Indirect Solar Wind Measurements Using Archival Cometary Tail Observations

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Abstract
The paper addressed to the problem of the solar wind behaviour during the Maunder Minimum. Records on plasma tails of comets would allow to shed light on the physical parameters of the solar wind in the past. We analyse descriptions and drawings of comets to the eighteenth century. To differentiate dust and plasma tails, we address to their color, shape and orientation. Basing on the calculations made by F.A. Bredikhin, we found that deviation of cometary tails from the antisolar direction on average exceeded 10\degree, that is typical for dust tails. Catalogues of Hevelius and Lubieniecki are also examined. The first indication of plasma tail was revealed only for Great comet C/1769 P1.

1. Introduction
Apart from spacecraft measurements, the plasma tails are natural probes of the interplanetary space. Physical parameters of the solar wind during the so-called Grand minima are still the outstanding puzzle [Eddy (1976)]. For the Maunder minimum (thereafter MM) from 1645 to 1715, [Parker (1976)] conjectured that whether a fast and persistent solar wind emanated from a coronal hole, entirely covering the Sun, or whether the solar wind just did not blow.

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Bessel (1836) suggested that cometary particles move under the action of the effective repulsive force. This idea formed the basis of the mechanical theory of cometary shapes. Bredikhin (1879a, 1880, 1886) revised Bessel’s calculations and created a well-known classification of cometary tails. This classification was further developed by Orlov (1935) and Wurm (1954). However, the mechanical theory could not explain the large acceleration of cloud masses observed in type I tails. Biermann (1951) showed that the acceleration of the ionized particles in cometary tails can not be explained by the repulsive force of light pressure. He suggested that the ions are accelerated by the flow of the electrically charged particles emanating from the Sun, referred to as the solar wind, whose mathematical theory was developed by Parker (1958).

Suess (1979) proposed that during the MM the solar wind speed or the interplanetary magnetic field or both were low and not irregular. Mendoza (1997) evaluated average velocities of the solar wind using proxy $a_{\alpha}$ index and obtained $194.3\ \text{km s}^{-1}$ from 1657 to 1700 and $218.7\ \text{km s}^{-1}$ from 1700 until now. Cliver, Boriakov, and Bounar (1998) extrapolated observed solar wind variations to the MM conditions and suggested that average velocities have an upper limit of $340 \pm 50\ \text{km s}^{-1}$, and that of the interplanetary magnetic field, $0.3 \pm 0.1 \text{nT}$. Idea of the lowest conceivable solar wind magnetic field (the floor) was developed by Svalgaard and Cliver (2007) and Cliver (2012).

The scenario of a giant coronal hole over the entire solar disk at the MM might imply the solar wind speed $800\ \text{km s}^{-1}$ (Steinhilber et al., 2010). Wang and Sheeley (2013) simulated the axial solar dipole during grand minima and concluded that a factor of 4 – 7 decrease in the total open flux should result in a similar suppression in the solar wind densities not affecting the solar wind speeds. Using geomagnetic indices as a proxy for the solar wind speed, Lockwood and Owens (2014) conjectured that solar wind speeds would be relatively uniform in the MM (between 250 and 275 km s$^{-1}$). Riley et al. (2015) argued that disappearance of the solar wind during the MM is not compatible with the presence of geomagnetic activity and aurora which did not cease. Owens, Lockwood, and Riley (2015) noted that during the MM solar maximum regime prevailed with short-living fast wind at high latitudes. Results agree with the MM coronal magnetic field configuration constructed in a global MHD model by Riley et al. (2015).

Gulyaev (2015) analysed historic drawings of comets using the mechanical classification of cometary tails. He concluded that straight type I tails depicted by observers in the MM correspond to the plasma tails, which in turn indicates the solar wind is a persistent phenomenon.

