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Three case reports on the cometary plasma tail in the historical documents

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Abstract – Cometary tails visually manifest the solar wind and became an initial hint for its discovery. While the solar wind is being directly monitored with satellites, its time series before the space age has been controversially reconstructed with multiple proxies. Recently, archival reports of cometary plasma tails have been subjected to consideration to indirectly measure the solar wind but brought conclusion that no plasma tails had been reported prior to 1769 probably due to their brightness. However, historical records have occasionally reported comets with two tails even before 1769. These cases have been tentatively associated with visual reports of cometary plasma and dust tails. Therefore, we examined three such cases (C/1577 V1, 1P/837, and 1P/760), and compared the descriptions in historical records with calculated direction of their plasma tails. Our comparisons show that the records and calculations agree in these cases and plasma tails were visually recorded corresponding to these three great comets. These cases certify the capability of plasma tail observations with the unaided eye even before 1769, qualitatively imply their extreme brightness, proximities with the Sun and the Earth, relative enhancements of UV radiations, and interaction of cometary neutral atmosphere with solar wind plasma and magnetic field, while the lack of their detailed length or kink hinders us from their quantitative measuring. Further investigations will likely lead to the re-discovery of even more visual evidence of cometary plasma tails and, hence, improve our understanding on past space climate.

Keywords: space climate / cometary plasma tail: solar wind / UV radiation

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1 Introduction

Pointing almost towards the antisolar direction (Fig. 1), the cometary tails have provided visual hints for the solar wind (Biermann, 1963; Abe et al., 1997; Mendis, 2007; Vaquero & Vázquez, 2009; Mendis and Horányi, 2013; Iju et al., 2015; Verscharen et al., 2019). This typical motion of the cometary tails allowed Ahnert (1943) and Biermann (1951) to formulate their hypotheses on solar radiation and outward gas streamers from the Sun, respectively (Schröder, 2008; Obridko & Vaisberg, 2017). Parker (1957, 1965) explained Biermann's hypothesis on outward-streaming gas emanating from the Sun and later named this as "solar wind" (see also Kane, 2009). The solar wind has, since then, been directly confirmed with satellite observations (e.g. Gringauz et al., 1960; Neugebauer & Snyder, 1962) and subjected to regular monitoring afterwards (Verscharen et al., 2019).

Before the onset of such modern monitoring, the time series of the solar wind has been controversially reconstructed on the basis of multiple proxies such as the sunspot number, coronal structure, magnetic indices, and cosmogenic isotopes (Lockwood et al., 1999; Svalgaard & Cliver, 2005; Owens et al., 2017; Usoskin, 2017; Cliver & Herbst, 2018), including that of the Maunder Minimum (Cliver et al., 1998; Svalgaard & Cliver, 2007; McCracken & Beer, 2014; Riley et al., 2015; Usoskin et al., 2015; Owens et al., 2017). It is however challenging to extend its reconstructions before the onset of sunspot observations in 1610 due to the limit of direct scientific observations (Vaquero & Vázquez, 2009; Owens, 2013), while the cosmogenic isotopes in the natural archives show us its variability on the basis of the anti-correlation between the solar-wind magnetic field and the source galactic cosmic rays (e.g., Beer et al., 2012).

Even before being the earliest visual hint for the solar wind, comets have been frequently recorded in history over a few millennia (e.g., Yeomans & Kiang, 1981; Stephenson et al., 1985; Yeomans et al., 1986; Kronk, 1999; Murata et al., 2021). Therefore, cometary tails can also account for the reconstruction of the historical solar wind and space climate as a spot marker (e.g., Mendis, 2007; Mendis & Horányi, 2013). Since the plasma tail is blown with the solar wind almost towards the antisolar direction, records thereof have been investigated in historical documents to indirectly infer and measure the solar wind before the onset of instrumental observations (Gulyaev, 2015; Zolotova et al., 2018). Figure 1 of Zolotova et al. (2018) shows that the plasma tails are blown mostly towards the antisolar direction and that the dust tail curves according to its mass and physical property (see also our Fig. 1). They examined the shape, orientation, and colouration of cometary tails in historical documents, pointed out the lack of mentions on the plasma tail in historical records before C/1769 P1 (Fig. 2), and explained their conclusion with poor visibility of plasma tails through unaided-eye observations or early telescopes.

However, historical records have occasionally reported comets with probable two tails even before 1769 (e.g., Kronk, 1999; Silverman, 2008; Nogami, 2012; Hayakawa et al., 2017; Isobe, 2017) and some of them may have recorded plasma tails. If this is truly the case, these records probably indicate extremely bright plasma tails beyond the detection threshold of unaided-eye observations and merit discussions on the historical space climate in the distant past. Therefore, in this article, we discuss three case reports of great comets (C/1577 V1, 1P/837, and 1P/760) with two tails and compare their descriptions with simulated orientations of the cometary tails, in order to determine whether plasma tails were visible before C/1769P1 (c.f., Zolotova et al., 2018) and whether cometary records can be used to progress in our understanding of the space climate in the past.

2 Method

Here, we first need to note that the unaided-eye visibility of plasma tail is attested with several modern observations such as C/1858 L1 (Donati) and C/1995 O1 (Hale–Bopp) (e.g., Seargent, 2009). We also need to be aware of difference of unaided-eye observations from instrumental observations. When the emissions are not bright enough, human eyes cannot detect their colouration and perceive them without colour (Minnaert, 1993, pp. 193 – 209). As the brightness of plasma tails is much weaker, it is not guaranteed that the plasma tail always looks bluish to human unaided eye.

The key issue to identify the plasma tails is their quasi-antisolar direction, as they are ionised and blown with the solar wind. This can be computed when we known the relative positions of the Sun, the Earth, and the comet in question.

