On the population of very bright meteors in meteor streams

M. Gavajdová

Astronomical Institute of the Slovak Academy of Sciences
842 28 Bratislava, The Slovak Republic

Received: November 29, 1993

Abstract. The present paper summarizes the analysis of a set of 1028 photographic orbits of meteors with magnitudes brighter than -3. The analysis was made separately for subsets of the meteors brighter than magnitude -3, -5, -7, -9. Fireball streams were sought using the method of Southworth - Hawkins' D-discriminant considering radiants, their daily motions, sizes and shapes of the radiant areas. Most of the detected fireball streams belong to known meteor streams; a few of them were classified as new meteor streams. The mean orbits, radiants, periods of activity and velocities of the streams are presented in Tables 1-8.

Key words: meteor streams – fireballs

1. Introduction

The representation of very bright meteors, fireballs, in various meteor streams varies and relates to the age of the stream. Relatively young streams (Leonids 1966, Lyrids 1982, etc.) consist predominantly of smaller meteoroids or faint meteors, while older and more dispersed streams (Taurids) are know as streams consisting mainly of brighter meteors. A stream comprising very bright meteors, resulting from larger meteoroids, is considered to be a fireball stream.

Terenteva dealt with the problem of existence of fireball streams and has analysed (1990) the orbits of 554 fireballs photographed by the American and Canadian fireball networks. According to her results, 68% of the fireballs are members of 78 streams, which is much larger than the percentage for standard photographic meteors - 43% (Lindblad 1971).

The present paper aims to verify the reality of the existence of fireball streams and also Terenteva is result on the basis of a statistically more significant set of fireball orbits catalogued in the IAU Meteor Data Center in Lund (Lindblad 1991). At the end of 1990, this set of precise photographic orbits included more than 3500 meteors, brightness data being available for 2955 meteors.

In order to emphasize our results meteors with magnitude -3 were already taken as fireballs. Consequently, in the first approximation 1028 fireballs were found in the Meteor Data Center catalogue. A search for fireball streams among photographic meteors brighter than magnitude -3 was made in our previous analysis (Porubčan and Gavajdová 1994) and here we present a more detailed stream search among various sets of fireballs brighter than magnitude -3, -5, -7 and -9.

2. Analysis

The analysis was based on a computerized stream-search (Porubčan and Gavajdová 1994). The stream-search procedure utilizing Southworth-Hawkins' D-criterion consist of several steps and was applied to each of the sets containing fireballs in different intervals of magnitude.

Fireballs with the value of $D \leq 0.25$ were taken to be possible members of a stream. In most cases of searching for members of meteor showers a more rigorous criterion ($D \leq 0.20$) is commonly used. But in the analysis one also has to consider the fact that a more appropriate limit of D depends on the size of the set and the dispersion of the stream. Since fireball streams are probably more dispersed than normal meteor streams, a larger value of D was used for the analysed material.

The definitive mean orbits of streams were obtained by successive iterations. Meteors which fulfil certain conditions were found for each meteor of the set - the deviation of the radiant's right ascension from the mean radiant is $\leq \pm 20°$, the deviation of the ascencion node from the mean value is $\leq \pm 20°$. Owing to this we have limited the streams' period of activity to 30 days. Subsequently, the similarity of the orbits was estimated with the aid of the D-criterion, the mean orbit of the subset with meteors conforming to condition $D \leq 0.25$ was computed, and the calculation was repeated with regard to the new mean orbit. The calculation was terminated only when the mean orbit from the last iteration was identical to the one from the previous iteration.

In the following step the radiants of the individual stream members were plotted, and fireballs with deviations in the right ascencion with regard to the daily motion of the radiant larger than $\pm 20°$ and deviations in the ascencion node larger than $\pm 15°$ were excluded from the stream. Fireballs occurring in two or more streams simultaneously were included in the stream in which they had the least value of D. In the final step of the procedure, the deviations in velocity, size and shape of the radiant area with regard to the daily motion of the radiant were considered. An association of at least 3 orbits satisfying the above conditions was taken as a stream.

