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On the frequency of interstellar meteoroids

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Abstract. Analysis of 2910 photographic meteor orbits collected in the IAU Meteor Data Center in Lund from different catalogues shows that the vasting majority of the 347 hyperbolic orbits with $e > 1$ and $a < 0$ are subject to erroneous determination of their heliocentric velocity or other parameters, and approximately 50 percent of them belong to the known meteor showers. The analysis of meteors from the most precise Harvard catalogues and their comparison with the other data, separately for the extreme values of the excess of hyperbolic velocities sets the frequency limit for hyperbolic meteors, with the excess corresponding to the possible interstellar meteors, to 2×10^{-3}. The average velocity excess of hyperbolic meteors is one order lower than expected for interstellar meteors, moreover neither any concentration of radiants to the Sun's apex, nor any distribution following the motion of interstellar material has been found.

Key words: meteors, meteorids – comets: general – astronomical data bases: miscellaneous – ISM: dust

1. Introduction

The existence of hyperbolic meteors and of interstellar meteoroids has been discussed by many authors. A summary of data prior to 1970 was given by Štohl (1971). It was shown, ignoring old and very unprecise observations, that the contribution of hyperbolic orbits of meteors in different orbital data is relatively high, reaching in some cases 10 or even 20 percent of orbits. However, the level of the contribution was found to be dependent on the precision of data. As was shown by Jacchia & Whipple (1961), within the 413 most precise orbits from the Harvard Super-Schmidt photographic meteors there were only 7 hyperbolic orbits present. Moreover, four of these belong to the poorest quality group while a reexamination of the three remaining ones led to the conclusion that they are within the error limits of elliptical orbits. Inspite of this, recent investigations by Tkatchuk & Kolomijec (1985) of 1304 "nearly parabolic" orbits from the sample of 50 000 radar meteors led to the selection of 436 with eccentricity $e \geq 1$ and semimajor axis $a < 0$. Kolomijec (1986) later modified the proportion of hyperbolic orbits to 1 - 2 % for the most precise data and 5 % for radar orbits with a lower precision. Similar results were presented by Andrejev et al. (1987). Recently Baggaley et al. (1992) on the basis of new radar detection system speak about the possible significant contribution of non-closed orbits for meteors down a size of 100 μm. All these results show that the question of hyperbolic and moreover of interstellar meteors is still open and to a certain extent controversial.

The present work is based on the meteor orbits data collected in the IAU Meteor data center (MDC) in Lund. The series of observations included in MDC have been listed by Lindblad (1987a). The necessary documentation with the description of programs, formats of data and references to the original sources have been used according to Lindblad (1987b), with an additional improvement of some data. Since photographic orbits are, in general, more precise than radar orbits, and, moreover, since the photographic data are supported by geophysical characteristics, it seems to be reasonable to analyse, first the photographic orbits contained in MDC. The results obtained in the next sections are based on the analysis of 2910 photographic meteor orbits of MDC, after removing the less precise orbits determined by graphical methods of McCrosky & Posen (1961).

2. Results following from the concentration of showers among the hyperbolic orbits

The presence of orbits with the elements almost identical to those of the known meteor showers but apart from having $e > 1$, and $a < 0$, can be used as a clear evidence of errors arising in most cases from the determination of the meteor velocity. The value of a is very sensitive to the value of the heliocentric velocity v_{H} especially near the parabolic limit. Hence any error in the determination of v_{H} can create an artifiacial hyperbolic population, where non really exists. To follow the influence of such errors on the samples of orbits considered to be hyperbolics, for all photographic meteor orbits of MDC catalogues, it is useful to construct diagrams, showing the position of radiants of orbits (right ascension and declination) for the selected intervals of values of $1/a$ close to the hyperbolic limit and beyond. Figures 1a - f show the positions of radiants for six intervals starting with $0.1 < 1/a < 0.2$ towards the negative values of $1/a$ and ending with $1/a < -0.5$ as defined in caption to Fig-

