Meteor showers of comet C/1917 F1 Mellish

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Accepted 2010 October 26. Received 2010 October 18; in original form 2010 August 20

ABSTRACT
December Monocerotids and November Orionids are weak but established annual meteor showers active throughout November and December. Analysis of a high quality orbits subset of the SonotaCo video meteor data base shows that the distribution of orbital elements, geocentric velocity and also the orbital evolution of the meteors and potential parent body may imply a common origin for these meteors coming from the parent comet C/1917 F1 Mellish. This is also confirmed by the physical properties and activity of these shower meteors. An assumed release of meteoroids at the perihelion of the comet in the past and the sky-plane radiant distribution reveal that the December Monocerotid stream might be younger than the November Orionids. A meteoroid transversal component of ejection velocity at the perihelion must be larger than 100 m s⁻¹. A few authors have also associated December Canis Minorids with the comet C/1917 F1 Mellish. However, we did not find any connection.

Key words: catalogues – celestial mechanics – comets, individual: C/1917 F1 Mellish – meteorites, meteors, meteoroids.

1 INTRODUCTION
The comet C/1917 F1 Mellish, formerly designated as 1917 a (Mellish) or Mellish 1917 I, was discovered by J.E. Mellish on 1917 March 20 and was observed for 96 d (Asklöf 1923, 1932) from many places on the Earth. In the Southern hemisphere, the comet reached up to +1 mag. Astronomer J.F. Skjellerup noted that the brightness of the cometary head was about +3 mag, with the diffuse coma and narrow tail about 10° long on 1917 April 19 (Orchiston & Skjellerup 2003). The comet is a Halley-type comet, with a relatively low inclination, and has one of the smallest perihelion distances. It was observed only at one apparition. Despite the relatively long observational arc, the precision of the orbital elements is questionable. Asklöf (1932) published a slightly modified orbit of the comet and noted that the orbit is given with a period of 145 ± 0.8 yr (Chamberlin et al. 1997). The nominal orbital elements, according to JPL Solar System Dynamics data base (Chamberlin et al. 1997), are presented in Table 1. Although the ascending and descending node of the nominal orbit are currently far away from the orbit of the Earth, we noted a small difference in the eccentricity (e.g. Δe ~ −0.002) would change the orbit into an Earth-crossing orbit as the heliocentric distance of the ascending node would become equal to 1 au. The orbit has a notably small perihelion distance (0.19 au). Several authors (Porter 1952; Hasegawa 1962) determined that the comet–Earth distance is close enough to observe a meteor shower and predicted the radiant positions and activity of the shower on Dec. 15 (Dec. 20, respectively) and the geocentric velocity of meteors ~40 km s⁻¹. The first few meteors associated with the comet C/1917 F1 Mellish were obtained by the Harvard Super Schmidt photographic survey (Whipple 1954; McCrosky & Posen 1961). Several candidates of this meteor stream, later designated as the December Monocerotids (MON), were also detected and distinguished by radar surveys (Nilsson 1964; Sekanina 1973). Another study connecting the December Monocerotids with the comet C/1917 F1 Mellish was made by Drummond (1981), Olsson-Steel (1987). Surprisingly, the radar data published by Nilsson (1964) and Sekanina (1973) revealed that the meteors having similar radiant positions, activity and geocentric velocities appear to have 10° lower inclinations. Kresáková (1974) noted that December Monocerotids seem to have two components. The author also speculates that the stream may have a common origin with the Geminid meteor stream. Moreover, Harvard radio data revealed a possible meteor stream with low inclined orbits but almost the same orbital elements as the December Monocerotids, active between November 27 – December 7 (Nilsson 1964; Sekanina 1973). The possible genetic connection between the comet and the December Monocerotids was studied by Fox & Williams (1985).

