

Interstellar Meteoroids in the Japanese tv Catalogue

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Abstract

The present work is based on an analysis of the 14763 precise determined meteor orbits collected in the Japanese tv catalogue (SonotaCo 2009), with the aim of determining the real proportion of interstellar meteors in this database. If interstellar meteors are present among the registered meteor orbits, the distribution of the excesses of their heliocentric velocities should correspond to the distribution of the radial velocities of close stars. For the velocity $v_i = 20 \text{ km s}^{-1}$ of an interstellar meteor, with respect to the Sun, we obtain a heliocentric velocity of $v_H = 46.6 \text{ km s}^{-1}$ of an interstellar meteor arriving at Earth. Any error in the determination of v_H , especially near the parabolic limit, can create an artificial hyperbolic orbit that does not really exist. The analysis of the data did not produce any convincing arguments in favour of the existence of true hyperbolic meteors in the catalogue. It was shown that the vast majority of the 484 hyperbolic orbits has been caused by an overestimation of their velocity, and approximately 50% of them belong to meteor showers. Furthermore, the hyperbolic excesses of the velocities in all cases are very low, about one order less than the velocity distribution of neighbouring stars suggest. The upper limit of the proportion of possible interstellar meteors to interplanetary ones among all investigated meteor orbits in the database is 1.3×10^{-3} .

Key words: hyperbolic — interplanetary medium — interstellar meteors — meteors: meteoroids — meteor showers — orbits

1. Introduction

A search for hyperbolic meteors and, among them, for interstellar particles has a long history. The substantial question whether interstellar meteors are present among the registered hyperbolic orbits and, if so, then how great is their frequency, is still open. From the position of the whole Solar System in the Galaxy and the studies of processes in the interstellar medium, it is clear that the Solar System is not an isolated system. Its interaction with the interstellar medium should lead to the presence of interstellar particles. The questions, how many interstellar particles we should register and how great is their abundance according to their mass and to their velocities, have led to many searches. In view of the present investigation, it is interesting to note that the first Catalogue of Bolides by Hoffmeister, from 1925, as well as the results of Öpik's Arizona meteor expedition, from 1931–1933 (Öpik 1934), supported the leading opinion of the first half of the last century that the majority (up to 80%) of meteors are of interstellar origin. A substantially different opinion was given by the Harvard photographic meteor program, by means of Super-Schmidt cameras, published by Jacchia and Whipple (1961), which allowed a much more precise determination of bolide velocities. The results gave so few hyperbolic velocities that they raised the question of whether interstellar meteors exist at all. Moreover, Whipple (1940) has shown that the main stream of “interstellar meteors” in Hoffmeister's Catalogue is associated with the Comet Encke, the comet with the shortest period of revolution and aphelion in the asteroidal belt. This history may be in some way instructive for present-time conclusions about the detection of interstellar particles, without giving

reliable results on the velocity determination of those particles (Hajduk 2001), because accurate velocity measurements lead to solutions to the problem of interstellar meteoroids.

The search for interstellar particles is going on using different techniques, covering a mass scale of more than 20 orders, with attempts to map the galactic sources of interstellar dust (Baggaley et al. 2007). The proportion of interstellar particles to interplanetary ones, was found to be much higher for small particles obtained from cosmic detectors in comparison with the results of photographic and video observations in the range of larger meteoroid particles. This contradiction could be explained by the different mass distribution of interstellar and interplanetary particles (Hajduková & Hajduk 2006).

Weryk and Brown (2004) searched for interstellar meteoroids and analysed more than 1.5 million orbits of meteors detected by Canadian Meteor Orbit Radar. After a proper error analysis, they determined the lower limit of the proportion of registered possible interstellar meteoroids as being 0.0008%.

Hawkes and Woodworth (1997), in their optical search for interstellar meteoroids, came to the conclusion that meteoroids incoming on hyperbolic orbits represent about 1% of the total number of detected meteors (meteoroids for limiting mass about $5 \times 10^{-8} \text{ kg}$) by the video technique.

The analysis of the IAU MDC photographic catalogues (Hajduková 1994) set the frequency limit for hyperbolic meteors of a possible interstellar origin as 0.002%. It was shown (Hajduková 2008) that the vast majority of hyperbolic orbits has been caused by an erroneous determination of their heliocentric velocity or other parameters, and that the number of hyperbolic meteors in the investigated catalogues of IAU MDC does not represent in any case the number of interstellar

meteors in observational data.

The present work is based on the analysis of precise determined meteor orbits collected in the Japanese meteor shower catalogue from video observations by SonotaCo 2009,¹ with the aim of determining the real proportion of interstellar meteors in this database. The meteors observed continuously in the years 2007–2009 by the SonotaCo network are detected mostly up to +2 magnitude (the average absolute magnitude of detected meteors is -0.87), and 63% of them create a large set of sporadic meteors.