Therefore, in this study, we examined three cases of comets with reports of probable two tails: C/1577 V1 (Kronk, 1999; Silverman, 2008), 1P/837 (Kronk, 1999; Nogami, 2012), and 1P/760 (Hayakawa et al., 2017; Isobe, 2017). We analysed the original observational reports, identified the sites where they were seen, and clarified their tail directions. Furthermore, we compared the description in historical records and the expected direction of cometary tails corresponding to those days to check whether these three cases have indeed shown plasma tails before 1769.

We calculated the positions of these comets and the courses of their tail directions at each observational site with the Stella Navigator 11/AstroArts.[1] Using this software, we have specified the time and site of these observations and displayed how the sky appeared at that time and location. Here, we applied the orbital elements of Marsden & Williams (2008) to C/1577V1, 1P/837, and 1P/760, and calculated their motion and tail directions. Table 1 summarizes the orbital elements used in this study.

3 Historical cases of unaided-eye plasma tails

3.1 Case 1: C/1577 V1

The first comet studied here is C/1577 V1 (see Kronk, 1999, pp. 317–320; Silverman, 2008). This comet was ≈ 0.63 AU away from the Earth at its perigee on 1577 November 10 and it reached a brightness of magnitude (m) ≈ −3 on 1577 November 8 (Seargent, 2009, p. 247). For this comet, at least three independent accounts indicated its separated cometary tails. Firstly, Chaim Vital's account involved a Palestinian cometary observation at Safed (N32°58′, E35°30′) during the

[1] https://www.astroarts.co.jp/products/stlnav11/index-j.shtml

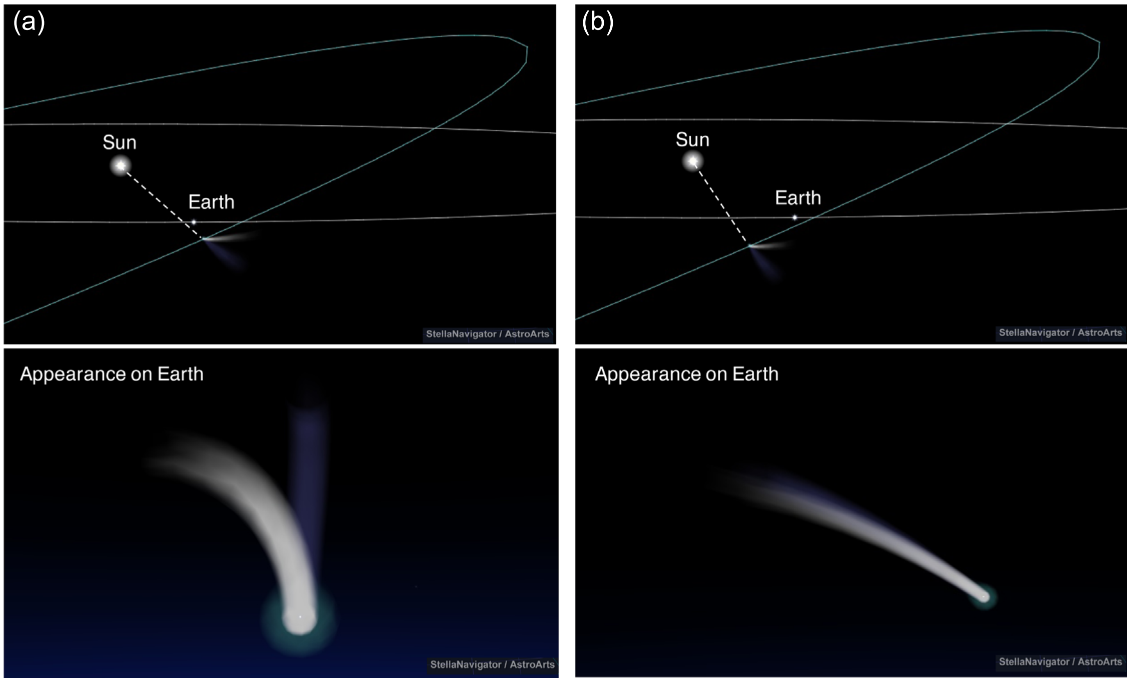


Fig. 1. Directions of two tails (plasma and dust tails) of a comet in comparison with the Sun and its orbit, with courtesy of Stellar Navigator 11/AstroArts. These diagrams show that the plasma tail extends to the quasi-antisolar direction and that the dust tail curves according to the orbit of the associated comets. While comets have plasma and dust tails, up to the relative angle with the Earth, two tails are visible (a) or apparently overlap with each other and cannot be distinguished by the terrestrial observers (b).