In this article, we are raising the issue whether observers had reported the plasma tails of comets in the distant past. In Section 2, the main parameters of a cometary tail which may help specify its nature (dust or plasma) are mentioned. In Section 3, we analyse color, shape, and orientation of the cometary tails from historic archives. Catalogues of Hevelius and Lubieniecki are also discussed. Section 4 accumulates conclusions.
Figure 1. (a) Mechanical classification of cometary tails according to Bredikhin (1879b). ξ is the prolonged radius-vector. ϵ is the angle between the observed tail and the antisolar direction. Colors denotes type of tail. (b) Schematic illustration of the transit of a comet in the Solar System.

2. Parameters of Cometary Tails

In mechanical theory, the ratio of the outward radial force $F_r$ to the gravitational force $F_g$ given $|F_r/F_g| = R$ (the effective repulsive force) is used to divide the cometary tails into three types. Type I tails have $R > 12$; type II, $2.2 < R < 0.9$; and type III, $0.75 < R < 0.2$ (Bredikhin, 1879b). In different editions, these values slightly vary. Type I tails are narrow, nearly straight and point almost directly away from the Sun. Type II tails are smooth, curved and distant from the prolonged radius-vector of a comet. Type III tails are short and broad. Figure 1, shows the classification of the tails according to Bredikhin (1879b). Blue color denotes type I tail which consists of hydrogen. Yellow color denotes type II tail which is composed of medium-heavy elements. Pink color corresponds to heavy metals of type III tail. ξ is the prolonged radius-vector. ϵ is the angle between the observed tail and the antisolar direction. The lighter the chemical element, the closer its path to the prolonged radius-vector, and the greater R for this element. Here, we emphasize that this classification is no longer valid.

The modern theory distinguishes two basically different types of tails which are composed of either plasma or dust. Figure 1 schematically illustrates the transit of a comet in the Solar System. Yellow decagon depicts the Sun. Dashed curve with arrows denotes a cometary orbit. A white circle is a coma complemented by a wide and curving dust tail and a thin and straight plasma tail. $V_c$ is the comet’s orbital speed; γ is the angle between the cometary speed $V_c$ and antisolar vector.
Simple calculations give that deviation of the plasma tail from the prolonged radius vector is defined as \( \epsilon \approx \arctan \left( \frac{V_c \sin \gamma}{V_{sw}} \right) \), where \( V_{sw} \) is the radial component of the solar wind flow (Mendis, 2007). Figure 1 shows values of \( \epsilon \) and \( V_{sw} \) for typical value of the transverse component of the comet’s orbital speed \( V_c \sin \gamma \approx 20 \text{ km s}^{-1} \). Due to the retrograde orbit, Haley’s comet has one of the highest velocities \( V_c \approx 70 \text{ km s}^{-1} \). Sophisticated calculations yield that typical value of \( \epsilon < 6^\circ \) for the plasma tails (Brandt, 1967; Mendis, 2007). Deviation of dust tail from the antisolar direction amounts to first tens of degrees. For historic observations, magnitude of \( \epsilon \) was restored by Bessel and revised by Bredikhin. In order to specify the nature of the tails reported by observers in the distant past, we will rely on this parameter.

Another feature of the dust tail is its curvature. In other words, if observer write that cometary tail became curved, this denotes dust tail. However, in the case of non-stationary outflow of cometary particles and at a short distance from a nucleus, the dust tail may appear straight. For a visual observer to discover the curvature of a tail, its length should be at least 6 – 7°.

Next circumstance that has to be taken into account is the projection effect. The closer the Earth to the comet’s orbital plane, the straighter the dust tail.

Finally, a bright comet often exhibits white dust tail which may assume a yellowish or reddish tint, accompanying the dim bluish plasma tail. For a naked-eye observer, dust tail shining by reflected sunlight is much brighter than that of plasma whose light is caused by the fluorescence of ionized gases. Their bluish radiation is located on the edge of the visual spectrum, to which the human eye is poorly sensitive. Therefore, historic reports on bright light emanating from cometary head also indicate the dust tail.

3. Results

3.1. Color of Cometary Tail

We analyse text descriptions of comets from the eleventh to eighteenth century. The older reports often mention the color of a comet. To find observations of bluish cometary tails, we address to Svyatsky (2007), who collected astronomical events from the Complete collection of Russian chronicles; Williams (1871), who translated the Chinese annals; catalogues of Kronk (1984, 1999), and other numerous reports of individual European observers.