Various photographic searches confirmed the existence of a weak stream at RA = 90.6°, Dec. = 15.7° on November 27, with v₉ = 43.7 km s⁻¹ (Lindblad 1971). The stream was named as ξ-Orionids (ξ-Orionids, o-Orionids), currently recognized as established meteor shower November Orionids (NOO) within the IAU Meteor Data Center (IAU MDC) catalogue (Ohtsuka 1989) and later by Lindblad (1999). Moreover, other photographic December Monocerotids were published (Ohtsuka 1989) and complex analysis of December Monocerotids and ξ-Orionids done by Lindblad & Olsson-Steel (1990). Even some historical records of fireballs might...
confirm that December Monocerotids were active in past centuries (Fox & Williams 1985; Hasegawa 1999).

In 1969, Hindley published his celestial meteor observation from 1964 December 11 and assigned five meteors to the new stream called 11 Canis Minorids. Hindley (1969) computed that these meteors have parabolic orbits and much higher inclinations (over $100^\circ$). A year later, the author suggested a connection between the shower and comet C/1917 F1 Mellish (Hindley 1970) and determined the activity during December 9–14. Kresáková (1974) revealed that nine meteors that create the second component of the December Monocerotids might be 11 Canis Minorids active within December 4–15. Their inclination was determined as $i = 29.1^\circ$ and the perihelion distance as $q = 0.092$, which is closer to the Sun compared to the nominal orbit of the comet C/1917 F1 Mellish. The radiants might look like an extension of the MON activity, however, the shower might be active during the MON activity. The geocentric velocity is similar $v_g \approx 40 \text{ km s}^{-1}$. The maximum activity of 11 Canis Minorids is expected at $L_\odot = 252.4^\circ$ (December 3).

Now, the December Monocerotids and November Orionids are weak (few meteors per hour at maximum) but annual established meteor showers. The shower 11 Canis Minorids (December Canis Minorid according to IAU nomenclature) is classified as a ‘working’ shower. Despite several investigations, past publications analysed only a small number of orbits and provided disperse data on the mean orbit, the position of radiant, the activity and precision of orbits, and did not reveal the orbital evolution of the meteoroid particles released from the parent comet, in order to explain the current state of these meteor showers. A significant number of the analysed orbits are hyperbolic or parabolic.

This work uses recent and precise video multistation orbits, obtained by the SonotaCo video network in Japan, which provide the highest number of relatively precise meteor orbits detected continuously between the years 2007–09. The network operates with over 25 similar video-optical systems and uses the same software for meteor detection and orbit analysis (UFOCapture, UFOAnalyser and UFOOrbit; SonotaCo 2009). Our goal is to provide a more complex description of meteor showers related to the comet C/1917 F1 Mellish and reveal some of their obscured characteristics. The eventual objective is the investigation of the orbital evolution of meteors and the parent comet, and determination of ejection velocities near the perihelion.

## 2 December Monocerotids and November Orionids from SonotaCo Data Base

The freely accessible data base of the meteors detected by the SonotaCo network contains 64 540 multistation meteor orbits with additional parameters such as the beginning and terminal height, absolute magnitude, equatorial and ecliptical coordinates of the radiant, the stream assignment, etc. Although the SonotaCo method uses its own shower assignment algorithm, we have demonstrated (Vereš & Tóth 2010) that its results are consistent with the widely used Southworth–Hawkins D-criterion $D_{SH}$ (Southworth & Hawkins 1963) for meteor stream identification. In accordance with several restriction criteria developed in our previous work (Vereš & Tóth 2010), we selected a high quality subset of orbits for further analysis. The criteria fulfilled 111 of 250 December Monocerotids and 110 of 333 November Orionids detected in the years 2007–09.