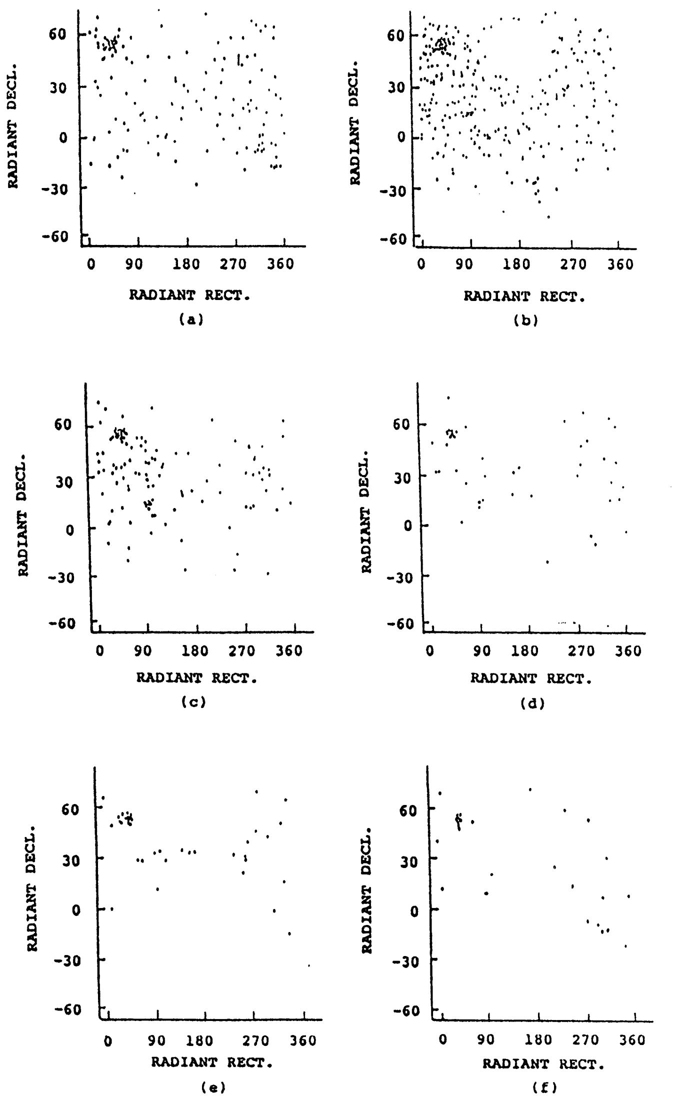

Fig. 1a–f. Positions of radiants (in α and δ) selected from all 2910 photographic meteors of MDC catalogues, within a chosen limits of reciprocal semimajor axis, as follows: **a** $0.1 < 1/a < 0.2$, **b** $0.0 < 1/a < 0.1$, **c** $-0.1 < 1/a < 0.0$, **d** $-0.2 < 1/a < -0.1$, **e** $-0.5 < 1/a < -0.2$, **f** $1/a < -0.5$

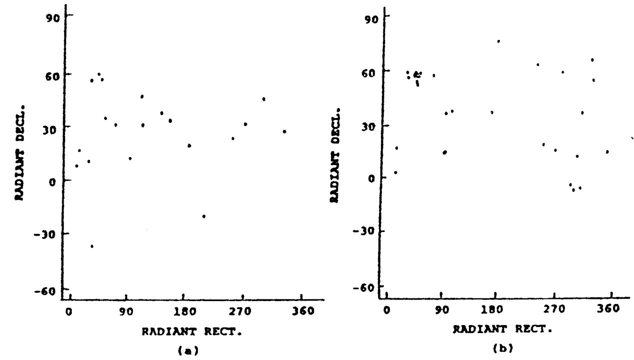

Fig. 2a and b. Comparison of the positions of radiants of hyperbolic meteors from **a** Harvard catalogues, and **b** other catalogues

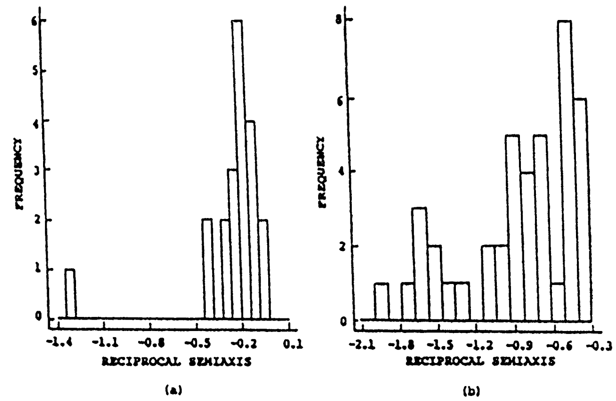

Fig. 3a and b. Comparison of the distribution of reciprocal semimajor axis $1/a$ in **a** Harvard catalogues, and **b** other catalogues

