Icarus 420 (2024) 116165

Contents lists available at ScienceDirect

Icarus

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

New and improved orbits of some historical comets: 6TH and 7TH centuries

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ARTICLE INFO

Keywords:
Comets
Data reduction techniques
Orbit determination

ABSTRACT

Five comets from the 6th century and three from the 7th century are studied. In some cases, new orbital elements are provided, or existing ones are refined to better fit the observations. In addition, comments are presented on specific questions raised by other authors about these historical comets, such as their periodicity, association with meteor showers, or even their mere existence. We consider in particular the cases of C/539 W1 and 1P/607H1 (Halley), both particularly interesting from a historical point of view and for the questions they raise in this regard. Finally, we also examine the proposed membership of some 6th-century comets to the Kreutz Sungrazer group.

1. Introduction

Following our aim of re-examining or proposing orbits for medieval comets in the light of contemporary European data, in this paper, we present the study of some comets from the 6th and 7th centuries. Given that in our previous paper we already explained the methodology and the formulas used, we refer the interested reader to this document (Martínez et al., 2022). Although we will take advantage of Oriental sources, European and Arabic records will also be used, for our study, when they provide relevant data.

The total visual magnitude of the coma H, is obtained from the well-known formula (Meeus, 1998):

$$H = m - 5log\Delta - 2.5nlogr \tag{1}$$

being m the visual magnitude, Δ and r the geocentric and heliocentric distances (in au), and n the photometric index, assumed as $n = 4$ to provide the standard total magnitude H_{10}.

Sometimes the tail length appears accurately stated in the texts and can be a tool for specifying or choosing a set of orbital elements. Reliable assessments may be obtained using Kammerer's formula (Kammerer, 1994):

$$logL = -0.26(\pm 0.01)H_e + 2.25(\pm 0.07) \tag{2}$$

that provides the length of the tail in millions of kilometers, being H_e the heliocentric magnitude, $H_e = m - 5log\Delta$. Formula (2) was later used by De Donà (1997) to simulate the longitude of the tail in degrees ψ:

$$sin\psi = \frac{L}{TF} sin\theta \tag{3}$$

being TF is the linear distance from Earth to the end of the comet's tail. Since meteorological data are rarely included in manuscripts, transparency and visibility conditions may be far from optimal, significantly affecting the parameters estimated in (1) and (3), which therefore need to be considered with some care. Through the paper, we use Julian dates. As specified in our previous paper, the orbital elements, in heliocentric ecliptic J2000.0, were obtained using Find_orb (version March 17, 2019, projectpluto.com/find_orb.htm) and software developed at Sormano Observatory. Unless otherwise is specified, star charts have been drawn using MAPPA2 (v. 5.8).

The integration of the orbital elements has been arranged using the Horizons Command-Line Interface from the JPL (see https://ssd.jpl.nasa.gov/horizons/ for details) or RA15 (Radau) integrator (Everhart, 1985) from the package Mercury 6 (Chambers, 1999; Chambers and Murison, 2000).

2. European context and general sources

The situation in the European territory, broadly understood as the area corresponding to the ancient Roman Empire and extending

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https://doi.org/10.1016/j.icarus.2024.116165
Received 6 March 2024; Received in revised form 16 May 2024; Accepted 5 June 2024

throughout the Mediterranean basin, was complex in the 6th and 7th centuries. The Western Roman Empire had completely disappeared as a distinct and separate political entity, and almost anything remained of its social and economic structure.

The various invasions of Germanic peoples of the previous century had given rise to settlements that, after the 5th century, began to play a significant role in Western Europe, while new communities of Slavs established in the east: Britain was invaded by Angles and Saxons, Ostrogoths occupied Italy, Visigoths were in Spain and southwest France, Burgundians in southeast France, and Franks in the north France. The latter being the first Germanic people to develop a large and stable kingdom in the early 6th century in Northwestern Europe.

As for the eastern part of the ancient Roman Empire, known as the Byzantine Empire, resisted barbarian invasions and survived until the 15th century. Political power was centralized in the emperor and the capital, Constantinople, reaching its peak in the 6th century, during the reign of Justinian I, when milestones were produced, including the creation of the Justinian code, the most important code of laws of the time, or the conquest of Italy and North Africa, which involved control of the Mediterranean. However, the great plague epidemic of AD565 weakened the entire structure of the Empire. In addition, although the Byzantine Empire survived the siege of Constantinople in AD627, the appearance of the Arab Caliphate in the 7th century caused the loss of more than half of its territory, including the African and Eastern provinces. Later, for centuries, Byzantium was forced to maintain a defensive position against the Muslims (from the east and south) and the Slavic peoples (from the north).

Perhaps no event of the 7th century was more significant in shaping our modern world than the Muslim expansion. Prophet Muhammad emerged into historical prominence in Mecca around AD610, when the Qu'ran was said to have been first revealed to him. He began teaching in Mecca before migrating in AD622 to Medina, the Hijrah, with his companions, an event that marks the first year of the Islamic Calendar. Muhammad died in AD632, but the spread of Islam continued under his successors. Byzantine and Sasanian forces were regularly defeated, first under the Rashidun Caliphate and then in the 7th century by the Umayyads. By the mid-7th century, Mesopotamia and Persia were also under Muslim domination, and the Sasanid Empire had ended.

The birth and expansion of Islam are generally referred to in Western chronicles as the rising of a great evil, supported by celestial signs as omens that include mentions to great eclipses and comets.

This period also saw a change in the system of reckoning the years, which would not be popularized until the 8th century, with the Venerable Bede. Until the 6th century, years had been defined by the Roman consuls who held the position that year. Dionysius Exiguus (in Assemani (1721)) first invented the Anno Domini dating system in AD525, calculating that 525 years had elapsed between the birth of Christ and his time. This way of counting time would gradually replace the others.

A climatic phenomenon also had significance in the 6th century: in AD536, temperatures in the Northern hemisphere dropped up to 2.5° Celsius, triggering catastrophes throughout Europe. Although the exact cause is unknown, it is believed to have been the result of a volcanic eruption in Iceland or North America (there are many papers dealing with this historical topic (see, e.g. Sigl et al. (2015)). Crop failures, famine, and countless plagues, exacerbated by the dropping temperatures, were recorded by many medieval scholars.

Another constant during these two centuries was the decrease in size and population of inhabited cities in the Germanic kingdoms of Western Europe and the Byzantine Empire. The decay of life in the cities and high-volume trade across the ocean was accompanied by a cultural degeneration. Literary production suffered setbacks and slowed down, concentrating around monasteries and some courts of significant figures.

Since AD420, China had been divided in two in a period known as the Northern and Southern dynasties but was reunited again under the Sui and then Tang dynasties towards the end of the 6th century. In China, literacy never declined as drastically as it did in the Roman Empire.

As regards Western astronomical records, an extensive database has been collected by the authors, based on information contained in cometographies like those in the first volume of Kronk (1999) or Pingré (1783) and other catalogs such as Biot (1843) or Williams (1871).

For the Eastern reports, we refer to three geographical areas: China, Japan, and Korea, and the work of Ho (1962), Hasegawa (1979, 1980, 2002), and Hasegawa and Nakano (2001). We consider in particular the book of Pankenier et al. (2008), who corrected some dating errors and provided careful and updated translations of Eastern records.

Concerning Chinese documents, the main sources remain the same as for the 5th century including the *Wei Shu* (AD572), *Jinshu* (AD635), or *Nan shi* (AD670), which are contemporary and may contain eyewitness testimony for this period.

Japanese and Korean documents are once again of little relevance in this period and appear only sporadically. Only Japanese Nihon shoki (720) and Korean secondary sources were used, the latter mainly deriving from three official history books: *Amagasaki* (AD1145), *Goryeosa* (AD1451) and *Joseonwangjosillok* (AD1392–1863) described in detail by Yang et al. (2005).

Our major European source for the 6th and 7th centuries has been the *Monumenta Germaniae Historica* (*MGH,* http://www.mgh.de/ (in German and English)), along with other little-known documents from Spain, Portugal and Italy, from both collections and individual sources. In particular, they cover from fragments of annals and chronicles, the main genres of historical writing in the Middle Ages. In the 6th century, the most interesting are the *Chronographía* of Ioannes (1831), the *Historia Francorum* of Gregory of Tours (Gregorius Turonensis, 1561), the *Chronicon* of Marcellinus Comes (1894), and the *Chronicon* of Victor of Tunnuna (Victor Tunnunensis, 1866). From the 7th century, on the other hand, mention can be made of the *Chronicon Paschale* (Chronicon Paschale ad exemplar Vaticanum recensuit, 1832), the *Historia de Regibus Gothorum, Vandalorum et Suevorum* by Isidore of Seville (Barney et al., 2006), and the *Chronicle of Fredegard*, see Fredegarii Scholastici (1699). Specifically, England saw the copying of older books and the composition of original literature, which was rare elsewhere in Western Europe at that time. The English churchman Bede (672–735) composed a history of England's people to describe how the Anglo-Saxons had adopted Christianity (Beda, 1838).

Chronicles in Europe and neighboring countries were written in Latin and vernacular throughout the Middle Ages. There remains the problem, which already appeared in the 5th century and was present in later centuries, of the interpretation given by the scribe to various natural phenomena in the literary sources (Neuhäuser et al., 2021), so it is necessary to examine the context carefully. The same events are sometimes reported in different years, perhaps also due to transcription errors from the original manuscripts. However, this change could also be deliberate to make them coincide with particular political or social events. In this sense therefore, the study of the context, the origin of the manuscript, and the reliability of its author are essential elements for choosing the best solution.

3. Overview of 6TH century comets

As previously stated, this century was marked by the settlement and creation of several kingdoms of Germanic origin in Western Europe and by the figure of Emperor Justinian, whose long reign of 38 years determined an entire era in the politics and society of the time, in Eastern Europe. Many remarkable events occurred during this period, including the promulgation of the *Corpus Iuris Civilis*, the epidemic known as the “plague of Justinian”, the long war against the Goths, and the sack of Rome by Totila after a prolonged siege in AD546.

During the 6th century, no <22 comets were detected and reported in Eastern or Western literary sources. Among all of them, the passage through the perihelion of 1P/530Q1 (Halley) stands out. Excluding the latter, only three of these comets have provided enough data to allow the computation of tentative orbits or improve the currently published ones (see Table 4).

Since we will also use data from oriental sources, it is worth mentioning that Eastern astronomers divided the Celestial Sphere into Lunar Mansions (LM henceforth) defined by determinative stars. The names of the 28 asterisms are also used for the 28 LMs, which from the Western perspective, are right ascension ranges from the determinative (or leading) star of one LM to the next. We must warn that when it is indicated that a comet is located within a certain LM, it does not follow that it is necessary inside the asterism with the same name. It could just mean that the comet was about the same Right Ascension range. For convenience, the names of the LMs that appear in this paper, along with their determinative stars, are listed in the appendix.

Some comets of the 6th and 7th centuries appear to belong to the possible Kreutz Sungrazers (KS henceforth) lists. In particular, England (2002) assumes six KS comets for these two centuries, while Hasegawa and Nakano (2001) consider only one in the 7th century. England has come up with a ranking between 0 (not a sungrazer) and 10 (definitive sungrazer), based on ten properties, including brightness, tail length, and characteristic motion across the sky. All comets proposed for these centuries have a low rank. However, we will briefly discuss those cases where new information from European sources may help clarify the question.

3.1. C/539 W1

The primary contemporary Eastern sources for this comet are *Wei shu* (c. AD554) and the *Sui shu* (AD636) (Ho, 1962; Pankenier et al., 2008), which show its possible path through Sagittarius, Capricornus, Aquarius, Pisces, Pegasus and Aries. There is a consensus about the date of the first observation, November 17, but the last visibility remains more doubtful. For some scholars, this would be December 1, AD539 (Burckhardt (1807), Williams (1871), Ho (1962), Yeomans (1991)), while others prefer January 30, AD540 (Pingré (1783), Hasegawa (1979), Kronk (1999)). However, since Eastern astronomers are generally considered to have followed comets until they were no longer visible, whereas European observers only recorded observations until the object was no longer conspicuous in the celestial sphere, the current agreement is around December 27, AD539, for western and January 30, AD540, for eastern observations.

As mentioned above, C/539 W1 has several literary references from Europe and Asia, which provide assorted data. These data have been the subject of numerous controversies that are beyond the objectives of this paper (see, e.g., Kronk (1999)). Using the translation of Pankenier et al. (2008), the *Wei shu* and the *Sui shu* report that the comet appeared on November 17, AD539 in NANDOU [LM 8], pointing SE and disappeared after reaching LOU [LM 16]. An important point is a statement in the *Wei shu* about the comet's approach to a distance of 3 chi (3–4°) from Venus at the end of November.

