New shower in Cassiopeia

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The Croatian Meteor Network Catalogue of Orbits for 2007 contains 1211 orbits, out of which 358 belong to previously known streams. The radiant analysis pointed to a possible new stream with radiant in Cassiopeia, at $\alpha = 6{}^{\circ}\!.9$, $\delta = 50{}^{\circ}\!.7$ and $v_g = 57.3$ km/s. The maximum activity is around solar longitude of $113{}^{\circ}\!.2$. This stream was assigned IAU shower number 444 and three-letter code ZCS. The proposed name of the shower is Zeta Cassiopeiids. The analysis of data for the following years (2008–2011) shows that the meteors belonging to the new stream were present in each year.

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1 Introduction

The year 2007 was the first year of operation of the Croatian Meteor Network (CMN). The network itself is described in more detail in Andreić & Šegon (2010) and Andreić et al. (2010). From all double and multiple station detections in 2007 a catalogue of 1211 orbits was obtained. Out of those, 358 belong to previously known streams. The catalogue is described in detail in Šegon et al. (2012) and can be downloaded from: `http://hmm.homeip.net/home/hmm/downloads/downloads.html`.

2 New shower 444 ZCS

Radiant analysis of the remaining 853 orbits extracted 13 orbits that belong to the new shower. Individual orbits of meteoroids were tested with the D-criterion, using the commonly adopted Southworth-Hawkins method (Southworth & Hawkins, 1963). Starting from the most grouped orbits evident in the dataset, a first estimate of the shower's mean orbit was calculated. Then a D-criterion search of our database using this mean orbit gave the 13 resulting orbits summarized in Table 1.

Based on these 13 orbits, the mean orbit of the shower was recalculated with two most commonly used methods, namely the Jopek-Rudawska method for determining the mean orbit of the stream (Jopek et al., 2006, 2008) and the standard arithmetic average method (i.e. taking the arithmetic average of the orbital elements of individual meteors for the orbital elements of the mean orbit). The mean orbit of the shower determined from these data is given in Table 2. The resulting D_{SH}'s for individual orbits in the final column of Table 1 are referred to the mean orbit from Table 2.

In accordance with the procedure of reporting new showers (Jenniskens et al., 2009) we informed the IAU Meteor Data Center and proposed the name Zeta Cassiopeiids. In response, the shower was assigned IAU shower number 444 and the three-letter code ZCS.

3 CMN data on 444 ZCS shower

As the next step, we expanded our search for meteors that could belong to the Zeta Cassiopeiid stream to the complete CMN database for the next three years. Based on orbital elements given in Table 2 we ran through our databases for 2008, 2009 and 2010 and extracted all orbits that satisfy the condition $D_{SH} < 0.3$. In the last step we used only orbits that satisfy $D_{SH} < 0.15$ and used them to refine the mean orbit of the Zeta Cassiopeiids. Finally, all data were reprocessed by one of the authors (Peter Gural) using his software procedures, providing an independent check of data accuracy and versatility. These new trajectory and orbit determination procedures that were described at last year's IMC (Gural, 2012a,b) provide error estimations for resulting trajectories and dynamics, and consequently all orbital elements.

Zeta Cassiopeiids were found in each following year. Afterwards we again processed all available data which allowed us to refine the orbital and radiant data for the new stream. The CMN orbits (calculated using this multi-parameter fit method) for all years, that satisfy $D_{SH} < 0.15$, are given in Table 3 and resulting orbital parameters are summarized in Table 4.

The fact that CMN photometry calibration is not good for meteors brighter than −2 mag does not impact F-values (Koten & Borovička, 2001; Fleming et al., 1993) for ZCS light curves. We have found out that the mean F-value for 25 CMN ZCS is 0.68 ± 0.09 (1-sigma). The graph of F-values is given in Figure 1.

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Table 1 – Individual orbits of meteoroids in CMN database from 2007 that belong to the new shower. Data processing for these orbits finished with UFOOrbit software orbit calculations. ID is the identification number of the orbit in the database, $\lambda_\odot$ solar longitude corresponding to the time of impact of the meteoroid, M_{abs} absolute magnitude of the meteor, α and δ are coordinates of the radiant, v_g is geocentric velocity, q perihelion distance, e eccentricity, ω argument of perihelion, Ω longitude of ascending node, i inclination (ω, Ω and i in degrees). D_{SH} is the value of the Southworth-Hawkins distance function, calculated for each meteor as a distance from the mean orbit (Table 2) that is calculated from this same dataset.

