct in Kiang (1972) and/or because it was considered as special case and "unusually precise" (Kiang, 1972). YK81 did not revise the historical Chinese observations for AD 760, but used those from Kiang (1972); by comparing their orbital solutions, they found a difference of +1.83 day for their new perihelion time (AD 760 May 20.67) compared to Kiang (1972).

mansions *Mao* (LM 18) to *Liu* (LM 24), i.e. right ascension ranges (Fig. 8); the comet crossed some of them before it reached the NE corner (before conjunction with the Sun). The extant record neither gives any dates for these lunar mansions nor more precise positions. In the orbital fit, we require the comet to go through these LMs. The Chinese wording "passing through" (*li*) indicates a transit without necessarily contacting an asterism; hence, if the LM asterisms (with the same name as the LMs) were meant, the comet would not need to travel a very curvy path from asterism to asterism, inconsistent with a real comet orbit. Indeed, our final orbit does not cross the asterisms *Mao* to *Liu*, but it passes through the lunar mansions LM 18–24. This is the first time in the *Tang* dynasty that so many LMs are given for a comet path, see Pankenier et al. (2008) for the texts.

(C4) After crossing LM 24, the comet was in "*Xuanyuan*"; THY explicitly wrote " *Xuanyuan xiu*"; the term "*xiu*" is normally translated to "lunar mansion" or "lodge". However, there is no lunar mansion with that name, *Xuanyuan* is just an asterism consisting of stars in Leo and some in Lynx, but "lodge" could emphasize a position in *Xuanyuan*; the same THY source gave credible information for a comet on June 9 in the west (possibly in *Xuanyuan*, see below). Alternatively, the characters for "*Xuanyuan*" and "*xiu*" ("lodge" or plural "lodges") could have been transposed, so that "*xiu*" would be connected to the LMs listed just before (however, to use "*xiu*" in this way is rare, e.g. in AD 178, a comet is reported to "pass through more than 10 *xiu*" by meaning 10 LMs, see Pankenier et al., 2008, Ho, 1962 no. 106).

We can constrain the position further: since the object is mentioned to have *passed* LM 24, but not LM 25, we can exclude those stars of *Xuanyuan*, which lie in LM 24; since the list of LMs ends with LM 24, but not with LM 25, we can also exclude LM 26 (otherwise LM 25 would have been mentioned to have been crossed). A location in *Xuanyuan* and in LM 25 yields a right ascension range of 8 h 26 m 25 s (α Hya, determinant star LM 25) to 8 h 51 m 54 s (upsilon Hya, determinant star LM 26), while the declination range is given by the stars of *Xuanyuan*, which are also inside LM 25 (ε, μ, and 15 Leo), i.e. $\delta = 31.9 \pm 3.1^\circ$ (always epoch of date); we did exclude omicron Leo here, which is much further south, but this star was known well as " *Xuanyuan* right horn", mentioned otherwise often and being somewhat significant.

We now have a position (in *Xuanyuan*), but without a date. The sources of the second comet report give here further information: THY reported that an *ominous star* "seen at west (*xi*) direction" on June 9 (the most credible source for Ho no. 274, see Section 3.1); this is a clear date, but the position ("west direction") is not well constrained. From the *Chronicle of Zuqnīn* and Michael the Syrian (Section 4d), we know that the comet was seen in the evenings in the NW quarter since June 3 or 4, so that we may assume that the Chinese date (June 9) can be combined with the position in *Xuanyuan*, which was at that time indeed in the west. The sources for what was considered the second comet suggested that the observation on June 9 was a first detection of a new comet: it is plausible that this transmission originated from a different source and/or place, where due to rainy and foggy weather (see JTS), the observers did not see the comet before conjunction: maybe, the exact position provided (*Xuanyuan*) was later lost or got separated from the date – *Xuanyuan* is still present in all sources of the first report. This would then be a newly derived dated position, which was not considered before, in particular not for solving the orbit. The observation in *Xuanyuan* then took place at the beginning of the night June 9/10 at Chang'an, now Xi'an, mainly during astronomical twilight and a bit later, around June 9.58 UT (±1h). Still, because the combination of location and date is not fully certain, we will use in the orbit fit only the position, not the date. (The orbital fit below, Section 5, then provides a date for the position in *Xuanyuan*, namely indeed June 9.)

The text in THY gives the west azimuth: "intercalary 4[th] month, 21 [st] day (June 9), [an] ominous star seen at west (*xi*) direction"; XTS also gives the *west* azimuth. Therefore, we can constrain the position for June 9 to azimuth 270 ± 45°.[36] Together with the *Chronicle of Zuqnīn*, which gives NW quarter for this time span, we can reduce this azimuth range to 292.5 ± 22.5°. (The above determined position in *Xuanyuan*, probably on June 9, would also be within this azimuthal range.)

(C5) The final position is given as "reaching *Taiwei Youzhifa* 7 *cun* position" (JTS); THY: "reaching *Taiwei* west (*xi*), *Youzhifa* west (*xi*) 7 *chi*"; XTS omitted "*Taiwei*" and the separation, it has only "reaching *Youzhifa* west (*xi*)". The Chinese term for "reaching" (*zhi*) is regularly used for specifying the last position (see, e.g., comets up to AD 800 in Pankenier et al., 2008). The JTS record gives a precise position, just 7 *cun* within β Vir, the star *Youzhifa* in the western wall of the enclosure *Taiwei* ("Privy Council", the "Spring Palace of *Huangdi*", SK97); 7 *cun* correspond to only about 0.7 to 1°, indeed, the Chinese could give precisely an angle as small as about 0.7 to 1° (Kiang, 1972; Kiang, 1980; Stephenson and Green, 2002); another such case is found in AD 821 March 7 (JTS): "about 7 *cun* from the first star" (Pankenier et al., 2008). Conservatively, we use a position of 1° around β Vir[37] – the oldest text (JTS) did not specify that it was west of β Vir. We will test the 1° error circle in our independent orbit fit for AD 760 below.

Several practical and text-critical arguments speak in favour of such a small and precise value instead of 7 *chi* for about 7° in the later THY. If the comet would have been 7° west of β Vir, it would have been closer to σ Leo (in Chinese "*Xi shangjiang*" for "west upper general", SK97), both on the horizontal and the equatorial system, so that this star would have been mentioned in comparison. In the THY text, not only the separation "7 *chi*" is corrupt, but it also brings "west" twice: "reaching *Taiwei* west, *Youzhifa* west 7 *chi*". While β Vir indeed is in the western part of the *Taiwei* enclosure, it would not be necessary to specify this, because the Chinese name of β Vir, "*Youzhifa*", literally means "right law administrator" (SK97) or "right gate keeper" or "enforcer of the right" gate of *Duanmen*, "right" (*you*) on sky-view is "west"; the two stars β Vir and η Vir at the southern ends of the western and eastern *Taiwei* walls, respectively, were very significant as the two gate keepers or enforcers of the gate *Duanmen* (SK97). The hint "*Youzhifa* west" in THY and XTS may mean 7 *cun* west of *Youzhifa*, and it is indeed included in our 1° error circle around β Vir.

Furthermore, the *Taiwei* enclosure had particular importance in Chinese astro-omenology: while the north polar region was considered the palace, so that moving object (e.g. comets) or (other) guest stars could be used as portents for the court, the planets and the Moon of course do not move through the north polar region; hence, an additional area on sky was considered also relevant for emperor and court, which was close enough to the ecliptic, namely the *Taiwei* enclosure (Ho, 2003, p. 142). The movement of the comet toward β Vir, the right gate keeper of this enclosure, was therefore certainly closely watched – and we can trust precise measurements.

Down to which magnitude could the Chinese astronomers detect the

[36] Stephenson and Yau (1985) did not consider these data for the orbital reconstruction.

[37] Stephenson and Yau (1985) use 7° west of β Vir, based on THY, partly because the YK81 orbit would not allow a much closer approach, but the YK81 orbit is based on the positions in Kiang (1972), who used 1° west of β Vir on "around July 9" (the 54th day of those "more than 50 days") in their orbit fit leading to "rather more than 1°" (namely 3.5°) separation from β Vir on July 9. The orbital fit by Kiang (1972) for July 9 ended up at right ascension 158.2° and declination 7.3°, but this would be closer to upsilon Leo, the brightest star in the asterism *Mingtang*, so that this would have been mentioned in the historical report; upsilon Leo does not fit to 7 *chi* nor 7 *cun* off or west of β Vir. In Stephenson and Yau (1985), the closest approach to β Vir would be 3.7° on July 12, and a position of 7° west of β Vir would be reached on July 3, considered as "last visibility", but this is less than "more than 50 days" since May 17; a separation of 3.7° would not favour a figure of 7° off β Vir from THY (compared to about 1° from JTS).

comet so close to β Vir? Good naked-eye observers can resolve Mizar and Alcor (2.3 and 4.0 mag, respectively) at 0.2° separation (both known to pre-telescopic Arabic astronomers). In Ptolemy's Almagest star catalog (Toomer and Ptolemy, 1984), there are also a few close faint pairs, e.g. "the nebulous and double star at the eye [of Sgr]", which are ν^1 (V=4.9 mag) and ν^2 Sgr (V=5.0 mag) at a separation of only 0.2° at the epoch of the Almagest star catalog. Furthermore, Bedouine observers considered ν Cap (4.75 mag) as the *sheep* of α Cap (α^1 Cap has 3.55 mag), see Kunitzsch (1961, p. 101), their separation at epoch AD 760 was 1/3 degree only. While it may be uncertain whether *Tang* dynasty astronomers did resolve these pairs, they did present other close pairs separately on the *Dunhuang* maps: *Zui* with ϕ^1 Ori (4.4 mag), ϕ^2 Ori (4.1 mag), and λ Ori (3.7 mag) with mutual separations from 0.4 to 0.7°, and also λ Sco (1.6 mag) and υ Sco (2.7 mag) in *Wei* at 0.6° separation (epoch AD 700). Hence, the Chinese court astronomers should have been able to resolve a comet down to about 5.5 to 6 mag separated by about 1° from β Vir (3.6 mag), even if without tail.

The duration of visibility is given in JTS as "in all more than 50 days, only then [it] disappeared" (XTS: "[it was] not seen" instead of "disappeared"). In other observing records of comets, we find the wording of "more than" in combination with days in 10-day steps (Pankenier et al., 2008), e.g. 50 or 60 days; hence, "more than 50 days" means somewhere from 51 to 59 days. The 51st day since May 17 is July 6, so that the comet disappeared some time from July 6 to 14. This is consistent with the specification in XTS 32.838, "only [when] reaching 5 [th] month, [it] disappeared" (similar in THY), which means that it went out of sight sometime during the 5th lunar month ending on July 16 (new-moon on June 17 and July 17). (This is also consistent with the *Chronicle of Zuqnīn*, see Z5.)