Of all the European records, the most detailed is that of Procopius (c. AD553), who states that *the comet appeared, at first, as long as a tall man but later much larger. And the end of it was towards the west and its beginning towards the east, and it followed behind the Sun itself. For the Sun was in Capricornus, and it was in Sagittarius (…), it was seen for more than forty days* (Procopiis, 1833). This is an especially valuable report because it comes from an individual who presumably witnessed the phenomenon. For a discussion of this paragraph and other minor European sources and how they may help to fit an improved orbit, see Martínez and Marco (2021) and Sicoli et al. (2023).

The first scholar who attempted to calculate an orbit for this comet was Johann Karl Burckhardt (1773–1825), who obtained two different sets (Burckhardt, 1807), but the currently accepted orbit was proposed by Hasegawa (1979). According to this author, the comet was detected at sunset in Sagittarius. Later, as it moved away from the sun and its brightness decreased, it moved towards the north of the celestial sphere. Two especially relevant phenomena occurred on November 24 and December 11, when the comet was still at its maximum brightness, consisting of the transit a few degrees from Venus and about 10° from Jupiter, respectively.Three other sets of orbital elements were calculated (Sicoli, 2020; Martínez and Marco, 2021, and Sicoli et al., 2023), considering different interpretations of the comet's apparent approach to Venus (see Table 1). The paths of the comets from these orbits are shown in Fig. 1. (See also Fig. 4.)

First, we will discuss the characteristics of the comet based on each of the calculated orbits. One of the major problems concerns its magnitude and visibility in the days or months before its perihelion passage. For instance, Kronk (1999), using Hasegawa's orbit, took a magnitude of $H_{10} = 0.5$ assuming that the Chinese astronomers followed the comet until it vanished. Considering this date as January 30, the comet's magnitude must have been around 5.5. This also means the comet would have been perfectly visible in September at sunrise, reaching a negative magnitude in October with an elongation that would have made it visible even in twilight. Comparing the magnitude curves of Hasegawa's orbit and the one obtained by Martínez and Marco (MM henceforth) shows that a magnitude of $H_{10} = 0.8$ would be compatible with the assumptions under which the orbit that we present in this paper has been calculated, which provides a much less bright comet that, in addition, would have been invisible on the dates before perihelion due to its proximity to the sun. Sicoli's comet, even if it had also reached a considerable brightness, would not have presented visibility problems prior to its perihelion passage due to its apparent position close to the sun.

On the other hand, the contemporary descriptions do not depict the AD539 comet as a particular impressive phenomenon since the Japanese chronicles assign a length of one zhang or one chi (about 10° or about 1°) at the time of its discovery and one zhang at the time of its approach to Venus. We have simulated the tail of the comet using Kammerer (1994), see details in Martínez et al. (2022). The estimate of the tails of Hasegawa's and Sicoli's comets does not correspond to these characteristics (see Fig. 3) since they would have exceeded 80° in length. Both comets would have had a tail length consistent with the sources taking $H_{10} = 6$ but, in this case, the behavior would be the opposite of that indicated by the records, with a tail that would decrease in length instead of growing, as indicated by the sources. In addition, its visibility period would be drastically cut to the point of ceasing to be visible long before the sources indicated (See Fig. 2).

Jenniskens et al. (2020) proposed a relationship between the 15-Bootids[1] and C/539 W1 after obtaining the orbital parameters of this

Table 1
Different sets of orbital elements for C/539 W1 (heliocentric ecliptic J2000.0).

T (UT)	q	e	ω	Ω	i	Source
539 Oct 21	0.341	1.0	256	60	10	Burckhardt (1800)
539 Oct 21	0.341	1.0	75	240	10	Burckhardt (1800)
539 Nov 6	0.16	1.0	246	33	19	Hasegawa (1979)
539 Nov 1.5	0.28	1.0	262	55	14	Sicoli (2020)
539 Nov 4	0.36	1.0	274	57	11	Sicoli et al. (2023)
539 Oct 31	0.63	0.9931	253.35	33.27	19.19	Martínez and Marco (2021)*

We have included both the orbit calculated by Burckhardt for completeness. (*) This set is the result of integrating the orbital elements of 15-Bootids, and then adapting the perihelion time based on historical observations (see text).

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[1] Currently, 15-Bootids is a meteor shower included in the working list maintained by the IAU with number #923 (https://www.meteornews.net/2019/07/17/outburst-15-bootids-fbo923/).

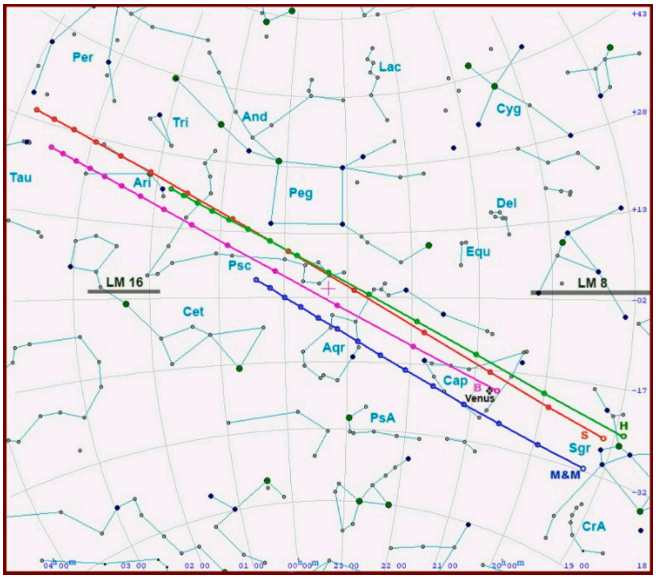

Fig. 1. Path of comet C/539 W1 (step 5 days) from Nov. 17,AD539 (blank circle) to Jan. 21, 540 CE from orbital elements, included in Table 1: (H) Hasegawa (Green), (S) Sicoli 2023 (Red), (B) Burckhardt's first orbit (Pink), and (MM) Martínez and Marco (Blue). For convenience, the widths of the two LMs are shown as grey lines on the celestial equator. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

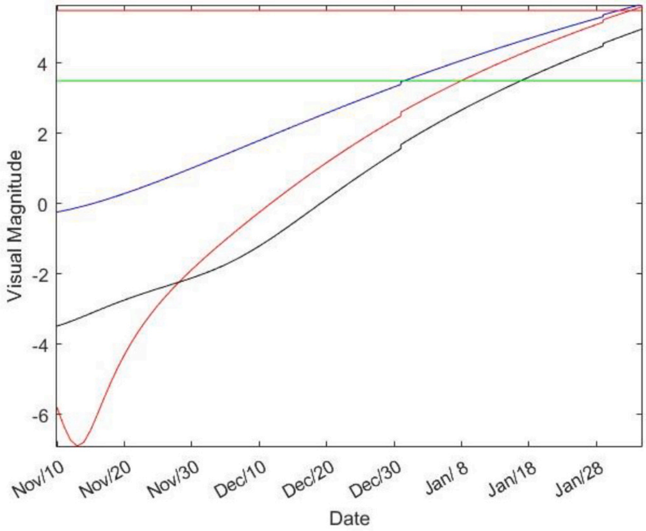

Fig. 2. Apparent magnitude of comet C/539 W1 using Hasegawa's orbital elements (red). MM (blue), and Sicoli 2023 (black) The red horizontal line represents the limit of naked eye visibility $m_v = 5.5$, the green horizontal line stands for $m_v = 3.5$, the approximate magnitude at which a comet is first discovered by a naked-eye observer. We have used an $H_{10} = 0.8$ for all the comets, slightly higher than the suggested by Kronk (1999). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

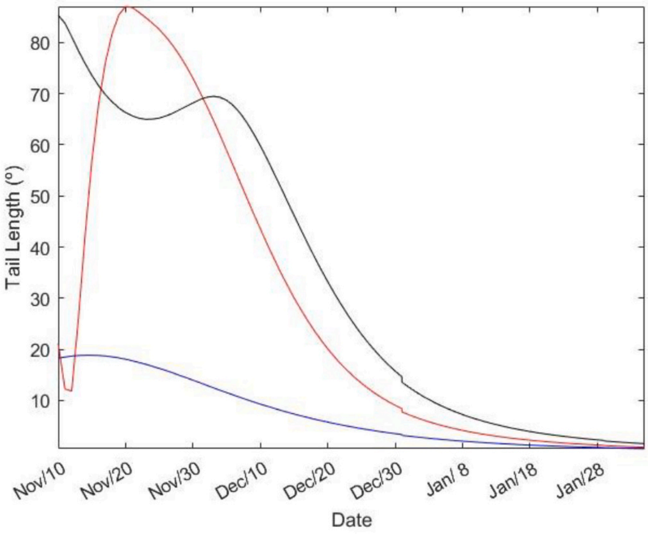

Fig. 3. Simulation of the tail length for C/539 W1 using Hasegawa's orbital elements (red), MM (blue), and Sicoli's 2023 (black), $H_{10} = 0.8$ for all the comets. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

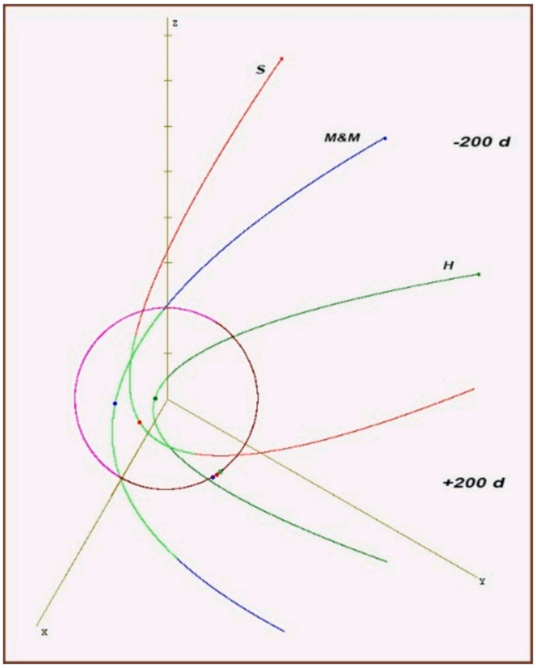

Fig. 4. Earth and comet C/539 W1 positions at the comet's perihelion, in an axonometric oblique projection according to three different orbits: S (Sicoli 2023), MM (Martinez and Marco 2021) and H (Hasegawa, 1979).

meteor shower and comparing to the ones calculated by Hasegawa for the comet, finding a good agreement between them, except for the perihelion distance. According to the orbit proposed by MM, on April 4, AD539, the distance from Earth's orbit to the comet's descending node was <0.02 AU, which makes this proposal feasible. Notice that, in general, comets with Earth minimum orbit intersection distance (MOID) within 0.1 au can produce observable meteor showers (Jenniskens et al., 2021).

Following this idea and considering their suggestion about a possible return of the parent comet in the middle of the 13th century, a further research was carried out by Martínez and Marco (2021), finding that comet C/1245D1 met the required criteria so it could be a suitable candidate to consider. Since we do not intend to repeat the process followed in that paper, we will limit ourselves to giving the general lines: In the first place, the orbital elements of the 15-Bootids (see Table 2) were integrated backward to the 13th century, and then we revised the perihelion date, which provided a new perihelion passage time for AD539 after a new backward integration. The AD1245 and AD539 new

Table 2
Orbital elements of the 15-Bootids and sets of orbital elements (referred to J2000.0) for the two assumed observed perihelion passages of the 539 CE comet.

T (UT)	q	e	ω	Ω	i	Source	P (yr)
15-Bootids	0.64	0.964	254.9	30.9	18.9	Jenniskens et al. (2020)	–
539 Oct 31	0.63	0.9931	253.35	33.27	19.19	1st perihelium	872
1245 Mar 13 ± 20	0.62	0.9923	254.36	31.75	19.31	2nd perihelium	722
Around AD2004	0.63	0.9927	255.85	30.13	19.46	3rd perihelium	801

The second perihelion passage would correspond to C/1245 D1. We have added the next perihelion passage in the 20th century calculated from the orbital elements of 539 CE, which must be considered merely speculative since a search through the databases has not provided results to identify it with any observed comet. The P column shows the period in years obtained from the orbital elements.

sets of orbital elements obtained were finally used to recalculate a new orbit for C/539 W1 (See Martínez and Marco (2021) for details), which met the conditions of magnitude, visibility, and the close approach to Venus. The paper provided an orbit for comet C/1245D1, considering it as a second perihelion passage of the comet of AD539 (and that, therefore, would be a long-period periodic comet) and supported the relationship between this comet as parent comet of the 15-Bootids. Thus, a secondary aim was to show the possibility that the comet of 539 CE was also the one detected AD1245, which, in this case, would have different orbital elements than those calculated by Hasegawa but, as we will see, it is completely compatible with the contemporary observations.