It was clearly demonstrated many times that the proportion of hyperbolic orbits in data depend on the quality of observations and the accuracy of measurements (Štohl 1971; Hajduková 1994). The latest version of the Japanese catalogue represents 64650 video-observed meteoroids. Among them, 7489 orbits (11.58%) are hyperbolic. The abundance of hyperbolic orbits decreased strongly using a subset of meteor orbits, selected from the SonotaCo network simultaneously observed meteor data by Vereš and Tóth (2010), after an analysis of their qualitative aspects. Among these 14763 precise tv orbits, there are 484 hyperbolic meteors, which represent only 3.28%. Therefore, in our search for interstellar meteors, the selection of quality orbits was used.

2. Hyperbolic Meteor Orbits and Interstellar Meteoroids

Meteoroids entering the atmosphere of the Earth and coming from the interstellar medium have heliocentric velocities of $v_H > v_p$, where v_p is the parabolic velocity with respect to the Sun, and the hyperbolicity of their orbits (with semimajor axis $a < 0$ and eccentricity $e > 1$) is not caused by planetary perturbations inside the Solar System. The difference between the hyperbolic and parabolic heliocentric velocity, the hyperbolic excess of heliocentric velocity, is defined as

$$\Delta v_H = v_0[(2/r - 1/a)^{1/2} - (2/r)^{1/2}], \quad (1)$$

where a is measured in AU and v_H in km s^{-1} ; v_0 is the mean heliocentric velocity of the Earth, 29.8 km s^{-1} , and $r = 1 \text{ AU}$ is the heliocentric distance of the meteoroid at its encounter with the Earth. For this approximation, we selected and analysed individual meteors from the SonotaCo tv catalogue. If interstellar meteors are present among the hyperbolic orbits, the distribution of the hyperbolic excesses of their heliocentric velocities should correspond to the distribution of radial velocities of close stars. For the velocity of an interstellar meteor of around $v_i = 20 \text{ km s}^{-1}$, which represents the relative velocity of the Sun in the nearby stellar environment, and taking into account the equation $v_i^2 = v_H^2 - v_p^2$, with $v_p = 42.1 \text{ km s}^{-1}$, we obtain a heliocentric velocity of $v_H = 46.6 \text{ km s}^{-1}$ for an interstellar meteor arriving at Earth.

Moreover, if the observed meteors are interstellar, a concentration of radiant to the Sun's apex ($\alpha = 272^\circ$, $\delta = 37^\circ$), or a distribution following the motion of interstellar material, should be observed.

3. Errors in the Velocity Determination and Hyperbolic Meteors

The value of the semimajor axis a is very sensitive to the value of the heliocentric velocity, v_H , especially near the parabolic limit. The equation $da = 2v_H a^2 dv_H$ shows that, for a big value of the semimajor axis, a , even a small error in the velocity determination can change an elliptic orbit to a hyperbolic one. Hence, any error in the determination of v_H can create an artificial hyperbolic population that does not really exist.

There are different reasons for an error in the heliocentric velocity, such as the instrumental effects, measuring errors, irregularities in the atmospheric deceleration, errors in radiant determination and timing errors affecting the subtraction of the motion of the Earth from the geocentric velocity in order to find the heliocentric velocity. All of these different sources of errors vary widely in importance, and cannot be readily separated from one another.

Therefore, it is difficult to recognize meteoroids of interstellar origin in the sporadic interplanetary background inside the error interval. The accuracy of the velocity in the Japanese tv database depends on the geometric conditions of simultaneous observations; thus, the accuracy is different for each meteor (SonotaCo 2009). As additional information, the difference in velocity determination from different stations (in percent) is given for each meteor in the catalogue. In general, varying precision of measurements, depending on the conditions and quality of observations, causes a natural spread in the velocity distribution. The shape of this spread gives a scattered Gaussian distribution, which in the vicinity of the parabolic limit of the velocity exceeds the difference between the heliocentric velocity of a particular meteor and the parabolic velocity, resulting in it being designated as a “hyperbolic orbit”. The velocity distribution of all the 14763 tv meteors and that of 238 sporadic hyperbolic meteors of the catalogue is shown in figure 1.