3. Results

Tables 1-8 show the results of the analysis of 1028 orbits of fireballs with absolute photographic magnitudes $\leq$-3, $\leq$-5, $\leq$-7, resp. $\leq$-9, compiled from all photogra-

Table 1. Mean orbital parameters of the known meteor streams derived from the fireballs of the absolute photographic magnitude $M_{ph} \leq -3$

Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
Quadrantids	Jan 4 - Jan 17	233.1	49.1	38.9	0.977	2.383	0.589	68.6	169.3	286.0	95.3	6
Virginids	Mar 6 - Mar 21	181.2	4.4	28.2	0.451	3.239	0.860	4.4	281.0	353.7	274.7	4
σ *Leonids* (*S*)	Mar 21 - Apr 15	178.6	-7.7	16.8	0.747	2.012	0.630	4.1	69.6	192.2	261.8	5
Lyrids	Apr 22 - Apr 25	272.7	33.7	47.6	0.928	-59.486	1.016	80.3	212.0	32.6	244.6	4
α *Scorpiids*	May 12 - May 28	247.0	-28.8	31.0	0.330	2.640	0.875	9.8	116.5	236.8	353.3	3
θ *Ophiuchids* (*N*)	Jun 1 - Jul 10	271.9	-17.3	22.9	0.566	2.390	0.764	4.5	271.2	91.7	362.9	6
θ *Ophiuchids* (*S*)	Jun 22 - Jul 12	276.4	-27.5	19.6	0.650	2.142	0.693	2.6	84.3	279.4	3.7	5
ι *Aquarids* (*N*)	Jul 27 - Aug 10	326.9	-9.3	34.4	0.238	3.580	0.929	5.7	306.7	129.5	76.2	3
α *Capricornids* (*N*)	Jul 22 - Sep 12	315.1	-8.9	21.0	0.617	2.318	0.734	5.1	267.1	137.3	44.4	16
α *Capricornids* (*S*)	Aug 13 - Aug 28	328.7	-16.0	21.6	0.597	2.414	0.753	2.8	87.3	327.0	54.3	6
δ *Aquarids* (*N*)	Aug 1 - Aug 16	342.0	-1.6	40.5	0.089	3.246	0.972	18.9	328.4	136.5	104.9	5
δ *Aquarids* (*S*)	Jul 29 - Aug 16	345.7	-14.6	40.5	0.097	3.228	0.969	25.8	147.1	314.7	101.8	10
Perseids	Jul 25 - Aug 24	45.2	57.6	59.4	0.947	44.351	0.981	113.0	150.9	137.9	288.8	201
κ *Cygnids*	Aug 6 - Aug 25	278.4	52.3	21.7	0.991	3.513	0.718	33.0	197.7	142.0	339.7	13
September Perseids	Sep 7 - Sep 13	47.2	38.9	65.4	0.733	-23.209	1.031	140.5	242.6	166.2	48.8	3
Piscids (*S*)	Sep 12 - Oct 28	344.0	1.7	24.5	0.529	2.987	0.823	3.9	92.4	65.4	157.8	7
Andromedids	Sep 25 - Oct 9	356.6	8.1	21.7	0.603	2.467	0.756	4.5	265.7	188.2	93.9	5
October Draconids	Oct 10 - Oct 28	274.7	52.4	16.7	0.995	2.392	0.584	25.5	178.2	203.9	22.1	7
Taurids (*N*)	Oct 21 - Nov 23	49.8	22.9	28.1	0.390	2.241	0.831	4.8	290.1	222.6	152.7	14
Taurids (*S*)	Oct 13 - Dec 2	52.0	13.2	27.9	0.373	2.121	0.826	5.6	112.4	41.8	154.2	19
Orionids	Oct 7 - Oct 29	93.6	16.2	67.3	0.581	26.753	0.977	164.8	80.3	27.2	107.5	12
Leonids	Nov 15 - Nov 21	153.2	22.0	70.9	0.985	13.972	0.929	162.4	173.1	234.9	48.8	5
σ *Hydrids*	Nov 30 - Dec 12	124.2	3.1	60.2	0.294	37.046	0.991	132.5	114.4	73.2	187.6	4
χ *Orionids* (*N*)	Dec 3 - Dec 11	82.1	26.4	26.9	0.417	2.271	0.815	3.3	286.6	254.2	180.8	7
χ *Orionids* (*S*)	Dec 4 - Dec 19	81.1	17.6	23.3	0.528	2.193	0.758	4.4	94.3	78.5	172.8	6
Geminids	Dec 8 - Dec 16	112.0	32.6	35.0	0.137	1.386	0.901	24.4	324.7	260.2	224.9	19