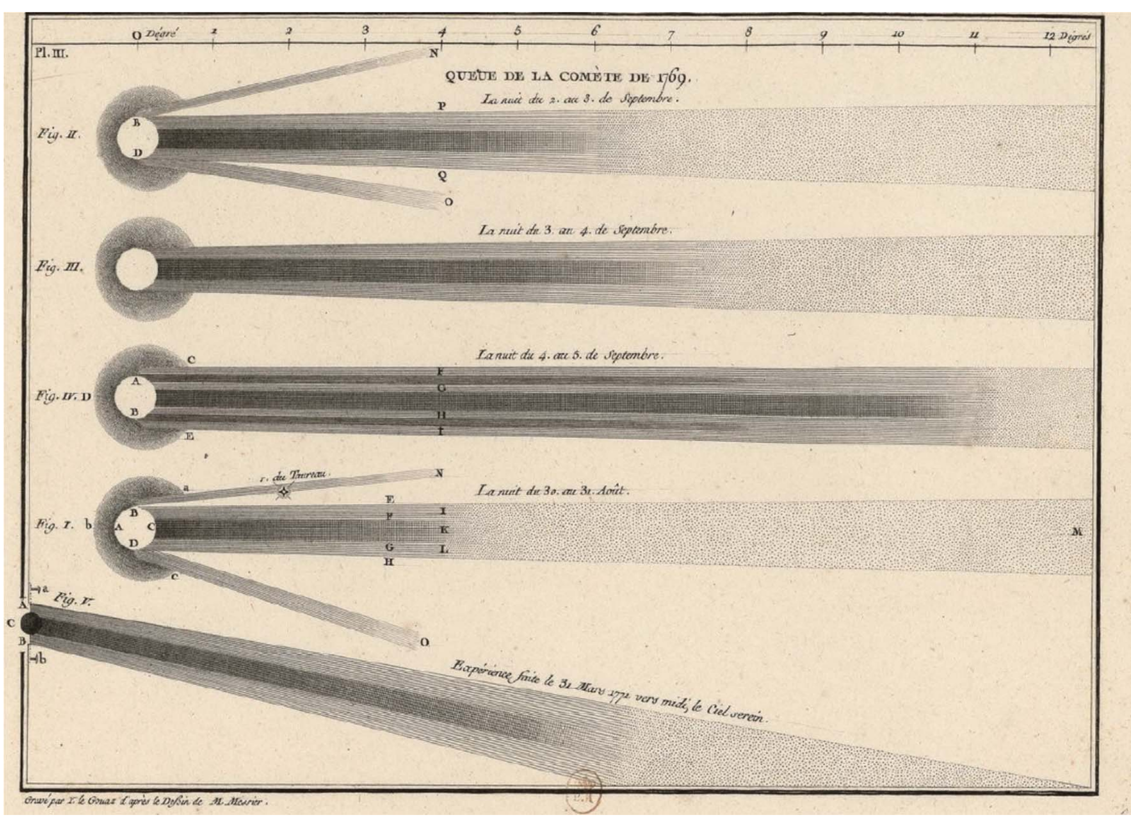


Fig. 2. Cometary diagrams by Messier and Le Gouaz (1775) for C/1769 P1, with courtesy of Bibliothèque nationale de France. Its branched tail was interpreted as a plasma tail in Zolotova et al. (2018), using Messier's different diagram.

Table 1. Cometary orbital elements for the great comets examined in our article: C/1577 V1, 1P/837, and 1P/760.

	Time of perihelion passage (T)	Argument of perihelion (ω)°	Longitude of the ascending node (Ω)°	Inclination (i)°	Perihelion (q) au	Eccentricity (e)
C/1577 V1	1557 Oct. 27.448	255.673	31.237	104.883	0.1775	1.0
1P/837	837 Feb. 28.270	100.101	44.930	163.447	0.58232	0.96781
1P/760	760 May 20.671	99.997	44.687	163.443	0.58184	0.96785

evening of 1577 November 10 (Silverman, 2008). The occurrence was described as "after sunset, a large star with a long tail, pointing upward, was seen in the southwestern part of the sky. Part of the tail was also pointing eastward. It lingered there for 3 h. Then it sank in the west behind the hills of Safed. This continued for more than fifty nights" (Faierstein, 1999, p. 95; modified with Silverman, 2008, p. 123). This coincides with a possible description of tail separation on November 8 in Japanese records, whereas their late compilation reserve caveats on their record reliability (Ho, 1962).

Secondly, Cornelius Gemma, a professor of the Catholic University of Leuven, reported the separation of these cometary tails in late November with his diagram (Fig. 3). He stated that, after a violent thunderstorm, on 1577 November 28: "Thus thereupon it became clear, so to speak, the branch of another tail spread downwards, likewise from the neck and the head. It remained in this way for many days, until the whole mass burnt down, scattering or weakening gradually" (Gemma, 1578, pp. 25–26; see also Van Nouhuys, 1998, p. 172). Gemma's diagram shows a shorter straight tail and a longer curved tail. Gemma described the position and extension of these cometary tails as: "Consequently, it was remaining (and) carrying the remembrance of wings now straight expanded, the end of whose aponeurosis stretched beyond the nose of Pegasus: the smaller one advanced up to a nearer and southern small star (Australem) in the forehead of Equuleus. The remaining parts (of tails) were passing over between the forehead and the nose of Equuleus. . . . Distance from the mouth of Pegasus 12 deg. 40 min., from brightening wings 15 deg. 26 min. The sign-bearing point 10 = latitude 24 deg. The extension of tail 18 deg. at most" (Gemma, 1578, pp. 25–26).

Among these records, Gemma's diagram and description are the most informative. Assuming the observational site as the Catholic University of Leuven (N50°53′, E4°42′), we tried to represent his observation by adjusting the equipped parameters: the physical length of the tails (L_d and L_p for dust and plasma tails, respectively), the periods during which materials that generate each cometary tail were released (D and I for dust and plasma tails, respectively), and maximum and minimum value of beta (β_{max}, β_{min}). β is defined as the solar radiation pressure to gravity ratio on a dust particle, and the values determine the shape of a dust tail. β is known to depend not on the distance from the Sun but on the dust size, density, material, etc. The selected values are $L_d = 0.3$ au, $L_p = 0.3$ au, $D = 23$ days, $I = 2.5$ days, and $\beta_{max} = \beta_{min} = 0.5$. We selected the option for automatically adjusting D and I depending on the distance from the Sun. Although the upper curved tail in his sketch implies it is a dust tail, our calculation shows that the dust tail should locate below the plasma tail. This apparent discrepancy requires us to be slightly cautious on the existing cometary orbit in

Fig. 3. Gemma's diagram of the comet C/1577 V1, captioned as "The shape of the entire body and refraction [of the comet] ca. in the end of November", adapted from Gemma (1578, p. 26).