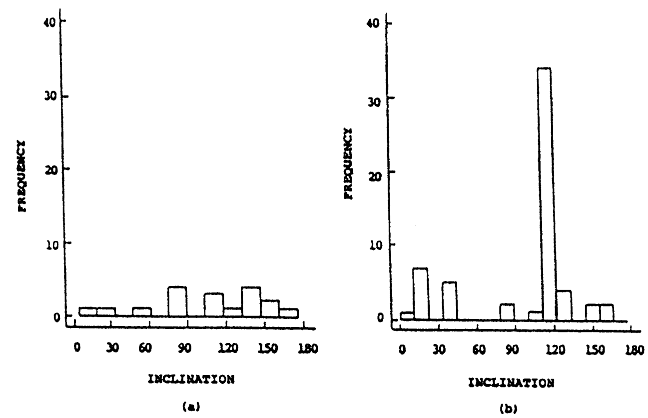

Fig. 4a and b. Comparison of the distribution of inclinations from **a** Harvard catalogues, and **b** other catalogues

ure 1. The presence of Perseid meteors with the mean radiant position $\alpha = 46^\circ$, $\delta = 58^\circ$ for their period of activity between July 15 - August 25 with a maximum at Aug. 12 is clear. Other shower radiants can also be clearly distinguished for the Orionids ($\alpha = 95^\circ$, $\delta = 15^\circ$), Leonids ($\alpha = 152^\circ$, $\delta = 22^\circ$), Lyrids ($\alpha = 272^\circ$, $\delta = 32^\circ$) and some others.

We would expect some gradual decreas in the concentration of shower radiants with the decreasing values of $1/a$, but their concentration around known radiant points among the orbits of highest hyperbolic excess as seen in Fig. 1f is actually higher (reaching the proportion nearly 1:1, including the α Capricornid meteor shower with $\alpha = 290^\circ$, $\delta = -6^\circ$) than in the earlier diagrams. This suggest that photographic orbits are, in general, not as precise as is claimed. To save the idea of very precise photographic orbit determination it was argued that Perseid meteors may have a hyperbolic branch due to a jet effect (Ceplecha et al. 1964) or particle splitting (Simakina 1968). The Perseids are connected with the comet P/Swift-Tuttle with a period of 120 years, $e = 0.96$, $\omega = 138^\circ$, $i = 114^\circ$. Apart from the difficulties of explaining theoretically velocity differences reaching some km.s^{-1} for the relatively large particles, it can be shown by the comparison of the radiant positions from different catalogues that the concentration of Perseid radiants strongly dependens on the precision of data. This is shown in Figs. 2a and 2b. Fig 2a is constructed from data in the Harvard catalogue including the data of Whipple, Jacchia and Whipple, Posen and McCrosky, Hawkins and Southworth, McCrosky, Shao and Posen and data from catalogue of Halliday, Griffin and Blackwell. Figure 2b is from the data of Dushanbe, Odessa and Kiev observatories. The distribution of reciprocal values of a for both samples, shown in Figs. 3a and 3b respectively, gives the possibility of a direct comparison of the precision of both sets of data and Figs. 4a and 4b, which represent the distribution of inclination in both sets of data give a definit explanation on the reason of the concentration of Perseid radiants in the first set of data. These observations were essentially carried out during the Perseid shower period.

At least two conclusions can be derived from the above analysis:

Assuming that the shower orbits have been determined, in general, with the same precision as nonshower data, and taking into account the large proportion (reaching 1:1) of orbits belonging to meteor showers among orbits with hyperbolic parameters, there is a lack of statistical argument for the presence of real hyperbolic orbits among the 2910 MDC photographic orbits. In order to judge the presence of real hyperbolic orbits in the catalogues it will be necessary to analyse special cases individually.

3. Extreme hyperbolic orbits and their origin

As it was shown above, the statistical analysis of the data of photographic meteors in MDC catalogues did not produce any convincing argument in favour of the existence of true hyperbolic meteors, in spite of the existence of many orbits with a determined value of a, less than zero. The errors should be considered substantially larger than usually estimated by the authors of catalogues. Therefore we have selected for individual analysis cases with very large values of hyperbolic excess.