In 11 volumes of the Complete collection of Russian chronicles, we did not find a single mention of the bluish tint of comets. On the contrary, red color of comets is often mentioned, usually as omen of bloodshed. Note, that a significant portion of comets was observed at sunset or at sunrise when the sky is painted with orange and red light. In European reports, we also did not come upon the bluish color of tails. In Eastern chronicles (Chinese, Korean, and Japanese), luminous envelopes and tails of comets are usually reported as white light objects. We would like to point out two translations of the report on comet C/1462 M1 from the Chinese annals. Williams (1871) wrote that colour of a star (comet) was a bluish white, while Kronk (1984), that color was darkish white.
To conclude, we did not find robust support of hypothesis that observers saw bluish tails. Below we list comets whose observations were detailed.

### 3.2. Great Comet C/1471 Y1

The comet was reported by Toscanelli (Uzielli and Celoria, 1893), who drew comet with a short tail. Bredikhin (1886) defined $R = 6.5$ (he proposed type I). Perihelion of the comet is on March 11, 1472. On January 20, $\epsilon = 6^\circ$, and February 2, $\epsilon = 18^\circ$, that indicates the dust tail. However, the comet was near the ecliptic plane, therefore the projection effects were significant, that results in large errors of calculations.

### 3.3. Great Comet C/1577 V1

On November 23, 1577, the cometary tail was pointed at evening. The head of the comet was above the front of the Equiculi constellation (modern Equuleus). The tail was curved, the convex part at Zenith. The tail ends in the front of the Pegasii constellation (modern Pegasus). The head of the comet was white, but not as bright as the light of stars. The tail was dim and reddish, especially near the head, like a flame breaking through the smoke, as we translate it from Brahe (1610 “Caudam porrigebat hoc vespere, in eam Stellulam, quæ est superior in fronte Equiculi... Erat autem, à capite versus dictam Stellam, paulum more solito incurvata, conuexam partem in Zenith tollens, adèo, ut si à capite per dictam Stellam ulteriorius protrahiri fingeretur, suo ductu obliquo versus eam pertingeret, quæ est in fronte Pegasii. Color autem capitis Cometæ suit albus, non tam clarus, sed pallidior, neque ita lucidus, ut Stellarum lumen. Cauda vero obscuram rubedinem, præsertim quo erat capiti vicinior, ostendebat, quæ sēque solet esse flammæ alicujus, per fumum densum eluctantis...”). Numerous engravings by Hayck (1578, see here Figure 2a), Bazello (1578); Busch (1577); Graminaeus (1578); Mastilino (1578), and others describe a long and curved cometary tail, which corresponds to the dust nature of the tail.

Bredikhin (1886) also defined that the comet had the dust tail with $0.02 < R < 2.8$. From November 13, 1577 to January 12, 1578, the angle of deviation of the asymptote of the hyperbola of the cometary tail from the antisolar direction varied from 12.5° to 33.5° and on average was 20° (Bredikhin, 1879a). Here, we may conclude that observers reported the dust tail.
3.4. Comet C/1580 T1

The comet was reported by Graminaeus (1581). Bredikhin (1886) defined $R = 1$ and $\epsilon = 15^\circ$ that indicates the dust tail. However, since there is only one observation of the tail, the inaccuracy of the estimates is large (Bredikhin, 1862).

3.5. Great Comet C/1582 J1

Basing on three observations by Tycho Brahe on May 12, 17, and 18 1582, Bredikhin (1879b, 1886) defined $R = 0.2$ and $\epsilon = 37.5^\circ$ (dust tail). Note that the orbital elements are uncertain, due to lack of observations.

3.6. Great Comet C/1618 W1

There are numerous drawings of this comet by Bainbridge (1619); Cysato (1619); Kepler (1619); Montl’hery (1619, see here Figure 2b), and etc. Bredikhin (1886) calculated $0.6 < R < 2.1$. From November 30 1618 to January 16 1619, $\epsilon$ varied from $16^\circ$ to $41.6^\circ$ and on average was $25^\circ$ (Bredikhin, 1879a), indicating the dust tail.