Of 111 MON meteors, only eight have hyperbolic orbits and among 110 NOO meteors, 14 have semimajor axes larger than 100 au or eccentricity higher than 1.0. We also employed $D_{SH}$ to distinguish possible rogue sporadic meteors among MON and NOO assigned to the showers by SonotaCo. In comparison with the nominal orbit of the comet C/1917 F1 Mellish, all MON and NOO meteors fall within $D_{SH} < 0.4$. Even within stricter $D_{SH} < 0.15$, 105 MON and 97 NOO are found (according to SonotaCo shower assignment). Independently, we selected the MON and NOO shower members by using the iteration procedure according to Porubčan & Gavajdová (1994). In the iteration for the $D_{SH} = 0.15$, 105 MON and 97 NOO were identified. This result is almost identical to SonotaCo assignment of both shower members. The showers appear very narrow in the orbital element space. The mean orbits are presented in Table 2, in comparison with the mean orbits by other authors. Each orbital element was calculated as the median, with given standard deviation. The photometric mass was computed for each meteor according to Betlem et al. (1999) and its mean value for the showers

| Element | Value |
|---------|-------|
| $a$ | 27.6473325 au |
| $e$ | 0.993121 |
| $q$ | 0.190186 au |
| $i$ | 32.6828$^\circ$ |
| $\omega$ | 121.3190$^\circ$ |
| $\Omega$ | 88.6683$^\circ$ |
| $M$ | 0.0259325$^\circ$ |
| Epoch (JD) | 242,1334,0 |
| Heliocentric distance of Ascending Node | 0.7835657 au |
| Heliocentric distance of Descending Node | 0.250005 au |

Table 2. The mean orbital elements, geocentric velocity, photometric mass of meteoroids and activity intervals of high-quality orbits of December Monocerotids and November Orionids from the SonotaCo data base, compared with other authors. No = number of meteors.

| Elements | $a$ | $e$ | $q$ | $i$ | $\omega$ | $\Omega$ | $v_g$ (km s$^{-1}$) | Mass (g) | Activity | No. | Author |
|---------|-----|-----|-----|-----|-------|-------|---------------|--------|----------|-----|--------|
| MON s.dev | 8.86 | 0.979 | 0.186 | 34.7 | 129.6 | 77.9 | 41.2 | 0.6 | Nov 26 – Dec 21 | 111 | This work |
| MON s.dev | 19.88 | 0.991 | 0.188 | 34.9 | 128.9 | 80.1 | 41.6 | 15 | OH89 |
| NOO s.dev | 7.49 | 0.026 | 0.012 | 3.9 | 4.3 | 5.4 | 2.1 | 1.7 | Nov 27 – Dec 17 | 12 | LIND90 |
| NOO s.dev | 20.79 | 0.990 | 0.187 | 34.9 | 128.9 | 80.4 | 41.82 | 0.4 | Nov 16 – Dec 16 | 110 | This work |
| NOO s.dev | 11.36 | 0.898 | 0.125 | 23.51 | 139.3 | 69.3 | 42.0 | Nov 16 – Dec 7 | 38 | LIND99 |
| NOO s.dev | 12.86 | 0.9915 | 0.1093 | 24.7 | 140.4 | 67.2 | 42.6 | Nov 16 – Nov 29 | 16 | JEN06 |
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finding is consistent with the radar data, where NOO are more significant than MON (Nilsson 1964; Sekanina 1973).

We determined the maximum activity of the MON for the longitude of the Sun \( L_\odot = 259.5^\circ \) (December 11) with the duration of the shower from November 26 to December 21. The maximum of MON occurs 1 d earlier in the SonotaCo data than in the IAU MDC catalogue. The radiant position during the maximum activity was determined as RA = 98.8°, Dec. = 8.6° and the daily motion is given by the following equations in the equatorial and ecliptical coordinates:

\[
\text{RA} = (101.4 \pm 0.1)^\circ + (0.65 \pm 0.01) (L_\odot - 259.5^\circ) \\
\text{Dec.} = (8.0 \pm 0.1)^\circ - (0.14 \pm 0.02) (L_\odot - 259.5^\circ) \tag{1}
\]

\[
\lambda = (101.7 \pm 0.1) + (0.67 \pm 0.01) (L_\odot - 259.5^\circ) \\
\beta = (-14.9 \pm 0.1) - (0.09 \pm 0.01) (L_\odot - 259.5^\circ), \tag{2}
\]

where 259.5° represents the solar longitude of the December Monocerotid’s maximum, derived from the SonotaCo data (equation 2000.0).