In what follows, we have carried out a recalculation of the process outlined in the previous paragraph. For this, we have used RA15 (Radau) integrator (Everhart, 1985) from the package Mercury 6 (Chambers, 1999; Chambers and Murison, 2000). The model of the Solar System used in the integrations included eight planets, and the Earth and Moon were considered as a barycenter. It should be emphasized that the reliability of the results obtained considering long periods has been questioned by Kornos et al. (2015). They found that the results in a long integration were disturbed not only depending on the method used but also on small variations in the perihelion date. In our case, we found that it is not the perihelion date of the original comet (that of AD539) that significantly influences the integration but the eccentricity value. Thus, taking $e = 0.9930$, we get that the next perihelion would occur in AD1231, whereas with $e = 0.9931065$, the perihelion would be on March 13, AD1245.

Regarding the possibility of comet C/1245D1 as a return of C/539 W1, we have carried out new computations considering the more accurate orbit obtained for the former (see Table 1, MM). On this occasion, the orbital elements have been calculated by different feedback processes after performing forward and backward integrations in time. Let us recall that the primary sources of information on C/1245D1 come from Japan (Pankenier et al. (2008)). From them, it can be deduced that the comet's visibility period ocurred between AD1245 February 24, when it was detected in the SE, and April 4. On February 25, the comet was seen southeast of TIANSHIYUAN in the space of DOU [LM 8]; On February 26, it was seen south of lunar mansion NIU [LM 9], where it would also remain on February 27 and 28. However, on February 27, it could not be observed due to bad weather. Finally, on March 30, the comet was found between SHI [LM 13] and BI [LM 14]. This comet was also recorded in a contemporary European source, the *Annales* Stadenses (1826), as a new reddish star that appeared "*about the time of the Ascension*" in the area of Capricornus (see Martínez and Marco (2021) for details and a discussion).

According to the integrations, the comet would have had two perihelion passages after the sixth century (see Table 2), being the first that of the comet previously denoted as C/1245D1:

From the orbital elements in Table 2 and choosing March 26, 1245 as the perihelion time, the calculated path of comet C/1245D1 may be seen in Fig. 5. With this parameter, the characteristics of the comet are fully compatible with the data from the literary sources.

According to the set of orbital elements given in Table 2 for the AD539 perihelion passage, comet C/539 W1 would have a semiaxis of about 91 au and a period of about 870 yr. This means that it is a long-period comet (LPC), whose possible associated meteor shower would have some characteristics studied by Jenniskens (2006) and Jenniskens et al. (2021). As an LPC, the comet is supposed to decay near the sun,

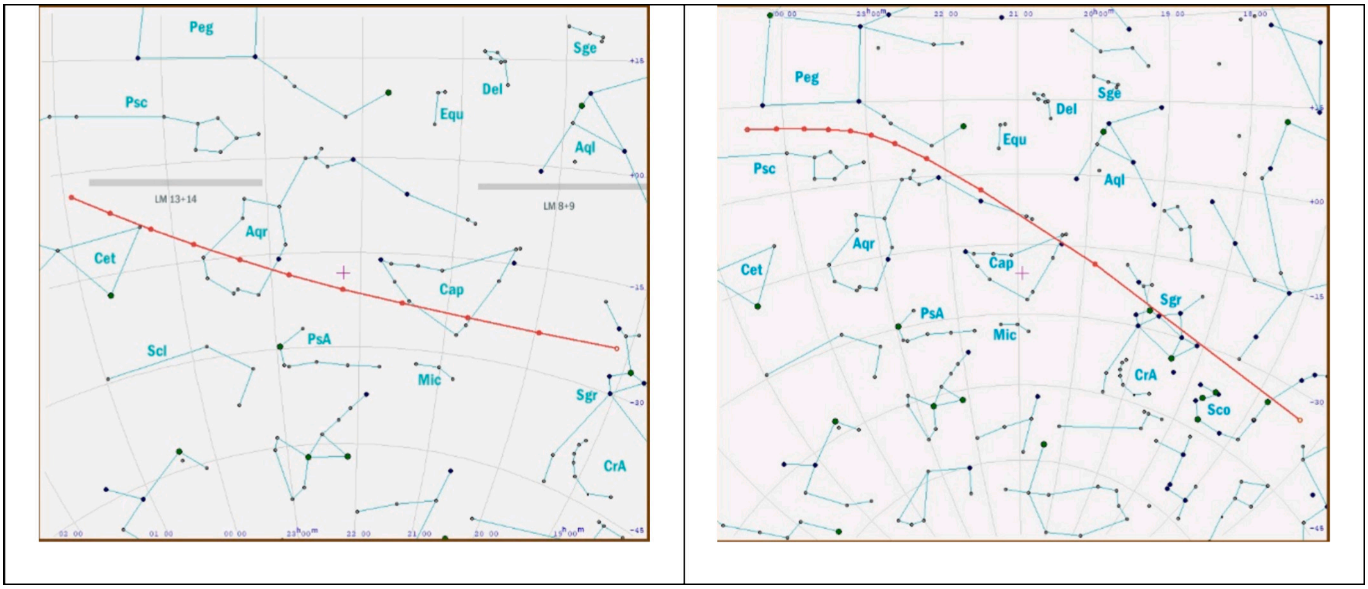

Fig. 5. Path of comet C/1245D1 (step 5 days) from Feb. 20 (blank circle) to Apr. 11, 1245. On the left, from the orbital elements in Table 2 and considering T = March 26. On the right, for comparison, from the orbital elements published by Hasegawa (1979).

leaving behind a trail of debris. After a second revolution, the trail is immediately widely dispersed due to the induced changes in the orbital period. As a result, parts of the trail catch up on each other, and a broad distribution of dust results that has traditionally been called the "Filament" of the shower. LPCs differ from shorter-period comets because a "Filament" may already be formed after only one revolution. It is also worth noticing that the outbursts do not necessarily correlate with the return of the parent comet to perihelion. However, in our case, we would need more observations, not available currently, of the possible meteor shower to confirm this scenario. However, it must be recognized that even the orbit calculated independently by Sicoli satisfies all of the above conditions of visibility, although it fails to link the comet of AD539 and the 15 Bootids.

Other properties listed by Jenniskens et al. (2021) are that meteoroid streams associated with an LPC are expected to disperse eventually, resulting in longer showers with a more diffuse radiant. Over time, precession[2] and other secular dynamical processes may cause the streams to change their mean orbital elements (Jenniskens, 2006). It is unclear that Poynting-Robertson drag plays a significant role in an LPC-associated shower evolution unless a very long period of time, more than 30kyr, is considered.

To perform a simple further test, let us consider 1000 test particles, representing meteoroids, ejected by the comet at the AD539 perihelion. We assume an ejection uniformly in all directions, with a single value of ejection velocity of 50 m/s, similar to the computed for other LPC, such as comet Thatcher and the Lyrids (see Arter and Williams (2002) and Kornos et al. (2015)) After the ejection of the test particles, we integrated their orbits in time forward until completing one orbital period. In this way, we followed the dynamical evolution of the stream. We assumed that the eight major planets gravitationally perturbed the particles in this integration. We disregarded the non-gravitational Poynting–Robertson (P–R) effect, which is not likely to affect over such a period of time. The distribution obtained for the particles can be seen in Fig. 6 on the left, and the distribution function of their expected periods is expressed in years on the right. After one passage through perihelion, we can see that most of the particles have stabilized in orbits of around 500 years, and another peak appears around 950 years.

After carrying out this simulation, we studied which meteoroids would enter the earth's atmosphere, understanding as such those that passed at a distance of <0.02 au, following the general lines of a similar simulation carried out by Hajduková and Neslušan (2021). We ran several simulations with different sets of 1000 ejected items and found that approximately 0.7% of them met this requirement with a solar longitude of $\lambda_{\odot} \approx 29^{\circ}$. Then we used the formulas given by Ryabova (2020, formula 4.1, p 34) to calculate an approximate radiant $\alpha \approx 14$ h, $\delta \approx 18^{\circ}$ (J2000), which may be compared with the currently observed values for the 15 Bootids $\lambda_{\odot} \approx 30.9^{\circ}$, $\alpha \approx 14.2$ h, $\delta \approx 11.2^{\circ}$ (J2000). Taking into account all the elements that can modify the orbit and the structure of a meteor stream, we think that the possibility of C/539 W1 as the parent comet of the 15-Bootids is feasible, provided that the meteor shower is, in turn, confirmed by successive observations.

Of course, although we have demonstrated the possibility of a relationship between comets C/539 W1, C/1245D1 and 15-Bootids, doubts remain and some elements of this association are questionable e.g. the fact that comet MM disappears around LM14 and not in LM16, as reported by Chinese sources. In this regard, it is worth considering the alternative options (Table 1, First's Burckhardt (1800) and Sicoli (2020,2023)) better compatible with old observations but less, concerning magnitude and tail length. Obviously in this case one would have to give up any 15-Bootids relationship.

3.2. C/565 O1

Eastern sources mention two possible comets for this year: on April 21, and another between July and October (Ho (1962), Hasegawa (1980), Kronk (1999)). The lack of information about the first comet does not allow further studies. However, the second was well documented in Eastern chronicles, as usual, but also in Western countries, where the death of Emperor Justinian on November 14 was associated with its appearance.

The comet was first detected on July 22, before dawn in Ursa Major. After a few weeks in the north polar zone, it crossed the Milky Way probably in the area of Cassiopea and Lacerta, moving south towards Pegasus and Aquarius. More specifically, Chinese sources agree on its appearance at SANTAI or WENCHANG on July 22–24. Then, it passed the west wall of ZIGONG, growing to 1 zhang (about 10°) and pointing towards SHI [LM 13] and BI [LM 14]. It disappeared in XU [LM 11] and WEI [LM 12]. According to Chinese documents, it was visible for 100 days.

Western sources shorten its visibility to 70 days (Marius Aventicensis, 1894), between August and October 1 (Agnellus of Ravenna (ca. 800-ca. 850), (Ravennatis, 1723), or extend it to one year (Gregory Bar Hebraeus in (Hind, 1859)), perhaps to refer to an unusually long period of visibility.

Among Western sources, the one that provides the most information is a relatively less-known contemporary reference found in a "commentary on Aristotle" (Neugebauer, 1975), (Bezza, 1993), possibly notes taken during the lectures on Aristotle's Meteorology by Olympidorus of Alexandria (c.495–c.570). Following this text, the comet was detected in the head of Draco in Mesore (27 July-25 August). It crossed the Milky Way, reaching Capricornus at the end of Thoth (31 August-29 September). Taking all sources into account, the location in the head of Draco would correspond to that occupied by the comet at the end of August, and that of Capricornus at the end of September. The *Liber Pontificalis* (Ravennatis (1723), p. 114) is more accurate about the final date of sighting, stating that the comet was visible until the Kalendas Octobris (October 1st), while the Chronicle of Zuqnīn (Harrak, 1999) gives an incorrect year and month, May 885 Seleucid era (573–574 CE), but affirms that it disappeared after Justinian's death (!), after two or three months of visibility. Since we know that Justinian died in Novembre 565 CE the discrepancy in dating may be due to an error or the mixing up of two different eras used in the manuscript the Seleucid and the Philip era (Whitby, 1992).

A pair of similar orbits were calculated by Burckhardt (1804), (see Table 3) who also noticed some resemblance with the elements of comets that appeared in AD1683 and AD1739, but both were later disregarded. Considering all the above historical sources, we present a set of orbital elements, which provide a similar path, at least initially, to that obtained from Burckhardt's first orbit (see Fig. 7). However, differences appear regarding the visual behavior of the comet. First, the comet suggested by Burckhardt, with an absolute magnitude $H_{10} = 1.5$ (Kronk, 1999), could have been seen and detected after the sunset long before the proposed date since it was below magnitude 3 even before mid-June. Second, the comet would never have reached Capricornus. Attempting to lower the absolute magnitude, for example, to 2.5, implies a substantial reduction in the tail length, with a comet that would have remained around magnitude 3 and thus hardly had been described in the Middle East as "very long" (Witakowski, 1996). In this sense, our orbit is better adapted to observations since, with a lower requirement in absolute magnitude, it has a smaller range of visibility (see Fig. 9), providing a visual magnitude compatible both with the eastern and western data, and a significantly longer tail length (Fig. 8).