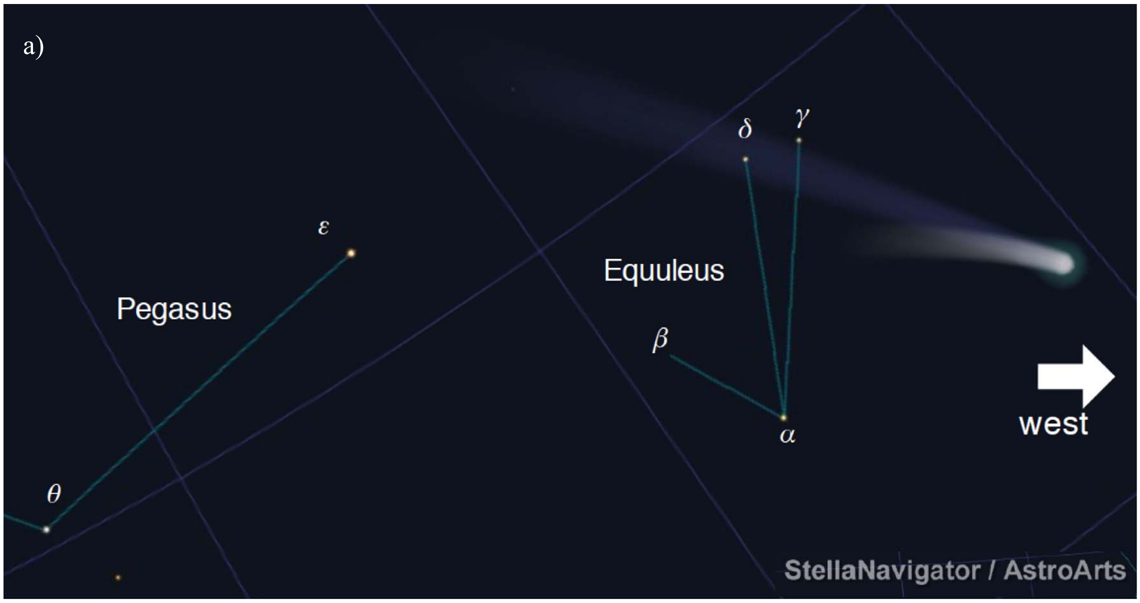
Marsden & Williams (2008), based on early calculations in Woldstedt (1844).

If we set the curvature of the tails in the diagram aside, the best we could reproduce with the orbital elements in literature (Woldstedt, 1844; Marsden & Williams, 2008) is shown in Figure 4a. Our calculation shows that these two tails were indeed deviated. We attempted to further adjust the reproduced image by slightly modifying the perihelion argument (ω) from 255.673° to 253.0° (Fig. 4b). This comparison certifies that the plasma and dust tails were separated with each other as well. Therefore, we conservatively confirmed the divided appearance of these two cometary tails, while we refrained from identifying the physical nature of each cometary tail.

We then applied the same settings to Vital's account. Assuming its observational site as Safed (N35°30′, E32°58′), our calculation with the existing orbital element shows that the cometary tails certainly deviated significantly from each other (Fig. 5). The reported visibility "after sunset" implies its observing time as ≈ 18 LT because the comet sets immediately after sunset. This comparison securely allowed us to associate the two reported tails with its plasma tail and dust tail. These two case reports confirm that the reported two cometary tails of C/1577 V1 were certainly observations through the unaided eye.

3.2 Case 2: Halley 1P/837

The second case involves Chinese records of Halley 1P/837 (see Xu et al., 2000; Nogami, 2012). At its perigee on 837 April 10–11, Halley 1P/837 was only ≈ 0.03 to 0.04 AU away from the Earth. As such, it became significantly bright, reaching levels of up to $m \approx -4$ (Yeomans et al., 1986, p. 74; Kronk, 1999, pp. 125−127).



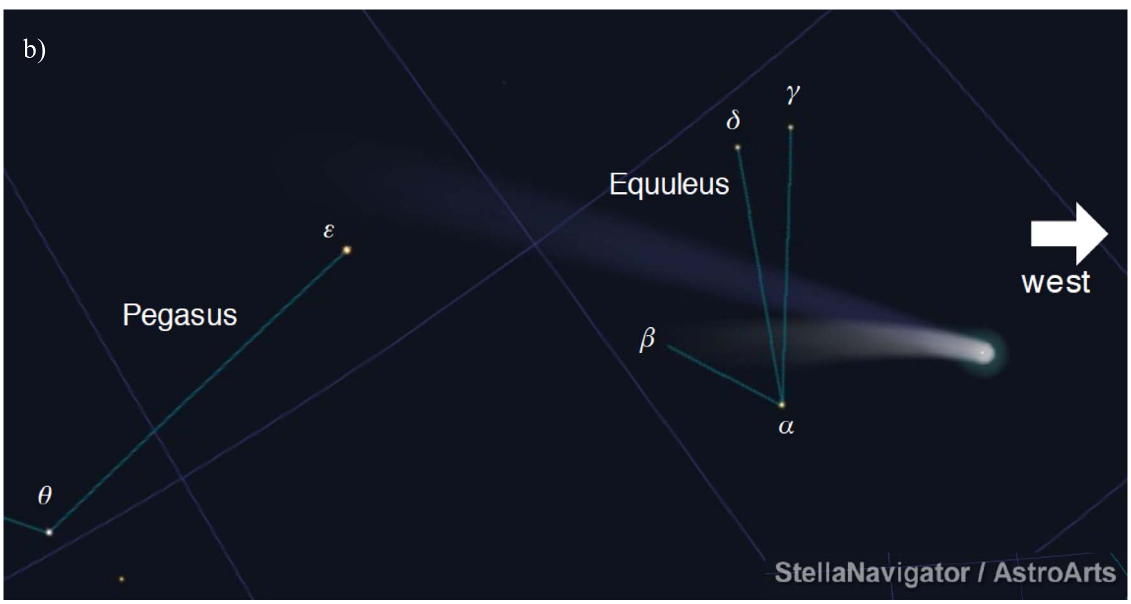


Fig. 4. Computed cometary tails at Leuven on 1577 November 28 with (a, above) the existing perihelion argument (ω = 255.673°) (Woldstedt 1844; Marsden and Williams, 2008); and (b, below) the modified perihelion argument (*ω* = 253.0°) using Stellar Navigator 11.