While the number of days in connection with "in all" often are precise to the very day (e.g. Pankenier et al., 2008), the text seems to indicate that around the 50th day since May 17, the brightness of the object was still sufficient to measure a position as precise as "7 *cun*". The exact date may not matter much, because normally comets do not move much at the end of their visibility; we use July 5 ± 2 days (1σ error) as date for the last measurement for the orbit fit. The observation in the early evening of July 5/6 (±2d) at Chang'an, now Xi'an, was then at around July 5.6 (± 2d) UT.

We note that the first Chinese sighting on May 17 fits well with the Chronicle of *Zuqnīn* (May 18), also the motion toward the NE corner (*Zuqnīn*: until the night May 31/June 1), and the specifications toward the end of visibility: for June 29 or a bit later, the comet was newly detected in the SW quarter (*Zuqnīn*) – β Vir and, hence, the nearby comet were in the SW [quarter] at the beginning of astronomical twilight.

4. The comet of AD 760 as reported in further East Mediterranean and West Asian chronicles

In addition to the Chronicle of *Zuqnīn*, the comet of AD 760 was also mentioned as eastern and western comet in four other East Mediterranean and West Asian chronicles:

(a) Theophanes (died AD 817 in Byzantium) wrote his world chronicle in his last years:

"In the same year [AD 760/1] a brilliant apparition appeared in the east for ten days and again in the west for twenty-one" (Turtledove, 1982).

A duration of 10 days in the east (before conjunction with the Sun) and 21 days in the west (after conjunction) is slightly shorter but consistent with the reports from *Zuqnīn* (and China) for the comet of AD 760. Theophanes' chronology is sometimes uncertain by 1–2 yr (Mango and Scott, 1997) – here one year, since the Byzantine year runs from 760 Sep 1 to 761 Aug 31.

(b) Nuᶜaym ibn Ḥammād (died AD 843 in Baghdad, Iraq):

"We saw the comet rising in *Muḥarram* in the year [Anno Hijra, AH 145 = AD 762/3] with the dawn from the east, and we would see it during the dawn for the rest of *Muḥarram*; then it disappeared. Then we would see it after the sunset in the twilight, and afterwards between the north and the west for two month or three. Then it disappeared for two or three years."[38]

Given other dating errors in this quite apocalyptic Hadith collection, it may be dated to AH 143, i.e. AD 760/1 (Cook, 1999). With new-moon on 760 Apr 20 and May 19, the month of *Muḥarram* would run from AD 760 about Apr 21 to May 20 (±1 or 2 days depending on the first detection of the crescent moon), but the comet of AD 760 did not disappear at around May 20. However, the source used by Nuᶜaym ibn Ḥammād could have given the date on a western calendar system, e.g. as May, which would have been converted loosely to *Muḥarram*, probably based on a Christian source using e.g. the West Syrian Seleucid calendar as, e.g., the Chronicle of *Zuqnīn*. A scribal error is then required only for the year number (AH) "145", which should be 143. Then, the text would be fully consistent with the Chronicle of *Zuqnīn*: seen first since some time in the month of May of AD 760 in the morning dawn ("with the dawn", *Zuqnīn*: "*šafrō*") in the east and also like that for the rest of that month "during the dawn" (*Zuqnīn*: "*nōgah*") – instead of "rest of *Muḥarram*", we should read "rest of *iyyōr*/May"; the Chronicle of *Zuqnīn* reported the last visibility before conjunction with the Sun for the early morning of the night May 31/June 1 ("Pentecost"). Then, according to Nuᶜaym the comet was seen after conjunction "after the sunset in the twilight between the north and the west for two month or three", i.e. again similar as in *Zuqnīn* (for 25 evenings in the NW and later again for "many days"), after conjunction the comet was definitely seen in two different months (June and July). When Nuᶜaym ibn Ḥammād mentioned a reappearance "two or three years" later, he could either mean some other comet or transient object, or he could have interpreted the text in the Chronicle of *Zuqnīn*, which is found in the report for SE 1075 (AD 763/4), which is, however, again about the comet of AD 760: "The effect of 'the broom' seen a short while before, was clearly seen in reality, as it swept the world like a broom that cleans the house" (Harrak, 1999), see Section 2.1 for full citation (given that the Chronicle of *Zuqnīn* does not mentioned any other comet or celestial sign in between the comet report in AD 760 and this short statement later, it is likely that the latter short note points to the comet of AD 760). Therefore, given all the similarities (except the offset by 2 years), it is likely that the (direct or indirect) source used by Nuᶜaym ibn Ḥammād is the Chronicle of *Zuqnīn* – this would be the first hint that our chronicle was active before been buried in a Sinai monastery in the 9th century.

(c) Agapius of Manbij (died AD 941/2, Melkite bishop of Manbij (Syria), author of a world chronicle running until the 770ies):

"In this year [AD 760] the star with a tail appeared, and it was in Aries before the Sun, and the Sun was in Taurus. It proceeded until it was under the rays of the Sun, then went behind it and stayed 40 days" (Cook, 1999; Vassiliev, 1911), from which Cook remarks: "This observation is probably from Theophilus of Edessa himself". (Note that Cook (1999) incorrectly gave "and the Sun was in Leo", while the text clearly gives Taurus, see Vassiliev, 1911.) We will discuss this text with the next one, because they both depend on the same source(s).

(d) Michael the Syrian (AD 1126–1199, a patriarch of the Syriac Orthodox Church since AD 1166, author of a world chronicle): in the French translation of Michael's Chronicle by Chabot (1899–1910), this comet report was related to the *Zuqnīn* report on a comet in SE 1080 (AD 768/9), see Harrak (1999, p. 226) – presumably dated SE 1076 by Michael. The comet of SE 1080 in *Zuqnīn* was actually seen in AD 770 according to other well-dated oriental sources, while the comet record

[38] This report by Nuᶜaym ibn Ḥammād then continues with: "Then we saw a mysterious star with blazing fire the length of two degrees, according to what the eye saw, near Capricorn, orbiting around it like the orbit of a planet during the months of Jumada [July] and [some of the] days of Rajab [Oct] and then it disappeared" (as translated by Cook, 1999 with his additions in brackets, dated by him to AH 145 = AD 762/3). This and the following reports definitely do not belong to the comet in AD 760.

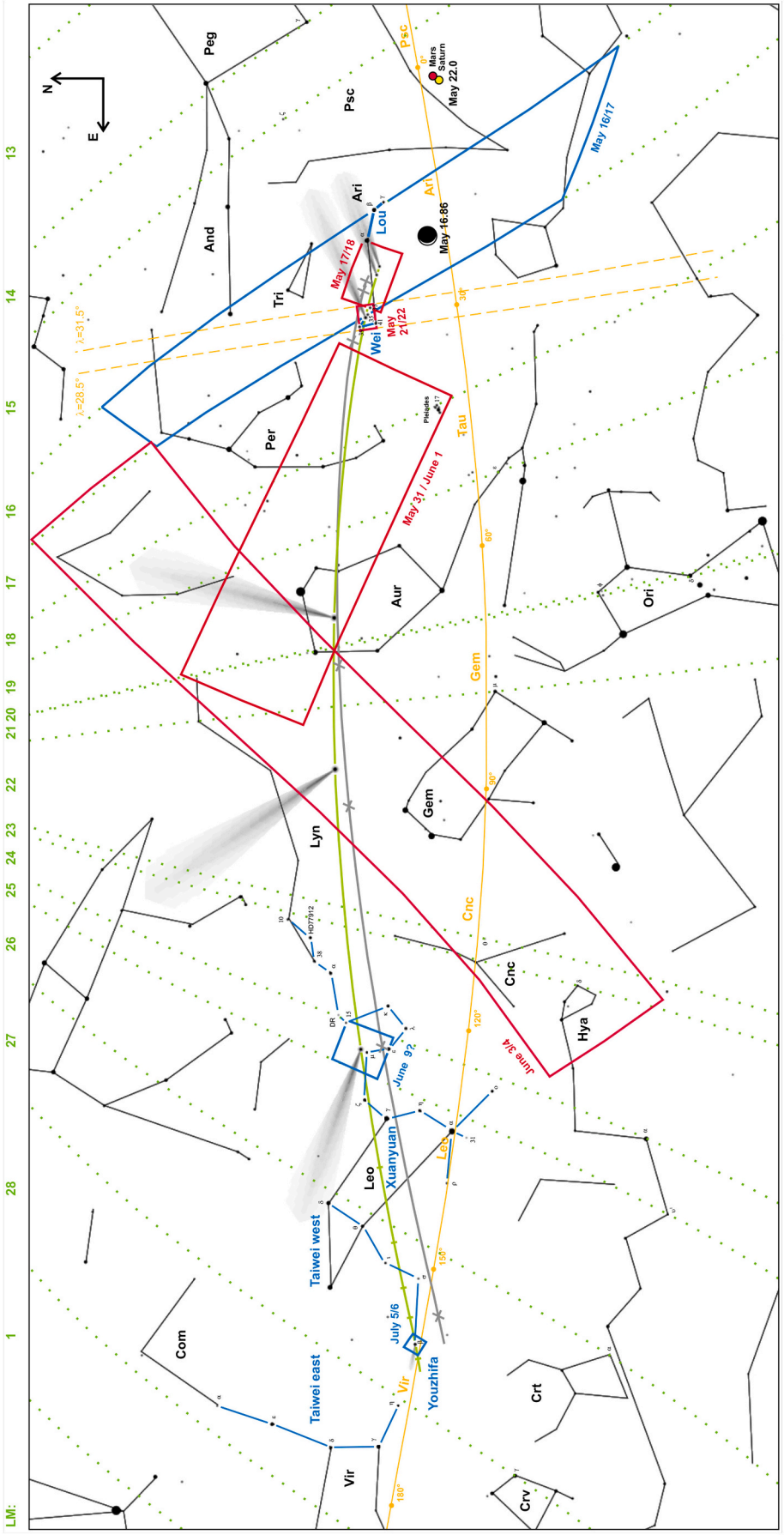

Fig. 8. This equatorial plot shows the whole comet path for the AD 760 perihelion (north up, east left): borders of the Chinese lunar mansions (right ascension ranges) are indicated as dotted lines (numbers on top) always going through their determinative star. The Chinese asterisms Lou, Wei, Xuanyuan, and Taiwei east and west (with Youzhifa in Taiwei west) are shown as blue skeletons. The ecliptic is shown as orange line with dots every 30° to indicate the borders of zodiacal signs. The planets Mars and Saturn are shown in close conjunction for May 22 at 0 h UT, the waning crescent moon for May 16.86 (UT). The positions derived here for the comet (Table 1) are shown as coloured boxes. Our new orbit is shown in green, the previous (YK81/JPL) orbit in grey, both from May 17 at 0 h UT (in Aries, right) until July 15 at 0 h UT (in Virgo, left), comet positions are shown as *comet symbols* on our new orbit on the dates of observation, and as crosses on the old orbit; the software *Cartes du Ciel* v3.10 shows the plasma tail directed away from the Sun. We can see that on June 9.58 (UT), the comet is indeed in Xuanyuan. Tick marks are shown on the new orbit on June 14.0, 19.0, 24.0, 29.0, and July 10.0 (UT) showing that the comet slowed down and got too faint (Section 5). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Keplerian elements of our best fitting orbital solution for the AD 760 perihelion passage of comet 1P/Halley (heliocentric ecliptic J2000.0) – first our best solution, then the JPL orbits for AD 760 and 1986 for comparison, than finally our parameters for non-periodic solutions. Our solutions are based on six astrometric data points observed within a span of time of 50 days. The best closed orbit has $\chi^2_{red} = 0.09$, clearly indicating that the given astrometric and timing uncertainties are overestimated.