Table 2. Mean orbital parameters of the fireball streams with $M_{ph} \leq -3$ do not belonging to the known meteor streams.

No.	Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
1	α *Cancrids*	Jan 13 - Feb 7	135.4	6.3	19.3	0.484	1.167	0.583	7.2	112.6	123.5	236.1	3
2	β *Cancrids*	Jan 31 - Feb 10	121.3	9.5	14.8	0.794	1.981	0.603	4.6	61.4	136.2	197.6	3
3	March Cassiopeids	Mar 4 - Mar 21	359.6	50.6	13.4	0.930	2.322	0.600	15.2	146.3	350.5	136.8	4
4	γ *Coma Berenicids*	Apr 7 - Apr 21	193.1	22.9	16.7	0.839	2.680	0.687	11.9	232.5	22.1	254.6	5
5	ε *Corvids*	Apr 16 - Apr 29	181.3	-21.1	13.9	0.862	2.127	0.593	7.2	51.5	211.5	263	3
6	β *Librids*	Apr 24 - May 3	226.8	-8.7	28.3	0.418	2.531	0.836	9.1	286.5	38.3	324.8	3
7	η *Ursa Maiorids*	Apr 21 - May 15	212.0	47.7	14.8	0.963	2.205	0.570	19.1	207.6	39.4	247	3
8	β *Cassiopeids*	Jul 3 - Aug 19	352.9	58.8	50.4	0.995	18.194	0.962	89.1	192.1	125.5	317.6	6
9	λ *Aquilids*	Aug 14 - Aug 31	287.0	-3.8	8.6	0.956	1.795	0.466	4.5	213.2	149.5	2.7	4
10	δ *Piscids*	Sep 12 - Sep 19	7.0	7.0	30.4	0.272	1.977	0.862	5.2	305.2	172.6	117.8	3
11	λ *Cygnids*	Oct 20 - Nov 7	319.1	34.9	12.3	0.972	2.768	0.649	13.9	199.4	212.5	51.9	3
12	α *Aurigids*	Dec 19 - Dec 31	87.7	42.5	19.5	0.694	2.296	0.700	11.2	253.6	274.0	167.6	3
13	τ *Geminids (N)*	Dec 22 - Jan 5	107.7	26.8	26.3	0.359	1.567	0.767	5.2	298.4	271.5	209.9	5
	τ *Geminids (S)*	Dec 27 - Jan 16	108.4	16.4	23.0	0.529	2.010	0.735	4.5	94.9	104.2	199.1	6

Table 4. Mean orbital parameters of the fireball streams with $M_{ph} \leq -3$ do not belonging to the known meteor streams.