3.7. Comet C/1652 Y1

The comet was observed more than a month after the perihelion. According to the reports of Hevelius (1668) and Weigel (1653), on December 20 1652 (December 10, Old Style) the comet passed through the foot of Orion and its tail had the largest size among the entire set of its observations (Figure 3). Hevelius drew a straight tail $5^\circ$ in length, and Weigel, slightly curving tail $6^\circ$ in length. Recall that a short tail (less than $6 - 7^\circ$) seems for a visual observer almost straight.

Of particular interest is the dynamics of the cometary tail in Figure 3. Hevelius (1668) described observations as follows. At half past six, the comet was visible in position c, tail passed through the star $e$ and star $b$ which is above the foot of Orion in Eridan. Moreover, Regel (moderm Rigel), star $b$, and the comet form an almost equilateral triangle... Distance between the comet and the star $b$ was $3^\circ 25^\prime$... At 9 hours 52 minutes, the comet was already slightly higher at position d. The tail was still located along the foot of Orion in Eridan and pointed toward the star $f$ in the hilt of the sword... “Horâ dimidiâ circiter septimâ, Cometa in c primâm nobis illuxit, caudam extendens per e Stellulam

Figure 3. Fragments of drawings of comet C/1652 Y1 by Hevelius (1668) (a) and (b), and Weigel (1653) (c).
... & Stellulam \( b \), supra pedem Orionis in Eridano, \( b \) supremam cinguli circiter vers\( \iota \)s. At\( \omicron \) tum Triangulum fer\( \grave{e} \) æquilaterum, cum Regel, \& dict\( \grave{a} \) Stell\( \grave{a} \) supra pedem Orionis constituebat... Distantia autem... inter Cometam \& stellam \( b \), 3 grad. 25 min... At hor\( \acute{a} \) 9 52\( ^{\prime} \), Cometa jam paul\( \grave{o} \) altiorem occupaverat locum, nempe \( d \)... Cauda ver\( \grave{o} \) adhuc per stellam pedis Oriones in Eridano, us\( \acute{q} \); fer\( \grave{e} \) stellam \( f \) in Ensis manubrio...”). Thus, in three and a half hours the position angle of the tail has changed by 18\( ^{\circ} \). Such dramatic changes are hardly probable even under the influence of the local inhomogeneity of the solar wind.

Bredikhin (1879b) defined average \( R = 1.5 \). On December 20, \( \epsilon = 15^{\circ}15^{\prime} \); December 23, \( \epsilon = 13^{\circ} \); and December 26, \( \epsilon = 7^{\circ} \). As only three observations were available, the uncertainty is high. However, all of the above findings indicate that observers reported the dust tail.

3.8. Comet C/1661 C1

The comet was observed by Hevelius (1668); Megerlino (1661); Welper (1661), and others. Welper drew a slightly curved tail. According to Hevelius (Figure 4a), the maximal length of the tail was 5–6\( ^{\circ} \) on February 3 1661. Such short tails seem for a visual observer almost straight. Bredikhin (1862) noted poor quality of the observations.

3.9. Great Comet C/1664 W1

This comet was observed by Cassini (1665); Montanari (1665), and others. According to Hevelius (Figure 4b), on December 21 1664, the comet had the longest and curving tail (Figure 4b). Bredikhin (1879b, 1886) evaluated \( R \approx 1.2 – 1.7 \) and \( \epsilon = 27^{\circ} \), which corresponds to the dust tail. Also note that at the beginning of the observations the Earth passed through the plane of the cometary orbit, and then the full moon interfered with the observations. The cometary orbit was inclined by 21\( ^{\circ} \) to the ecliptic, therefore the projection effects might be significant. Therefore, the quality of the observations is poor, and the value of \( \epsilon \) is inaccurate.
3.10. Great Comet C/1665 F1

The comet was observed in the morning twilight, not far from the horizon. Hevelius [1666] drew a wide, straight tail (Figure 3). Lubieniecki [1681] also showed a schematic comet with a straight tail. However, notice that Lubieniecki made his drawing from the words of Thomas Bartholin, who observed in Copenhagen.