Orbital parameters	our new orbit	JPL orbit (1)	JPL orbit (2)	Non-periodic
Epoch	760 June 2.0 JD=1,998,800.5	760 June 2.0 JD=1,998,800.5	1986 perihelion (JD=2,449,400.5)	Our solutions for AD 760
Perihelion time T_p	760 May 19.1 ± 1.7	760 May 20.671	1986 Feb 5.895317(5)	760 May 18.1–21.6
Eccentricity e	0.9667 ± 0.0016	0.96785	0.967142908(5)	(e=1)
Perihelion distance q	0.60 ± 0.02 au	0.58184 au	0.58597812(9) au	0.58–0.62 au
Inclination i	166.7 ± 2.2°	163.443°	162.262691(7)	165.2–168.2°
Argument perihelion ω	89.9 ± 8.5°	99.997°	111.33249(1)°	84.7–95.8°
Longitude asc. node Ω	40.1 ± 9.3°	44.687°	58.420081(9)°	31.3–46.7°
Period P	76.5 ± 6.7 yr (3)	77.0 yr	75.3 yr	–

Remarks: (1) based on YK81, but precessed to J2000.0 (Marsden and Williams, 2008), as given on ssd.jpl.nasa.gov without error bars; Yeomans and Kiang (1981) gave error bars on perihelion times for 9 other perihelia from AD 141 to AD 1301 as ±0.05 to ±1.7 days; the perihelion time for AD 760 in Yeomans and Kiang (1981) was fixed by historical observations, but just those from Kiang (1972) without any revision; Kiang (1972) fixed the perihelion time for AD 760 with two historical observations (revised by us) and obtained 760 May 22.5. (2) https://ssd.jpl.nasa.gov (error of last digit in brackets). (3) Calculated from q and e.

by Michael, presumably dated to SE 1076, obviously means the comet of AD 760 May (SE 1071)[39]:

"And in this year in the month of *iyyōr* (May), a comet star [*kawkbō qumiṭus* – the latter obviously from the Greek *kometes*] was seen before the Sun in Lamb (Aries), when the Sun was in Taurus. It looked like a pillar/column [*ʿōmūdō*] and was extending its rod[40] to the south. It moved close to the Sun for twenty days, and became below the rays of the Sun for three days. Thereafter, it was behind the Sun for forty days. Due to its appearance, fear gripped everyone."

The expression "and in this year" refers to SE 1076 (AD 764/5), if related to the preceding account which deals with an earthquake in Khorasan. However, chapter 25 of Michael the Syrian, in which the comet report appears, covers the period from SE 1066 to 1076 – this cast doubt about the expression "and in this year". When Michael the Syrian quotes large texts, he names his sources, but when he gathers information to include in a Chapter, he picks and copies, but not necessarily in chronological order.

This text by Michael the Syrian on a comet has many similarities to the previously studied reports, the relationship to Agapius of Manbij is obvious: Michael "a comet star", Agapius "the star with a tail"; Michael "before the Sun in Lamb", Agapius "in Aries before the Sun"; Michael "moved close to the Sun for twenty days", Agapius "It proceeded"; Michael "became below the rays of the Sun", Agapius "it was under the rays of the Sun"; Michael "Thereafter, it was behind the Sun for forty days", Agapius "then went behind it and stayed 40 days". Agapius says for the first sighting "the Sun was in Taurus" (before comet conjunction with the Sun), and Michael says the same: "when the Sun was in Taurus". There is otherwise no information in Agapius that is not found in Michael. However, Michael has a few extra details: "month of *iyyōr* (May)", "looked like a pillar/column and was extending its rod to the south" (c.f. Chronicle of *Zuqnīn*: "one was tilting to the south side"), "close to the Sun for twenty days", "below the rays of the Sun for three days", and the final astrological interpretation ("fear"). All information, in particular also the "3 days" of invisibility due to conjunction with the Sun, are fully consistent with the Chronicle of *Zuqnīn*, and actually confirms both the Chronicle and our close reading, e.g. regarding the first sighting in *iyyōr* (May) and the number of days of invisibility due to conjunction with the Sun.

The specification "It moved close to the Sun for twenty days" for the time before conjunction with the Sun (June 1) could point to a slightly earlier discovery than by all other observers (China since May 17; *Zuqnīn* May 18). This consideration is supported by the specification "Sun in Taurus", which is an alternative dating, namely the month when the Sun was thought to be in the zodiacal sign of Taurus, which was since antiquity set to Apr 17 to May 17 (afterwards in Gemini)[41]; if the same rule was applied with this date range, the observation started before May 18. The period of invisibility "for three days" during conjunction with the Sun (last seen by *Zuqnīn* the night May 31/June 1 in the morning) points to a reappearance on June 3 or 4 in the evening (see Section 2.6, position Z5). A visibility of 40 days after conjunction with the Sun is consistent with *Zuqnīn* (and China); the duration of 20 and 40 days could, however, be somewhat rounded.

According to Cook (1999), the text by Agapius (and then also parts from Michael) are probably based on an observation by Theophilus of Edessa, a Maronite Christian astrologer/astronomer, AD 695 (Edessa) to 795 (Baghdad). The transmission to both Agapius and Michael could also originate from the otherwise lost Chronicle of Dionysius of Tell-Maḥrē (died AD 845), a major source for Michael the Syrian, whom he extensively quoted for the 8th and the first part of the 9th century.

The comet of AD 760 has been reported and transmitted extensively by Christian scholars, and Nuʿaym ibn Ḥammād, the Muslim author of a Hadith collection, may had one of those Christian records as his source, namely the Chronicle of *Zuqnīn*. All positions and dates are compiled in Table 1.

5. Reconstruction and discussion of cometary orbit for AD 760

To summarize, the author of the Chronicle of *Zuqnīn* gives five, maybe even six dates with positions (mornings of May 18 and 22 relatively precise).

Modern studies of the Chinese records mention only two dates with positions, namely for the first and last observation (e.g. Kiang, 1972). Our close reading and historical-critical interpretation of the Chinese records yield corrected dates and positions as well as constraints on

[39] Our translation is based on Ibrahim (2009, pp. 477–478); for a French translation, see Chabot (1899–1910).

[40] What is translated as "rod" points to the tail. Chabot translated it as "chevelure", i.e. "lock of hair" (Chabot, p. 524 n.3). The 16th century Edessan manuscript emended the term *šabuqō* ("rod") to *šōbqō* ("emission"), and Chabot interpreted this word as (curled) hair.

[41] This rule is mentioned by, e.g., Pliny in his *Natural History*, namely that the Sun is located in a zodiacal sign from the 15 Calends to 16 Calends of the next month, also otherwise still in use in the 8th/9th century, e.g. by the Carolingians based on Bede citing Pliny (Wallis, 1999, p. 86). According to the 10th century Calendar of Cordoba, Al-Battāni (AD ca. 858–929) would have said that the Sun enters Aries on Mar 16 (McCluskey, 1998, p. 167). According to Byzantine practice (John of Damascus, AD 675/6–749), the Sun would be in Taurus Apr 23 to May 23 (Tihon, 1993).

Table 3
Residuals (O-C) of the best fitting orbital solution of comet 1P/Halley for its perihelion passage in AD 760 with their significances, listed in brackets, which take into account astrometric as well as timing uncertainties (we give the modern names of the towns, where the comet was observed, see Table 1).

Location	Dates 760	Δ RA (σ)	Δ Dec (σ)
Xi'an	May 16.86	−0.95° (0.18)	+1.75° (0.05)
Diyarbakır	May 18.00	−0.23° (0.09)	+0.62° (0.20)
Diyarbakır	May 22.00	+0.02° (0.01)	−0.13° (0.14)
Diyarbakır	Jun 1.00	−10.80° (0.66)	−1.19° (0.08)
Diyarbakır	Jun 3.74	−0.29° (0.01)	−3.28° (0.12)
Xi'an	July 5.60	+0.01° (0.01)	+0.05° (0.04)

further positions.

In total, we can derive from the Chinese and Syriac three dated positions with relatively small error bars (May 17/18, 21/22, and July 5/6), four with less well constrained positions, plus one well-constrained position without a certain date (in *Xuanyuan*, possibly on June 9). This may allow to fit an orbit for this perihelion passage only from historical sources (see Tables 1-3).

We used the software *find_orb* (version Nov 6, 2017, projectpluto.com/find_orb.htm) for fitting an orbit based on the dated positions in Table 1. Due to relatively large astrometric (±1° and more) and timing (±0.7h and more) uncertainties of these observations, a bundle of Keplerian orbital solution exists, which all fit the given astrometric data of the comet, but yield very different orbital properties. In order to explore the characteristics of these well-fitting orbits, in numerous runs the astrometric position as well as the observing time of the comet were randomly chosen for all observing dates within their given astrometric and timing uncertainties. In each run the best fitting Keplerian orbital solution was then determined by least squares fitting, which yielded the orbital elements of this orbit together with their uncertainties, taken from the derived covariance matrix. Thereby only runs were considered for further orbit characterization, which yielded orbital solutions with $\chi^2_{\rm red} < 2$, and 1 million such runs were carried out in total.

The vast majority of all runs (99%) results in non-periodic orbital solutions (eccentricity $e \geq 1$). The Keplerian elements obtained for the non-periodic solutions (e=1) are displayed in Fig. 9 and compared in Table 2 with those for periodic solutions and the current JPL orbits for AD 760 and 1986.