ID	$\lambda_\odot$	M_{abs}	α	δ	v_g	q	e	Ω	ω	i	D_{SH}
67	112.897	−3.4	6.06	50.75	57.29	0.999	0.961	112.9	164.7	107.2	0.02
101	114.018	0.9	7.67	51.93	57.41	0.995	0.996	114.0	163.4	106.6	0.04
61	112.109	−5.3	4.68	50.72	56.78	1.000	0.939	112.1	165.2	106.3	0.05
87	113.932	−4.7	7.40	51.79	56.59	0.996	0.928	113.9	163.2	106.1	0.06
77	113.095	−0.5	6.72	51.10	58.22	0.997	1.044	113.1	164.4	107.7	0.07
65	112.144	−4.8	2.89	51.53	55.89	1.004	0.922	112.1	167.0	104.2	0.09
78	113.846	0.2	9.71	51.31	57.34	0.987	0.947	113.8	160.0	107.9	0.09
112	114.821	−0.9	8.02	51.65	56.11	0.997	0.872	114.8	163.6	106.2	0.11
32	110.075	−2.5	2.65	49.22	58.79	1.003	1.078	110.1	167.2	108.4	0.13
73	113.006	0.4	3.82	50.13	55.28	1.007	0.801	113.0	168.2	105.7	0.19
57	112.068	−0.4	8.71	49.70	55.66	0.981	0.773	112.1	157.0	107.9	0.24
95	113.973	1.2	9.00	42.61	59.58	1.011	0.785	114.0	171.0	119.4	0.30
102	114.019	1.0	7.85	50.41	61.40	1.001	1.271	114.0	166.7	110.9	0.30

Table 2 – Results of radiant analysis for the members of the new shower, based on CMN orbits from 2007. Orbital data are given as: semimajor axis a (in A.U.), its reciprocal value $1/a$, and q, e, i, Ω, ω as defined in Table 1.

parameter	Jopek-Rudawska method	arithmetic average
a	42.8	46.7
$1/a$	0.02335 ± 0.04437	0.02140 ± 0.04437
q	0.9960 ± 0.0022	0.9958 ± 0.0022
e	0.977 ± 0.044	0.979 ± 0.044
i	107.1 ± 0.5	107.1 ± 0.5
Ω	113.4 ± 0.3	113.3 ± 0.3
ω	164.9 ± 1.0	164.9 ± 1.0

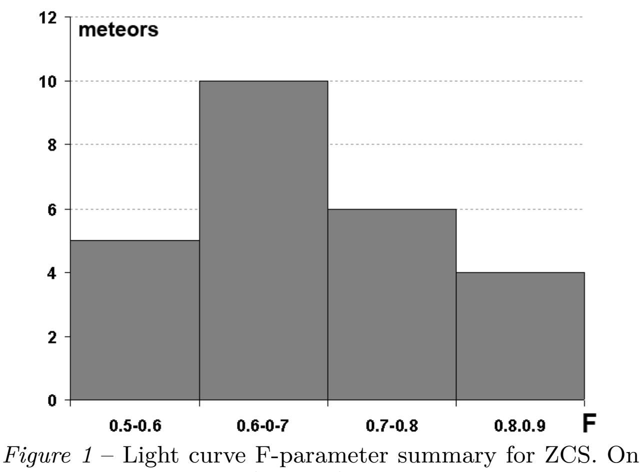

Figure 1 – Light curve F-parameter summary for ZCS. On x-axis are F-parameter bins and on y-axis respective meteor counts.

4 Other sources 444 ZCS data

A SonotaCo database search based on mean orbital data resulted in 30 orbits satisfying the $D < 0.15$ criterion, whose orbital data are presented in Table 5 and resulting mean orbital data in Table 6.

We also searched the IMO Video Meteor Database results from the analysis done for 2006 (IMO, 2007), 2009 (IMO, 2009) and 2012 (IMO, 2012; Molau, 2012).