We define the hyperbolic excess of heliocentric velocities as

$$\Delta v_{\mathrm{H}} = v_0 \left[\left(\frac{2}{r} - \frac{1}{a} \right)^{1/2} - \left(\frac{2}{r} \right)^{1/2} \right] \tag{1}$$

where a is measured in AU and v_{H} in km.s^{-1}, for v_0 is the mean heliocentric velocity of the Earth, 29.8 km.s^{-1}, and r = 1. For this approximation we have selected individual meteors separately from both above mentioned series of data, i.e. for the Harvard catalogue and for the other series. The limit of Δv_{H} = 1 km.s^{-1} was set up for the Harvard material and Δv_{H} = 5 km.s^{-1} for the other, less precise data. The list of meteors satisfying these criteria is given in Tables 1 and 2, giving 14 (Harvard) and 24 (other materials), in total 38 individual orbits with a hyperbolic excesses greater than 1 km.s^{-1}.

If interstellar meteors were present among the hyperbolic orbits, the distribution of the excesses of their heliocentric velocities should correspond to the distribution of radial velocities of close stars. This gives a very high velocity with a typical value of about 20 km.s^{-1} with respect to the Sun. For the velocity v_{i} = 20 km.s^{-1} of an interstellar meteor (with respect to the velocity of the Sun), having into account the equation $v_{\mathrm{i}}^2 = v_{\mathrm{H}}^2 - v_{\mathrm{P}}^2$, with v_{P} = 42.1 km.s^{-1} we obtain v_{H} = 46.6 km.s^{-1}. Moreover, a concentration of radiants to the Sun's apex (α = 272°, δ = 37°) should be observed. Considering a broad distribution of stellar velocities, in principle, all values of Δv_{H} in our Tables 1 and 2 can be of interstellar origin. However we should analyse them for each meteor in connection with their orbital and physical parameters.

In Table 2 there are 6 meteors with $\Delta v_{\mathrm{H}} > 10$ km.s^{-1}. By looking at values of α and δ of their radiant we can conclude that meteors No 4 and 6 are almost certainly Perseids and a high probability that No 2 also. No 1 correspond to the α Capricornid shower and No 5 is very close to it. This leaves meteor No 3. Its orbit has a high inclination and it could have been influenced by planetary perturbations. Unfortunately this orbit comes from observations of lowprecision.

Judging by radiant position, it is seen from Tables 1 and 2 that both samples contain a large proportion of shower orbits (6:8 and 15:9 respectively) leaving sporadic meteors with proportion of 0.45 in minority. This again raises the question of errors and their possible origin: Error can arise from:

a) Incorrect identification of a meteor seen from two stations, when more than one meteor occurs on the same plate. This error leads to an incorrect height determination. This could be the explanation for meteors No 6, 8, 14, 15, 18 and 22 in Table 2, with heights H_{B} below 80 km and above 120 km.

b) Incorrect time being recorded by one observer when data are obtained by independent visual observer and stable cameras. This error will not change the declination of the radiant, but it does affect the right ascension, corresponding to 15° for every hour. This changes the elongation of the radiant from apex and hence the determination of v_{H} derived from v_{g}. Meteor No 2 in Table 2 may well be affected in this way, since its R.A. is in error by some 25-30°.

c) Incorrect determination of the radiant, when the inclination of the apparent orbits of the meteors is close to 0° or 180°. This error leads to incorrect heights as in cases (a). The extremely low height of No 14 could be caused by this error.

d) Changes in rotation velocity of a sector or other equipment failure may affect measurement of meteors from the same night. This could be the case for meteors No 6, 18 and 21, all from the same night of Aug. 12, 1958 from Dushanbe.

e) Other errors may occure especially for short trails with a small number of segments. From this point of view meteor No 3 with H_{B} - H_{E} = 5 km is of the interest.

An interesting fact is that the four meteors with the highest geocentric velocities all belong to showers: No 8 Orionid meteor (77.3 km.s^{-1}), No 2 Perseid (76.0 km.s^{-1}), No 4 Perseid (75.9 km.s^{-1}) and No 17 Orionid (73.8 km.s^{-1}).