Bredikhin [1879a, 1886] wrote that quality of the observations is poor. $R$ changes from 2.9 to 115.8; $\epsilon$ from $-2$ to 12.9. Bredikhin [1862] concluded that large variation of $R$ raises doubts that the comet had type I tail.

3.11. Great Comet C/1668 E1

Cassini [1730] reported this observation as meteorological phenomenon similar to that of 1683. In 1702, Maraldi [1743] also reported another similar phenomenon at the same place. Observational data are poor to define the nature of this object.

3.12. Comets C/1672 E1 and C/1677 H1

Comet C/1672 E1 was drawn by Hevelius [1672] and Weigel [1672], and comet C/1677 H1, by Honold [1677]; Hooke [1678]; Voigt [1677]. The tails of comets were too short to define their nature.

3.13. Great Comet C/1680 V1

The first Astronomer Royal John Flamsteed reported the comet from December 10 1680 to February 5 1681. On the first day, he noted that the cometary tail was thin and stood straight up from the Horizon, as translated by us from Flamsteed (1725, “Cometæ Caudam prætenuem advertimus, ab Horizonte sursum erectam...”). On the next day, the tail was like a beam standing straight up from the Horizon and slightly deviating to the right of the vertical (“Cauda quasi trabs ab Horizonte sursum erecta conspiciebatur, ad dextram etiam parum a perpendiculo declinaris...”). Note that “trabs” could be translated as timber, beam, rafter, or tree trunk. On December 21 (perihelion on December 18), the tail was located to the right of the Dolphin constellation, slightly curving (“Cauda fixas Delphini `a dextra reliquerat, incurvata paulul` um...”). On December 26, the tail was thinner and shorter than before (“Cauda rarius quam antehac & brevior...”). On January 13 1681, the tail was very weak, but sufficiently wide (“Cauda valde debilis satis tamen lata fuit”).

The comet had small perihelion distance ($q = 0.006$ AU) and was observed overall in Europe. There are numerous engravings of this comet with straight (Mayern, 1681; Cassini, 1681) or curved (Merian, 1691; Voigt, 1681, Figure 3) tail.

Figure 3 shows a fragment of the painting by Lieve Verschuier “The Great Comet of 1680 over Rotterdam”. To the right of bright tail, another dim tail is depicted. Plasma tails well known to be always located on the leading edge.
of dust tails. One can hypothesize that bright tail is a syndyne, and dim tail, a synchrone. Syndyne is the locus of the dust particles for a given radiation pressure and synchrone being the locus of particles emitted at the same time.

For the bright tail, Bredikhin (1880, 1886) defined \( R = 1 \) and \( \epsilon \) varied from 1° to 20° (generally \( \epsilon > 10° \), dust tail). Figure 5c shows the hyperbola asymptote (red curve) of the cometary tail and the prolonged radius-vector \( \xi \). Figure is sketched from Bredikhin (1880).

3.14. Halley’s Comet 1P/1682 Q1

The comet (Figure 6) was observed by Hevelius (1685); Honold (1682); Kirch (1682); Montanari (1682), and others. Hevelius (Figure 5e) drew a bright, short, and curving jet emanating from the nucleus: on September 8, in the evening, the comet’s head was visible in the optical tube. The nucleus not only kept its oval shape. A bright curving jet (or ray) prolonged from the nucleus to the tail Hevelius (1685) “Die 8 Sept. vesp... Caput Cometae hac die die Tubum Opticum merebatur videri; non solum quod--constantar clarissimum nucleum figuræ ovalis conservaret, sed simul incurvatum splendidissimnum radium, ad ipso nucleo in Caudam usque, sese extendentem exhiberet.”).