According to SonotaCo data, the maximum activity of the NOO occurs on \( L_\odot = 249.5^\circ \) (December 1) and it is active from November 16 until December 16. The maximum occurs 4 d after the maximum predicted by the IAU MDC catalogue (\( L_\odot = 245.0^\circ \)). The motion of the radiant is given by equations 3 and 4:

\[
\text{RA} = (92.6 \pm 0.2)^\circ + (0.62 \pm 0.03) (L_\odot - 249.5^\circ) \\
\text{Dec.} = (15.3 \pm 0.1)^\circ - (0.06 \pm 0.02) (L_\odot - 249.5^\circ) \tag{3}
\]

\[
\lambda = (92.5 \pm 0.1) + (0.60 \pm 0.02) (L_\odot - 249.5^\circ) \\
\beta = (-8.1 \pm 0.1) - (0.06 \pm 0.02) (L_\odot - 249.5^\circ). \tag{4}
\]

The sky-plane positions of the radiants in the equatorial and ecliptical grid are depicted in Fig. 5. The radiant positions calculated using the nominal orbit of the comet C/1917 F1 Mellish and computed by several methods by DOSMETH software (Neslušan, Svoreň & Porubčan 1998) are shown as well.

A possible common origin of both meteor showers can also be inferred from Fig. 6 depicting the heliocentric distance of the ascending and descending nodes of the MON and NOO as a function of solar longitude. As expected, the ascending node lies very close to the value of 1 au but the descending node gradually rises with the solar longitude and both meteor showers overlap without any gap or visible difference in the descending node.

Other common properties might be derived from the beginning and terminal heights of individual meteors. Fig. 7 shows clearly that heights of the MON and NOO are practically identical. The geocentric velocity and entry geometry is almost the same for both meteor showers; therefore, the beginning and terminal height would mostly depend on the physical properties of meteoroids, such as the mass, the bulk density and internal structure. The heights are given in Table 3 and the heights as a function of photometric mass

\[
\begin{array}{|c|c|c|}
\hline
\text{Shower} & \text{Beginning height (km)} & \text{Terminal height (km)} \\
\hline
\text{MON} & 102.6 \pm 2.7 & 86.1 \pm 4.8 \\
\text{NOO} & 101.5 \pm 3.9 & 85.1 \pm 5.3 \\
\text{GEM} & 95.6 \pm 3.3 & 80.2 \pm 7.0 \\
\hline
\end{array}
\]

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in Fig. 7. In Table 3 we also compare the heights of MON and NOO with the high quality Geminids orbits from the SonotaCo data base. Geminids from the SonotaCo data base have beginning and terminal heights 5 km lower than other video observations made by similar techniques (Koten et al. 2004). MON and NOO meteors have beginning heights 6–7 km higher than Geminids, which could indicate that meteors from C/1917 F1 Mellish have lower bulk densities and are more fragile. On the other hand, Geminids with similar geocentric velocities belong to the densest and most rigid meteors observed (Rendtel 2004).

The data base does not contain any December Canis Minorids, yet we tried to find some representatives among the high quality data set. The published mean orbit of December Canis Minorids has a very low semimajor axis, $\omega$ similar to a previously published value, and $i$ and $\Omega$ similar to MON. According to SonotaCo (http://sonotaco.jp/doc/J5/index.html), the shower might be active from November 30 until December 9, with the maximum on December 4. Nevertheless, the data base does not contain any meteors of this stream. Because of the little information there is about the stream, we tried to select candidates from the high quality subset of orbits. The subset was selected using the iteration method (Porubčan & Gavajdová 1994) with respect to the IAU MDC catalogue shower parameters. Only six meteors fulfilled our criteria (Table 4). Meteors were detected during the activity of both MON and NOO. The D-criterion of meteors was on average greater than 0.3 with respect to the assumed parent comet. It is even doubtful if