To demonstrate clearly the degree of influence errors can have on the determination of orbits in different catalogues we have compared the proportion of hyperbolic orbits from the limited area of $120° \leq \Omega \leq 150°$ and $100° \leq i \leq 130°$, which includes the radiant of Perseids with the proportion of hyperbolic orbits in all material of a given catalogue. The advantage

Table 1.

	q	$-a$	e	$v_{\rm H}$		D	α	δ	$H_{\rm B}$	$H_{\rm E}$	No	Ω	i	$\Delta v_{\rm H}$	
1	1.013	2.348	1.431	46.11	P	580812	30.1	56.6	108.3		11752	139.0	114.3	4.3	Per α
2	0.926	3.439	1.269	44.95	P	580916	69.4	32.6	121.5		11933	172.7	160.2	3.0	
3	0.073	3.806	1.019	45.09	P	561213	112.5	32.3	100.6		96600	261.3	50.8	2.7	Gem q
4	0.763	3.965	1.193	44.67	P	570405	251.8	24.8	114.4		10244	15.3	87.2	2.6	
5	0.972	4.145	1.234	44.76	P	581110	142.6	39.0	120.0		12399	227.3	141.6	2.5	
6	0.918	5.900	1.156	43.74	W	500421	270.2	33.1	111.7	83.3	1910	30.7	81.5	1.7	Lyr
7	0.469	5.990	1.078	44.15	W	500120	185.5	20.5	101.5	81.2	1918	299.8	130.6	1.7	Cam
8	0.272	6.900	1.040	43.26	W	500625	331.0	29.0	109.0	94.0	2061	273.2	134.3	1.5	
9	0.721	7.173	1.100	43.61	P	581017	93.8	12.9	113.8		12169	23.3	159.9	1.4	Ori
10	0.953	7.352	1.130	43.22	P	530808	41.5	59.9	109.5		18660	135.5	109.5	1.4	Per
11	0.898	8.224	1.109	43.19	P	570904	52.9	35.6	108.0		10804	161.5	151.7	1.3	
12	0.630	8.860	1.071	43.59	W	501213	156.1	34.6	107.1	87.3	2578	260.9	133.0	1.2	
13	0.770	10.272	1.075	42.85	J	530814	34.1	-36.1	112.8	102.1	8576	321.6	89.1	1.0	
14	0.652	10.403	1.063	43.16	P	581015	8.0	8.8	90.7		12125	201.2	3.6	1.0	

Table 2.

	q	$-a$	e	$v_{\rm H}$		D	α	δ	$H_{\rm B}$	$H_{\rm E}$	No	Ω	i	$\Delta v_{\rm H}$	
1	0.406	0.506	1.181	59.20	K	650729	305.6	-6.0	99.6	84.4	112	126.3	21.6	∗17.3	αCa
2	0.873	0.591	2.480	57.10	D	580817	72.0	57.4	111.0	102.7	82862	144.4	122.7	∗15.1	Per
3	0.401	0.600	1.680	57.00	N	640731	346.8	14.9	96.7	91.8	363	128.5	129.6	14.9	
4	0.983	0.604	2.630	56.80	D	590811	43.5	57.8	114.2	99.0	93244	138.3	120.6	∗14.8	Per
5	0.548	0.616	1.890	56.50	D	570726	294.8	-7.1	98.3	84.0	70707	123.4	17.1	∗14.6	αCa
6	0.992	0.639	2.550	56.05	D	580812	42.2	58.2	138.3	117.1	80812	139.6	119.7	∗14.1	Per
7	0.912	0.939	1.970	52.10	K	641114	305.6	37.1	91.9	76.9	104	171.9	35.6	10.0	
8	0.696	0.944	1.740	52.20	D	581022	93.9	15.4	130.8	106.4	84123	28.0	164.9	∗10.0	Ori
9	0.991	1.020	1.970	51.20	N	620812	40.5	58.4	106.7	96.6	321	138.7	117.1	∗9.0	Per
10	0.878	1.050	1.834	51.00	N	610901	298.8	12.3	80.0	70.7	272	159.0	19.8	9.1	
11	0.977	1.070	1.920	50.80	D	590811	43.7	57.9	109.9	99.9	93211	138.2	117.9	∗8.9	Per
12	0.989	1.080	1.920	51.00	D	591011	174.9	75.9	104.9	60.5	95985	197.8	86.2	8.8	
13	0.965	1.090	1.886	50.70	K	640809	45.2	52.1	106.7	97.5	81	136.3	126.4	∗8.8	Per
14	1.015	1.140	1.884	50.20	K	570702	236.3	63.5	75.0	54.0	2	100.6	41.5	8.4	
15	0.997	1.170	1.850	50.10	N	620812	39.7	57.8	135.4		329	139.6	117.3	∗8.2	Per
16	0.604	1.260	1.479	49.50	K	630722	290.1	-3.8	95.7	84.7	076	119.1	18.3	7.7	αCa
17	0.617	1.290	1.480	49.70	D	601020	90.6	14.5	129.3	89.9	361	27.3	162.0	∗7.5	Ori
18	0.974	1.360	1.720	49.00	D	580812	45.9	58.0	126.7	117.1	82551	139.6	117.7	∗7.1	Per
19	0.976	1.410	1.690	48.80	D	580809	41.2	57.4	121.3	91.2	82381	136.5	117.0	∗6.9	Per
20	1.004	1.410	1.710	48.80	D	590807	246.8	19.3	107.4	97.4	92794	134.3	17.9	6.9	
21	0.966	1.420	1.680	48.80	D	580812	47.6	57.6	113.0	98.0	82564	139.6	118.3	∗6.9	Per
22	0.969	1.440	1.670	48.70	D	590808	41.2	56.9	133.0	110.5	92964	135.4	117.3	∗6.8	Per
23	0.962	1.830	1.527	47.30	K	640809	44.3	54.3	111.3	86.7	082	136.3	121.4	∗5.4	Per
24	0.976	1.990	1.490	46.90	N	650821	319.7	65.7	112.2	88.9	414	148.4	112.3	5.0	