Around the perigee, official Chinese astronomers reported a peculiar tail branch of this comet. The original records (*Jiùtángshū*, v. 17, p. 568; v. 36, p. 1333) described the tail branch as: "[On the night of April 10], the bloom star was as long as 5 *zhàng*. It branched into two tails. One pointed Root (*Dī*, 氐) and one covered Room (*Fáng*, 房). [It situated 10 *dù* in Dipper (*Dòu*, 斗)]" and "on April 11 … at night, it was as long as 6 *zhàng*. Its tail was not branched. [It directed northward.] It situated 7 *dù* in Neck (*Kàng*, 亢)".[2] Later on, this comet was also recorded in *Xīntángshū* as, "on April 10, it was as long as 6 *zhàng*. Its tail branched into two. One pointed Root (*Dī*) and one covered Room (*Fáng*). On April 11, it was as long as 6 *zhàng*. It was not branched. It pointed north and situated 7 *dù* in Neck (*Kàng*)" (*Xīntángshū*, v. 32, p. 839). These records explicitly indicated where these two tails were directed during the night of 837 April 10/11: one covering *Fáng*, i.e., π Sco, ρ Sco, δ Sco, and β Sco; and the other pointing towards *Dī*, i.e., α Lib, ι Lib, γ Lib, and β Lib.[3] It was further described that these tails converged by the night of 837 April 11/12.

Assuming the observational site as the court observatory at Cháng'ān (N34°14′, E108°56′) in the capital city of Táng Dynasty (see e.g., Stephenson et al., 2019), we have calculated

[2] The passages enclosed with square bracket are found only in the astronomical treatise (v. 36).

[3] See Pan Nai (1989) to know which stars were categorized in which Chinese constellations.

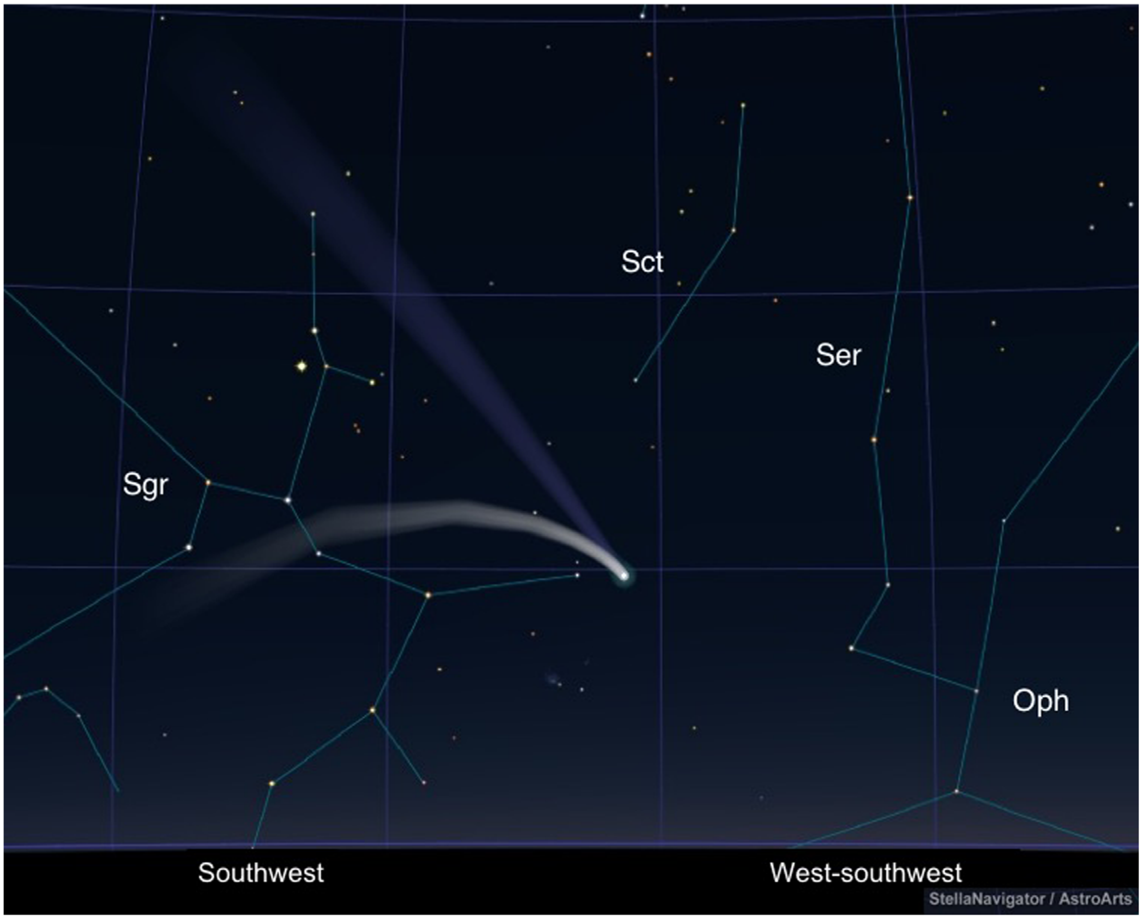


Fig. 5. Computed cometary tails at Safed on 1577 November 10, computed with the existing perihelion argument (ω = 255.673°) (Woldstedt, 1844; Marsden & Williams, 2008) using Stellar Navigator 11.

the tail directions of Halley 1P/837 with Stella Navigator 11. The selected settings are L_d = 0.5 au, L_p = 0.5 au, D = 32 days, I = 1.5 days, β_{max} = 0.8, and β_{min} = 0.5. Our calculation shows α Lib involved in *Dī*, to which one of cometary tails was pointed, being situated anti-solar direction from this comet at that time. As shown in Figure 6, our calculation shows that its tails certainly branched during the night of 837 April 10/11 (Fig. 6a), whereas the tails almost converged during the night of 837 April 11/12 (Fig. 6b). Interestingly, during the night of 837 April 10/11 at Cháng'ān, its dust tail was exactly directed towards *Fáng* (π Sco, ρ Sco, δ Sco, and β Sco), whereas its plasma tail was directed towards α Lib, the western part of *Dī*. Therefore, the Chinese historical records and the reproduced cometary configuration consistently confirm that the "two tails" which branched into *Fáng* and *Dī* were most probably the dust tail and the plasma tail of Halley 1P/837.