No.	Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
1	α *Cancrids*	Jan 13 - Feb 7	135.4	6.3	19.3	0.484	1.167	0.583	7.2	112.6	123.5	236.1	3
2	β *Cancrids*	Jan 31 - Feb 10	121.3	9.5	14.8	0.794	1.981	0.603	4.6	61.4	136.2	197.6	3
3	March Cassiopeids	Mar 4 - Mar 21	359.6	50.6	13.4	0.930	2.322	0.600	15.2	146.3	350.5	136.8	4
4	γ *Coma Berenicids*	Apr 7 - Apr 21	193.1	22.9	16.7	0.839	2.680	0.687	11.9	232.5	22.1	254.6	5
5	ε *Corvids*	Apr 16 - Apr 29	181.3	-21.1	13.9	0.862	2.127	0.593	7.2	51.5	211.5	263.0	3
6	λ *Aquilids*	Aug 14 - Aug 31	287.0	-3.8	8.6	0.956	1.795	0.466	4.5	213.2	149.5	2.7	4
7	δ *Piscids*	Sep 12 - Sep 19	5.8	6.6	30.0	0.280	1.934	0.855	5.3	304.5	171.7	116.2	2
8	τ *Geminids (N)*	Dec 19 - Dec 23	105.0	26.9	27.7	0.339	1.697	0.801	5.4	299.2	268.8	208.0	4
	τ *Geminids (S)*	Dec 27 - Jan 11	107.1	16.1	23.4	0.516	2.018	0.742	4.9	96.3	102.3	198.6	5

Table 3. Mean orbital parameters of the known meteor streams derived from the fireballs of the absolute photographic magnitude $M_{ph} \leq -5$

Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
Quadrantids	Jan 4 - Jan 17	236.7	49.6	39.7	0.977	3.321	0.703	68.4	169.5	288.4	97.9	3
Lyrids	Apr 22 - Apr 24	272.7	33.7	47.4	0.928	439.180	0.999	80.2	212.1	32.2	244.3	3
α *Capricornids (N)*	Jul 22 - Sep 6	316.5	-8.4	21.0	0.613	2.277	0.731	5.4	268.3	138.6	46.9	11
α *Capricornids (S)*	Aug 19 - Aug 28	335.5	-15.3	22.9	0.551	2.364	0.767	4.1	92.9	330.3	63.2	4
Perseids	Jul 25 - Aug 22	45.3	57.7	59.4	0.948	33.016	0.973	112.9	150.5	137.8	288.3	67
κ *Cygnids*	Aug 6 - Aug 21	279.7	52.3	21.7	0.989	3.339	0.708	33.2	198.4	141.4	339.8	9
September Perseids	Sep 7 - Sep 13	47.2	38.9	65.4	0.733	-23.209	1.031	140.5	242.6	166.2	48.8	3
October Draconids	Oct 10 - Oct 28	274.4	51.9	16.3	0.994	2.315	0.571	24.9	178.0	203.3	21.3	6
Taurids (N)	Oct 21 - Nov 23	50.8	22.6	28.7	0.344	2.104	0.836	4.9	296.2	221.2	157.4	8
Taurids (S)	Oct 27 - Dec 2	61.7	14.8	26.3	0.436	2.268	0.809	5.5	104.5	54.8	159.3	9
Orionids	Oct 23 - Oct 29	95.6	16.7	67.2	0.544	23.659	0.978	165.7	84.2	30.6	114.8	5
σ *Hydrids*	Nov 30 - Dec 12	123.1	3.0	59.4	0.264	166.999	0.999	129.3	117.7	73.7	191.4	3
χ *Orionids (N)*	Dec 3 - Dec 10	81.5	26.8	26.7	0.418	2.211	0.809	3.7	286.8	253.6	180.4	6
χ *Orionids (S)*	Dec 4 - Dec 19	80.8	17.8	22.6	0.544	2.130	0.744	4.1	92.7	79.0	171.7	4
Geminids	Dec 13 - Dec 16	112.8	32.3	34.6	0.141	1.396	0.899	23.5	324.1	261.6	225.7	6

Table 5. Mean orbital parameters of the known meteor streams derived from the fireballs of the absolute photographic magnitude $M_{ph} \leq -7$

Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
Lyrids	Apr 22 - Apr 23	272.4	33.8	47.5	0.928	999.999	1.000	80.1	212.1	31.8	243.9	2
α *Capricornids (N)*	Aug 12 - Aug 14	312.6	-12.2	18.8	0.700	2.466	0.716	3.2	255.1	139.9	35.0	2
Perseids	Jul 30 - Aug 22	45.3	57.6	59.5	0.951	25.934	0.965	113.2	151.4	138.1	289.5	34
κ *Cygnids*	Aug 6 - Aug 21	279.7	52.3	21.7	0.989	3.339	0.708	33.2	198.4	141.4	339.8	9
September Perseids	Sep 7 - Sep 13	47.2	38.9	65.4	0.733	-23.574	1.031	140.5	242.6	166.2	48.8	3
October Draconids	Oct 14 - Oct 28	280.7	53.1	16.1	0.995	2.291	0.566	24.5	182.5	205.2	27.7	3
Taurids (N)	Oct 21 - Nov 23	50.1	22.0	29.5	0.314	2.068	0.845	4.9	299.8	218.8	158.6	7
Taurids (S)	Oct 27 - Dec 2	62.4	14.7	26.1	0.441	2.273	0.807	5.6	103.9	55.7	159.6	8
Orionids	Oct 23 - Oct 29	95.3	17.1	67.8	0.540	89.552	0.994	166.5	82.7	30.3	113.0	4
χ *Orionids (N)*	Dec 3 - Dec 10	80.3	27.1	26.3	0.430	2.193	0.802	4.0	285.5	253.0	178.5	5
χ *Orionids (S)*	Dec 4 - Dec 19	80.8	17.8	22.6	0.544	2.130	0.744	4.1	92.7	79.0	171.7	4

Table 6. Mean orbital parameters of the fireball streams with $M_{ph} \leq -7$ do not belonging to the known meteor streams.

No.	Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
1	*α Cancrids*	Jan 13 - Feb 7	135.4	6.3	19.3	0.484	1.167	0.583	7.2	112.6	123.5	236.1	3
2	March Cassiopeids	Mar 16 - Mar 21	7.9	46.8	12.9	0.916	2.228	0.590	13.1	141.6	357.4	139.0	2
3	*γ Coma Berenicids*	Apr 7 - Apr 21	193.1	22.9	16.7	0.839	2.680	0.687	11.9	232.5	22.1	254.6	5
4	*ε Corvids*	Apr 21 - Apr 29	187.9	-21.0	14.9	0.837	2.193	0.616	6.8	56.2	214.2	270.4	2
5	*λ Aquilids*	Aug 14 - Aug 31	287.0	-3.8	8.6	0.956	1.795	0.466	4.5	213.2	149.5	2.7	4
6	*δ Piscids*	Sep 12 - Sep 19	5.8	6.6	30.0	0.280	1.934	0.855	5.3	304.5	171.7	116.2	2
7	*τ Geminids (N)*	Dec 19 - Dec 23	105.0	26.9	27.7	0.339	1.697	0.801	5.4	299.2	268.8	208.0	4
	τ Geminids (S)	Dec 27 - Jan 11	107.1	16.1	23.4	0.516	2.018	0.742	4.9	96.3	102.3	198.6	5

Table 7. Mean orbital parameters of the known meteor streams derived from the fireballs of the absolute photographic magnitude $M_{ph} \leq -9$

Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
Perseids	Aug 6 - Aug 22	46.3	58.1	60.1	0.955	-86.689	1.011	113.3	152.6	139.0	291.6	13
κ Cygnids	Aug 8 - Aug 19	278.9	51.4	21.8	0.986	3.650	0.729	33.0	199.1	140.7	339.8	4
September Perseids	Sep 7 - Sep 13	47.2	39.5	64.9	0.730	-65.676	1.012	139.3	243.3	166.6	49.9	2
October Draconids	Oct 14 - Oct 28	280.7	53.1	16.1	0.995	2.291	0.566	24.5	182.5	205.2	27.7	3
Taurids (S)	Oct 27 - Nov 29	59.4	14.1	25.6	0.443	2.094	0.788	5.7	104.5	52.4	156.9	5
χ Orionids (N)	Dec 3 - Dec 8	78.2	26.0	24.7	0.457	1.983	0.770	2.8	283.7	252.0	175.7	3

Table 8. Mean orbital parameters of the fireball streams with $M_{ph} \leq -9$ do not belonging to the known meteor streams.