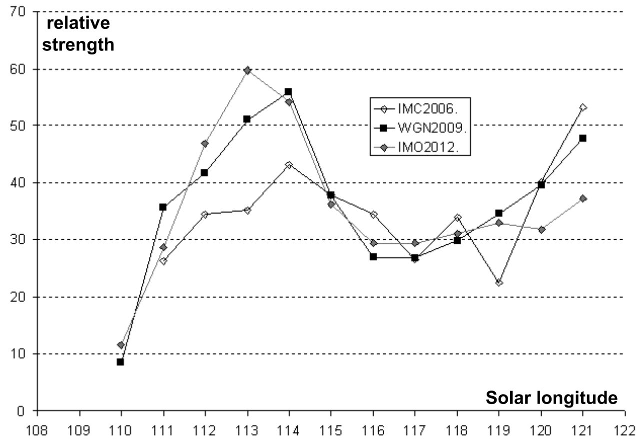

Figure 2 – IMO activity plot for $\lambda_\odot = 108-122°$ shows ZCS activity peak (at $\lambda_\odot = 113°$), followed by regular Perseid activity increase. Data presented as for 2006, 2009 and 2012 represent results from IMO analysis for respective years.

We have found that the ZCS radiant has been detected in all analysis runs, and it was the most active radiant during its activity period ($\lambda_\odot = 109-118°$) – moreover, we have found that the relative strength for this radiant has increased from 2006 to 2012 (Figure 2). Most probably due to the small number of meteors, ZCS could not be distinguished from the Perseid radiant so the analysis from 2009 (Molau & Rendtel, 2009) had recognized ZCS as PER and thus expanded the Perseid activity period as early as $\lambda_\odot = 109°$.

5 Discussion

All together, in CMN and SonotaCo databases we have found 55 orbits that satisfy $D_{SH} < 0.15$. The radiant plot of all orbits is shown in Figure 3, and the daily mean motion in Figure 4. Such a large number of orbits allows us to find average orbital elements and a good estimate of radiant position and mean daily motion (Table 7). The magnitude distribution of ZCS meteors is presented in Figure 6, showing that the average

Table 3 – Individual orbits (calculated by multi-parameter fit method) of meteoroids from 2007 to 2010 that satisfy $D_{SH} < 0.15$. Year and JD are given in the first two columns: individual meteors are identified by JD as the catalogues for years 2008–2010 are not finished yet. Remaining column headings are as in Table 1.

Year	JD	$\lambda_\odot$	α	δ	v_g	q	e	Ω	ω	i	D_{SH}
2007	2454298.457505	113.932	7.66	51.44	57.38	0.996	0.974	113.9	163.6	107.1	0.02
2007	2454297.579870	113.095	6.47	50.85	57.17	0.998	0.950	113.1	164.3	107.2	0.02
2007	2454299.389098	114.820	8.73	51.82	57.39	0.995	0.974	114.8	163.3	107.2	0.03
2007	2454297.372443	112.895	5.75	50.93	57.30	1.000	0.973	112.9	165.2	106.9	0.04
2010	2455392.543153	112.326	5.63	50.51	56.99	0.998	0.935	112.3	164.4	107.0	0.04
2007	2454298.367210	113.844	9.20	51.60	57.23	0.988	0.955	113.8	160.6	107.3	0.05
2007	2454298.548669	114.019	9.71	51.05	57.62	0.989	0.957	114.0	160.7	108.4	0.05
2007	2454298.547440	114.018	7.76	52.90	56.38	0.992	0.955	114.0	161.8	104.9	0.06
2010	2455392.548651	112.332	4.67	52.10	56.28	0.998	0.956	112.3	164.2	104.5	0.06
2010	2455393.599077	113.334	6.53	50.88	56.46	0.998	0.892	113.3	164.1	106.7	0.07
2009	2455027.451945	112.479	4.35	51.28	57.11	1.002	0.991	112.5	166.2	105.9	0.07
2009	2455029.582944	114.514	9.05	51.56	58.23	0.994	1.031	114.5	163.0	108.1	0.08
2010	2455394.583478	114.273	7.92	51.18	58.28	0.998	1.032	114.3	164.7	108.1	0.08
2009	2455031.397587	116.244	11.13	53.70	56.80	0.987	0.974	116.2	160.4	105.5	0.09
2009	2455026.540393	111.611	4.36	48.39	58.29	1.005	0.972	111.6	167.8	109.8	0.10
2010	2455391.514169	111.344	4.91	49.74	56.37	0.998	0.868	111.3	163.7	107.1	0.10
2009	2455029.541139	114.474	8.23	53.19	55.50	0.990	0.889	114.5	160.9	104.1	0.10
2010	2455393.567368	113.303	9.09	47.58	59.72	0.998	0.995	113.3	164.5	113.5	0.11
2010	2455393.568925	113.305	7.54	50.38	56.30	0.995	0.849	113.3	162.4	107.4	0.11
2008	2454664.515121	114.693	11.82	50.18	59.20	0.986	1.026	114.7	160.3	111.2	0.11
2010	2455389.385128	109.311	4.89	46.02	58.86	0.998	0.928	109.3	164.3	112.8	0.12
2010	2455393.599900	113.335	4.46	52.38	54.81	1.001	0.848	113.3	165.2	103.2	0.14
2007	2454297.486554	113.005	4.31	50.30	55.71	1.005	0.836	113.0	167.4	106.0	0.14
2008	2454667.510702	117.551	13.95	52.72	56.57	0.983	0.881	117.6	158.5	107.5	0.14
2009	2455032.513815	117.310	15.29	51.69	59.00	0.981	1.023	117.3	158.5	110.6	0.15
Average:					57.24	0.995	0.947	113.7	163.2	107.5	
st. dev.:					1.18	0.006	0.058	1.7	2.4	2.4	