4. Shower Meteor Data among the Hyperbolic Orbits

There are 484 formally hyperbolic orbits among the total of 14763 video-observed meteors in the catalogue (SonotaCo 2009). More than half of them (246 orbits) have been identified, by authors of the catalogue, with the meteor showers. The presence of orbits with $e > 1$ and $a < 0$, but with other elements almost identical to those of the known meteor showers, can be used as clear evidence of errors arising, in most cases, from the determination of the meteor velocity. Here, it has to be mentioned that the hyperbolic excesses of almost all cases of “hyperbolic” shower meteors are very small, which suggests small measurement errors. The largest values of Δv_H in different showers vary from 0.16 km s^{-1} of a Lyrid, through 1.47 km s^{-1} of a Leonid, to 3.03 km s^{-1} of a December Monocerotid. The dispersion of the measured velocities of hyperbolic shower meteors gave us a lower limit for the real hyperbolic excesses in sporadic data, and allowed us to estimate the proportion of detected interstellar meteors in the database.

To follow the influence of such errors on the sample of

¹ (<http://sonotaco.jp/doc/SNM/>).

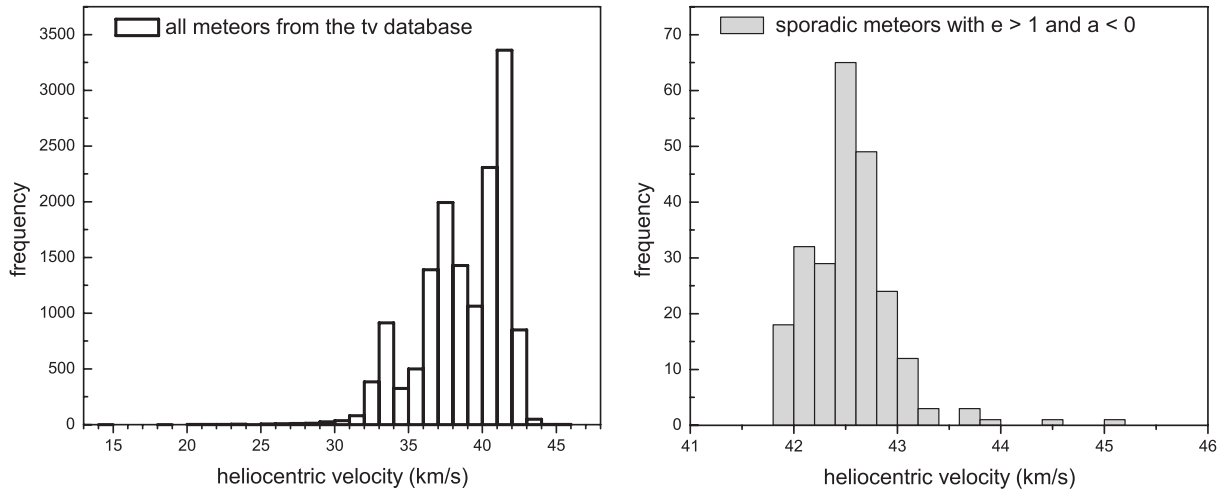


Fig. 1. Distribution of heliocentric velocities of all 14763 tv meteors from the SonotaCo tv meteor data set (left) and that of 238 sporadic hyperbolic meteors (right) shows a scattered Gaussian distribution, which in the vicinity of the parabolic limit of the velocity results in the designation of a “hyperbolic orbit”.