**Figure 2.** Distributions of the of orbital elements and geocentric velocity (using b-spline) of the December Monocerotids and November Orionids. The arrow shows the orbital evolution of the comet C/1917 F1 Mellish over the last 5000 yr, the dot shows its nominal orbital parameters.
Table 4. The mean orbital elements of 6 December Canis Minorids candidates. With respect to the parent comet, the subset has relatively low D-criterion, \( D_{SH} \sim 0.33 \pm 0.08 \)

| a (au)  | e       | q (au)  | i      | \( \omega \) | \( \Omega \) | \( v_g \) (km s\(^{-1}\)) | \( L_\odot \) | RA      | Dec. |
|--------|---------|---------|--------|-------------|------------|----------------|----------|--------|------|
| 1.8 ± 1.5 | 0.95 ± 0.02 | 0.11 ± 0.02 | 30.2 ± 7 | 144.7 ± 4.9 | 78.6 ± 3.1 | 39.7 ± 2.4 | 254.1–261.6 | 107 ± 4 | 14 ± 2 |

Figure 3. December Monocerotids, November Orionids and the comet C/1917 F1 Mellish in the phase space of perihelion distance and inclination.

Figure 4. Cumulative distribution of absolute magnitudes of December Monocerotids and November Orionids.

the December Canis Minorids is a regular shower or it is only an occasional shower observed when the Earth crosses a narrow filament of the meteoroid particles, or these meteors are just scattered meteors of the MON–NOO complex; or that even these meteors belong to the sporadic background.

3 ORBITAL EVOLUTION OF THE COMET AND METEOROIDS

The first orbital evolution analysis of the comet C/1917 F1 Mellish 800 yr to the past (Carusi et al. 1984) revealed that its orbit evolves slowly; notably, the nodes evolve very slowly. The inclined orbit avoids giant planet encounters and there is only a little chance of substantial gravitational interaction with the terrestrial planets near the perihelion. Fox & Williams (1985) and Hasegawa (1999) studied the option that the ancient fireballs observed between December 6 and 18 apparently emanated from the same radiant. They worked out that these bolides could not be connected to the Geminid meteor stream because of its rapid orbital evolution but might belong to the MON. Fox & Williams (1985) confirmed the slow evolution of the ascending node in the 2400 yr integration of the cometary orbit to the past. Their work also confirmed that the heliocentric distance of the MON ascending node is stable as well and is close to 1 au one thousand years to the past or to the future.

As mentioned previously, the orbit of the parent comet was determined with a low precision. In our study, we set out to calculate the orbital evolution of nominal and cloned orbits of the parent comet. We created 100 clones within the 0.8 yr uncertainty of the orbital period (Asklof 1932), with fixed perihelion distance and altered semimajor axis and eccentricity accordingly. We could not modify other orbital elements because their uncertainties are unknown. Another set of 100 clones was made in order to create orbits with the heliocentric distance of ascending node close to 1 au while neither nominal orbit nor first 100 clones have the ascending node close enough to the orbit of the Earth to create an observed meteor shower. In this case, the eccentricity, the semimajor axis and the perihelion distance were altered. The beginning of the integration was set at the epoch of the perihelion passage of C/1917 F1 Mellish (JD 2421334.0, equation 2000.0). The multistep
Figure 6. The heliocentric distances of the ascending and descending nodes of the December Monocerotids and November Orionids as a function of the longitude of the Sun, compared with the ascending and descending nodes of the comet C/1917 F1 Mellish. Range of the theoretical radiants computed by DOSMETH for the parent comet is displayed with a heavy line. Vertical lines represent the maxima of the meteor showers.

Figure 7. The beginning and terminal heights of the December Monocerotids and November Orionids as a function of the photometric mass.

Adams-Bashforth–Moulton type up to twelfth order numerical integrator, with variable step-width, was used. All planets were considered as perturbing bodies and the Earth and Moon were treated separately.