No.	Shower	Period	α	δ	V_g	q	a	e	i	ω	Ω	π	n
1	*γ Coma Berenicids*	Apr 7 - Apr 21	194.3	20.9	17.0	0.820	2.507	0.671	11.8	236.2	21.3	257.5	4

phic catalogues. The tables contain the mean orbital parameters of the fireball streams, the periods of their activity, their radiants, geocentric velocities and numbers of the streams' members.

Among the fireballs with magnitude M_{ph} $\leq$-3 (1028 members) 21 known meteor streams including their nothern and southern branches were found. The number of fireballs belonging to these streams is 395, i.e. they represent 38% of the whole population (Table 1).An additional 13 fireball streams were found (Table 2). However, in 8 cases with 3 members only. These streams contain a total of 54 fireballs. On the basis of this we can conclude that, of the set of fireballs with M_{ph} $\leq$-3, 449, i.e. 44% are members of streams. It should be mentioned that the Perseids form a considerable part of this set; their members number is 201. If the Perseids are not taken into account, the percentage of fireballs belonging to the streams decreases to 30%.

Among the fireballs with M_{ph} $\leq$-5 (622 members), 12 known meteor streams were distinguished, their members numbering 147. They represent 24% of the whole population (Table 3). 8 fireball streams, not belonging to the known meteor streams, were found among the set of fireballs with M_{ph} $\leq$-5 in 3 cases with 3 members, and in 1 case with 2 members only (Table 4). The "stream" with 2 members was taken into account, because it has 3 members in the set of the fireballs with M_{ph} $\leq$-3. The unknown streams comprise a total of 33 members. Of the whole set of fireballs with M_{ph} $\leq$-5, 180, i.e. 29% are members of the streams (known or unknown).

Among the set of fireballs with M_{ph} $\leq$-7 (420 members) 9 known streams with 81 members (19%, Table 5) and 7 unknown streams with 27 members were found (Table 6). However, in one case with 3 and in two cases with 2 members only. Among this set of fireballs 108, i.e. 26% are members of the streams.

Among the set of fireballs with M_{ph} $\leq$-9 (221 members) 6 known streams with 30 members (14%, Table 7) and only 1 unknown stream containing 4 fireballs were found (Table 8). Among this set of fireballs, 34, i.e. 15% are members of streams.

Two unknown fireball streams belong to the group of most realistic - they contain 5 members at least and the period of activity is not longer than 21 days (in the set of fireballs with M_{ph} $\leq$-3). They are: γ Coma Berenicids, northern and southern branch of τ Geminids.

The results of the analysis show that a substantial part of the fireballs does not form any special fireball streams, but that they are members of known meteor streams.

Finally we can conclude that the degree of clustering of fireballs is substantially lower than that found by Terenteva (68%). Our result is consistent with Lindblad's estimate of 43% for the ordinary photographic meteors (Lindblad, 1971) and with Halliday's et al. (1990) estimate of 18% for the larger meteoroids identified as sources of meteorites of at least 0.25 kg. We obtained 15% for the set of fireballs with M_{ph} $\leq$-9.