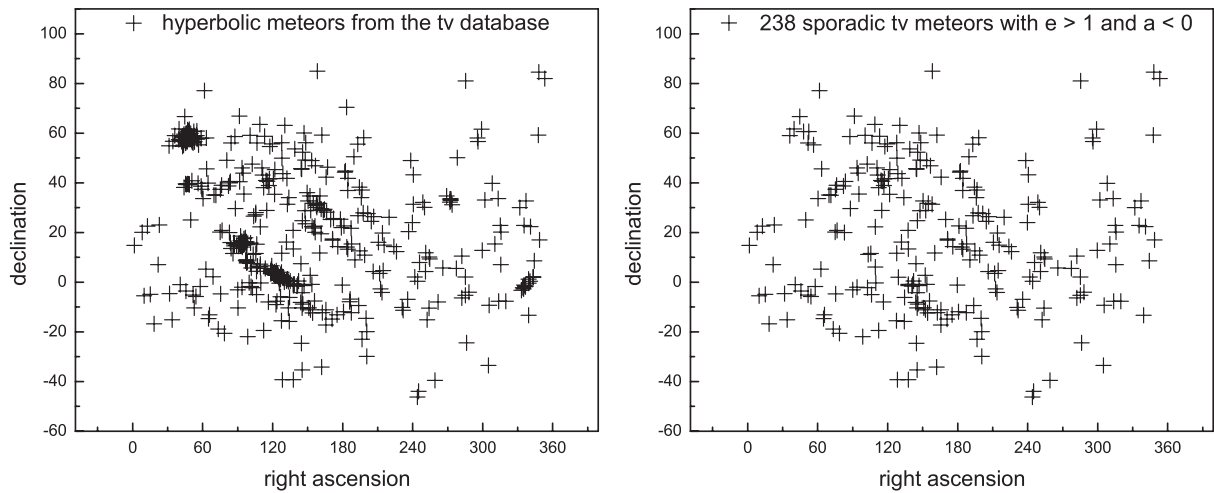


Fig. 2. Positions of radiants of all 484 hyperbolic meteors with $e > 1$ and $a < 0$ from the SonotaCo tv meteor data set (left). Among them, about 50% belong to meteor showers. The best seen are Perseids, Orionids, Lyrids and Leonids. Possible interstellar meteors may be found in a subset of 238 sporadic hyperbolic meteors (right).

orbits considered to be hyperbolics, we constructed diagrams showing the position of the radiants (right ascension and declination) of the meteors. Figure 2 (left) shows an overall view of the radiant distribution of all hyperbolic meteors. The graph still shows a high concentration around the radiants of the meteor showers, particularly around the radiant of meteor showers with a mean velocity close to the parabolic limit. The graph in figure 2 on the right, constructed from sporadic meteors with hyperbolic orbits, shows a subset of meteors, where the possible interstellar meteors may be found after a detailed error analysis.

The proportion of hyperbolic orbits in the database is different in different meteor showers. Four meteor showers having a heliocentric velocity, v_H , close to the parabolic limit ($\sqrt{2}v_0$, where v_0 is the Earth’s velocity) were examined. The data are given in table 1. Figure 3 on the left shows

the eccentricities and geocentric velocities of the 4 selected meteor showers. A considerable dispersion is noticeable in both parameters. As can be seen from table 1, as well as from figure 3 on the right, a clear dependence of the contribution of hyperbolic orbits between shower meteors on the mean heliocentric velocity of particular meteor shower was found. An increasing number of hyperbolic orbits inversely proportional to the difference between the parabolic velocity and the mean velocity v_H of particular meteor shower ($\Delta v = \bar{v}_H - \sqrt{2}v_0$) is evident. This is in agreement with a previous analysis of the photographic and radar hyperbolic meteors of the IAU Meteor Data Center (Hajduková 2008), which also has clearly shown the dependence $N_{e>1}/N = f(v_H)$. For the sake of comparison, it may be mentioned that among the 1488 Geminids (with the main heliocentric velocity of only 36.6 km s^{-1}) from the SonotaCo tv catalogue there is not one case of

Table 1. Selected shower meteor data from the Japanese video catalogue for meteor showers with high heliocentric velocity.

Meteor shower	No. of meteors	No. of hyp. meteors	Hyperbolic meteors (%)	Mean geoc. vel. \bar{v}_G (km s ⁻¹)	Mean helioc. vel. \bar{v}_H (km s ⁻¹)	$\Delta v = \bar{v}_H - \sqrt{2}v_0$
Lyrids	75	6	8.0	47	41.92	-0.22
Perseids	1124	65	5.8	59	41.70	-0.44
Orionids	743	40	5.4	67	41.52	-0.62
Leonids	143	6	4.2	71	41.43	-0.71