3.3 Case 3: Halley 1P/760

The third case regarding a possible two-tail comet is a Syriac record of 1P/760 at Amida (N 37°55′, E 40°14′) in the *Zūqnīn Chronicle* (Hayakawa et al., 2017; Isobe, 2017; Mitsuma & Hayakawa, 2017). At its closest approach on June 2, Halley 1P/760 was only ≈ 0.41 AU away from the Earth. Hence, it became significantly bright, with up to $m \approx 0$ (Yeomans et al., 1986, p. 73; Kronk, 1999, pp. 116–118). Note that the astronomical body will be brighter when the magnitude is smaller. For example, the brightness magnitude of the full Moon and the Sun are −12.7 and −26.7, respectively (see e.g., Krisciunas & Schaefer, 1991). As such, the Halley comet was closer to the Earth and hence apparently brighter in case 2 than in case 3. Because the information was not enough to reconstruct the appearance of the comet, we adopted the same parameters that we used for 1P/837.

According to the *Zūqnīn Chronicle* (MS Vat.Sir.162, f. 136v; Chabot II, p. 217; Harrak, 1999, p. 198; Hayakawa et al., 2017, p. 12), this comet appeared "before early-morning, in the north-eastern side". This chronicle further stated that: the comet "was still in Aries (*emrā*), at its head (*rêšeh*), in the first degree (of the sign), two (degrees) from those wandering stars, Kronos (*qrāwnās*) and Ares (*arrês*), which are slightly to the south, on the 22nd of the month. And the sign remained for 15 nights, until the dawn of the Pentecost feast. And one end of it was narrow and duskier, one star was seen in its tip, and it was turning to the north. And the other one, being wide and darker, was turning toward the south. And it (the sign) was going bit by bit to the northeast. This is its shape: [drawing: Comet, Ram (= α Ari, β Ari, and γ Ari), Ares (= Mars), and Kronos (= Saturn)]".

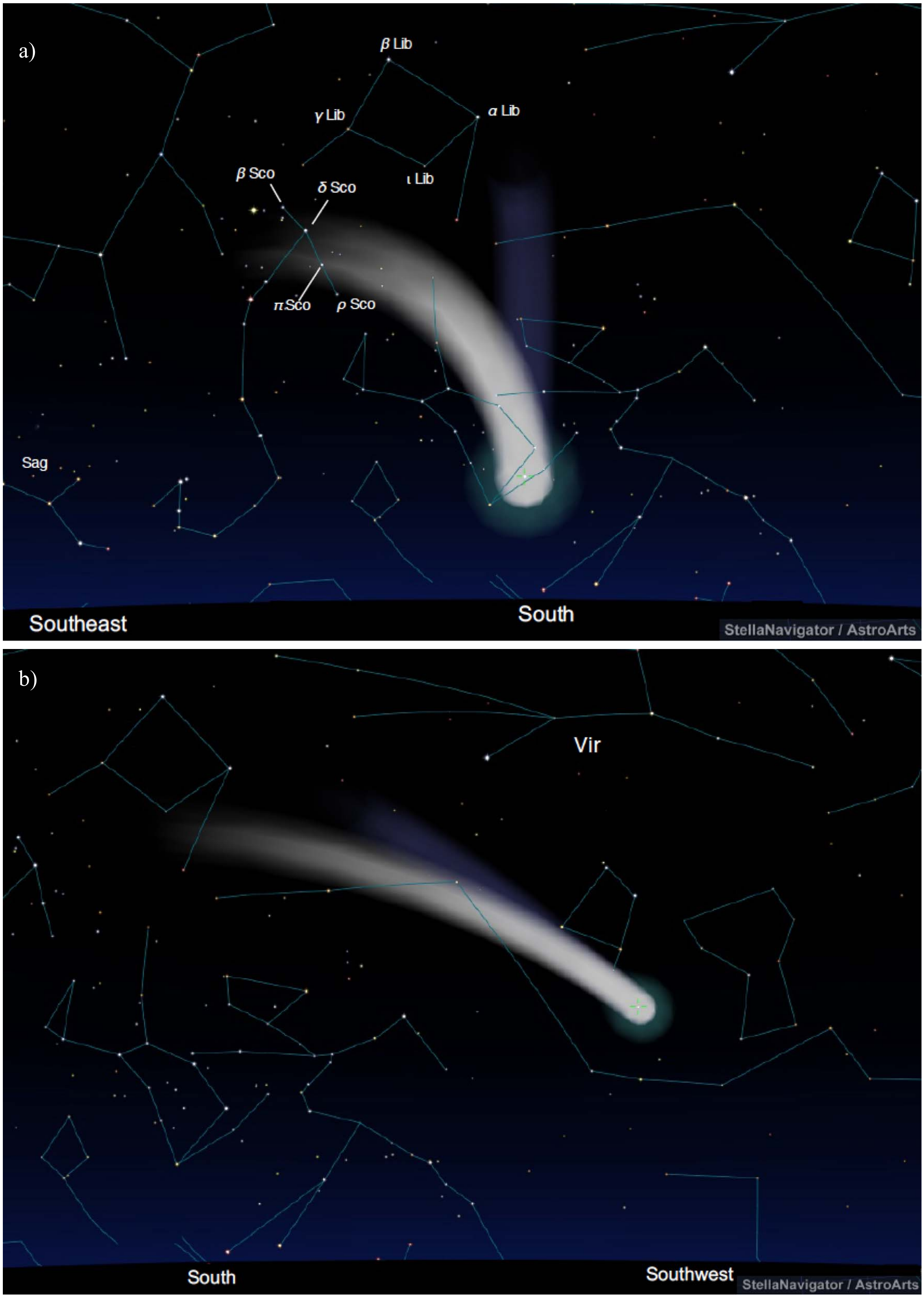


Fig. 6. Calculated cometary tails during nights of (a) 837 April 10/11 (April 11, 01:00 LMT) and (b) 837 April 11/12 (April 12, 0:00 LMT) with Stella Navigator 11 using orbit element in Marsden & Williams (2008) and Yeomans & Kiang (1981). During the night of April 10/11, 837, its dust tail (white) was shown directed towards *Fáng* (π Sco, ρ Sco, δ Sco, and β Sco) and its plasma tail (blue) directed towards α Lib in the western part of *Dī*.