According to Bredikhin (1886), the orientation of the Halley’s cometary tail 1P/1682 Q1 corresponds to type I with \( R = 12 \) and \( \epsilon = 23° \) (Figure 5f). Black
arrows mark the comet’s path, $\xi$ is the prolonged radius-vector, and red curve is the asymptote of the tail. The value of $\epsilon$ indicates the dust nature of the Halley’s cometary tail.

3.15. Comets C/1739 K1 and C/1742 C1

Comet C/1739 K1 was drawn by Zanotti (1739), and comet C/1742 C1, by Zanotti (1742) and Wiedeburg (1742). The tails of both comets are too short to define their nature.

3.16. Great Comet C/1743 X1

The comet had quite complex structure. Few days after the perihelion, numerous observers (Cheseaux, 1744; Euler, 1744; Heinsius, 1744; Zanotti, 1744) reported multiple tail. Figure 6 shows that the cometary tail is curved and significantly delayed relative to the prolonged radius-vector, that is typical for dust tails.

Bredikhin (1880, 1886) quantified $R = 1; 2.4; 12$; and 17; he concluded that the multiple tail belongs to type I and II.

3.17. Great Comet C/1769 P1

According to Pingre, on September 4 1769 he clearly saw the ripples in the tail similar to that seen in the aurora borealis. The tail was curved, its convex side faced toward the North. Sometimes the tail formed in its extremity a smaller arc, the convexity of which faced to the South, as translated by us from Pingre (1784, “des ondulations dans la queue, analogues à celles que l’on aperçoit dans les aurores boréales... La queue était feniblement arquée, sa partie convexe tournée vers le nord; quelquefois même elle formait vers son extrémité un second arc plus petit, dont la convexité regardait le sud...”). Pingre also referred to the
observations by La Nux who reported 97\degree length of the tail on September 11. Curving cometary tail was also reported by Cassini de Thury (1773).

According to Messier, on the night from 4 to 5 September, the sky was serene. Between the first and second hours of the morning, the comet was clearly visible. The tail was 43\degree long, located below the third Orion star. The distant half of the tail shone with very weak light. Also, the tail was curved with bulge to the North. Up to 8\degree from the nucleus, the tail was intermittent along its length by luminous and dim parts. The nucleus had the same color as the day before, it was white with slightly reddish or orange tint Messier (1778, “La nuit du 4 au 5 de Septembre, le ciel serein; entre une heure & deux heures du matin, on apercevoit très-distinctement la Comète à la vue simple, avec une queue très-longue, qui passoit au-dessous de la troisième étoile d’Orion... ayant quarante-trois degrés; plus de la moitié de la queue vers sa fin étoit d’une lumière très-foible; elle se courboit sensiblement, & la convexité étoit tournée vers le Nord. La queue depuis le noyau jusqu’à huit degrés de distance environ, étoit partagée suivant sa longueur par des parties lumineuses, & par d’autres qui étoient obscures; ces traces lumineuses & obscures étoient dans des directions parallèles. Le noyau de la Comète étoit de la même couleur que la nuit précédente, d’une lumière blanchâtre, tirant un peu sur le rouge ou l’orangé...”).

Figure 6b shows the fragment of the drawing in a concave cylindrical projection by Messier (1778). On contrary to the text description, the comet was depicted with straight tail. On August 30 and September 2 1769, the cometary tail had complex structure. On the right and left of the main tail, Messier painted two short tails less than 5\degree in length (red blocks in Figure 6b).

For the bright and long main tail, Bredikhin (1880, 1886) defined $R = 12$ and $\epsilon$ varied from $-5\degree$ to $13\degree$, on average $\epsilon \approx 4\degree$. He discussed the type of the tail (I or II). Approaching the perihelion (October 8 1769), the nucleolus became bright, but the tail became dim. Therefore, the calculations were made from August 20 to September 12 and from October 25 to November 27 1769.

The small average value of $\epsilon$ signifies that observers might have seen plasma tail whose ray structure indicates non-stationary flow of the solar wind. Large scatter of $\epsilon$ might indicate either sudden changes in the solar wind speed, or uncertainty in observations and further calculations. To clarify this issue, more sophisticated research is required.