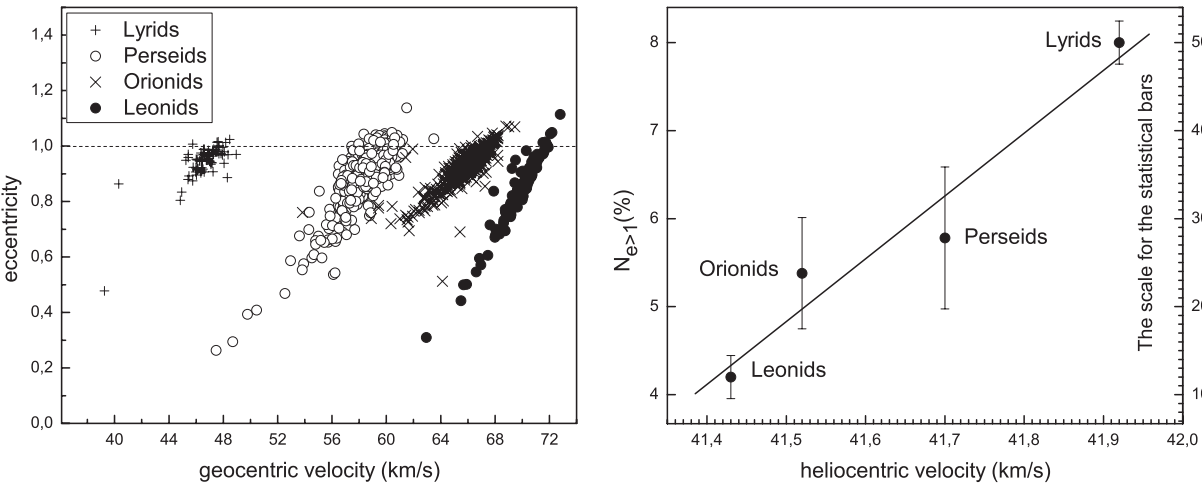


Fig. 3. (Left) Distribution of the eccentricities and geocentric velocities of 4 selected meteor showers from the SonotaCo tv meteor data set. (Right) A clear dependence of the contribution of hyperbolic meteors on the mean heliocentric velocity of particular meteor shower. For each meteor shower, the statistical bars (right scale) described by standard deviation (the values are 2.45 for Leonids and Lyrids, 8.06 for Perseids and 6.03 for Orionids) in the Poisson distribution are also shown.

Table 2. Overview of recorded hyperbolic orbits in the SonotaCo tv meteor data set.

Number of all meteors in the tv catalogue	$N_{\text{all}} = 64650$
Number of hyperbolic meteor orbits with $a < 0$ and $e > 1$ among N_{all}	$N_{\text{all}, e>1} = 7489$
Number of the quality orbits in the Japanese tv catalogue	$N = 14763$
Number of hyperbolic meteor orbits with $a < 0$ and $e > 1$ among N	$N_{e>1} = 484$
Meteors with velocity expected for interstellar meteoroid $v_H > 46.6$ km s ⁻¹	$N_{v_H>46.6} = 0$
Meteoroids belonging to meteor showers	$N_{\text{show}} = 7113$
Meteoroids belonging to meteor showers with $a < 0$ and $e > 1$	$N_{\text{show}, e>1} = 246$
Sporadic meteoroids	$N_{\text{sporad}} = 7650$
Sporadic meteoroids with $a < 0$ and $e > 1$	$N_{\text{spor}, e>1} = 238$
The proportion of hyperbolic meteors in the database	$N_{e>1}/N = 0.0328$
The proportion of hyperbolic meteors between the shower meteors	$N_{\text{show}, e>1}/N_{\text{show}} = 0.0346$
The proportion of hyperbolic shower meteors to $N_{e>1}$	$N_{\text{show}, e>1}/N_{e>1} = 0.508$
The proportion of hyperbolic meteors in the sporadic data	$N_{\text{spor}, e>1}/N_{\text{spor}} = 0.0311$
The proportion of sporadic hyperbolic meteors to all meteors	$N_{\text{spor}, e>1}/N = 0.0161$
The upper limit of the proportion of interstellar meteors to interplanetary ones	$N_{\text{ism}}/N = 0.0013$

a hyperbolic orbit.

The large proportion of orbits belonging to meteor showers among orbits with hyperbolic parameters (about 50%) and, assuming that the shower orbits have been determined with a similar precision to the non-shower data, a similar effect of erroneously-determined “hyperbolic orbits” should also be

ascribed to the sporadic meteors, at least for those velocities that are not too far from the parabolic limit. An overview of detected hyperbolic orbits in the SonotaCo tv catalogue and their abundance between shower and sporadic data is given in table 2.

Table 3. Orbital and geophysical parameters of sporadic meteors with the highest hyperbolic excesses from the catalogue.*