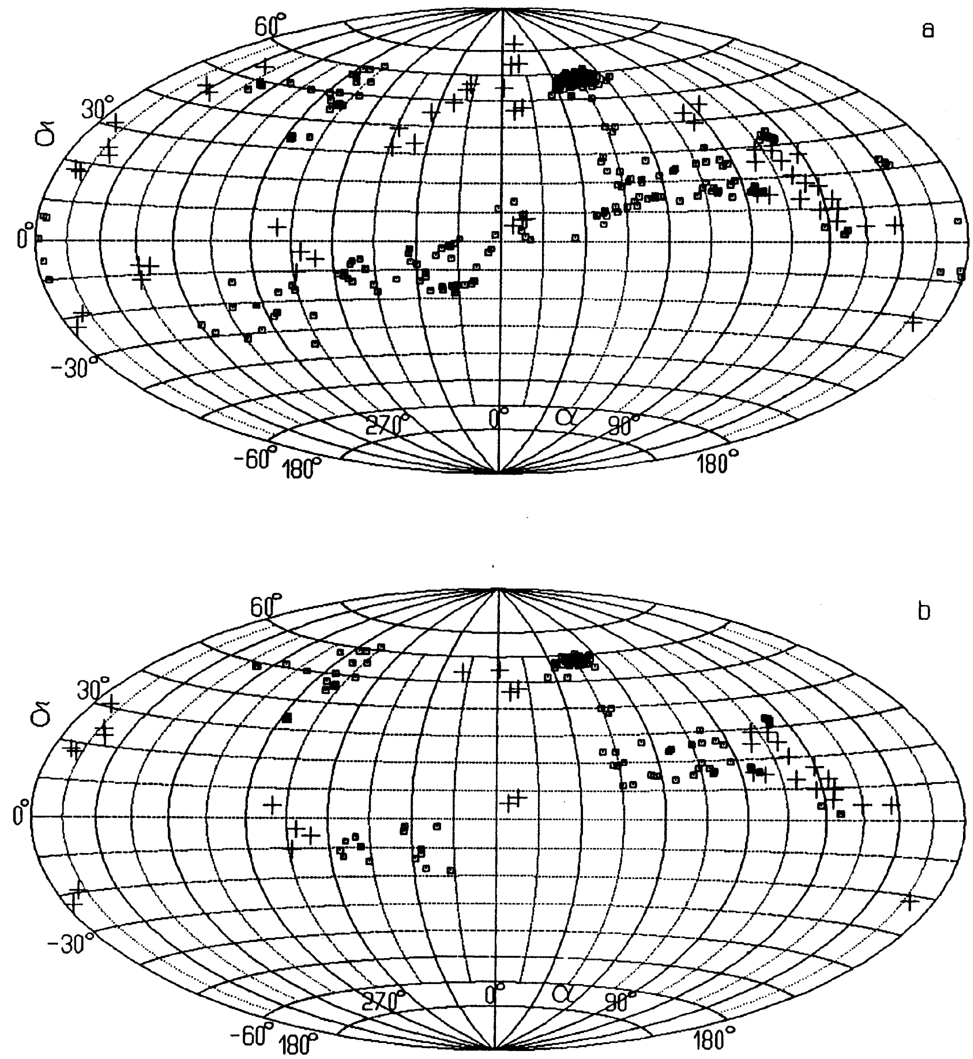

Figure 1. Distribution of radiants of stream fireballs with $M_{ph} \leq$-3 (a) and with $M_{ph} \leq$-5 (b) found by the stream search, in equatorial coordinates: squares - members of known meteor streams; crosses - members of new fireball streams.