The integration shows that both sets of clones behave in a similar way. Fig. 8 depicts the heliocentric distance of the ascending and descending node of the nominal orbit and the clones integrated 5000 yr to the past. The ascending node of the nominal orbit gradually falls and retreats from the orbit of the Earth to \( \sim 0.4-0.6 \) au from the Sun. The descending node is initially close to the Sun \( (\sim 0.25 \) au) and rises slowly to \( (\sim 0.3 \pm 0.1 \) au). Clones of the altered orbit, that start with the ascending node at the orbit of the Earth, behave the same way but remain within \( 0.05 \) au of the Earth’s orbit about 2000 yr to the past.

The evolution of the orbital elements of the comet and its clones is depicted in Fig. 9. The most probable value \((1 \sigma)\) of the semimajor axes of cloned orbits is in the range of \( a \subset (25;30) \) au, while the nominal semimajor axis rises up to 40 au 2500 yr. The inclination of both clones and the nominal orbit falls from initial \( 32^\circ \) down to \( i \subset (26;30)^\circ \). Even at 3000 bc, the inclination is not low enough to explain the low inclination of the NOO \((i \sim 23.5)\). The perihelion distance remains in the small heliocentric distances \((q \subset (0.14;0.23) \) au) and the summation of angular elements \((\text{longitude of perihelion} – \pi)\) rises gradually from \(210^\circ\) to \( \pi \subset (212;218)^\circ \) after 5000-yr integration to the past. Clones derived from the uncertain orbital period did not encounter the Earth but had close flybys within the Hill sphere of Venus \((2 \) per cent) and Mercury \((0.5 \) per cent). This gives a non-zero chance that comet C/1917 F1 Mellish might encounter Venus or Mercury. In fact, this could cause a sudden change in its inclination at least within 5000 yr in the past.

We also studied the orbital evolution of the MON and NOO meteors from the SonotaCo data base. For a chosen subset of high quality orbits \((\text{non-hyperbolic}, a < 100 \) au), the integration uses a beta parameter representing the solar radiation pressure \((\text{Klačka 2004})\) for each particle \( (\beta = 2 \times 10^{-5}) \) derived from an assumed low bulk density \((\rho = 750 \text{ kg m}^{-3})\) and the typical photometric mass of observed meteors \((0.5 \) g) and starts for the epoch and the orbital elements valid for the moment of the meteor observation. The numerical integration computed the orbital evolution for 5000 yr to the past (Figs 10 and 11).
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Unlike Fox & Williams (1985), perturbed orbits of the MON and NOO reduced their heliocentric distance of the ascending nodes as time goes to the past. It seems that it takes only two or three hundreds years until the ascending node reaches the nominal orbit of the parent comet. On the contrary, the semimajor axes of both the MON and NOO are generally constant over 5000 yr, which might be due to low perturbations of giant planets and higher inclinations. Even with the beta parameter, the semimajor axes remain far away from the nominal or even cloned orbits of the parent comet. Meteoroids could be injected to these orbits directly after the ejection from the cometary core. The inclination of the MON is quite consistent with the current orbital inclination of the comet C/1917 F1 Mellish. The orbital evolution in inclination implies that MON were released recently, generally hundreds, or at most, 3000 yr in the past. On the contrary, the NOO meteoroids have lower inclinations in the present day. The orbital evolution reveals that NOO meteoroids could have departed from the comet mostly 4000 yr prior and almost all low inclined NOO could be explained by an orbital evolution within the last 5000 yr – most of the NOO inclinations intersected the comet evolution path of its inclination. The longitudes of the perihelia of the MON attain the same values as the nominal cometary orbit in the recent centuries and then disperse. On the other hand, the longitudes of the perihelia of the NOO remain much longer along the evolved nominal orbit of the comet and disperse slowly after thousands of years, which could support the younger age of MON as well. A similar feature is visible for the perihelion distance of both showers. Currently the perihelion distance of MON fits well with the current orbit of the comet but gets more dispersed around 500 bc. The perihelion distance of NOO is slightly different during the last 2000 yr but generally intercepts the perihelion distance of the comet earlier than 1000 bc. The eccentricity of MON is dispersed much more in the past than in the case of NOO. The heliocentric distance of the ascending node of MON lies close to the current ascending node of the comet but disperses fast in the past. This distance is currently lower for NOO but could be explained by the orbital evolution (Fig. 11). These implications of the orbital evolution suggest that the NOO shower is older than the MON shower and both streams may originate from the same parent comet.