No	Δv_H	a	q	e	i	ω	Ω	v_G	v_H	H_B	H_E	α	δ	Date
1	2.906616	-3.1719	0.9873	1.3113	153.2990	17.5802	314.3032	72.2055	45.0466	116.4608	97.5654	40.8063	-1.0117	20090807
2	2.413593	-4.4687	0.4238	1.0948	172.4046	84.4393	216.3326	67.7870	44.5536	112.1436	97.1492	160.2762	11.7301	20091030
3	1.749275	-7.1290	0.3644	1.0511	92.1684	76.7512	306.9017	53.7345	43.8893	109.0628	93.5124	265.7705	5.73063	20090127
4	1.655059	-7.0150	0.9869	1.1408	138.8532	353.4157	158.5104	69.2782	43.7951	114.5988	107.8883	244.0461	-46.2328	20080228
5	1.637756	-7.2995	0.6479	1.0888	118.2225	250.1847	236.2207	61.6854	43.7778	110.5130	100.1769	128.0265	49.9482	20091118
6	1.517986	-7.5975	0.6115	1.0805	127.6048	74.8215	42.2466	63.4425	43.6580	110.0928	86.8926	102.7711	-2.2121	20091105
7	1.172435	-12.1111	0.6239	1.0515	113.4426	73.3922	83.0851	60.0501	43.3124	107.1496	96.2900	134.3140	-15.7582	20081215
8	1.116752	-12.4761	0.3427	1.0275	110.6198	286.6849	251.5134	57.4556	43.2568	107.9839	76.3223	128.7595	43.7464	20091204
9	1.065891	-10.9042	0.2650	1.0243	44.7305	116.6991	33.8677	42.3749	43.2059	106.4742	78.1823	57.8889	-1.7378	20071028
10	1.022281	-10.9347	0.9894	1.0905	138.6304	188.9884	206.7840	68.4448	43.1623	111.5236	98.0221	121.7677	45.3705	20071021
11	1.015846	-14.9901	0.8166	1.0545	144.9689	228.0297	266.3948	68.6731	43.1559	119.4170	90.5691	169.7854	25.2608	20071219
12	1.000133	-13.3490	0.5948	1.0446	104.7752	257.2814	234.9293	57.0778	43.1401	111.5325	92.6466	119.7808	55.6560	20071118
13	0.988334	-15.6856	0.0622	1.0040	29.4713	150.4318	117.5185	47.1615	43.1283	92.0160	75.6131	144.2607	7.4429	20090118
14	0.945392	-14.0671	0.8241	1.0586	105.1398	47.5380	51.4911	57.9997	43.0854	106.6146	100.3348	112.2150	-19.4376	20081114
15	0.924201	-17.6992	0.2590	1.0146	126.9657	117.5512	99.5250	59.7285	43.0642	106.0061	87.4463	145.3108	-4.1827	20080101
16	0.915649	-15.1945	0.4282	1.0282	109.4251	96.7721	57.3985	57.4667	43.0557	107.5014	92.1034	106.1021	-5.0183	20091120
17	0.910201	-17.1081	0.5668	1.0331	131.6527	80.5221	77.2677	63.7310	43.0502	109.0144	93.8300	134.4448	-6.1496	20071210
18	0.910102	-13.1827	0.7303	1.0554	93.1585	241.0439	215.3270	53.4044	43.0501	109.8385	91.2329	91.5430	66.8080	20091029
19	0.902751	-11.1621	0.4186	1.0375	150.2971	278.1843	16.0001	64.7418	43.0428	121.8153	73.6785	254.0254	-10.4049	20090406

* The symbols denote: Δv_H —the hyperbolic excess in heliocentric velocity, a —semimajor axis, q —perihelion distance, e —eccentricity, i —inclination, ω —argument of perihelion, Ω —ascending node, v_G and v_H velocities (geocentric and heliocentric), H_B and H_E beginning and end height in the atmosphere, α and δ —equatorial coordinates right ascension and declination of the radiant of a meteoroid, Date—year, month, day of observation.

5. Orbital Characteristics of Hyperbolic Meteors in the Japanese tv Catalogue

A statistical analysis of the data made above did not produce any convincing arguments in favour of the existence of true hyperbolic meteors, in spite of the presence of many orbits with determined values of $a < 0$ and $e > 1$. Therefore, we have selected here for a closer analysis meteors with the largest values of hyperbolic excesses. In the SonotaCo tv catalogue, there are no cases with $v_H > 46.6 \text{ km s}^{-1}$, which is the velocity expected for interstellar meteors. However, considering a broad distribution of stellar velocities, in principle, all values of the hyperbolic excesses, Δv_H , may be of interstellar origin, and it is necessary to analyse each meteor in connection with their orbital and physical parameters. In the catalogue, there are 38 orbits with hyperbolic excesses greater than 1 km s^{-1} . This sample contains a large proportion of shower orbits (66%), leaving sporadic meteors in a minority, which speaks again against the existence of true hyperbolic meteors.

Among the 7650 sporadic meteors from the investigated database, there are 238 hyperbolic, which represents 3.11%. The dispersion of the measured hyperbolic velocities, derived from hyperbolic shower meteors, gave us the limit for hyperbolic excesses, and created a subset of 19 meteoroids with the largest values of hyperbolic excesses being $\Delta v_H > 0.9 \text{ km s}^{-1}$. The orbital elements and other parameters of these meteoroids are listed in table 3.

The largest value of Δv_H is 2.91 km s^{-1} (meteor No. 1 in table 3). However, according to the authors of the database (SonotaCo 2009), the difference in the velocity determination from different stations for this meteor reached a value of 4.48 km s^{-1} ; thus, its hyperbolic excess is far inside the error interval. The same applies, except for 2 meteors (Nos. 3 and 7), to all meteors listed in table 3.

In general, meteor orbits with inclinations i close to 90° , which are well outside the interplanetary components concentrated mainly in the ecliptic plane, can be considered to be interstellar. In our subset, there are two such meteors, Nos. 3 and 18. Velocities measured from different stations for meteor No. 3, with its hyperbolic excess of 1.75 km s^{-1} , were determined with incredible accuracy, giving a difference of only 0.03 km s^{-1} , which leave us to regard this meteor as being interstellar. The error in the velocity determination for meteor No. 18 reaches the value of its hyperbolic excess.