With respect to the magnitude, taking an $H_{10} = 2$, the comet would have fulfilled the requirements to be observed until October 1 from Europe (with a magnitude a little above 3.5) and, although the magnitude would have been below 1 already at the beginning of July, as shown in Fig. 8, its positions near the sun would have made it difficult to

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[2] It should be noted that the term precession refers, in this case, to the slow secular changes experienced by the longitude of the perihelion in old comets or meteor streams (See Jenniskens (2006), p. 131).

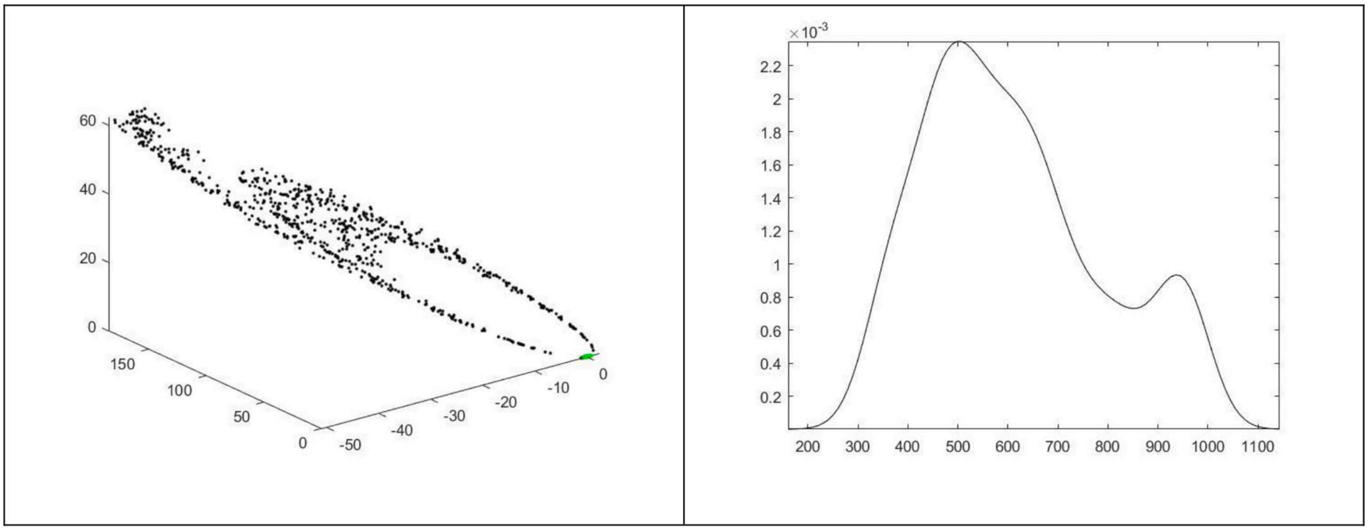

Fig. 6. Distribution of a sample of 1000 fragments ejected in the AD539 perihelion after one perihelion passage (AD1245, on the left. The small green circle on the right-hand side of the figure is the Earth's orbit Units in au) and function of the density of probability of the Periods. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 3
Orbital elements of comet C/565 O1 and for comparison C/1014 C1 (heliocentric ecliptic J2000.0).

Name	T (UT)	ω	Ω	*i*	*q*	*e*	*Author*
	Jul 19.2, 565	92	182	121	0.776	1.0	Sicoli, (this paper)
C/565O1	Jul 15, 565	79	180	121	0.832	1.0	Burckhardt (1804)
	Jul 9.5, 565	70	178	118	0.719	1.0	Burckhardt (1804)
C/1014C1	Apr 6, 1014	84	174	117	0.56	1.0	Hasegawa (1979)

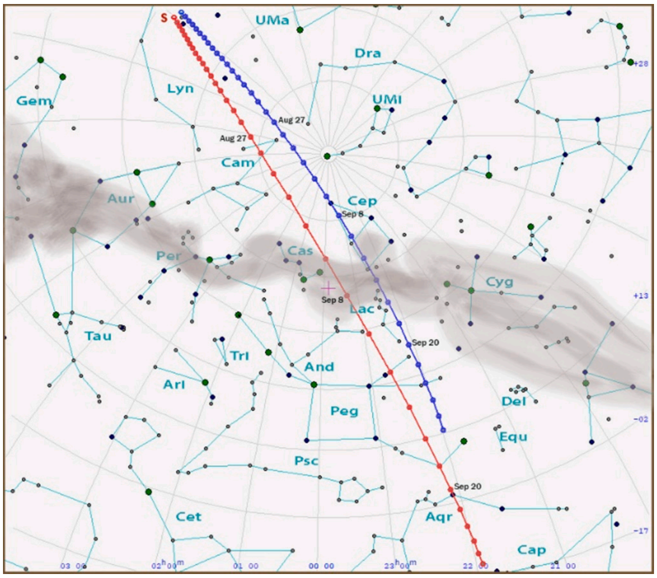

Fig. 7. Path of C/565O1, from July 22 to September 30, AD565 (2-days step), from Sicoli's set of orbital elements (red) and the first Burckhardt's (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

detect after the sunset before July 22. Also, the tail length, over 10° in July, would have reached 15° at the end of August (see Fig. 9), that is one zhang, as indicated by the Chinese.

Finally, we noticed that our elements are not very different from those published by Hasegawa (1979), for comet C/1014C1 (see Table 3).

Although we have found some arguments in favor of such an identification (e.g., the integration of the set of elements of the 11th-century comet to AD565 provides a comet that follows a path in the sky quite compatible with contemporary sources, considering a hypothetical perihelion date of 19 July AD565), other data are contradictory and, due to the paucity of data, there is no clear evidence to support this hypothesis. Despite this, we have carried out some calculations assuming

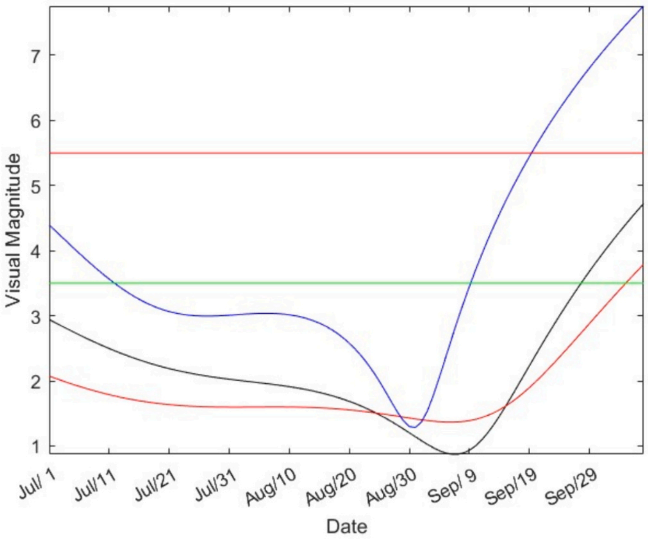

Fig. 8. Curve of visual estimated magnitude for C/565O1 and the first Burckhardt's accepted orbit (red), and absolute magnitude $H_{10} = 1.5$. In black, using the set calculated by Sicoli, taking $H_{10} = 2.5$, and in blue the integrated comet with an $H_{10} = 5$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

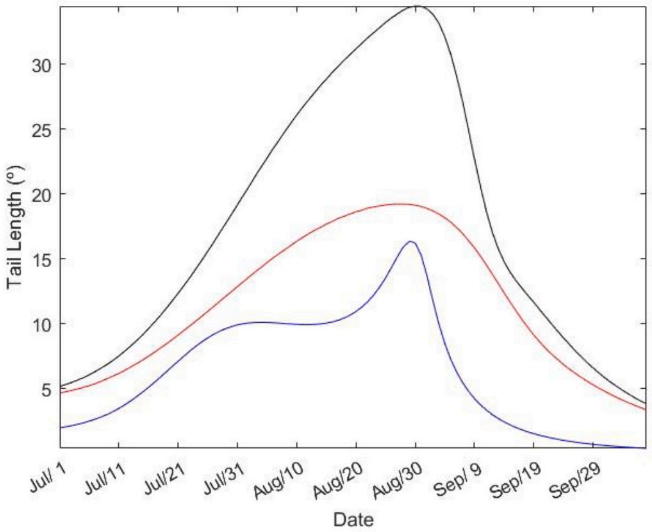

Fig. 9. Estimated length of the tail for comet C/ 565 O1 derived from the first Burckhardt's orbit (red), absolute magnitude $H_{10} = 1.5$, and Sicoli's (black), taking as $H_{10} = 2.5$ and the integrated comet (blue) with $H_{10} = 5$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

that the comet of the year 565 is a passage through the previous perihelion of the comet of the year 1014, integrating the orbital elements of this last comet (see Table 4). We have not been able to identify these elements with observed comets.

3.3. C/568 O1

Based on Eastern chronicles, two different comets appeared in AD568. The first was observed from July 20 for about a month (Kronk, 1999), but the data are too vague to attempt to calculate an orbit. The second, C/568 O1, was also visible from the end of July, to November (Ho, 1962; Kronk, 1999). Overlapping visibility periods led some authors to consider whether it was the same comet. However, its appearance in different parts of the celestial sphere and its different behavior led to discarding this hypothesis.

According to Pankenier et al. (2008), this second comet instead was first observed on September 3 and followed until early November. The primary source is the *Sui shu*, which contains a detailed description with quite accurate dates and positions. It seems that on September 3 the comet would appear in FANG[LM4] and XIN[LM5]; By the 8th month (Sept. 7 – Oct. 6), it entered TIANSHI, extending its length to 4 zhang. It would pass through HEGU, YOUJIANG (unknown asterism, our guess is γ Aql, Yòujiāngjūn), and HUGUA. Then XU[LM11] and WEI[LM12], entering SHI[LM13] and passing over LIGONG. On October 16, it entered KUI[LM15] and hovered about 5 chi north of LOU[LM16], where it was extinguished.

In the West, the comet went unnoticed, with the possible exception of a reference from Gregory of Tours (ca. 538–594) about a comet that appeared for a whole year after the catastrophic event that occurred in AD563 on the Swiss mountain of Tauredunum (today Grammont), south of Lake Geneve. However, it is doubtful whether Gregory is effectively referring to the comet of 568 or, though less likely, that of 565.

Table 4
Possible perihelion passages of comet C/1014 C1 integrating the orbit computed by Hasegawa (1979) after modifying the value of e in accordance.

Name	T (UT)	ω	Ω	*i*	*q*	*e*
C/1014C1	Jul 14, 122	84.26	174.98	116.85	0.5646	0.9906
	Jul 15, 565	84.11	174.03	117.01	0.5645	0.9904
	Apr 6, 1014	84.00	174.00	117.00	0.5600	0.9908
	Sep 27, 1475	84.00	174.22	117.06	0.5554	0.9910
	May 11, 1943	83.72	174.18	117.15	0.5558	0.9909

All the orbital elements are referred to J2000.0.

Several scholars have attempted to compute an orbit, including Hind (1844), Laugier (1846), and finally, Hasegawa (1979), who submitted the currently accepted set of elements. We propose an orbit which best fits the records. (See Table 5).

The sky path of Hasegawa's accepted orbit and the one we proposed is similar but not identical (see Fig. 10). Both appear in approximately the same area on September 3, although Hasegawa's would correspond more to a position of LM[3–4] than a LM[4–5] and continue their course entering TIANSHI. Our comet passes over HUGUA and LIGONG, entering SHI[LM13] on September 27, compared to October 2 when the other comet does. On November 5, both comets are quite close in positions in LOU[LM16].

Kronk gives the date of July 28 for the first detection of the comet by considering a record from the *shui shu* indicating the appearance of a "guest star" in DI[LM3]. Although some authors consider that this record corresponds to a nova, it should be noted that our comet has a compatible position for the given date. Instead, Hasegawa's comet would be in KANG[LM2].

The comet's visual magnitude and the tail's length present similar characteristics (see Figs. 11 and 12). Thus, with an absolute magnitude $H_{10} = 4$, both comets would have had a magnitude <3.0 at the beginning of August, which would have made them perfectly visible, and their tail would have reached a length of 4 zhang (about. 40°) on September 15 (ours) or September 25 (Hasegawa).