Table 4 – Results of radiant analysis for the members of the new shower, using 25 CMN orbits from 2007 to 2010. Symbols for orbital data a, $1/a$, q, e, i, Ω, ω as in Table 2.

parameter	Jopek-Rudawska method	arithmetic average
a	18.0	18.6
$1/a$	0.05544±0.01184	0.05371±0.01184
q	0.9930±0.0013	0.9949±0.0013
e	0.945±0.012	0.947±0.012
i	107.5±0.5	107.5±0.5
Ω	113.7±0.4	113.7±0.4
ω	163.2±0.5	163.2±0.5

observed ZCS is a bright −1 mag meteor. Last, but not least, the beginning and ending heights of ZCS meteors, plotted as a function of their absolute magnitude are shown in Figure 5.

From Table 4 and Table 6 it can be seen that data obtained with different capture and astrometry software, as well as trajectory and orbit calculation methods, result in very similar average orbits. Higher values of standard deviations for v_g and inclination in CMN data are most probably due to the fact that CMN uses 4 mm lenses and (in this dataset mostly) 384×288 camera resolution (typically 6 mm full D1 for SonotaCo data), otherwise the agreement is very good for all orbital parameters. Results found in the IMO database are showing that there seems to be a constant growth of relative activity during the observed period. While analysis from 2006 shows ZCS at 40% of relative strength, one may see an increase to 56% (2009) and 60% (2012), respectively. Deeper analysis and future observation will show if this is a correct assumption.

A parent body search for ZCS yields no resulting object at their average orbit. The closest comet (as one may suspect) is the Perseids' parent body, comet 109P/Swift-Tuttle. But the D-criterion value is of the order of 0.4, similar to Perseid mean orbits, meaning that at the moment we cannot consider it as the ZCS parent body. There are some obvious thoughts and questions jumping out at this point. The ZCS parent body could be an unknown comet (approaching the Sun, if the activity increase is to be confirmed), the parent body could be a fragment of Swift-Tuttle (due to similar orbital parameters), or ZCS could in fact be a heavily perturbed Perseid filament.

6 Conclusions

As for now, we found more than 55 orbits fitting mean orbital parameters by D-criteria with the limit $D_{SH} < 0.15$. First orbits are dating from 2007, but we found new shower members in our database for the next three years and in SonotaCo catalogues too, which helped in confirming the existence of the new shower, and in refining radiant position and orbital parameters.

Table 5 – Individual orbits of meteoroids from 2007 to 2009 that satisfy $D_{SH} < 0.15$ found in SonotaCo database (SonotaCo 2009, 2010). Column headings as in Table 3.