If the comet had an eccentricity $e \geq 1$, it would have had only one perihelion passage in the past (in AD 760). It is considered that the vast majority of naked-eye comets are long-periodic comets. The time span with particulary good data is relatively short, and one can see some potential in pre-telescopic comet records (see Introduction), so that it may be feasible to find more intermediate-period comets among them. In the context of our test case (comet of AD 760 with orbital solution from historical observations), we have to clarify under which conditions an identification with a known and, hence, periodic comet is possible.

According to the classical approach of Halley (1705, 1749), the orbital elements for perihelion passages have to be similar (except ω and Ω, which can change substantially from perihelion to perihelion, also of course T, see e.g. Yeomans and Kiang, 1981 for 1P/Halley) – or, even more, the periods between perihelia should be similar. Halley first tried parabolic solutions and then, since three had similar elements, he tried eccentric orbits and predicted the next return (Halley, 1705, 1749).

In our test case of comet AD 760, the parameters for parabolic and periodic solutions are fully consistent with the elements of 1P/Halley according to the JPL orbit (Table 2).

Nota Bene: For a comet with some 77 yr period, it is principally problematic to solve for the orbit with data from only a few months. Also Edmund Halley must have had this problem. In a similar approach, we have also solved for the orbit of the comet of AD 837, which turned out to be fully consistent with those of AD 760 and, again, comet 1P/Halley (D.L. Neuhäuser et al., in prep.; first results in D.L. Neuhäuser et al., 2018c and Mugrauer et al., 2018). The time between AD 760 and AD 837 is also fully consistent with the known period range of 1P/Halley. With the orbital elements q and e for closed orbits (Table 2), we estimate the period from the AD 760 data to be 76.5 ± 6.7 yr. (Furthermore, the light curve estimated with the absolute brightness and activity parameter as previously suggested for 1P/Halley, e.g. from recent telescopic observations, yield intrinsically consistent results for the AD 760 observations, see Fig. 14 below.)

Even when such conditions are fulfilled (and were also fulfilled in E. Halley's calculations), it cannot be totally excluded that a very unlikely coincidence happened, namely that the comet in AD 760 and also that one in AD 837 were both (different) non-periodic comets with very similar parameters – and similar to 1P/Halley (which then had to remain unobserved in AD 760 and AD 837). Even a confirmed prediction of a next return cannot prove the opposite. The comet cannot be observed all the time, but only near perihelion.

Since the comet of AD 760 shows clear indications of being consistent with a periodic comet, we will now consider only those solutions with eccentricity $e < 1$.

In 12,349 runs periodic Keplerian orbits were obtained, all with perihelion distances q larger than the solar radius, i.e. all are possible periodic orbital solutions around the Sun. Most of these closed orbits (~90%) are eccentric (0.33 < e < 0.99) and exhibit small semi-major axes in the range between 0.44 and 5 au (up to 11 yr period). The remaining orbital solutions are wider orbits (semi-major axis a > 5 au) which are all highly eccentric (e > 0.87).

In Fig. 10, we show the orbital elements for all closed solutions found. Most solutions for perihelion distance q and inclination i cluster within small ranges. The cumulative distribution functions of the Keplerian elements q and i from all solutions are shown in Fig. 11, their highest slopes (i.e. the peaks in the probability density distribution) are at $q \simeq 0.6$ au and $i \simeq 168°$ (i.e. retrograde).

We can now use these values for perihelion distance and inclination to clarify whether this combination of parameters is fulfilled by a known comet. As we show in Fig. 12, there is no comet known other than 1P/

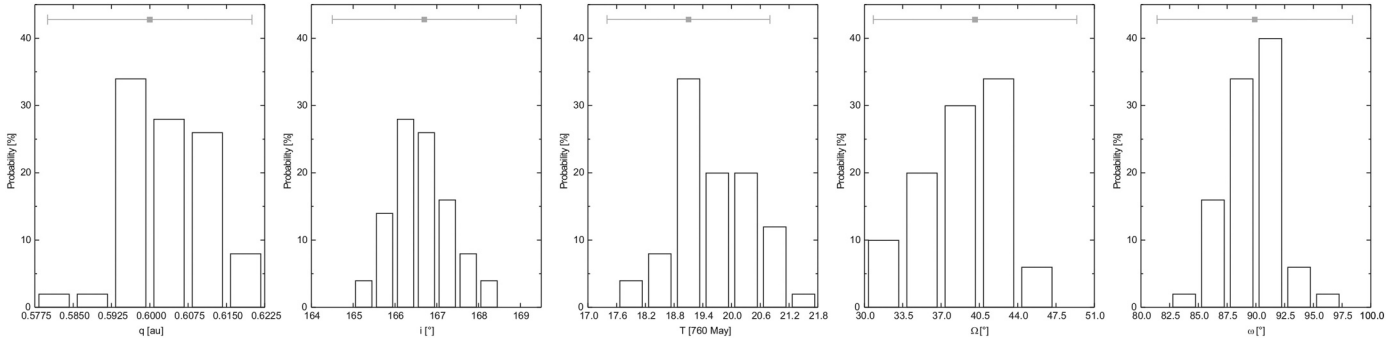

Fig. 9. Keplerian elements for non-periodic solutions (eccentricity e=1): They can be compared to (and are fully consistent with) the parameter ranges for periodic solutions with semi-major axes 17–19 au (Table 2, Fig. 13) shown as grey data points with error bars in the upper parts of the graphs.

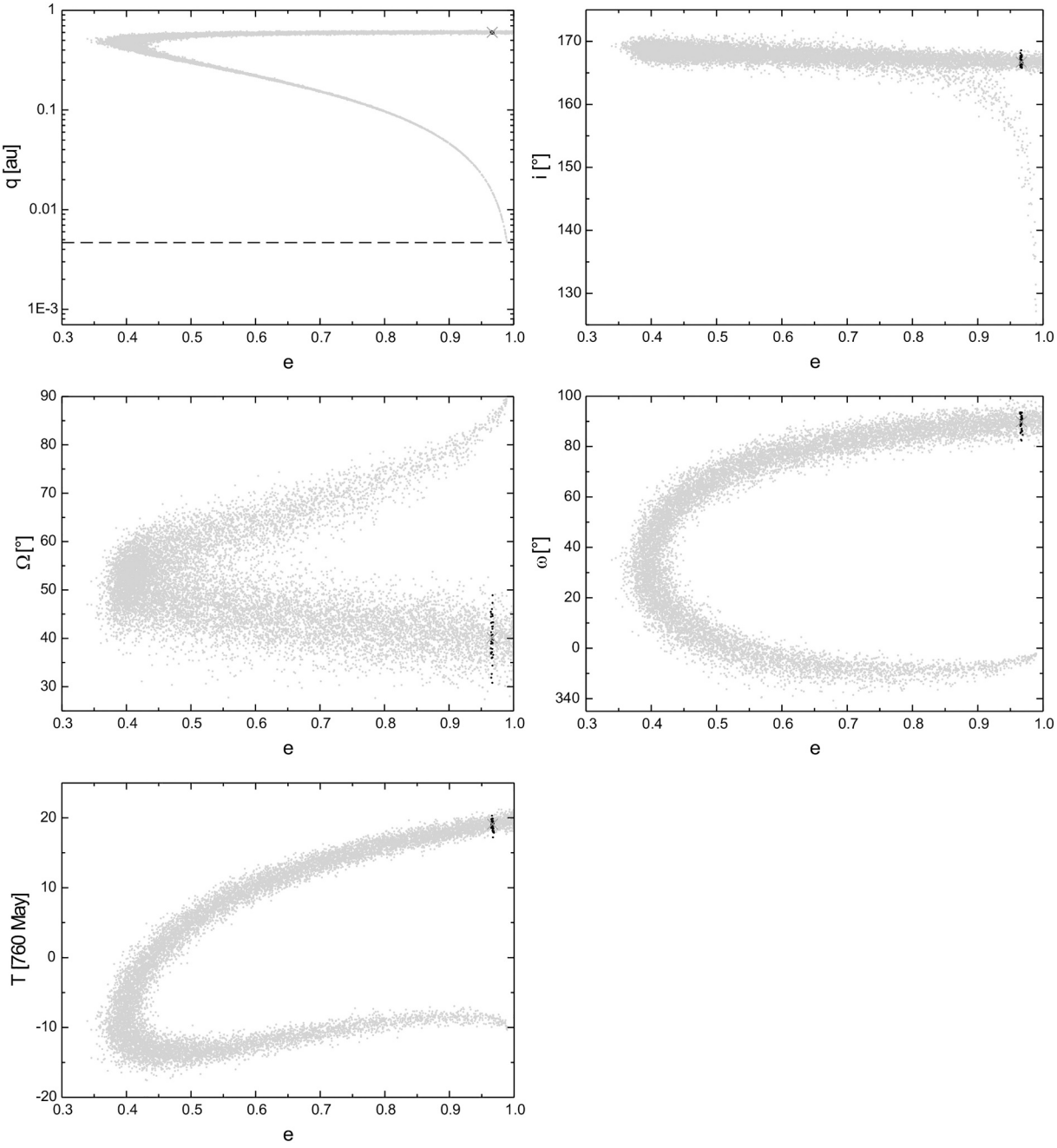

Fig. 10. Results from fitting the orbit: Correlations between the Keplerian elements, shown as light grey points, of all closed solutions found: perihelion distance q, inclination i, longitude of ascending node Ω, argument of perihelion ω, and perihelion time T (from top left to bottom). In the upper left, for q, we indicate the solar radius as dashed line. Since most solutions for perihelion distance q and inclination i cluster within small ranges, we can use these two to identify the comet of AD 760, see next two figures. Having identified the comet as 1P/Halley (Fig. 12), we constrain the solution to those with semi-major axes from 17 to 19 au as 1P/Halley – these are shown here as dark points, and the best fit among them as cross. For eccentricity $e = 1$, one can see the parameter range for non-periodic solutions.

Halley with similar values for q and i as our comet of AD 760, so that we can thereby identify the comet of AD 760 as 1P/Halley, see Fig. 12 caption for details.

Having identified the comet as 1P/Halley, we can constrain the solution to those with periods or semi-major axes as 1P/Halley – here conservatively to semi-major axes from 17 to 19 au. The best-fit solution among them and many similar ones exhibit a set of orbital elements, which is, within the uncertainties, the same as found for 1P/Halley, see Table 2.

The residuals of this orbital solution are summarized in Table 3. The best fitting orbit is shown in Figs. 3-8. We compare our new orbit with the one by YK81, which was, however, published without error bars. All the orbital elements are consistent within our 1σ uncertainties with YK81, except the inclination (consistent within 1.5σ) – but YK81 should have had similar if not larger error bars as our's (less historical constraints).