symbols:

- q perihelion distance (in AU)
- a semimajor axis (in AU)
- e numerical eccentricity
- $v_{\rm H}$ heliocentric velocity (in km.s^{-1})
- \- designation of a catalogue
- D date (year, month, day) of observation
- α right ascension (in degrees)
- δ declination (in degrees)
- $H_{\rm B}$ beginning height in the atmosphere (in km)
- $H_{\rm E}$ end height in the atmosphere (in km)
- No catalogue number of a meteor
- Ω longitude of the ascending node (in degrees)
- i inclination to the ecliptic (in degrees)
- $\Delta v_{\rm H}$ hyperbolic exces in heliocentric velocity (in km.s^{-1})
- \- identification with a meteor shower

of the selection of Ω and i instead of α and δ is that it does not exclude shower meteors with erroneous determination of α. This selection is also independent on the determination of showers by authors of catalogues. In a total, of 2910 meteors there were 501 Perseids, whilst from the same 2910 meteors 347 hyperbolic orbits. Of the 501 Perseids, 151 are hyperbolic ones. Amongst the Perseids 30 % are of hyperbolic orbits, whilst among other meteors there is only 8 % of hyperbolic orbits. Its true that in a chosen interval of Ω and i may not be only Perseids however it remains the fact of predominance of hyperbolic orbits among data and data from the other catalogues Tables 1 and 2 show the difference in precision of data.The Harvard data, contains only one Perseid and one Orionid meteor with low excesses, while the data from other observatories show a dominant group of Perseids even for highest excesses. Also present are α Capricornids (Ω = 125°, i = 20°) and two Orionids (Ω = 28°, i = 162°).

From this analysis it can be concluded, that since many apparent hyperbolic orbits are present in the low precision data this speaks against the existence of true hyperbolic meteors. In more precise data, among which shower meteors occur only exceptionally, there may be an argument for the presence of true hyperbolic orbits. However the hyperbolic excesses of the velocities in these cases are very low, about one order less than required from the velocity distribution of neighbour stars, which is an argument against the presence of interstellar meteor orbits even in the most precise data. From the contribution of sporadic radiants with extreme hyperbolic excesses to all data it follows that the frequency of meteors with excesses corresponding to the possible interstellar meteors in comparison with all photographic meteors do not exceed 2×10^{-3} and for the same mass interval they do not exceed 2×10^{-4}. For meteors with the size lower than 100 μm it is necessary to consider strong influences from internal forces of the Solar System (Kapišinský 1987), hence the analyses of Baggaley et al. (1992), supporting the significant presence of hyperbolic orbits among these particles, do not change too much on our results even for smaller particles.

It is worth nothing that the most recent study of 264 well-determined original orbits of long-period comets, made on the basis of Marsden's catalogue (Marsden 1989), which includes 18 hyperbolic orbits with - $1/a$ exceeding 4×10^{-5} AU leads to the same conclusion (Kresák 1992) that there is no evidence for any comet coming from the interstellar space.

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