Messier also reported more than 10 comets in the second half of the eighteenth century. We analysed their descriptions and drawings. Unfortunately, cometary tails were too short to defined their nature.

3.18. Catalogues of Hevelius and Lubieniecki

The catalogues of Hevelius and Lubieniecki collect comets that have been observed from ancient times. Cometographia (Hevelius, 1668) is devoted to analysis of the variety of cometary nuclei and tails in order to find regularities and explain them. He considered the structure of the sunspots observed by Scheiner (1630) to reveal the common structural features and matter from which they consist with those of comets. (Hevelius, 1668 Figure G therein) shows the author’s poetic cometary description in the distant past. The first object in Figure G of
Cometographia is the artistic imagination of a comet (“Cometan Solarem, seu Rosam”) portrayed as a flame- or red-coloured rose (“colore igneo seu rutilo”); the second object is a comet with bright flame rays. Comets were also compared to shields (“clypei”, the forth object in Figure G), hair, or mane movements (“Crines”, the seventh object), lamps or facula with straight rays (“adinstar Lampadis, seu faculae ardentis”, objects 11–13). Figure H and I depict comets with tails. All these drawings are the author’s vision of the shape of comets, according to ancient observations since the fifth century. In particular, object number 28 is the comet which was seen in 1099 and described as a scimitar or curved Persian sword. Cometary nucleus is depicted like a hilt of a sword. Objects 37 and 38 in Figure K portrayed vibrating (“vibrantibus”) tails. Hevelius also reported comets of the seventeenth century and his own observations. He discussed the parabolic, hyperbolic, and other forms of asymptotes of cometary tails (Hevelius, 1668, Figure Q therein).

We also analyse Historia Cometarum (Lubieniecki, 1666) and Teatrum Comticum by Lubieniecki, 1681. The author focused on the position of comets in the starry sky. Cometary tails are schematically shown as wide and straight.

Here we would like to conclude that the mentioned catalogues are not fruitful material for discussion of the plasma tails.

4. Conclusions

Plasma tails of comets are known as natural probes of the interplanetary space. Their physical parameters may shed light on the solar wind speed in the most intriguing period, the Maunder minimum.

In this paper, we considered descriptions and drawings of comets in the historical archives. To define whether plasma tails were reported in the distant past, we addressed to color, shape, and orientation of cometary tails.

Reviewing color of comets in European, Chinese (in the translations of Williams and Kronk), and Russian observations, we figured out a lack of convincing facts that naked eye observers saw bluish plasma tails. This finding is trivial, because bluish color originates from the violet bands of ionized carbon monoxide and is poorly recognized by the human eye.

Another crucial attribute of plasma tails is their antisolar orientation. The angle $\epsilon$ between the observed tail and the prolonged radius-vector of a comet is typically limited to $6^\circ$. Here, we provided Bredikhin’s estimations of $\epsilon$. Average deviation of cometary tails from the antisolar vector exceeds $10^\circ$, that in turn suggests to us that observers reported dust tails.

Differentiation of dust and plasma tails by their shape should be performed taking into account the projection effects. When a comet passes near the ecliptic plane, the dust tail appears straight and thin. Short dust tails also seem almost straight.

One may conjecture that solar cycle minima represent conditions similar to those during the MM, whose activity level became hotly debating again (Usoskin et al., 2015; Zolotova and Ponyavin, 2016). A prolonged minimum of Cycles 23–24 was remarkably spotless, but the Sun was not entirely shrouded in a
coronal hole, and the solar wind speed was although suppressed but not crucially. Moreover, Livingston et al. (2007) showed that the basal quiet atmosphere is unaffected by solar cycle. If so, we would like to hypothesize that comets in the distant past exhibited plasma tails, but they were not reported because they are hardly seen by the naked eye. Accumulating the light, telescopes could help a little to make out dark-dark bluish plasma tail in the night sky. However, early telescopes likely suffered from spherical and chromatic aberration (Svalgaard, 2017). Therefore, the first hint of plasma tail we figured out only for Great comet C/1769 P1.

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