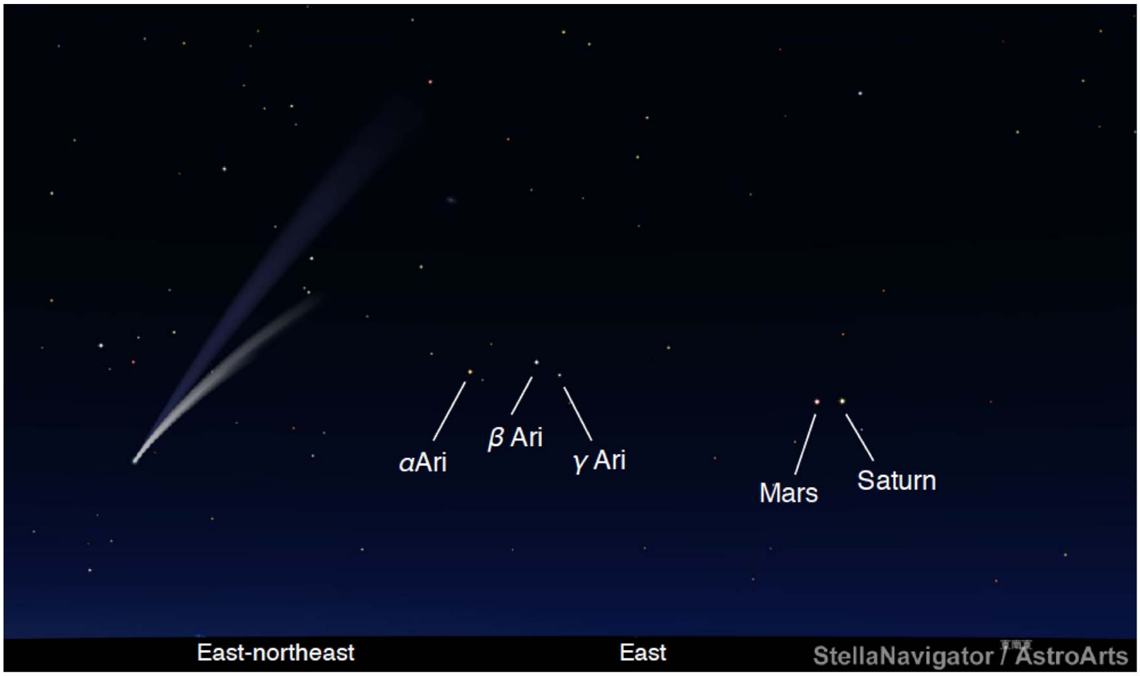


Fig. 7. Computed appearance of cometary tails on 760 May 24/25 at Amida, using Stellar Navigator 11 with the orbital elements in Yeomans & Kiang (1981) and Marsden & Williams (2008).

The Pentecost in 760 was on May 25 (Grumel, 1958; Hayakawa et al., 2017). Its night corresponds to the night of 760 May 24/25 since a Syriac day starts from the sunset of the previous civil day, beginning at midnight, likely to a day in the Bible (e.g. Grumel, 1958). The descriptions of the two ends (*rêšeh*) are especially intriguing, although this is not clearly depicted in the drawing itself (Figure 4 of Hayakawa et al., 2017). This is because one was described as "narrow and duskier, one star was seen in its tip, and it was turning to the north", whereas the other was described as "being wide and darker, was turning toward the south". As shown in Figure 7, our calculation shows that the plasma tail was turned relatively zenith-ward to slightly northward, while the dust tail was directed relatively southward. As time goes by, this plasma tail deviated towards the north according to the calculation.

Neither of these two ends were likely the head of the comet, considering that the head of comet is described separately (Harrak, 1999, p. 198; Hayakawa et al., 2017) and no notable stars were located around the head of the comet. Contrary to the foregoing, "one star was seen in the tip" of the "narrow and duskier" end. As this comet "was going bit by bit to the northeast" (MS Vat.Sir.162, f. 136v; Hayakawa et al., 2017, pp. 8 and 12), a cometary head would have been described not as northward, but as eastward, on the basis of relative direction in relation to the cometary motion. Therefore, it is plausible that the "narrow and duskier" end was the plasma tail and the "wide and darker" end indicated the dust tail. In this case, the northern tail is identified with its plasma tail.

4 Summary and discussion

We have analysed the positions of comets and directions of their tails in historical records for C/1577 V1, Halley 1P/837, and Halley 1P/760 in relation to the mentioned constellations, stars and planets and compared these descriptions with the simulated appearance of the comets. These cases show plausible visibility of unaided-eye plasma tails and their brightness beyond the threshold of unaided-eye visibility in combination with several modern cases such as C/1858 L1 (Donati). For C/1577 V1, our comparison shows that the plasma tail on 1577 November 10 and 28, was separately visible from the dust tail at Safed and Leuven, respectively, as recorded by Vital and Gemma. This confirms that Vital and Gemma both were able to study and report the cometary plasma tail without telescopes. For Halley 1P/837, our comparisons show that the reported directions of its plasma tail and dust tail are rather consistent with the simulated appearance in the sky. Likewise, for Halley 1P/760, our comparison implies that the cometary tail was certainly deviated at that time, given that the descriptions of its two ends likely showing the two tails of the comet and the relative position with the mentioned stars (α Ari, β Ari, and γ Ari) and planets (Mars and Kronos) showing a significantly accurate description as shown in the *Zūqnīn Chronicle*.