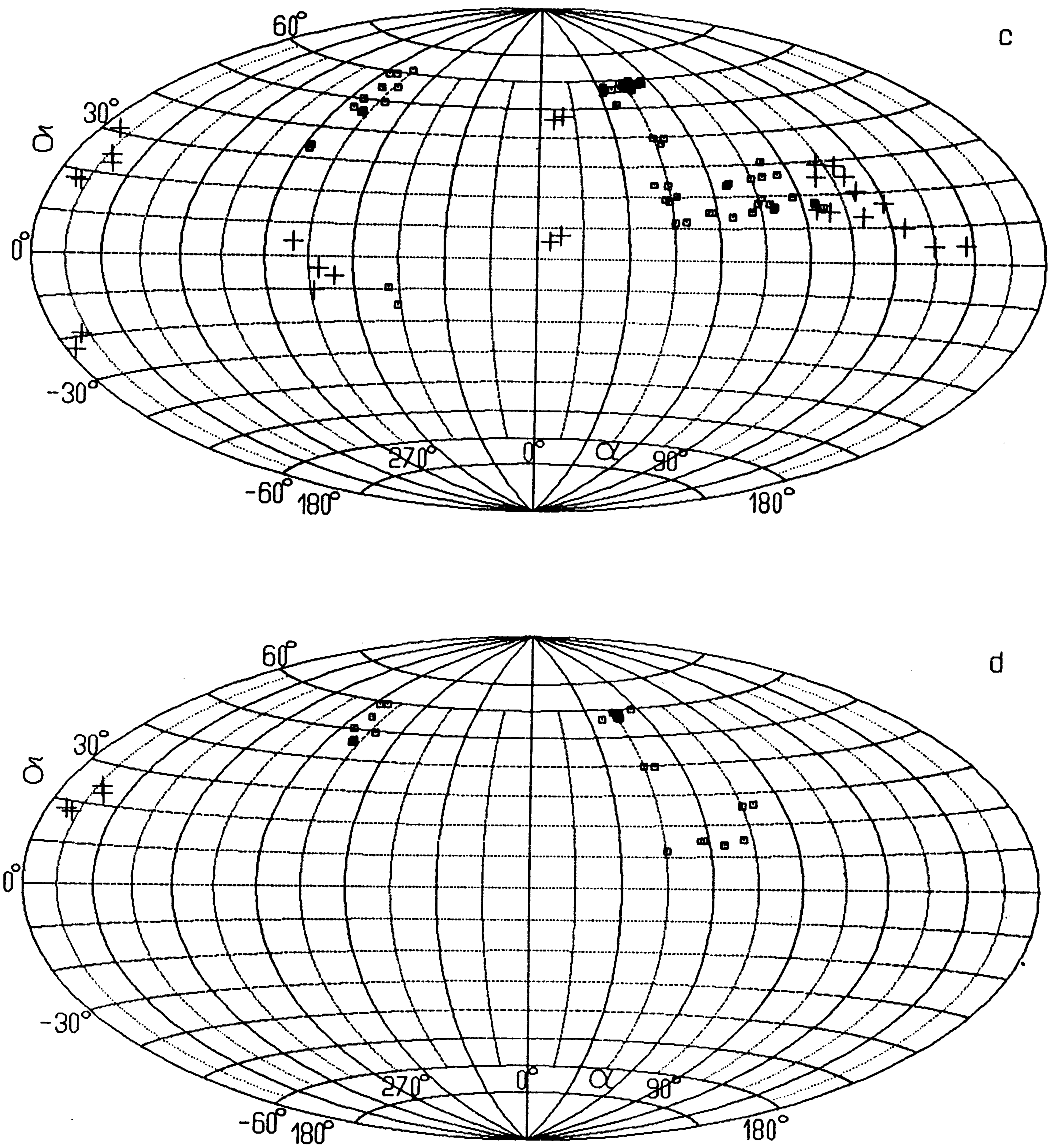

Figure 2. Distribution of radiants of stream fireballs with $M_{ph} \leq$-7 (c) and with $M_{ph} \leq$-9 (d) found by the stream search, in equatorial coordinates: squares - members of known meteor streams; crosses - members of new fireball streams.

Acknowledgements. This research was suported by the Slovak Academy of Sciences Grant No. 2/63/93.

References

Lindblad, B.A.: 1971, *Smithson. Contr. Astrophys.* **12**, 1
Lindblad, B.A.: 1991, in *Origin and Evolution of Interplanetary Dust*, eds. A.C. Levasseur-Regourd and H. Hasegawa, Kluwer Acad. Publ., 311
Porubčan, V. and Gavajdová, M.: 1994, Planetary and Space Sciences (in press)
Terenteva, A.K.: 1990, in Asteroids, Comets, Meteors III, eds. C.I. Lagerkvist, H. Rickman, B.A. Lindblad and M. Lindgren, Uppsala Univ., 579