Resulting from the nodal distances of the comet and the relatively fast evolution of the ascending nodes of the showers (centuries), there is a possibility that we observe the outer edge of a widely evolved complex stream. The streams (MON and NOO) might be observed as two streams as a result of a geometric selection effect. Meteoroids with inclinations between the MON and NOO might have nodes on non-Earth crossing orbits.

4 EJECTION OF METEOROID PARTICLES FROM THE PARENT COMET

The relatively large heliocentric distance of the ascending node of the parent comet and the much lower and stable semimajor axes of the meteors indicate that these particles were injected into these orbits immediately after ejection from the comet, while the comet might not have been on the same orbit at that time. The derivation of the ejection velocity depends on the model used. If we assume a spherical cometary nucleus with an albedo of 0.04, active surface 0.15 per cent (Ma, Williams & Chen 2002), bulk density 750 kg m$^{-3}$, a radius of the nucleus 3.1 km (Jenniskens 2006), ejection at the perihelion $q \sim 0.19$ au; and if the meteoroids are escaping only from the Sun-facing hemisphere with the Gaussian distribution of
Figure 10. The orbital evolution in $a$, $e$, $q$, and $i$ of the December Monocerotids, the November Orionids and the nominal orbit of the comet C/1917 F1 Mellish, with the possible variation shown with grey dashed lines, derived from the comet clones orbital evolution.
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Figure 11. The orbital evolution in $\pi$, the heliocentric distance of the ascending and descending nodes of the December Monocerotids, the November Orionids and the nominal orbit of the comet C/1917 F1 Mellish, with the possible variation shown with grey dashed lines, derived from the clones orbital evolution.

velocities with the centre on the subsolar point, the maximum ejection velocity might range from 5 m s$^{-1}$ (Impomente & Sigismondi 2001) to 112 m s$^{-1}$ (Crifo & Rodionov 1997; Ma et al. 2002). The escape velocity of the meteoroid particle changes its orbital elements so that we may calculate according to Pecina & Šimek (1997).

On the other hand, if we know the orbital elements of the comet (before the ejection of the meteoroid) and the meteoroid after the ejection (assuming that the observed meteoroid escaped the comet recently and did not undergo rapid orbital changes due to gravitational and non-gravitational perturbations), we may directly derive the ejection velocities from equations by Pecina & Šimek (1997) as a low estimate. The ejection velocity affects, at most, the semi-major axis. In the perihelion, the semimajor axis change is ruled by the transversal component of the velocity vector $\Delta v_\pi$. The range of ejection velocities derived according to mean, the peak and minimum–maximum values of the semimajor axis (Fig. 2) of each meteor shower, in comparison with the range of semimajor axes of the cometary clones, integrated 2000 yr to the past is presented in Table 5. The mean and peak values of the transversal ejection velocity components are in good agreement with the ejection model by Ma et al. (2002). While the eccentricity, the inclination and angular elements of the MON lie within the cometary clones’ range, the derivation of the radial and normal components of the velocity vector are ambiguous, following equations by Pecina & Šimek (1997). On the other hand, a difference in the inclination, the eccentricity and angular elements of the NOO could not be explained by the direct ejection of the particles into current orbits, but only by the following orbital evolution.
The transversal component of the meteoroid ejection velocity derived from the difference of the semimajor axis of meteor showers and the parent comet. The range of cometary semimajor axis lies within \( a \in (26:29) \) au.