3.4. C/574 G1

In AD574 two comets were reported by Eastern sources on similar dates and area of the sky (Ho (1962), Kronk (1999), Pankenier et al. (2008)). They traveled their paths in opposite directions, according to Chinese reports, but despite this, scholars have different opinion about the existence of one or two different objects.

The first comet, now cataloged as C/574G1, was first observed on the evening April 4 with a tail 3 chi (about 3°) long, South-East of WUCHE. It grew longer and entered WENCHANG on May 8, and on May 23 crossed the bowl of BEIDOU, getting smaller. It vanished after 93 days.

This second comet followed a path that, according to *Shuishu*, began on May 31 (or June 2, for *Zhou shu* and *Beishi*) outside the wall of ZIGONG (or in DONGJING[LM22], for *Beishi*), being 7 chi long. It pointed towards WUDIZUO and gradually traveled southeastward, lengthening slowly to 1 zhang 5 chi (about 15°). On June 9, it reached the north of SHANGTAI and was extinguished. We do not have enough data to calculate a set of orbital elements for this comet. However, it cannot be related to C/574G1 since traveling in the opposite direction, it finally reaches a circumpolar position far from the first comet.

Comet C/574 G1 was not reported to be a very amazing object, implying the best scenario a maximum length of 5 chi (about 5°). This makes it difficult to believe the 93-day visibility provided by *Sui shu*, which would imply visibility from April 4 to July 6. Considering that the last dated observation is April 24, when it leaves the box of the Big Dipper and gradually decreases its brightness, we are remaining with a gap of more than two months without any observation.

The absolute magnitude requirements increase under the assumption that the comet was tracked until early June, requiring a value of around $H_{10} = 1$ (Kronk assigned $H_{10} = 2.8$, but with this value, the comet would have reached magnitude 5.5 around June 5, so it could not have been naked-eye visible in early July). In any case, its visual magnitude would have been negative in mid-March, so by the end of February, it would have been a prominent element at sunset from China. One could not help but wonder why it was undetected in this period.

Assuming that the period of 93 days refers to the joint duration of the two comets, the second of which tracked from May 31 to June 9 but with

Table 5
Orbital elements of comet C/568 O1 (heliocentric ecliptic J2000.0).

Name	T (UT)	ω	Ω	*i*	*q*	*e*	*Author*
C/568O1	Aug 27.7, 568	34.9	301.8	4.0	0.870	1.0	Hasegawa (1979)
	Aug 29.8, 568	22.6	315.9	4.3	0.907	1.0	Laugier (1846)
	Aug 28.8, 568	20.4	316.3	4.2	0.890	1.0	Hind (1844)
	Aug 28.0, 568	10.3	331.7	4.1	0.950	1.0	MM (This paper)

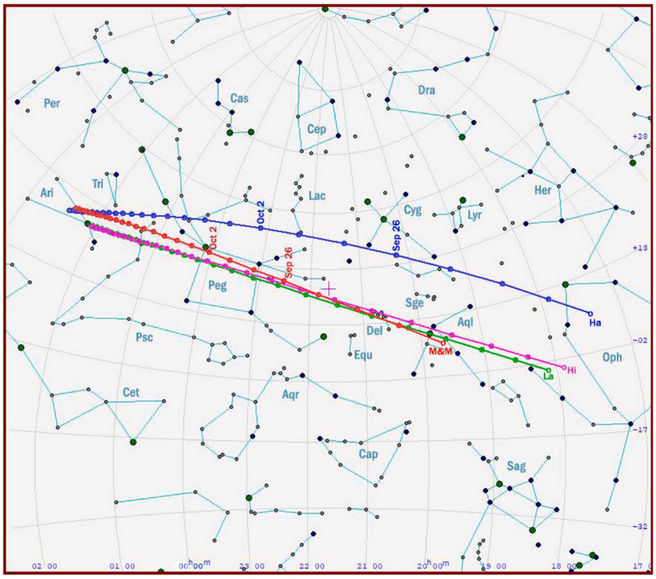

Fig. 10. Path of C/568O1 from September 18 (blank circle) to November 9, 568 CE, step 2 days according to Hasegawa (Blue), Hind (Pink), Laugier (Green), and MM's (red) orbit. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

no relation other than that of the time of appearance, we might lower the absolute magnitude requirements of the first comet to $H_{10} = 2.8$. In fact, such a period of visibility would made that a $H_{10} = 4$ for our proposed comet correspond exactly to the testimonies (see Fig. 13 for the paths of the comets and Fig. 14 for an estimation of their magnitudes).

The behavior of the tail of Hasegawa's comet does not seem compatible with that described in the sources since the tail length would be maximum at the end of March, reaching >20° in length, to decrease later. Our comet (see Table 6) best fits the path described by the sources. It has a slightly shorter tail that first gradually grows and then decreases after crossing the box of Big Dipper (Fig. 15).

Unfortunately, no definitive evidence from non-Eastern sources has been found, maybe with the possible exception of Gregory of Tours, who refers to "*crinitamultis*", that appeared around 575 CE preceding and succeeding the death of the king of Austrasia Sigebert I.

Finally, Nakano and Hasegawa (1994) noticed a similarity between Hasegawa's orbit and C/1993Y1 (McNaught-Russell). The suggestion anyway was made when the observational arc of C/1993Y1 was only two months so they had extrapolated an orbital period of about 1440 +/− 30 years. In addition, they realized that the inferred positions in the 574 passage could be roughly linked with the 1993 comet. In an attempt to make it compatible with the 574 CE observations, we forced the perihelion time to April 8, AD574. Although its path across the sky runs parallel southward with respect to Hasegawa's orbit, the problems with the size and length of the tail remain unchanged. We then recomputed the orbit of comet C/1993 Y1 using 353 of the 396 available observations (rms 0.81″) from 17 Dec.1993 to Sep. 8, 1994, including radial non-gravitational forces A1 = 1.81 and transverse A2 = 0.072. The data obtained in no way fit a period of about 1440 years. In fact, in close agreement with the JPL results, the data obtained led to a period of 1557.6 +/− 3.9 years, ruling out any possible connection between the two comets.

3.5. *Comet of AD582*

A comet was reported in Chinese annal *Sui shu*, in the SW, on January 15 or 20, 582 CE (Ho, 1962), (Hasegawa, 1980), (Kronk, 1999). This

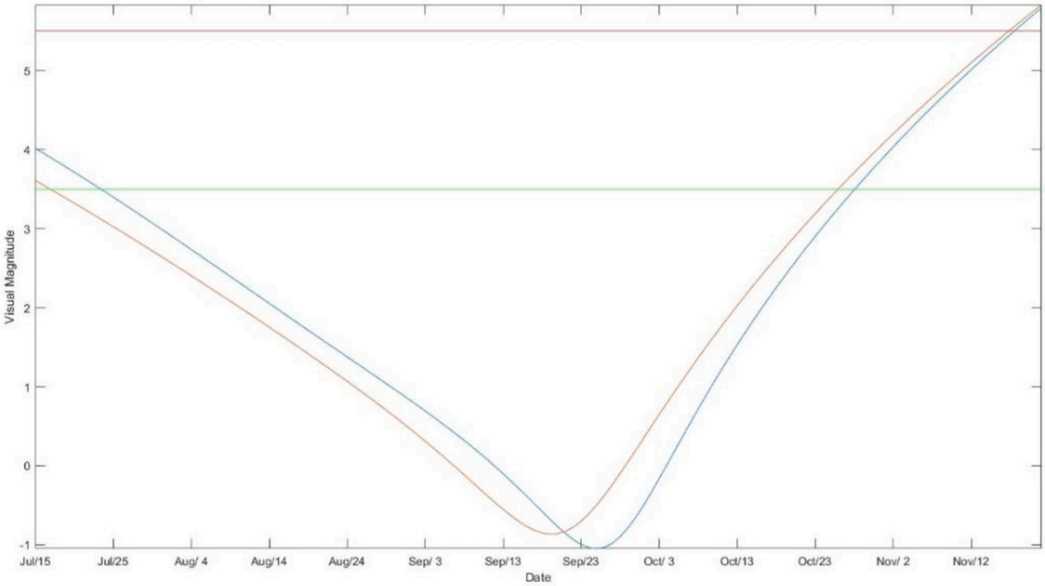

Fig. 11. Visual magnitude of C/568O1 considering $H_{10} = 4$, both Hasegawa (blue) and MM (red) show similar visual magnitudes behavior. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

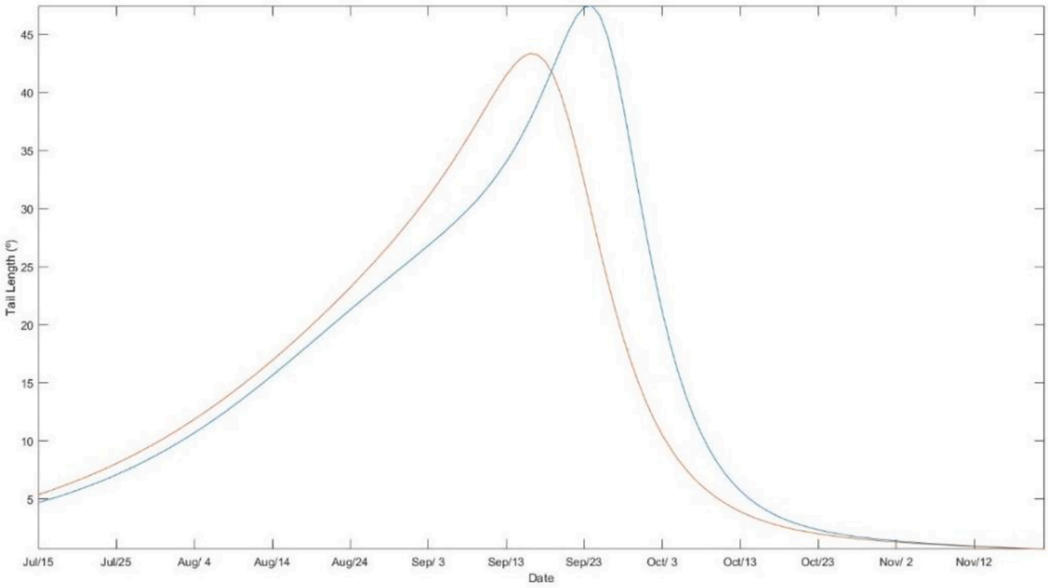

Fig. 12. Estimated length of the tails for comet C/ 568 O1 derived from Hasegawa's accepted orbit (blue), and ours (red) with absolute magnitude $H_{10} = 4$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

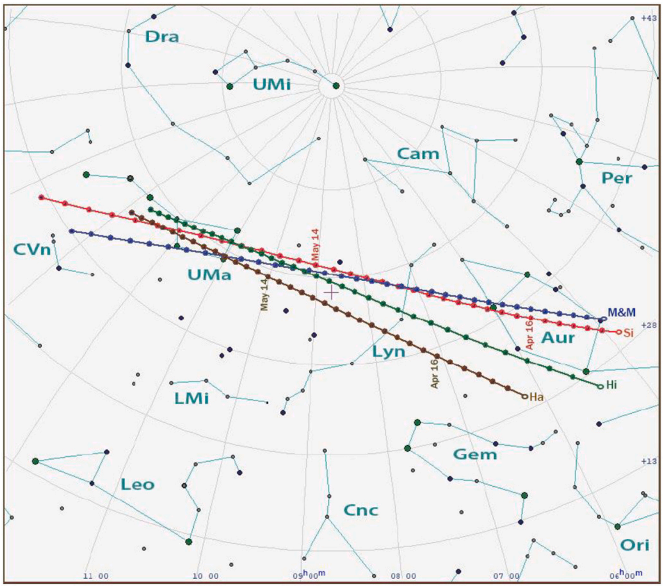

Fig. 13. Path of C/574 G1 from April 4 (blank circle) to June 9, 574 CE, step 2 days according to MM's orbit (blue), Sicoli's (red), Hind's (green)) and Hasegawa's orbit (black). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

comet is not included in Pankenier et al. (2008) because the record does not allow for the deduction of the date or the position in the celestial sphere with precision (Pankenier, pers. Comm, 2021).

In his *Historia Ecclesiasticae Francorum* (1561), Gregory of Tours (c.538–594), provides some additional information about a series of prodigies that occurred in that period, including that *it shone so brightly in the darkness that it was sparkling. From it also departed a ray of such large size as to resemble the smoke of a large fire seen from a distance. [The comet] was observed towards the west in the first hour of the night.* (Gregorius Turonensis, 1561) Later authors have misinterpreted Gregory of Tours' record by stating that the comet was seen on Easter Day or by attributing different years.