For the three dates with best positions (760 May 17/18 and 21/22, and July 5/6), the historically reported positions agree to within less than 1° with our orbital fit. Also for the other positions with large uncertainties, the new orbit passes through them. The position in *Xuanyuan* is indeed on June 9, as considered. The new orbit is well consistent with a position within 1° (within 0.2σ) around β Vir on July 5/6 (so that the text can indeed be 7 *cun* instead of 7 *chi*).

According to our new orbital elements, 1P/Halley has an orbital

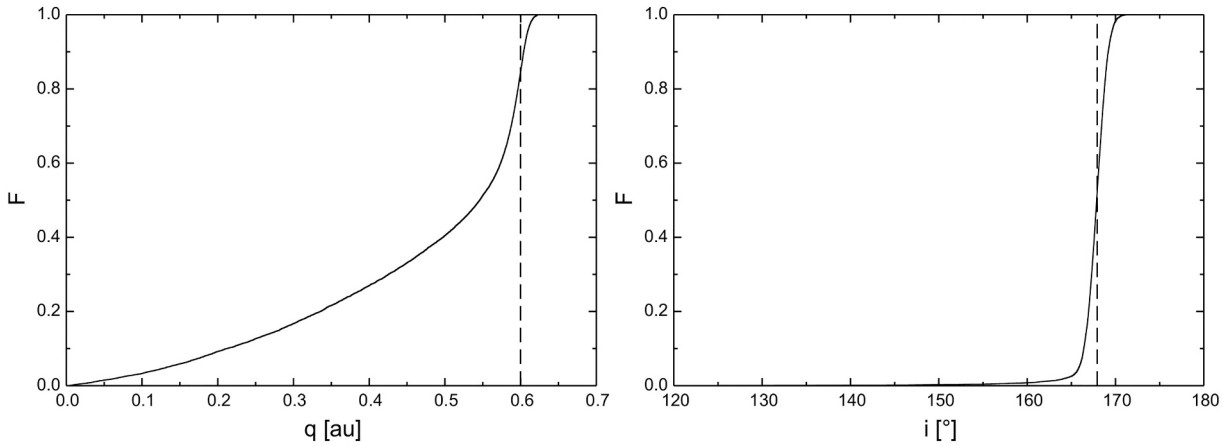

Fig. 11. The cumulative distribution functions for q (left) and i (right panel) (all solutions as in the previous figure): The highest slopes (i.e. the peaks in the probability density distribution) are indicated by vertical dashed lines and are located at $q \simeq 0.60$ au and $i \simeq 168^{\circ}$ (i.e. retrograde). We use these values for identifying the comet (Fig. 12).

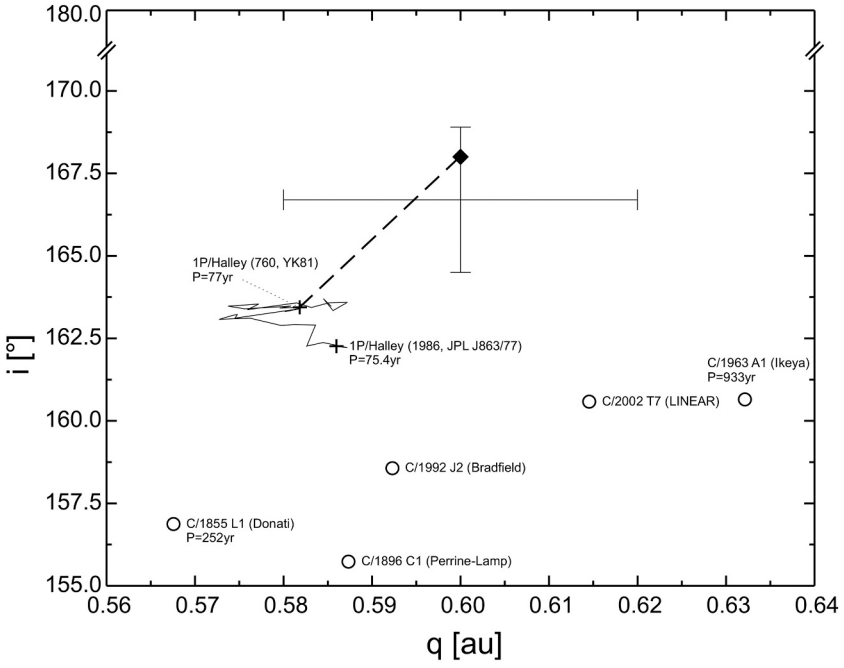

Fig. 12. Perihelion distance q versus inclination i. the comet of AD 760 (as constrained to $q \simeq 0.6$ au and $i \simeq 168^{\circ}$, Fig. 11, as diamond in the upper part) is compared to other presently known comets with values in the range of $i = 155 - 180^{\circ}$ and $q = 0.56 - 0.64$ au: C/1855 L1 (Donati) has a very uncertain period of about 252 yr, it was observed only for 14 days, C/1963 A1 (Ikeya) has a well-known orbit, but was not visible in AD 760; the three other comets shown as circles in the lower center are unperiodic. For C/1992 J2 (Bradfield) and C/1896 C1 (Perrine-Lamp) there is no evidence that they have periods less than many thousands of years, the case is similar for C/2002 T7 (eccentricity $e = 1.00048565(39)$, JPL 144, i.e. non-periodic). There are no comets with $i = 170 - 180^{\circ}$ in the plotted range for q. For comet 1P/Halley, we show the data pair for its perihelion in AD 1986 (plus sign) and all pairs from the orbital solutions in Yeomans and Kiang (1981) connected by a line (their data for perihelion AD 760 as plus), obtained from the JPL small-body database, precessed to 2000.0; the orbital elements from telescopic observations scatter more than those from extrapolation to pre-telescopic time. In the upper part, we show q and i of the best fitting solution for 17–19 au semi-major axes for the comet of AD 760: they are best consistent with comet 1P/Halley (YK81 did not specify error bars). Therefore, the identification of the comet in AD 760 as comet 1P/Halley is justified – for the first time for this perihelion only from historical data.

inclination of around 166.7° in AD 760; it was observed while being around inferior conjunction with the Sun. The *Chronicle of Zuqnīn* reports the last observation before (June 1.0, UT) and – together with Michael the Syrian – the first after (June 3.74 or 4.74, UT) comet-sun conjunction, and both are consistent only with our new orbit, while the conjunction is off by one day in the old (YK81) orbit – the precise dates of the invisibility of the comet at (inferior) conjunction turns out to be the most critical test of the orbital solutions (Fig. 14 lower panel). In the AD 760 perihelion, the comet had its perihelion passage on May 19.1 ± 1.7 (UT), its minimum solar elongation on 760 June 1.8 (UT) with 19.1° (unobserved the nights June 1/2 and 2/3), and then, on June 3.6 (UT), it had its closest encounter with Earth, namely 0.37 au.

Our new perihelion time (760 May 19.1 ± 1.7) is consistent with backward extrapolated orbits, e.g. perihelion on May 20.7 by YK81, May 20.7 by Landgraf (1986), and May 20.9 or 20.5 by Sitarski (1988), his table 5, for constant and parabolically changing non-gravitational forces, respectively. Offsets between the computed perihelion times (or conjunction with the Sun) and historically derived perihelion passages (or observed non-detection due to conjunction with the Sun) could be considered to be due to non-gravitational forces. However, since our perihelion time has an uncertainty of ±1.7 day (probably similar on the YK81 orbit), the difference is not yet significant; a precise determination of the conjunction with the Sun (e.g. explicitly reported non-detection close to the Sun as here in the Chronicle of *Zuqnīn* and by Michael the Syrian for two nights) can be considered as constraint on non-gravitational forces.

We have shown that it is possible to fit the orbit for this perihelion passage just with historical data, i.e. without extrapolating backward from modern telescopic observations. Given that all our dated positions as derived from historical texts are located quite centrally within the positional error boxes, our error bars are overestimated, i.e. conservative. The so-called standard orbit derived by YK81 from an extrapolation of telescopic data and then just fixed by problematic perihelion dates (first and last observation), is not inconsistent with our new, purely historically determined orbit, but there are also differences. We list here important results regarding the orbit:

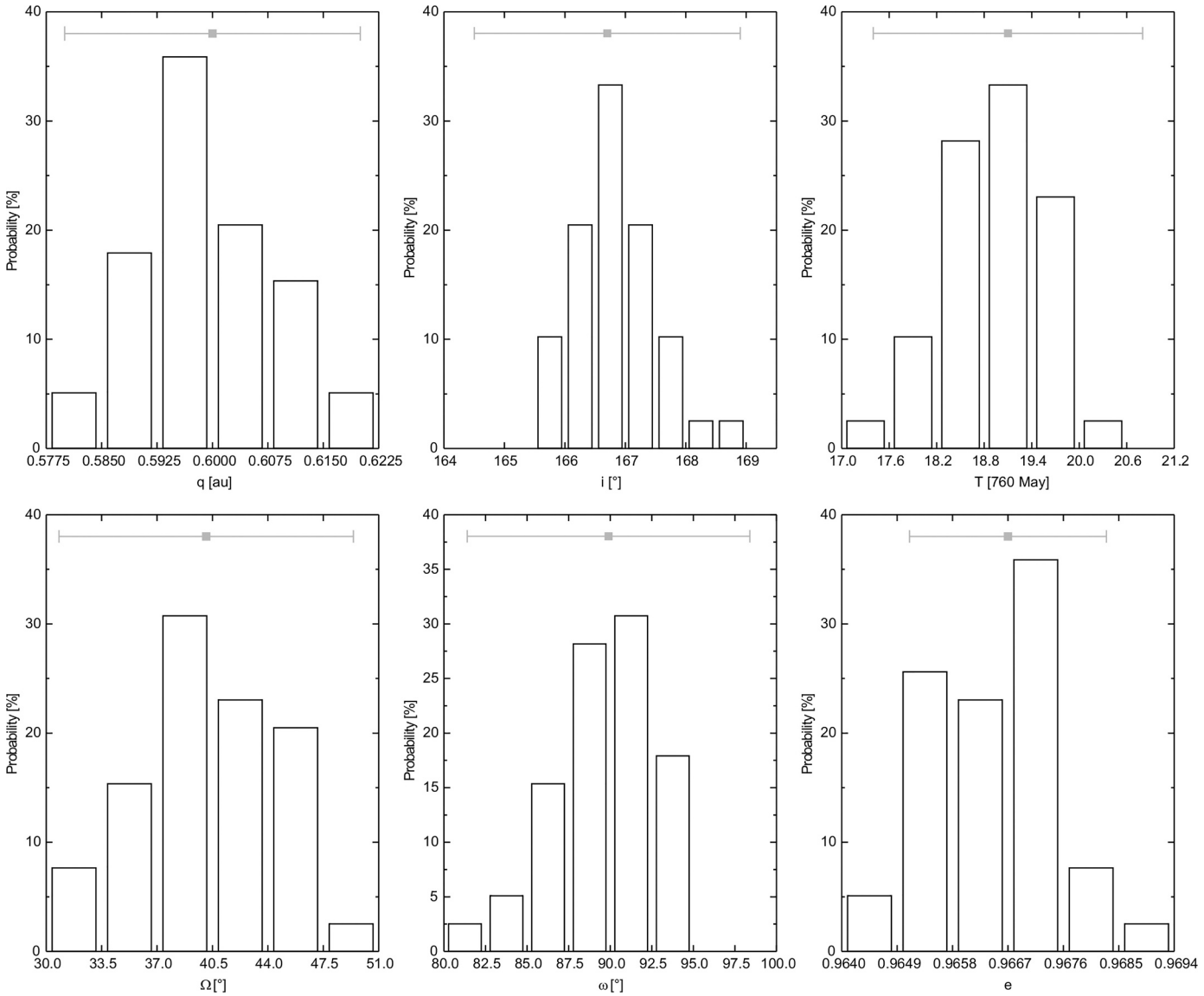

Fig. 13. Probability distribution of the Keplerian elements as found in the semi-major axes range of 17–19 au. Small grey squares with error bar indicate the best fitting solution (Table 2). The distributions of the elements correspond well with the elements of the best fitting solution – within their uncertainties.

- May 16/17 (C1): while the old orbit for this date is inside our reconstructed positional error box, the previously derived position between the asterisms of *Lou* and *Wei* may be correct only by coincidence, as we interpreted *Lou* and *Wei* as lunar mansions. (This is one of the two dated positions used by YK81 for fixing their orbit).
- May 17/18 (Z1): a new relatively precise dated position – the old orbit is consistent with it.
- May 21/22 (Z2): a new very precise dated position, the position of the old orbit is outside of our error box.
- May 31/June 1 (Z3): a new dated position – the old orbit is outside of this error box and located slightly below the horizon at the observational time derived by us (the YK81 orbit has the sun-comet conjunction in this night).
- June 3/4 or 4/5 (Z5): a new dated position, both consistent with the old (and new) orbit (Fig. 6).
- June 9/10 (C4): a new relatively precise position; the Chinese record did not explicitly gave the date for this position – probably June 9 was meant, which is consistent with both the old and new orbit.
- July 5/6 ± 2 (C5): our orbit fits the precise constraint from the most reliable Chinese text to be 0.7 – 1° ("7 *cun*") around β Vir, while the old orbit is too far off β Vir, and also not consistent with variant readings (Fig. 8). (This is one of the two dated position used by YK81 to fix their orbit extrapolated backward from telescopic observations.)
- Very slow motion since the beginning of July.
- Until June 27/28 or 28/29 (see Z5), the comet was located in the NW quarter since the start of astronomical twilight or earlier as recorded in the Chronicle of *Zuqnīn*.
- Around July 5, the comet was in the SW quarter at the start of astronomical twilight, which is probably reported in the Chronicle of *Zuqnīn*.

Then, both for the old orbit (YK81, JPL ephemeris) and our new orbit, we can estimate the apparent brightness m of the comet following

$$m = H + 5mag \cdot logd + 2.5mag \cdot n \cdot logr + m(\Phi) \quad (1)$$

with absolute brightness H in mag (defined as brightness m as seen from the Sun at a distance of 1 au), distance d in au between Earth and comet (well-known due to the orbit), activity parameter n depending on cometary and solar activity (n=2 for pure reflection), distance r in au between comet and Sun, and $m(\Phi) = -2.5mag \cdot \log \Phi$ as brightening due to light scattering on cometary dust with the phase function Φ, which is a compound Henyey-Greenstein function with $g_f = 0.9$, $g_b = -$

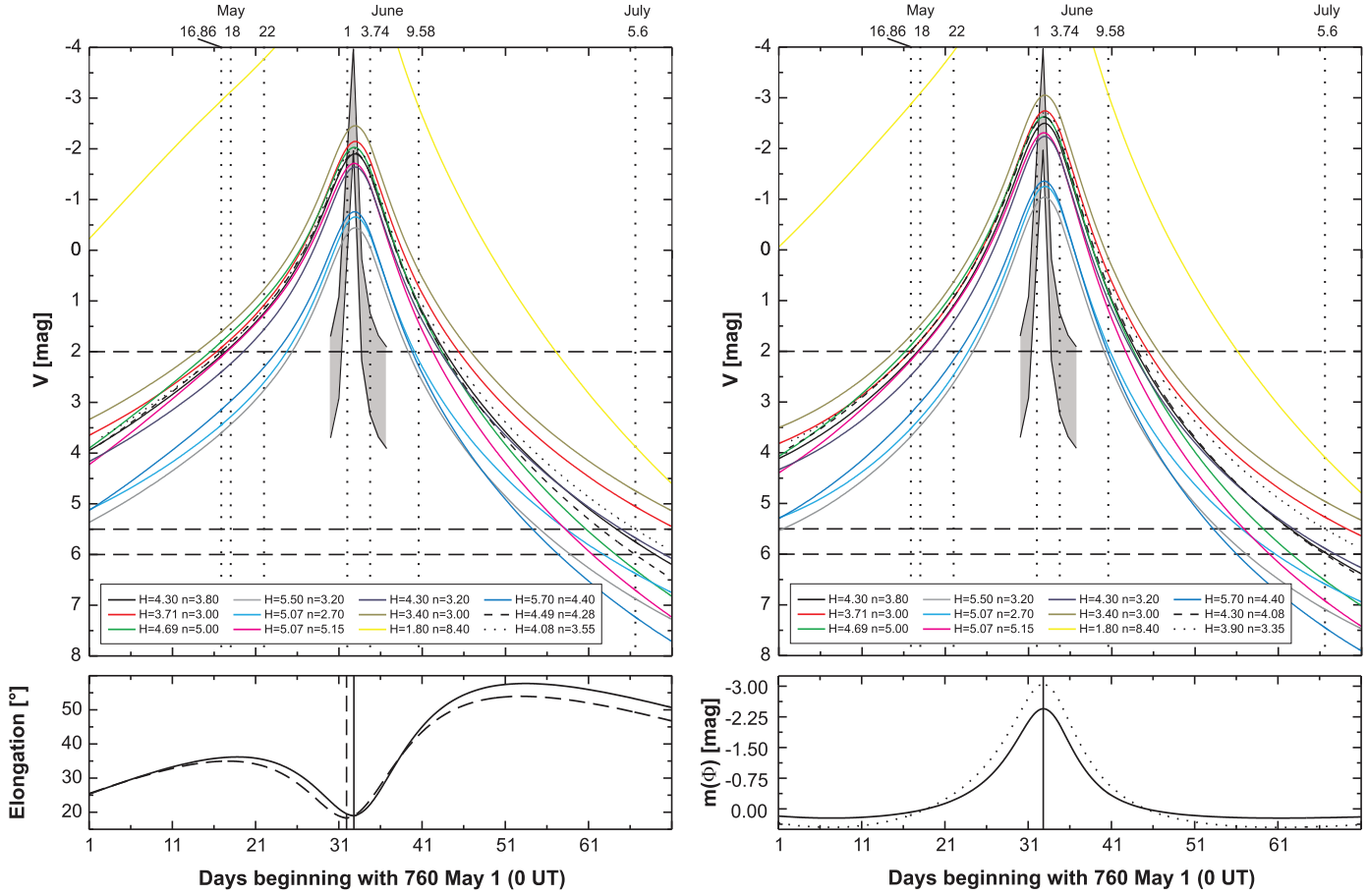

Fig. 14. Apparent brightness evolution for a usual comet, upper left panel: apparent brightness of comet 1P/Halley for our best fitting orbit during the perihelion passage AD 760 using Equ. 1 for usual comets with $\delta_{90} = 1$ (Marcus, 2007a, 2007b) in the phase function. We plot apparent V-band magnitude m (in mag) versus date until mid July (the difference between our new orbit and the old YK81/JPL orbit in terms of estimated brightness is only $\leq$0.1 mag). We plot the estimated magnitudes for all ten published parameter sets of absolute magnitude H and activity parameter n listed in Section 5. The comet was brightest around conjunction with the Sun early June. The vertical dotted lines indicate the observing dates (Table 1). The grey shaded area ($\pm 1\sigma$ error range) around conjunction displays the estimated background sky brightness at the location of the comet according to our new orbit – consistent with non-detection in the night June 1/2 (and probably also 2/3) as reported in the *Chronicle of Zuqnīn* and by Michael the Syrian. Two (horizontal) dashed lines are for 2 and 6 mag, which are the likely apparent brightness for first discovery (~2 mag) and last detection (~6 mag); assuming these two values and that both H and n would be constant during from first to last detection in AD 760, we fit H and n for this perihelion passage and obtain $H = 4.49$ mag and n=4.28 (bold dashed line) – but if we assume 5.5 mag for the last detection (very close to β Vir), we would obtain $H = 4.08$ mag and n=3.55 (dotted line). The fit from Broughton (1979) assuming first detection at 3–4 mag is shown as full pink line (one of the three bottom lines, H=5.7 mag, n=4.4). **Apparent brightness evolution for a dusty comet, upper right panel**: light curve as in upper left, but for dusty comets with $\delta_{90} = 10$ in the phase function (Marcus, 2007a, 2007b). Our best fit with 2 mag at discovery and 6 mag at last is now $H = 4.30$ mag and n=4.08 (bold dashed line), and $H = 3.90$ mag and n=3.35 (dotted line) for 5.5 mag for the last detection. The comet is now almost 1 mag brighter, even better consistent with detection until May 31/June 1 and non-detection for about the next two nights. **Elongation of comet 1P/Halley, lower left panel**: The full line is for our new orbit, the dashed line for the previous orbit (YK81) – the previous orbit, where conjunction happened on 760 May 31.9 UT (dashed vertical line) is inconsistent with the explicite last detection on June 1.0 UT, as reported in the *Chronicle of Zuqnīn*, but consistent with our new orbit, where conjunction is on June 1.8 UT (full vertical line). The first detection of this comet actually happened close to the maximal elongation (~36°) before perihelion passage. **Brightening of comet 1P/Halley due to light scattering by dust, lower right panel**: we plot the brightening $m(\Phi)$ (see Equ. 1) due to light scattering by dust for a usual comet ($\delta_{90} = 1$, full line) and a dusty comet ($\delta_{90} = 10$, dotted line). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