It is noticeable that all meteors, except two, listed in table 3 are in retrograde orbits. The only explanation is that the errors in the measured velocities increase toward higher velocities, belonging to retrograde orbits, and so they increase the proportion of orbits with $e > 1$. The sporadic meteors in retrograde orbits have in general higher velocities, like those in prograde orbits, and for those with $e > 1$ their velocity is overestimated and erroneous. These meteoroids belong to the group of closed orbits with $e < 1$, and we can not claim that they are interstellar due to their retrograde orbits.

Since the atmospheric height is proportional to the geocentric meteor velocity, it is expected that meteors incoming from interstellar space will have great beginning heights; 18 meteors from 19 in table 3 have beginning heights $H_B > 105 \text{ km}$. Woodworth and Hawkes (1996) in their study of high meteors in hyperbolic orbits concluded that at most a few percent of tv recorded meteors are hyperbolic, and there is no evidence for luminosity above about 120 km. They also noted that there are other mechanisms for high meteors that do not involve hyperbolic velocities. Regardless, meteors Nos. 1, 4, 11, and 19 from table 3, with their beginning heights of 116, 114, 119, and 121 km, respectively, seem to be meteoroids of possible interstellar origin. However, the velocity errors reach, or are greater than, the values of their hyperbolic excesses.