It cannot be completely ruled out that Gregory's testimony refers to the appearance of a fireball, but it is much more likely that the observation relates to a comet belonging to the family of Kreutz-Sungrazers (England, 2002). Computer simulations made by the authors for the city of Tours (0°41′E, 47°27′N), where Gregory was bishop from the year 574 show that a KS comet would agree with the given descriptions, as it would have been visible in the second half of January to the southwest setting almost simultaneously with the Sun. This fact would support the scenario II hypothesis by Sekanina and Kracht (2022) regarding the origin of this family of comets. In a more recent paper Sekanina (2023) relates this comet to a split during the perihelion in −371 into four pieces, which returned in the years 283, 363, 467, and 582, respectively.

4. Overview of the 7TH century comets

By the 7th century, at least 29 comets were recorded, including two perihelion passages of Halley's Comet (1P/607H1 and 1P/684R1), the first of which we will discuss in detail. With the available data, we will provide results for X/676P1 and the second comet of AD684, because for the rest of the comets of this century, it is not possible to venture orbital elements, not even for comet AD681. Of the latter, although numerous references exist, we can only locate its approximate trajectory on the celestial sphere. It appeared in the west after sunset on October 17, having already passed its perihelion, and ascending until reaching the zone of γ Aql in the vicinity of which disappeared 17 days later.

It has recently been suggested (Sekanina, 2023) the relationship of the second comet that appeared in the year 607 as one of the parent comets of the Kreutz Sungrazers family. We will also examine this issue in 4.1.

4.1. 1P/607 H1 Halley and X/607U1 comet

This passage of Halley's comet has the curious property of being described in the East in some detail, but paradoxically, it turns out to be one of the most puzzling in its history. The discussion is old, as Hind (1859) already noticed; apparently, neither the dates nor the positions, cited by the Chinese, fit with Halley's comet computations: "*the Chinese annals have several comets in that year. I find, by actual computation, that none of them present any decided indications of identity with the one which forms the subject of these remarks* [Halley's comet]*, and I am therefore inclined to fix its reappearance in the following year, 608*" (Hind (1849)).

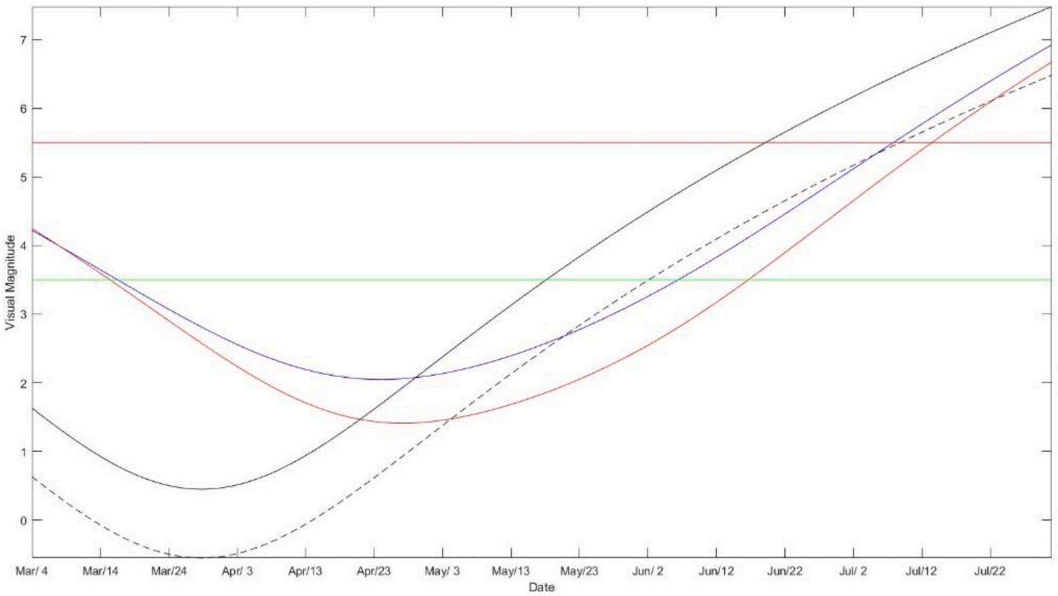

Fig. 14. Apparent magnitude of comet C/574 G1 according to MM's orbit (blue), Sicoli's (red), $H_{10} = 2$; and Hasegawa's orbit (black), $H_{10} = 2.8$. The black dotted line corresponds to the apparent magnitude of Hasegawa's comet with $H_{10} = 1$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 6
Different proposed orbits of comet C/574 G1. (heliocentric ecliptic J2000.0).

T (UT)	*q*	*e*	ω	Ω	*i*	Source
574 Mar 25	0.73	1.0	342°	155°	54°	Hasegawa (1979)
574 Apr 7.78	0.963	1.0	15.5	148	46.34	Hind (1844)
574 Apr 17	0.80	1.0	49.8	111.5	40	MM (Sicoli et al., 2023)
574 Apr 19	0.73	1.0	52	116	36	(Sicoli et al., 2023)

Cowell and Crommelin (1908) while acknowledging that the 607 observations are a “decided tangle”, using the technique of variation of elements, realized that “*the date of Hind 608 October 19 was about a year and a half too late*” thus confirming its perihelion in the spring of AD607.

Let us summarize and comment on the reports of this return of the Halley's to have a global view of the problem. The *Bei shi* states: *day bingzi* (February 28), *a long star extended across the sky. It appeared at DONGBI [LM 14]and after 20 days, it ceased.* Pankenier et al., 2008 include this record among those of the passage of Halley's comet in AD607 (with a typo in the paragraph, the year should be AD607 instead of AD608), but Hasegawa and Nakano (2001) had included it in a list of possible comets belonging to the Kreutz group (Comet No. 9) estimating a perihelion passage on February 26 ± 1, 607. Sekanina (2023) suggested that it could be a secondary fragmentation of comet −1124, more precisely −1124-ID, forming part of generation 4 and with an antecedent that would have gone unnoticed in the −260. We will come back later to this issue.

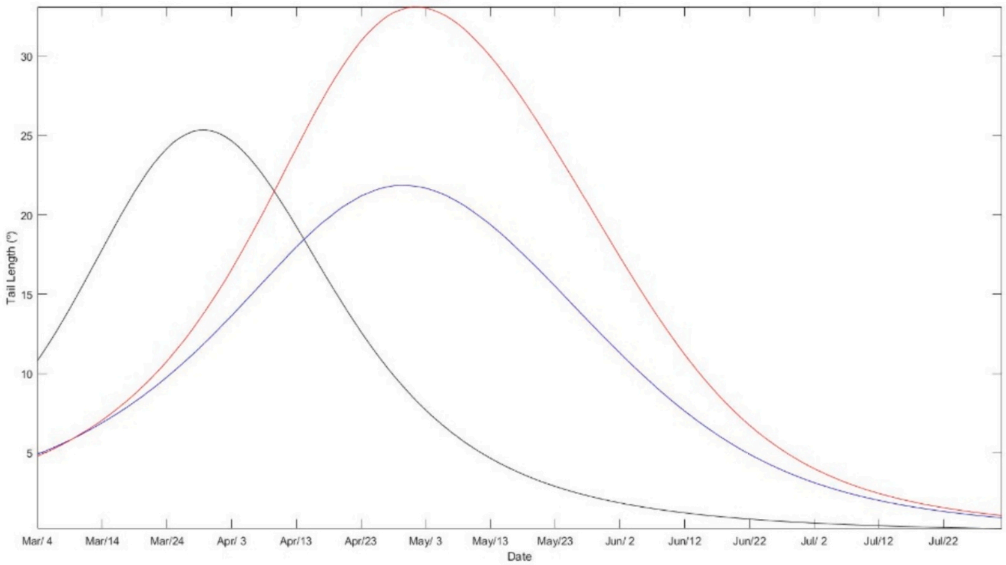

Fig. 15. Tail length of comet C/574 G1 with the orbits computed in this work according to MM's orbit (blue), Sicoli's (red) and $H_{10} = 2$, and Hasegawa's (black) and $H_{10} = 2.8$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Returning to the Chinese annals, the *Sui shu* continues: on April 4 *a long star was seen in the west. It stretched across the sky. It trespassed against and passed KUI [LM 15], LOU [LM 16], JIAO [LM 1], and KANG [LM 2], then disappeared.* Instead, the *Bei shi* affirms that on March 13, *a broom star was seen at DONGJING [LM 22] and WENCHANG. It passed DALING, WUCHE, and BEIHE. It entered TAIWEI and swept DIZUO. It ceased after >100 days* (Pankenier et al. (2008)). In addition, the *Bei shi* also refers briefly to another comet apparently seen on June 25: *a star became fuzzy in WENCHANG and SHANGJIANG.* Finally *Sui shu* reports another possible comet that starting on 21 October disappeared, maybe in FANG [LM4], on Jan 23, AD608, after having crossed all the Lunar mansions, except SHEN [LM21] and DONGJING [LM22].

Hence, at first glance from oriental sources, there could be up to four comets in that year: one in February, another between March and April, one at the end of June, and the last one seen between October 607 and January AD608. For their part, European sources indicate the appearance of just two comets: The first between April and May and the other, as Paulus Deaconus in his *De Gestis Langobardorum* (Diaconus, 1723), again in November and December. Agapius (1912), on the contrary, speaks of only one comet seen between October and April, probably mixing the two mentioned comets.

Including all the reported data, our opinion favors the existence of only two comets, the first being Halley's comet. Nevertheless, there are also other reasons for our preference. Indeed, careful analysis and evaluation of the Chinese texts allow us to support this conclusion and even lead to reconsidering the date of the perihelion passage at this return.

Again, the discussion about the actual date of the perihelion passage is not new. Michielsen (1968) and Brady and Carpenter (1971) by including the perturbations of all planets in their calculations found that, at least in the last 3–4 passages, nongravitational forces increased its orbital period by about 3 to 5 days on each return. Brady (1972), while not excluding the influence of nongravitational forces acting on the comet, ascribed this discrepancy to a possible perturbation due to a hypothetical trans-Plutonian object. However, this assumption was soon rejected (Seidelmann et al., 1972). Kiang (1972), confirming an average lengthening period of 4.1 days due to nongravitational forces, reexamining the Chinese records, was the first to compute the back motion of Halley's comet for over two millennia, from 238 BCE to AD1910, covering 28 revolutions. For AD607, his calculations strongly indicate that the perihelion occurred sometime in March. Attempting to adapt Halley's comet path with Chinese records, he considered that the day *jichou* 己丑, cited by *Bei Shi*, was actually a corruption of *Yichou* 乙丑 and that, consequently, the second month was to be revised to the third. This correction, changing the date from March 13 to April 18, allowed him to calculate the perihelion date as March 14.5, a value later adjusted to March 15.476 by Yeomans and Kiang, 1981, whose orbital elements, available at https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=1P, are the currently accepted. Although such a reconstruction fits the observations quite closely, Kiang himself (Kiang, 1972) concludes by saying: *The return of Halley's comet in 607 must rest on rather slender observational support pending further clarification of the records*.

We have therefore attempted to recreate an alternative scenario considering that, as pointed out by all scholars in the past, the Chinese accounts for this return were poorly transcribed, presenting dating errors and possibly mixing up the data of the comets seen that year. Assuming that the observation reported in February must be ascribed to Halley's comet, it is then possible that the day *bing zi* 丙子, first month, should instead be read as day *bǐng wǔ* (丙午), second month thus moving the date of the first observation of the comet from 28 February to 30 March. This change makes even more sense since in none of the orbits proposed in Table 7 the comet would have been visible on February 28 due to its position being excessively close to the sun. Similarly, the day *Guǐ yǒu*, fifth month, (June 25) would instead refer to the same day but of the third month, therefore shifting the date back to 26 April. By adopting these adjustments, on 30 March Halley's comet, as stated in the annals, would have been visible in the morning, for just over twenty days, in LM[14] while around April 26, in the evening, its tail would have crossed the WENCHANG region. Finally, according to this reconstruction, the date 18 April, proposed by Kiang, should instead be replaced with 30 April, thus moving the date of perihelion to 26.5 March AD607. A value surprisingly close to 26 March, calculated by Cowell and Crommelin (1908). About the first observation date of the comet, Stephenson and Yau (1985) had come to our same conclusion, stating that the observation of February 28 had to refer to Halley's comet, with the date of 30 March, even though they did not later suggest a possible alternative date for the passage to perihelion. For clarity, a summary of our proposed interpretation of the sources for comet 1P/607 H1 and X/607 U1 is given in Table 8.