0.6, $k = 0.95$, and $\delta_{90} = 1$ for *usual* comets, but $\delta_{90} = 10$ for dusty comets (Marcus, 2007a, 2007b), which becomes relatively large in our case due to the large phase angle of the comet (up to ~149°, lower conjunction) resulting in significant forward scattering by cometary dust. When we reconstruct the light curve below, we will consider both cases, a usual and a dusty comet (Fig. 14). For the absolute brightness H, values from 1.8 to 5.7 mag have been estimated for 1P/Halley, and for the activity parameter n, values from 2.70 to 8.40 have been obtained:

- H=4.30 mag and n=3.80 (lightcurve. narod.ru/curves/0001p.html),
- H=3.71 mag and n=3.00 (Kronk, 1999),
- H=4.69 mag and n=5.00 (Kronk, 1999),
- H=5.50 mag and n=3.20 (ssd.jpl.nasa.gov),
- H=5.07 mag and n=2.70 (Yazdi, 2014),
- H=5.07 mag and n=5.15 (Yazdi, 2014),
- H=1.80 mag and n=8.40 for r=5.2 to 1.5 au for pre-perihelion (Green and Morris, 1986, 1987),
- H=4.30 mag and n=3.20 for r=1.5 to 0.6 au also for pre-perihelion (Green and Morris, 1986, 1987),
- H=3.40 mag and n=3.00 for r=0.6 to 2.9 au for post-perihelion (Green and Morris, 1986, 1987),
- H=5.7 mag and n=4.4 (Broughton, 1979, fit to 7 best historical returns).

Note that the parameters obtained for the 1986 return do not necessarily apply to the 760 perihelion and that the activity parameter n can be different before and after perihelion as observed 1986 (Green and Morris, 1986, 1987). Furthermore, 1P/Halley is known to have experienced major outbursts, e.g. five years after the 1986 perihelion (West et al., 1991; Sekanina et al., 1992), and also in 1835 ten weeks after perihelion (Sekanina, 2008).

For these ranges of parameters and the known orbit, we can estimate the apparent brightness of 1P/Halley, see Fig. 14. It was brightest during conjunction with the Sun, partly just due to forward scattering of light by cometary dust.

Except the highest and the three lowest light curve reconstructions in Fig. 14, all would indicate a brightness of around 2 mag for May 16/17 and 17/18, the time when it was detected first in China and by the Chronicler of *Zuqnīn* (according to Michael the Syrian, the comet may have been discovered as early as May 13). There is no historical supernova known, where the estimated brightness was fainter than about 1.5 to 2 mag when discovered by the naked eye (Strom, 1994; Clark and Stephenson, 1977). While comets are more readily detectable than novae or supernovae, because they often display tails and often emerge first near the ecliptic, Broughton (1979) assumed that the first detection of a comet would be possible at 3–4 mag, which may be very ambitious; Broughton's (1979) solution appears to be too faint around both the first and last detection (Fig. 14).

Once a new celestial object is discovered (or detected anew after conjunction with the Sun), one can follow it until about 6 mag. Indeed, most models consistently show that the comet was observed until it was as faint as 5–6 mag. If we assume that the comet was discovered at 2 mag and detected last when at either 5.5 or 6 mag, respectively, we can then obtain the best fit for the two unknown parameters in Equ. 1, and we obtain for this perihelion passage H=3.90–4.49 mag and n=3.35–4.28 for 2 mag at discovery and 5.5–6.0 mag at the last dated position. Please note that in principle the parameters H and n can change even during a time as short as the period of visibility in 760 May–July (e.g. during the close approach to the Sun), so that they would have different values before and after perihelion passage.

For the time around conjunction with the Sun (late May and early June), we also computed the sky brightness for the location of the comet according to our new orbit (considering Moon and Sun) at May 30.0, 31.0, June 1.0, and June 2.0, all UT (astronomical morning twilight for Diyarbakır) and for June 1.74, 2.74, 3.74, 4.74, and 5.74, all UT (i.e. around 20:45 h local time Diyarbakır) – using the *Skycalc* code (with the exact Julian dates as input, for 10°C temperature, 20% humidity, Snellen ratio 1, average experience, 50 years observer age, and a height of 675 m as for Diyarbakır now; the extinction coefficient is then 0.27 mag). The uncertainties of the limiting visual magnitudes are then around ±1 mag. As we see in Fig. 14, indeed, the limiting visual magnitude (or sky brightness) is fainter than most of the comet brightness reconstructions for before June 1 and after June 3, so that the comet was detectable, while in the nights June 1/2 and probably also 2/3, the comet was fainter than the limiting visual magnitude (hence, remains undetectable). There is a good consistency between the observing reports on non-detection, our orbit, and the brightness reconstruction. The comet is detected on May 31/June 1 (at June 1.0) – even though of the relatively bright sky – only when considering forward scattering by cometary dust: we can see in Fig. 14 left (usual comet) that the expected comet brightness on May 31/June 1 (and also 2 or 3 nights later) is just about the sky brightness, while in Fig. 14 right (dusty comet), the comet is expected to be brighter than the sky – this may possibly be seen as evidence that 1P/Halley was quite dusty around the AD 760 perihelion. (This might have been partly facilitated by cometary and/or solar activity, the latter was high anyway around AD 760, see Neuhäuser and Neuhäuser, 2015a, 2015b.)

Since both the *Chronicle of Zuqnīn* and the Chinese records reported the "sign" and "tail" to be "white", we deal with an observed dust tail. The Chinese reported two dust tail lengths: "4 *chī*" (~4°) for 760 May 17 and "several *zhang*" (tens of degrees) most certainly for 760 June 9 (in the west, in *Xuanyuan*). The drawing in the *Chronicle of Zuqnīn* (Fig. 1) shows for around May 25 as impressive tail, and the tilting is explicitely reported for the time before conjunction with the Sun. The software Cartes du Ciel v3.10, as used in our figures, calculates and plots the *plasma* tail directed away from the Sun.

6. Excursus: The precession constant as used implicitly

We can consider whether and which observational technique and precessional shift was applied by the author of the *Chronicle of Zuqnīn* when he specified so precisely the ecliptic longitude of comet 1P/Halley on May 22: "while it was still in the same Aries at its edge/end/furthest part: in/at the initial degree [of] the second [sign] (i.e. Taurus) from these wandering stars, (*kawkbē*) Kronos (Saturn) and Ares (Mars)", i.e. at the same time in the initial degree of the sign Taurus ($\lambda = 30°$) and still in Aries (at its end). Indeed, for the correct precessional shift at epoch 760.5, the stars at the end of Aries (33, 35, 39, and 41 Ari) had an ecliptic longitude of about 30°; also the fact that he mentioned Mars and Saturn in Aries on May 22 (Z2), correct to within 2°, is consistent with a correct precessional shift.

Given that he knows well the three brightest stars of Aries[42] and the other end of Aries and that he specifies a location in degree within an ecliptic sign, he may have had some basic knowledge of Ptolemy's Almagest (from the 2nd century): it describes in detail the setup of an armillary sphere, how to use it to measure positions of stars, and gives positions with ecliptic coordinates for some 1000 stars. A copy of this work could have been available in the monastery library in its original language Greek; there is no evidence that the author of the *Chronicle of Zuqnīn* could read Greek, and he did not even call the comet of AD 760 with the Greek word "kometes", as he did for some other comets reported by him before his own lifetime from other sources (where he probably found in his sources that the Greek would call them

[42] α, β, γ Ari were also listed as the three brightest stars in Aries in Ptolemy's Almagest, but α Ari was described to be located outside the Aries constellation figure. Yet, possibly following the Almagest, for the chronciler of *Zuqnīn*, these three (brightest) stars were particulary prominent. See also footnotes 7 and 15.

"kometes"). The author could speak Arabic (Harrak, 1999), but the first Arabic translation of the Almagest was probably undertaken later.[43]

There was also an earlier Syriac translation of the Almagest (Kunitzsch, 1974, p. 59). E.g., the Syriac scholar Severus Sebokht of Nisibis (AD 575–667), a Christian bishop of Kennesrin, south of Aleppo, Syria (see, e.g., Sezgin, 1978, p. 111), has written books about the constellations and the armillary sphere in Syriac (Nau, 1910); in the former, he mentioned the Almagest as well as other books by Ptolemy (Nau, 1929–30), so that it may well be possible that he even translated the Almagest to Syriac (or used an older version).

Even some 100 years before Severus Sebokht, there was already the work "On the Use and Construction of the Astrolabe" by Johannes Philoponos (AD 490–575), who lived in Alexandria as a monophysite like the monks of *Zuqnīn*. Jacob of Edessa (AD 633–708), a student of Severus Sebokht and a known source of the *Chronicle of Zuqnīn*, has written in Syriac about Ptolemy's Almagest and works by Philoponos (Wilks, 2008, p. 233). These works could have been available at *Zuqnīn*. The monastery library was well known to scholars in the area with valuable books by, e.g., Eusebius and Socrates, sources of parts I and II of the *Chronicle of Zuqnīn* (Palmer and Brock, 1993, p. 70).

Since the Chronicler otherwise never specifies any celestial position in degrees (nor any device or other observational tools), it appears unlikely that he used an armillary sphere. Of course, we can hardly exclude that he got this observational report (and drawing?) with the precise longitude measurement from some other source, e.g. a visiting astronomer, but the wording, vocabulary, and grammar in the Halley story is all very typical for the author of the *Chronicle of Zuqnīn*.

One can of course also specify the initial degree of Taurus without an armillary sphere: even if one would not know the location of the start (0°) of Taurus on sky, one can measure it easily (e.g. with a Jacob's staff) when knowing the start of Aries, i.e. the location of the vernal equinox (Aries 0°) and that the zodiacal signs were 30° long. The fact that the ecliptic longitude of the stars in the end of Aries (33, 35, 39, 41 Ari) agrees with the initial degree of Taurus for the correct precessional shift in AD 760 is still surprising; we can conclude that knowledge of the current location of Aries 0° and Taurus 0° was available at *Zuqnīn* at around AD 760. George, the so-called Bishop of the Arabs (about AD 686–724), did write about precession in Syriac, namely that "all fixed stars fall back by 1° in 100 years" from Ptolemy's Almagest, where the limit from Hipparch was given (see Ryssel, 1893, p. 53–54 and Sezgin, 1978, p. 112–114); this value could have been known to our Chronicler, but he did not adopt it.