| Shower | Method | \( a \) (au) | \(-\Delta v_t \) (m s\(^{-1}\)) |
|-------|--------|-------------|------------------|
| MON   | Mean   | 8.8         | 104 ± 8          |
|       | Peak   | 6.5         | 117 ± 8          |
|       | Range  | 3–17        | 50–145           |
| NOO   | Mean   | 11.36       | 90 ± 8           |
|       | Peak   | 6.5         | 117 ± 8          |
|       | Range  | 2–17        | 50–150           |

5 CONCLUSIONS

We demonstrated that the December Monocerotids and November Orionids obtained from the SonotaCo data base of 3 yr observations (2007–09) have most likely a common origin and come from the comet C/1917 F1 Mellish. The common origin is supported by their similar orbital characteristics, the activity, physical properties assumed from the beginning, and the terminal heights of the meteors, the descending nodes of both showers as a function of the solar longitude, and the narrow Southworth–Hawkins D-criterion for most December Monocerotids and November Orionids with respect to the parent comet \( (D_{3Sat} < 0.15) \). Direct modelling of the stream was not an option, while the orbit uncertainty of the comet avoids the selection of reliable and real starting point of the numerical integration from the past to the current date. Therefore, we studied the orbital evolution of the nominal orbit of the comet, cometary clones within the known orbital uncertainties, and the orbital evolution of precise meteor orbits. The dispersion of the orbital elements, the radiants and nominal orbit of the parent comet, currently beyond the orbital elements, suggest that the November Orionids is an older stream than December Monocerotids. The orbital evolution of both streams, the nominal orbit of the comet and its clones imply that the orbital evolution is causing November Orionids to have \( 10^\circ \) lower inclinations than December Monocerotids. There is a non-zero chance of a close encounter of the comet with Venus or Mercury which could cause a sudden change in the inclination of the parent comet. Furthermore, a close encounter with a planet might cause the tidal breakup of the comet and create a significant release of matter. The scenario of the cometary core disintegration might also be supported by the extremely low perihelion distance of the parent comet and both meteor showers.

Another option is a gradual shift in the inclination, demonstrated in the simulation. But a change in the inclination of more than \( 10^\circ \) of the parent comet would be solved only through a longer orbital evolution. This option is also obscured while we do not observe any orbits between relatively well-defined clumps of the December Monocerotids and November Orionids in the \( q – i \) phase space and radiant sky-plane distributions. Eventually there is a wide and massive stream of the meteoroids but only some of them have ascending nodes close to the Earth’s orbit; and due to selectional effects, we may observe two distinguished streams and only the distant edge of the stream. The nodal distance of the comet is currently more than 0.2 au from the Earth’s orbit and it retreated in the past increasingly, as well as the ascending nodes of the observed meteors. The observed shower meteors might have left the cometary nucleus a few centuries ago but, due to the stable orbit of the comet, both streams might be replenished regularly and weak shower activity might be observed each year. The semimajor axes of both meteor streams are much lower than the nominal orbit of the comet or its clones’ evo-

lution 5000 yr to the past. Almost no change of the semimajor axes of meteoroids within the orbital evolution suggests that these particles were injected directly into these orbits right after ejection from the cometary nucleus. We determined that transversal component of the ejection velocity would be about 100 m s\(^{-1}\) if the ejection occurred at the perihelion. Further precise orbits and physical data of the December Monocerotids and November Orionids are needed for additional research.

The key question is the accuracy of the C/1917 F1 Mellish orbit. A new measurements of the photographic plates of the comet might reveal a more precise orbit and bring new light on to the orbital evolution of the comet and its meteors. Our work did not confirm any December Canis Minorids meteors in the SonotaCo data base; however, six candidates were selected. Their connection to the comet C/1917 F1 Mellish is uncertain.

ACKNOWLEDGMENT

This work was supported by Slovak Grant Agency VEGA, No. 1/0636/09 and by a grant of Comenius University, No. UK/245/2010.

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