Our orbital elements shown in Table 7 are obtained starting from the elements calculated and published for the well-documented passage of 1P/Halley in AD684 (Yeomans and Kiang (1981). Then its motion was integrated backward to the previous return in 607 CE, taking into account the gravitational forces of all planets and keeping Earth and Moon separate. The perihelion calculated by this procedure was thus found to be March 30.5, 607 CE. Then, using the new set and varying by fractions of a day the time T we searched for a date that best would fit our scenario: March 26.5, 607. In any case, this revised perihelion time does not affect the previous and subsequent returns of the comet.

Let us now focus on Halley's comet. Regarding the magnitude and tail of the comet, and considering the traditional Yeomans and Kiang's orbit, we see that at the beginning of February, its magnitude would have dropped from 3.5, remaining perfectly visible until the middle of February after the sunset, very close to Venus, although without developing a long tail. Subsequently, its proximity to the sun would have made it invisible until the first days of March, and then its brightness would have continued to increase, and its tail would have lengthened rapidly up to approximately 45°, being especially visible since its situation would have remained almost static next to Venus, remaining so until mid-April, reaching a negative magnitude. The length of the tail would have decreased to grow again until 60° at the end of April and would have begun a rapid decline, both in length and in magnitude, that would have made it invisible to the naked eye on June 1.

Our proposed elements for comet Halley imply that comet would not reach a magnitude accessible to the naked eye until the third week of March and could have been detected on March 30. On April 24 it could have been visible both to the east, before sunrise, and to the west thanks to its long tail, pointing to WENCHANG. The passage through DALING and WUCHE would have been on April 24–25 and that of BEIHE around April 28. On April 30, indeed, the comet would have been found at LM22 (see Figs. 16 and 17). With the conditions studied, the time of best visibility of the comet would have been consistent with European accounts, which limit it to April–May. Notice that using the elements provided by Yeomans and Kiang (1981), the brightness of the comet would have been more significant in March and April, while in the first days of May, it was already beyond the 2nd magnitude, decreasing quickly in the following weeks. On the contrary, our proposed orbit agrees with Western sources, given that on the first days of May, its magnitude was negative, ca. -0.2, and on May 10th, it should have been still clearly visible with a magnitude under 1.5.

Apart from achieving a better adjustment of the positions to the historical sources, the perihelion correction allows us to obtain better

Table 7
Orbital elements of comet 1P Halley in 607 CE (heliocentric ecliptic J2000.0).

T (UT)	q	e	ω	Ω	i	Source
Mar 15.476, AD607	0.58083	0.96804	98.799	43.261	163.476	Yeomans and Kiang (1981)
Mar 26.5 AD607	0.58084	0.96804	98.803	43.265	163.476	This paper (see text)

Table 8
Original and new interpretation of the eastern records relating to the positions of comets seen in the year 607 (data from Pankenier et al. (2008)).

Original	New Interpretation	Position Halley
1st month, day Bǐng zǐ = 丙子 (Feb 28) (*Bei shi*)	2nd month, day Bǐng wǔ 丙午 = 30 mar	a long star extended across the sky. It appeared at DONGBI [LM 14]. After 20 days, it ceased
3rd month Xīn hài = 辛亥 (Apr 4) (*Sui shu*)	3rd month Xīn wèi = 辛未 = 24 apr	a long star was seen in the west. It stretched across the sky. It trespassed against and passed KUI [LM 15], LOU [LM 16]
5th month Guǐ yǒu = 癸酉 (Jun 25) (*Bei shi*)	3rd month Guǐ yǒu = 癸酉 26 Apr	a star became fuzzy in WENCHANG and SHANGJIANG.
2nd month Jǐ chǒu = 己丑 (Mar 13) (*Bei shi*)	3rd month Dīng chǒu = 丁丑 (30 Apr)	a broom star was seen at DONGJING [LM 22] and WENCHANG. It passed DALING, WUCHE, and BEIHE.
Original	New Interpretation	Position X/607 U1
3rd month Xīn hài = 辛亥 (Apr 4) (*Sui shu*)	9rd month Xīn wèi = 辛未 = (Oct 21)	JIAO [LM 1], and KANG [LM 2], then it disappeared.
2nd month Jǐ chǒu = 己丑 (Mar 13) (*Bei shi*)	10th month Jǐ chǒu = 己丑 (Nov 8)	It entered TAIWEI and swept DIZUO. It ceased after >100 days.
9th month, day Xīn wèi = 辛未 (Oct 21) (*Sui shu*)	9th month, day Xīn wèi = 辛未 (Oct 21) (*Sui shu*)	It returned and was seen in the south. It again extended across the sky from JIAO [LM 1] and KANG [LM 2]. It swept DIZUO of TAIWEI. It trespassed against all of the other lunar mansions except SHEN [LM 21] and DONGJING [LM 22]. After the new year (AD608 Jan 23), it was extinguished.

visibility conditions for Halley's Comet in the months of April and May in terms of visual magnitude and tail (see Figs. 18 and 19), and would explain why it went unnoticed during March in Europe. The appearance of the comet in February is also excluded, so the association with the aforementioned Kreutz family would be meaningless.

Thus, according to our interpretation and in agreement with other authors and contemporary European sources, the Chinese mix data and dates of two different comets, 1P/607H1 and X/607 U1, which appeared in November of that same year. Table 8 shows the distinction between the records of one and the other.

4.2. *X/676 P1*

From the limited information available, it appears that this comet was first observed towards the end of August in the morning sky, and remained visible until the end of October. Eastern information is rather scarce and not entirely in agreement with each other. In China, it was detected on September 4, with a tail of 3 chi (about 3°) in DONGJIN [LM22], pointing to NANHE and JIXIN or BEIHE, depending on the source. Moving northeastward, it swept ZHONGTAI, pointing to WENCHANG, and disappeared after 58 days so that on November 1, it was no

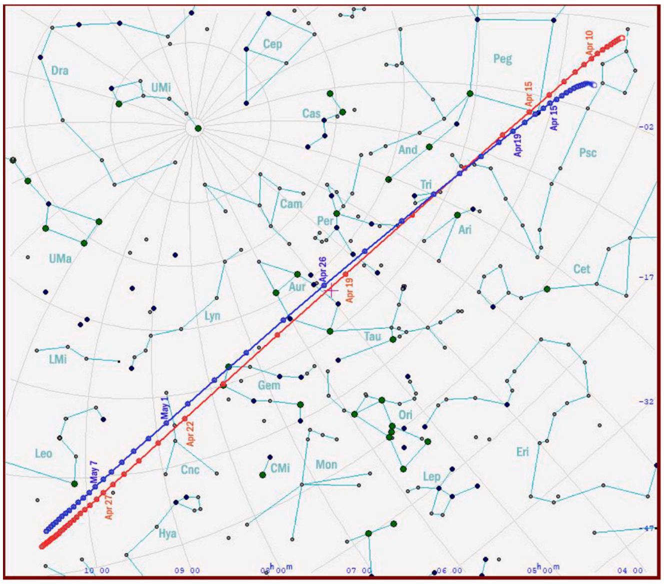

Fig. 17. Path of Halley's comet from March 30 (blank circle) to May 20, 607 CE, step 1 day, considering the parameters, from Table 7. Yeomans and Kiang (red) and Sicoli (blue).

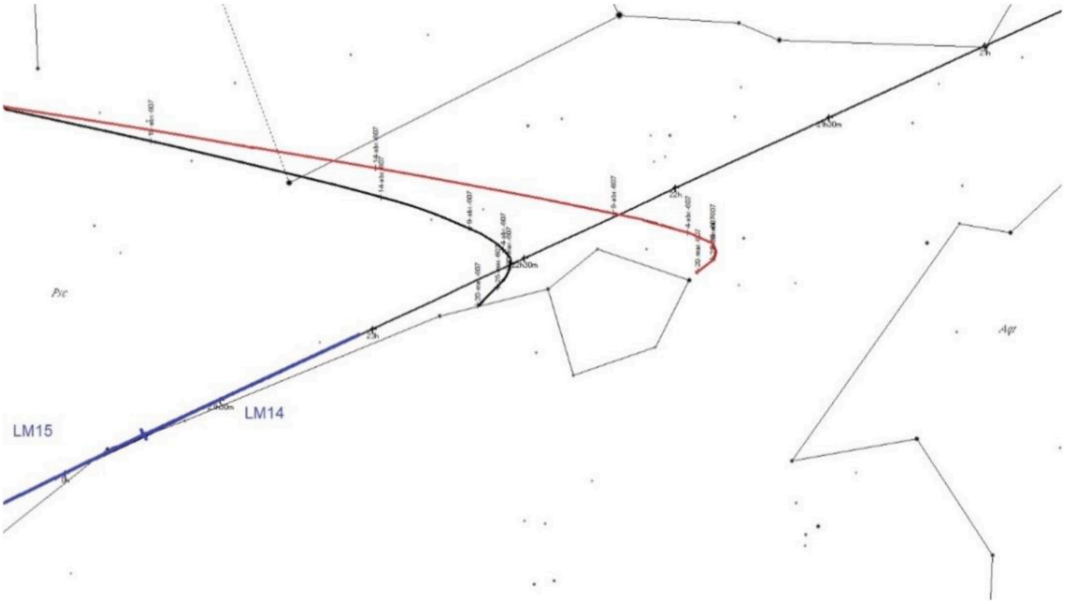

Fig. 16. Detail of the path followed by Halley's comet in March–April according to the orbital elements calculated by Yeomans and Kiang (red) and those that we propose (black) given in Table 7. Chart drawn using Mariott's SkyMap 11.0. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

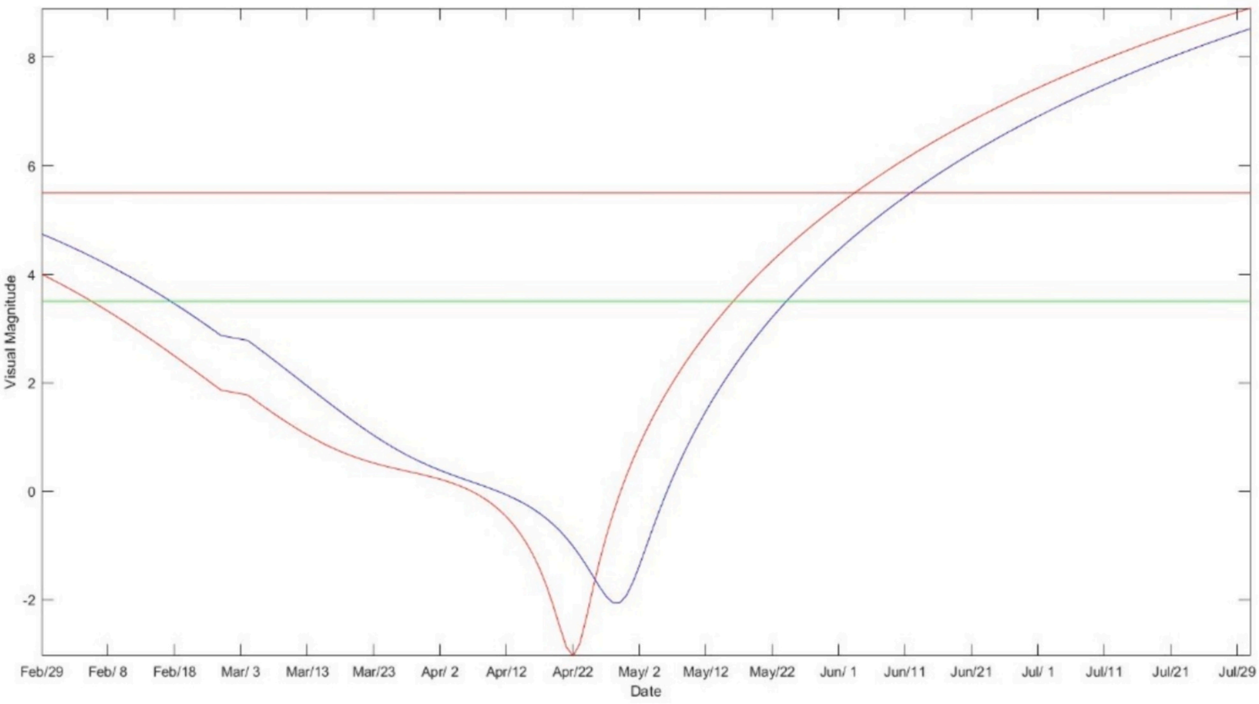

Fig. 18. Estimated visual magnitudes for Halley's comet with the original set of orbital elements (in red) and the one proposed with perihelion on march 26.5 (in blue). The estimated absolute magnitude is $H_{10} = 2.5$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