In principle, one could also just take the ecliptic longitudes of the stars 33, 35, 39, and 41 Ari from Ptolemy's Almagest and then apply some precessional shift to the epoch of AD 760.5. To shift 33, 35, 39, and 41 Ari from Ptolemy's longitudes ($\lambda = 19°10'$, $19°40'$, $21°20'$, and $21°40'$, respectively) to $\lambda = 30°$ from the epoch given by Ptolemy himself ("beginning of the reign of Antonius", i.e. AD 137/8, see Toomer and Ptolemy, 1984, p. 340) to AD 760.5, i.e. $9.5 \pm 1.2°$ in 623 yr with 33 Ari ($9.1 \pm 1.1°$ in 623 yr without 33 Ari), one would need to apply a precessional constant of 1° in 65.6 yr (or 1° in 68.5 yr without 33 Ari), close to today's best value (1° in 71.6 yr).

Al-Ṣūfī (AD 903–986) wrote in his "Book on the Fixed Stars" (in around AD 964) about precession that "the authors of al-Mumtaḥen tables and those who came after Ptolemy confirmed it to be 1° every 66 yr" (translation to English in Hafez, 2010, p. 86). The star catalog *al-Mumtaḥen Zij* was composed under Caliph al-Ma'mūn (caliphate AD 813–833) by Yehyā b. Abi Mansūr (died AD 830 in Aleppo, today Syria). With a value of 1° in 66 yr, one would shift the longitudes of 33, 35, 39, and 41 Ari given by Ptolemy (adopted for AD 137/8) to 28.8 to 31.1° by AD 760.5, consistent with the initial degree of Taurus, i.e. about Taurus 0°. Hence, those rather precise values given in the *Chronicle of Zuqnīn* confirm information from *al-Ṣūfī*, namely that the value of 1° in 66 yr was known since long ago (maybe from India, e.g. Sezgin, 1978).

7. Summary and future perspective

Our main results and conclusions are as follows:

- We have solved the orbit of the comet in AD 760 for the first time just with dated positions from historical observations. The application of text-critical methods for the understanding of historical sources leads to substantial improvements – as our test case shows.
- We independently identify the comet of AD 760 as comet 1P/Halley; the backward extrapolation by YK81 is not inconsistent with our new orbital solution from historical observations alone – e.g., the comet-sun-conjunction on May 31.9 (UT) on the YK81/JPL orbit is not consistent with the detection on June 1.0 (UT), as reported in the *Chronicle of Zuqnīn*, but it is consistent with our new orbit.
- We re-visited the Chinese records in detail, revised the dated positions and found new ones; the two dated positions used by YK81 to fix their orbit are problematic, the Chinese sources give a less precise position at the beginning, and a more precise one at the end – only our new orbit can fit all dated positions.
- We obtained a precisely observed perihelion time (760 May 19.1 ± 1.7) – this could be used for fixing further backward extrapolations of the comet orbit.
- We argue that only one comet in AD 760 was transmitted in the Chinese sources – not two, as considered in previous papers.
- We studied the comet's brightness evolution and determined its absolute brightness and activity – it was first detected at around 2nd mag, brightest at comet-sun-conjuntion, and lost at around 6th mag; the observations are best consistent when including brightening due to light scattering on cometary dust.
- We have used for the first time the detailed observations in the *Chronicle of Zuqnīn* for the orbit determination of this comet; we found that the position given in the *Chronicle of Zuqnīn* for May 22 is not only precise (within 1–2°), but also implicitly uses a surprisingly accurate precession constant – hence, this knowledge was (somehow) available.
- The positions and dates from China and *Zuqnīn* are mutually consistent with each other and with Keplerian motion, further sources from the Mediterranean and West Asian area were re-visited (e.g. Michael the Syrian) and support our two main sources – therefore, the transmissions have high credibility. A text in a Hadith collection by Nu^{c}aym ibn Ḥammād may be based on the *Zuqnīn Chronicle* – hence, this Chronicle was not only buried.

There are further perspectives for future studies:

- With our improved methods, orbital elements of further periodic and non-periodic comets can be determined just from historical records (both from known and new sources); and for comets, where not enough historical positions are available, it may be possible to identify them by linking them to well-known comets. Then, also links to meteor showers can be revisited.
- For comet 1P/Halley, it may well be possible to refine orbital elements from other historical observations, e.g. AD 837 (in prep.), maybe even to quantify non-gravitational forces.
- The multidisciplinary approach and our methods of very literal technical translation, source- and text-critique, as well as close reading can yield improvements in the correct understanding of historical records about celestial observation in general – in particular for positions of other transient phenomena like supernovae and novae.

[43] The Almagest was translated to Arabic first under Yaḥyā b. Khālid (AD 786–803 vizier of Caliph Hārūn al-Rashid, died 805), probably around AD 791 (Sezgin, 1978, p. 18), then by or under Abū Ḥassān and Salm (director of the Bayt al-ḥikma, some kind of science and translation academy, under Caliph al-Ma'mūn, reigned AD 813–833), both lost, and then by al-Ḥajjāj ibn Maṭar (AD 786–833), all mentioned by Ibn al-Nadim; al-Ḥajjāj's version is extant as an almost complete 11th century copy, from which al-Kindī cited the Almagest; and there are also two MSS with copies of an older version, namely by Isḥāq b. Ḥunayn (AD ca. 830–910) extant in Thābit b. Qurra's version, late 11th century (Kunitzsch, 1974, pp. 17–41).

Declaration of Competing Interest

None.

Acknowledgments

We would like to thank Peter Stein (U Jena) for his additional help with two details regarding the Syriac text. We acknowledge the Vatican Library for providing digital scans of the *Chronicle of Zuqnīn*. We are grateful to Jean Bonnet-Bidaud (CEA Paris) for further information on the *Dunhuang* maps and to the late Paul Kunitzsch (LMU München) for advice on the Syriac and Arabic versions of the Almagest. We also acknowledge advice from Alden Mosshammer (UC San Diego) on the Easter dating problem in AD 760. We used orbital data for comet 1P/Halley from JPL (ssd.jpl.nasa.gov), the software *find–orb* for fitting a new orbit, and John Thorstensen's Skycalc code (www.k3pgp.org/star.htm). We are grateful for very competent reviewing of two anonymous referees.

Appendix A. Appendix

In Fig. 15, we present the Syriac text from the *Chronicle of Zuqnīn* in transliteration. For the Syriac hand writing, see Fig. 1. A translation to English is found in Section 2.

In Fig. 16, we present the Chinese texts. Translation to English with partial transcription are found in Section 3.

Appendix: Syriac text

(in transliteration)

šnat alfō w-šabʿīn wa-ḥdō [bold point]

b-īraḥ iyyōr etḥazyat ōtō ḥewōrtō ba-šmayō [bold point]

qdōm šafrō [weak point] b-garbay madnaḥ [weak point]

b-malwōšō haw d-metqrē emrō [weak point]

l-garbyō men hōlēn tlōtō kawkbē [weak point] d-beh yatīr naṣīḥīn [weak point]

w-dōmyō-wōt b-eskīmōh [weak point] l-makneštō [weak point]

kad tūb īt-wō beh b-emrō b-rīšeh [double point]

b-mūrō qadmōytō $\overline{\text{b}}$ men hōlēn kawkbē ṭōʿayō [weak point]

qrōnōs w-arīs [weak point] a(y)k da-l-taymnō qalīl [weak point]

b-ʿesrīn wa-trēn beh b-yarḥō [bold point]

w-katrat hī ōtō laylāwōtō ḥamešta ʿsar [weak point]

ʿdamō l-nōgah ʿīdō d-penṭīqosṭī [bold point]

w-ḥad man rīšōh haw qaṭīnō [weak point]

yatīr bahūrō kawkbō metḥzē-wō b-rīšeh [bold point]

w-ṣōlē-wō l-afay garbyō [weak point]

haw dēn ḥrīnō patyō w-yatīr ʿamūṭō [weak point] ṣōlē-wō l-afay taymnō [weak point]

w-ōzlō-wōt qalīl qalīl l-madenḥay garbay [bold point]

eskīmōh dēn hōnā-w [4 points forming a rhomb]

nōgah dēn tlōtō d-bōtar penṭīqosṭī etḥazyat tūb b-ʿedōn ramšō [weak point]

men garbay maʿerbay w-katrat ramšē ʿesrīn w-ḥamšō [bold point]

w-ōzlō-wōt qalīl qalīl l-taymnō [4 points forming a rhomb]

w-tūb ebdat [bold point]

w-hōydēn hefkat etḥazyat b-maʿerbay taymnay [weak point]

w-hōkanō tamōn katrat yawmōtō sagīyē [weak point]

Fig. 15. Transliteration of the Syriac text on the comet of AD 760 (see also Fig. 1 and Section 2).

Appendix: Chinese sources

JTS 36.1324

唐肅宗……乾 元 ……三年四月丁巳夜五更，
彗出東方，色白，長四尺，
在婁、胃間，疾行向東北角，
歷昴、畢、觜、參、井、鬼、柳、軒轅，
至太微右執法七寸所，
凡五十餘日方滅。
閏四月辛酉朔，
妖星見于南方，長數丈。
是時自四月初大霧大雨，
至閏四月末方止。
是月，逆賊史思明再陷東都，
米價踊貴，斗至八百文，
人相食，殍尸蔽地。

JTS 10.258

丁巳夜，彗出東方，
在婁、胃間，長四尺許。

THY 43.767

唐肅宗……乾元三年四月二十七日，
彗見于東方，在婁胃閒，
色白，長四尺，疾行向東北，
歷昴畢觜參井鬼柳 軒轅宿，
至太微西，右執法西七尺許滅，
凡經五十餘日。
上元元年閏四月二十一日，
妖星見于西方，
長數丈，至五月滅。

XTS 32.838

肅宗……乾元三年四月丁巳，
有彗星于東方，在婁、胃間，
色白，長四尺，東方疾行，
歷昴、畢、觜觿、參、東井、輿鬼、柳、軒轅，
至右執法西，
凡五旬餘不見。
閏月辛酉朔，
有彗星于西方，長數丈，
至五月乃滅。
婁為魯、
胃、昴、畢為趙，
觜觿、參為唐，
東井、輿鬼為京師分，
柳其半為周分。
二彗仍見者，荐禍也。
又婁、胃間，天倉。

XTS 6.162-3

四 月 ……
丁巳，有彗星出于婁、胃。
己未，來瑱為山南東道節度使，
以討張維瑾。
閏月辛酉，有彗星出于西方。
……
己卯，大赦，改元，賜文武官爵。
……
是月，大饑。張維瑾降。

Fig. 16. The Chinese texts from JTS, THY, and XTS on the comet of AD 760 (see Section 3).

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