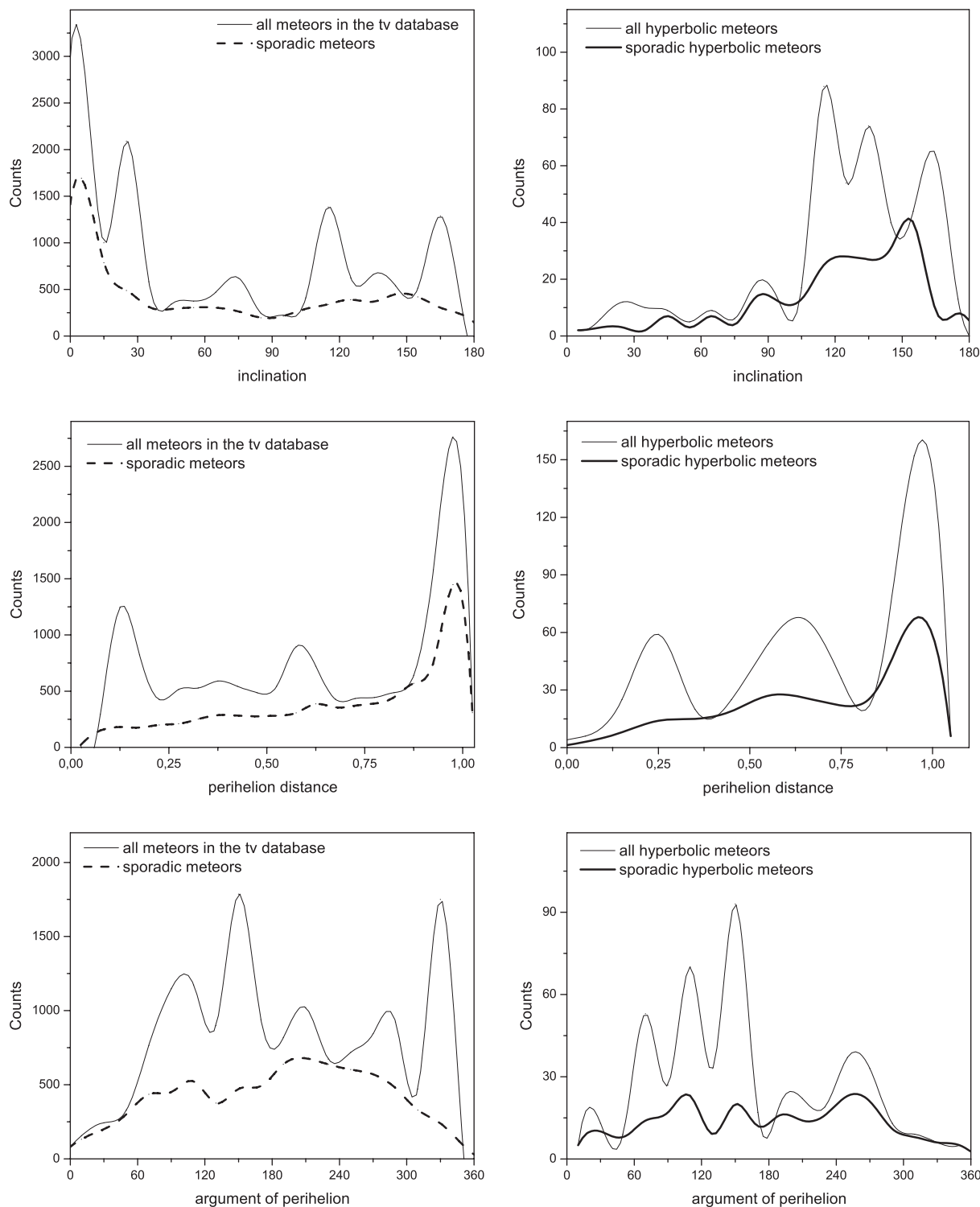


Fig. 4. Comparison of distributions of orbital elements (inclination, perihelion distance and argument of perihelion) of all meteors and of those recorded as hyperbolic has shown that the sporadic meteors with hyperbolic excesses (thick line) follows the distribution of all sporadic meteors (dashed line) as well as that of hyperbolic shower meteors (thin line) and have not shown any similar orbital characteristics, which could have supported their interstellar origin.

The analysis showed that the meteors with hyperbolic excesses do not show any similar orbital characteristics that could have supported their interstellar origin. The distributions of their orbital parameters are shown in figure 4. The sporadic meteors with hyperbolic excesses follow the distribution of all sporadic meteors, as well as that of hyperbolic shower meteors. Thus, objectively, it was possible to determine only the upper limit of the proportion of possible interstellar meteors to interplanetary ones among all investigated meteor orbits in the database. From the contribution of sporadic meteors with hyperbolic excesses greater than 0.9 km s^{-1} to all data, and taking into account the fact that the velocity of shower orbits has been determined with a similar precision to that of the sporadic meteors, it follows that the frequency of possible interstellar meteors in the SonotaCo tv meteor data set does not exceed 1.3×10^{-3} .

It is also necessary to mention that there is a possible population of hyperbolic meteors, the hyperbolicity of which was caused by planetary perturbations. It is obvious that in spite of their real hyperbolic orbits, these meteors are not of an interstellar origin. The first approximation showed that hyperbolic orbits caused by planetary perturbations in the SonotaCo tv catalogue are statistically minor. In the present work, we only approximately analysed possible perturbation by Jupiter. There are only 11 meteoroids in the database that have one of the nodes of their orbit at the heliocentric distance of 4.6 to 6 AU [$R_{ad} = a(1 - e^2)/(1 \pm e \cos \omega)$]. For 5 of them, the orbit perturbation caused by Jupiter could be excluded because these meteoroids collided with Earth before their perihelion, and the inclinations of all these orbits are high. In the other 6 cases, Earth met the meteoroid after its perihelion, but the determination of the node crossing time showed that the hyperbolicity of none of the meteoroids from these cases was caused by Jupiter's perturbations.

6. Conclusions

The present work is based on an analysis of the precise video meteor orbits collected in the SonotaCo tv meteor data set

(2009). Assuming that the shower orbits have been determined, in general, with the same precision to that of the non-shower data, and taking in to account the large proportion (exceeding 1:1) of orbits belonging to meteor showers among orbits with hyperbolic parameters, there is a lack of any statistical argument for the presence of real hyperbolic orbits among the 14763 orbits of the meteors observed by the multi station video meteor network located in Japan. A detailed analysis showed that, except for 2 meteors, all possible interstellar meteoroids can be found only within the error bars of the determined heliocentric velocity. The hyperbolic excesses of the heliocentric velocities in all cases are very low (there are no cases with the velocity expected for interstellar meteors $v_H > 46.6 \text{ km s}^{-1}$ in the data), about one order less than required from the velocity distribution of neighbouring stars. In addition, the meteors with hyperbolic excesses do not show any similar orbital characteristics. Furthermore, neither any concentration of radiant to the Sun's apex, nor any distribution following the motion of interstellar material has been found.

The proportion of hyperbolic orbits in the tv database decreased significantly after the selection of quality orbits from 11.58% of the total number of tv meteors to 3.28% of the quality selection. After an error analysis, the upper limit of the proportion of possible interstellar meteors among all investigated meteor orbits was determined to be 0.13%. Hence, the flux of interstellar meteors of mass range corresponding to the tv observations is much lower (at least 1 order less) than was expected from the high abundance of recorded hyperbolic orbits in the data.

Summarizing the above data, it can be concluded that, since many apparent hyperbolic orbits are presented in the Japanese tv catalogue, the analysis has called the occurrence of interstellar meteoroids in the vicinity of the Earth into question, at least for meteoroids of masses corresponding to the video technique detections.

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