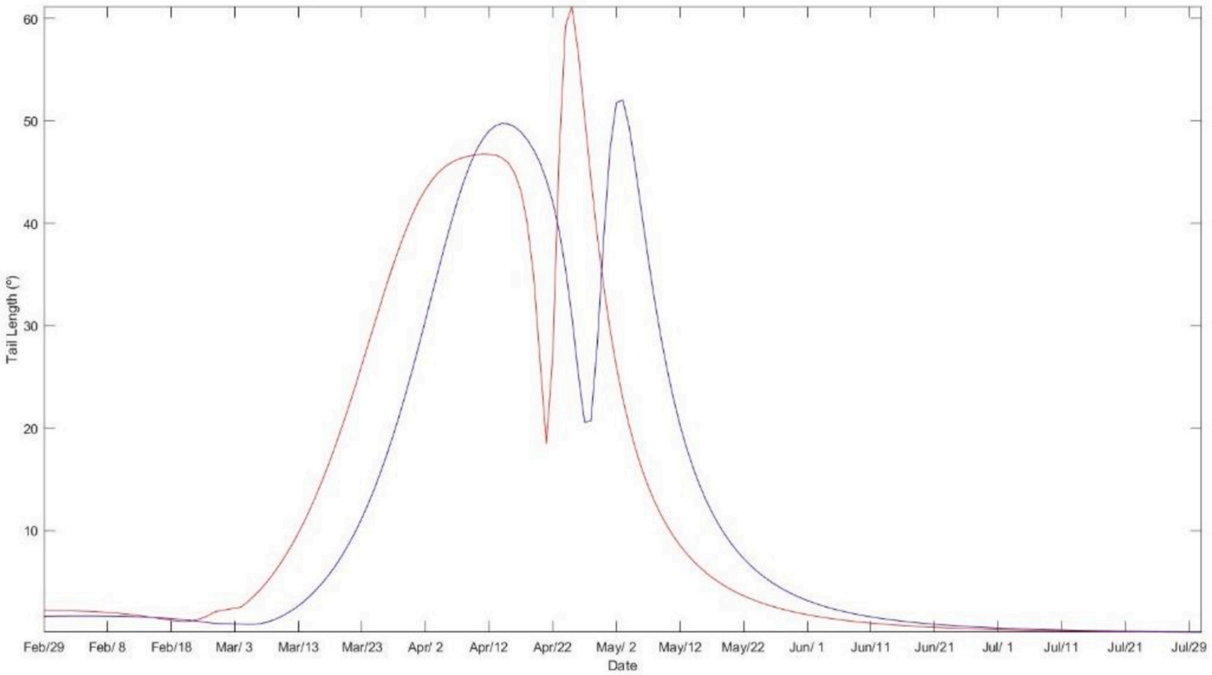

Fig. 19. Estimated tail's length for Halley's comet with the original set of orbital elements (in red) and the one proposed with perihelion on march 26.5 (in blue). The estimated absolute magnitude is $H_{10} = 2.5$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

longer visible. The Korean's *Samsuk sagi* (1145) independently from Chinese sources, reported that a broom star, 6–7 bu. (paces) long, was between BEIHE and JISHUI (Stephenson, 2014). A similar length, 7–8 chi (about 7–8°), was also recorded in the Japanese *Nihon Shoki* (720).

Few valuable astronomical details can be extracted even from European documents. They merely report the appearance of a morning comet in August after the election, probably in the same month, of Pope Donus (consecrated later on 2 November), which shone with very bright rays for about three months (three months and one day!, according to Matthaeus Parisiensis). This period is not to be taken literally but instead as an indication that the comet became visible in a period that included August, September, and October. In fact, the contemporary Jacob bishop of Edessa (about 640–5 June 708 CE), who is more precise about its duration, wrote that in the *year 56* [of the Hegira, AD676] *a terrible comet appeared in the morning; and it began on the 28th day of August and lasted till the 26th day of Octobe*r (Brooks, 1899). This information was later taken up by others (see Hoyland, 2011), such as Elias (1910) and Michel Syrien (1901).

Several sources also refer to the comet's extraordinary brightness, comparing it, indeed with some exaggeration, to that of the sun (see e.g. Parisiensis and Majora (1872)). We cannot forget the curious comment by some historians such as Paul the Deacon (c. 720 - c. 799) and Anastasius Bibliothecarius (c. 810 – c. 878) regarding the “star” that had retraced its own steps before disappearing. It is not easy to understand the real meaning of this assertion. We might think about the path described by the comet in its movement on the celestial vault or the placement of its tail, over the two months of observation. Regretfully, the available data are too poor to give any explanation for this comment. The Venerable Bede (c. 673–735), who erroneously dates the comet to the year 678, does not mention this fact. However, apart from this detail, the rest of his text is quite similar to that of Paul and Anastasius, a fact that would lead one to suggest that all three scholars may have drawn their accounts from an older source on the lives of the popes. On the other hand, it is no mystery that Bede had copies of the Liber Pontificalis in his library. (cfr. Poole (1918) and Colgrave and Mynors (1969)).

Although there is not enough evidence to propose a set of orbital elements, we were intrigued by the possibility of literally considering the comment of the comet that retraced its steps, which led us to wonder if this possibility could have occurred. From the historical data provided by the eastern sources, we have generated some possible orbits, but, in this case, none seems to confirm such a path. In any case, most solutions pointed to a comet with T between September 25 and October 10 and a value of $i < 30^\circ$.

4.3. X/684 Y1 (?)

Shortly after the appearance of Halley's comet in September and October AD684, another possible comet made its appearance between the end of the year and the beginning of AD685. Given the time coincidence, some people believed it to be a late observation of the same comet (Tsu (1934) and Ho (1962)). Others have instead considered it an exceptionally bright meteor (Williams (1871), Lundmark (1921), and Stephenson and Yau (1985)). Both options must be considered very unlikely since, in the first case, both eastern and western sources refer to a position in the celestial sphere near the Pleiades, making its identification with Halley's Comet unfeasible in this period. In the second case, the possibility of a meteor should be totally ruled out since the description of the phenomenon is incompatible with a sudden event.

After examining and comparing all accounts, the authors concluded that it is most likely a comet without a tail, which the Chinese call a “po”. The Japanese text Nihongi, for example, reports it in the following terms: *During the eleventh month a comet (po) appeared in the middle of the sky, moving together with the Pleiades (Mao) until the end of the month, when it disappeared from view* (Ho, 1962). In Italy, Paul the Deacon and Anastasius Bibliothecarius add an interesting detail: “Between Christmas and Epiphany, with a clear sky, a totally veiled star, similar to the Moon behind a cloud, appeared near the Pleiades”. A last piece of information about the same comet might finally come from the Middle East, where Michael the Syrian clearly differs this comet from Halley's when he reports a comet lasting seven days, appearing after Halley's comet, which was observed for 41 days in the month of August–September. Based on these considerations, the authors, therefore, made the proposal of giving the X/ designation, naming it X/684 Y1 (Sicoli et al., 2023).

This same comet was the subject of an interesting study by Kresákowá (1987a, 1987b), who considered, using statistical criteria, the relationship between three meteor showers observed by Japanese and Korean astronomers in November AD684 and January 1 and 3 AD685. The author states in her paper: “it was shown that the dates of appearance of ancient meteor showers of unidentified origin tend to concentrate to some extend towards the dates of observation of bright comets”, which could be accurate with the available data at the time the paper was written, but there are elements that cast doubt on the proposed association. The meteor shower observed in November (Λ approx. 247°, epoch of the date) is unrelated to that observed in January (Λ approx. 285°, epoch of the date). In his Table 1 (p. 610, shower 32), Jenniskens (2006) does not consider the November shower, but adds four more to the list of Kresakova. They were observed between the years 609 and 764 in the period between December 29 and January 7. He mentions the possible association with the comet above. However, in the text, he considers that this shower could be associated with the January Comae Berenicids (00090 JCO, currently on the working list of meteor showers) due to the progressive increase in solar longitude. This shower has been tentatively associated with comet 1913 I (Lowe), which was so poorly observed that its very existence remains doubtful (see Viljev (1913) and Gorelli (1999) In conclusion, on the basis of the studies and considerations made so far, if the possibility of identifying the phenomenon with a comet can be supported by a few clues, its connection with a known meteor shower certainly requires further research.

5. Conclusions

We have reviewed some comets from the 6th and 7th centuries after a laborious compilation as exhaustive as possible from Eastern and, especially, Western sources. The data obtained has allowed us to propose alternative or improved orbits for some of these comets and test some theories.

In particular, we have proposed new or modified orbital parameters for four comets observed in the 6th century, discussing the connection of C/539 W1 with the 15-Bootids meteor shower and showing that, while this is possible, it is not the only possibility that fits the historical reports. We have also discussed and renounced the connection of C/574G1 with C/1993Y1.

Seventh-century comets have provided fewer opportunities to calculate orbits. Although there is an extensive literature associated with them, this actually contains little useful information. The case of comet 1P/607H1 (Halley) has been treated with special care since the available data were very mixed, and there was much confusion even about the number of comets seen during the year 607. We propose an interpretation of the data that, in addition to differentiating the observations for each comet, leads us to propose a modification for the date of the passage through the perihelion of Halley's Comet on that date. We have also concluded that the observations of the years 676 and 684 correspond to comets, and, in the particular case of the latter, we have discussed its associations with meteor showers proposed by other authors.

CRediT authorship contribution statement

P. Sicoli: Writing – review & editing, Writing – original draft, Software, Investigation, Conceptualization. **R. Gorelli:** Writing – review & editing, Writing – original draft, Software, Investigation, Conceptualization. **M.J. Martínez:** Writing – review & editing, Writing – original draft, Software, Investigation, Conceptualization. **F.J. Marco:** Writing – review & editing, Writing – original draft, Software, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

List of Chinese Lunar Mansions, constellations and asterisms that appear throughout the paper, the first column is the Chinese name, the middle column is the English translation and the third column corresponds to the determinative star. For a complete list see Pankenier et al. (2008) and for a graphic representation of the sky see Ho (1962).

	CHINESE LUNAR MANSIONS	
JIAO[LM1]	Horn	α Vir
KANG[LM2]	Neck	κ Vir
DI [LM 3]	Root	α Lib
FANG[LM4]	Room	π Scor
XIN[LM5]	Heart	α Scor
NANDOU[LM 8]	Dipper	φ Sgr
NIU[LM 9]	Draught Ox	β Cap
XU [LM 11]	Emptiness	β Aqr
WEI [LM12]	Rooftop	α Aqr
SHI [LM 13]	Encampment	α Peg
DONGBI [LM14]	Eastern Wall	γ Peg
KUI [LM 15]	Swine	ζ And
LOU [LM 16]	Hillock	β Ari
MAO [LM 18]	Hairy Head	17 Tau
SHEN[LM21]	Hunter	δ Ori
JING[LM22]	Eastern Well	μ Gem
	CHINESE CONSTELLATIONS AND ASTERISM	
BEIDOU	Northern Dipper	α UMa
BEIHE	Northern River	α Gem
DALING	Great Burial Tumulus	9 Per
DIZUO	Emperor'sThrone	α_1 Her
HEGU	River Drum	α Aql
HUGUA	Dry Melon	α Del
JISHUI	Bilgewater	λ Per, a star within TIANCHUAN
JIXIN	Store-up Kindling	κ Gem
LIGONG	Summer Palace	λ Peg
NANHE	Southern River	α CMi
SANTAI	Three Steps	ι, λ, ν UMa
SHANGJIANG		δ Leo (star)
SHANGTAI	Upper Step	ι UMa
TAIWEI	Grand Tenuity Enclosure or Privy Council	β Vir
TIANSHI (TIANSHIYUAN)	Celestial Marketplace	ζ Oph
WENCHANG	Celestial Secretariat	θ UMa
WUCHE	Five Chariots	ι Aur
WUDIZUO	Inner Seats of the Five Sovereigns	γ Cep
YOUJIANG	Right-side general	γ Aql (?)
ZHONGTAI	Middle Step	λUMa
ZIGONG	the circumpolar region	κ Dra

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