These records date centuries back from the "earliest" description of the plasma tail of C/1769 P1 in 1769, identified in Zolotova et al. (2018). It is suggested that even unaided-eye observers prior to 1769 were able to observe the cometary plasma tail under suitable conditions, despite its relative faintness. These three cases analysed here are only a small fraction of existing cometary records in history. However, they imply that further examples of comets with a plasma tail can be re-discovered, especially in historical sources yet to be studied.

In order to see bright plasma tail without instruments, we need: (1) favourable short distance between the comet and the Earth; (2) favourable angle of the comet with the Earth and the Sun; and (3) enough brightness of the cometary tails.

In order to satisfy the condition (3) and make the cometary plasma tail itself bright enough, we need combination of relatively significant photoionisation and interaction of cometary neutral atmosphere with solar wind plasma and magnetic field, apart from larger mass of cometary nuclei to enable larger release amount of neutral gas. This is because the mass of cometary nuclei dominates an upper limit of gas release amount and we need UV radiation, solar wind flux, and charge exchange to ionise the cometary material (Wyckoff & Wehinger, 1976; Mendis & Horányi, 2013) and magnetic field of solar wind to blow the ionised materials along the magnetic field line (Mendis, 2007; Mendis & Horányi, 2013; Glassmeier, 2017). These components are enhanced when comets get closer to the Sun, whereas this is a trade off with their distance with the Earth, which enhances apparent brightness for the terrestrial observers.

Apart from the cometary distances with the Sun and the Earth, the solar parameters also vary with the solar activity. The UV radiation correlates well with the solar radio flux in the wavelength of 10.7 cm (Tapping, 2013; Tapping & Morgan, 2017), which has a fairly good correlation with the sunspot number (Clette et al., 2014; Svalgaard, 2016; Tapping & Morgan, 2017). The intensity of solar wind plasma and magnetic field, which interact with the cometary neutral atmosphere, also correlate with the sunspot number (e.g., Zerbo & Richardson, 2015; Samsonov et al., 2019). Therefore, it is assumed that the extremely bright cometary plasma tails are more frequently visible under enhanced space climate condition on the basis of its correlations with the UV radiations and the solar wind plasma and magnetic field.

A scenario with the foregoing conditions was, at least, the case with the great comet Messier C/1769 P1, associated with the "earliest" documented plasma tail (Zolotova et al., 2018). At its closest approach on 1769 September 10, Messier C/1769 P1 was only ≈ 0.32 AU away from the Earth and reached a brightness of $m \approx 0$ (Kronk, 1999, p. 442–451). Its approach coincided with the maximum of Solar Cycle 2 (Clette & Lefèvre, 2016) with several unaided-eye sunspot records (Hayakawa et al., 2019).

As discussed above, the three great comets in 1577, 837, and 760 have also probably satisfied at least the first two conditions. The comet C/1577 V1 was ≈ 0.63 AU away from the Earth at its perigee and reached a brightness of $m \approx -3$ (Seargent, 2009, p. 247). The comet Halley 1P/837 was only ≈ 0.03–0.04 AU away from the Earth and reached a brightness of $m \approx -4$ (Yeomans et al., 1986, p. 74; Kronk, 1999, pp. 125–127). Halley 1P/760 was ≈ 0.41 AU away from the Earth and had a brightness of $m \approx 0$ (Yeomans et al., 1986, p. 73; Kronk, 1999, pp. 116–118).

Therefore, it is possible that these three comets indirectly indicated relatively enhanced UV radiation and interaction of cometary neutral atmosphere with solar wind plasma and magnetic field in 1577, 837, and 760. Our inference is, at least, partially supported from the unaided-eye sunspot recorded on 837 December 22, visible until December 24 (XTS: v. 32, p. 834; see also e.g., Yau & Stephenson, 1988; Xu et al., 2000). Additionally, this is also consistent with the relatively high solar-wind condition around 1577 inferred from auroral reports (Silverman, 1986). Indeed, at least, no visible plasma tails have been reported from the Maunder Minimum (Zolotova et al., 2018). None of these three cases occurred in any of existing grand minima either: the Maunder Minimum (1645–1715), the Spörer Minimum (1390–1550), the Wolf Minimum (1270–1340), the Oort Minimum (1010–1070), and another un-named grand minimum (650–730) (see Usoskin et al., 2007; Usoskin, 2017; Silverman and Hayakawa, 2021). However, the brightness of plasma tail is also highly influenced with composition of the nuclei and its activities and requires us to be cautious on the cometary nuclei. This is typically the case with C/1577 V1, where we need to reserve possibility for the nuclei of C/1577 V1 to have been particularly large and have released larger amount of neutral gas. As stated previously, the increases of UV radiation and apparent brightness from the Earth form trade-offs between the distances of given comets from the Sun and the Earth. These issues may have led visibility of plasma tails of some great comets near the solar cycle minima: e.g., 1P/1986 (Halley), and C/1995 O1 (Hale–Bopp).

Moreover, the lack of apparent length and inclination of these plasma tails hindered us from quantitatively evaluating the UV radiation and the solar-wind conditions. It is also extremely difficult to derive the kink of cometary plasma tail from the textual descriptions of historical documents, without precise graphical evidence. Records with drawings or specific descriptions are required for their further quantitative measurements. For now, these records allow us to qualitatively know that these comets were fairly close to the Earth and the Sun, significantly bright, and accompanied by relative enhancements of UV radiations and interaction of cometary neutral atmosphere with solar wind plasma and magnetic field, and hence that of space climate. Further analyses on the historical cometary records and evaluations of the cometary nuclei and cometary positions would be beneficial to develop discussions on the historical space climate.

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Author contribution

HH and YIF designed this study. HH worked on historical aspect of this article. YIF simulated the appearance of the comets. KM, YM, YK, and YC contributed interpretations of the Latin, Syriac, and Chinese texts. NN contributed to interpretations of descriptions and directions of comet orbits. MNN contributed to the discussions on the sun-comet interactions. KI, HS, and KT supervised the astronomical aspects of this article. All the authors read and discussed the contents of this article.

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