Year	JD	$\lambda_\odot$	α	δ	v_g	q	e	Ω	ω	i	D_{SH}
2009	2455026.668999	112.210	5.06	50.84	57.39	0.999	0.989	112.2	165.1	106.8	0.03
2009	2455027.767234	113.258	5.49	51.16	57.41	1.002	0.993	113.3	166.1	106.7	0.03
2009	2455026.711793	112.251	5.84	50.49	57.21	0.997	0.951	112.3	164.0	107.3	0.03
2009	2455027.616052	113.114	6.97	50.41	58.24	0.998	1.014	113.1	164.5	108.5	0.05
2009	2455025.671709	111.259	3.66	50.92	57.14	1.000	0.994	111.3	165.3	106.0	0.05
2008	2454664.685657	115.333	6.78	51.74	57.01	1.004	0.958	115.3	167.4	106.5	0.05
2009	2455027.705544	113.199	6.30	50.74	56.90	0.999	0.925	113.2	164.6	107.1	0.05
2009	2455027.585657	113.085	6.43	49.27	58.32	1.002	0.979	113.1	166.4	109.7	0.05
2009	2455028.677628	114.126	8.94	50.49	58.23	0.995	0.990	114.1	163.1	109.2	0.05
2009	2455026.794915	112.330	6.23	48.97	58.20	1.000	0.963	112.3	165.4	109.8	0.05
2009	2455027.743681	113.235	5.42	52.49	56.22	0.998	0.954	113.2	164.3	104.4	0.05
2009	2455027.752801	113.244	5.80	49.44	58.04	1.005	0.969	113.2	167.5	109.1	0.06
2009	2455027.742058	113.234	7.08	48.77	58.36	1.002	0.953	113.2	166.0	110.5	0.07
2009	2455026.782431	112.318	7.51	50.55	58.18	0.991	1.016	112.3	161.9	108.4	0.07
2009	2455025.575451	111.167	2.67	49.90	57.27	1.005	0.974	111.2	167.8	106.8	0.07
2009	2455027.763597	113.254	5.87	51.31	56.30	0.999	0.906	113.3	164.6	105.9	0.07
2009	2455025.631829	111.221	4.04	52.57	56.13	0.994	0.979	111.2	162.7	103.6	0.08
2009	2455027.695694	113.190	6.83	50.92	56.55	0.996	0.900	113.2	163.3	106.8	0.08
2009	2455027.528176	113.030	5.58	51.34	56.12	0.999	0.897	113.0	164.5	105.6	0.08
2009	2455026.681068	112.222	4.17	49.13	57.20	1.006	0.912	112.2	168.1	108.2	0.09
2007	2454300.726042	116.574	12.01	52.42	57.83	0.989	0.992	116.6	161.2	108.0	0.10
2009	2455027.777439	113.268	10.13	49.79	58.45	0.986	0.974	113.3	159.9	110.4	0.10
2008	2454658.704619	109.630	2.35	47.77	58.40	1.005	0.990	109.6	168.0	109.6	0.11
2009	2455024.754306	110.384	2.44	52.65	56.59	0.996	1.043	110.4	163.9	103.2	0.11
2009	2455027.581852	113.081	8.49	50.03	56.95	0.990	0.880	113.1	160.9	108.6	0.12
2009	2455027.671187	113.166	6.38	49.86	56.49	1.000	0.856	113.2	164.8	107.8	0.12
2009	2455031.709511	117.020	11.89	52.34	56.52	0.991	0.881	117.0	161.2	107.2	0.14
2009	2455024.761519	110.391	4.25	49.17	56.22	0.997	0.846	110.4	163.2	107.3	0.14
2009	2455027.679282	113.174	8.14	49.15	56.88	0.995	0.840	113.2	162.3	109.4	0.15
2009	2455028.574896	114.028	5.42	51.11	58.92	1.006	1.114	114.0	168.6	107.8	0.15
Average:					57.32	0.998	0.954	112.9	164.6	107.5	
st. dev.:					0.83	0.005	0.060	1.6	2.3	1.8	

Table 6 – Results of radiant analysis for the 30 orbits from SonotaCo database. Symbols for orbital data a, $1/a$, q, e, i, Ω, ω as in Table 2.

parameter	Jopek-Rudawska method	arithmetic average
a	21.3	21.9
$1/a$	0.04703±0.01116	0.04568±0.01116
q	0.9970±0.0001	0.9982±0.0001
e	0.953±0.011	0.954±0.011
i	107.5±0.3	107.5±0.3
Ω	112.9±0.3	112.8±0.3
ω	164.6±0.4	164.6±0.4

So far the available data show that the radiant is active from 107–120° Solar longitude, corresponding to roughly July 9th to July 21st. Radiant position at the maximum of $\lambda_\odot = 113^\circ.2$ is at $\alpha = 6^\circ.9$, $\delta = +50^\circ.7$ with $v_g = 57.3$ km/s. The mean daily motion was found to be $+1^\circ.4$ in right ascension and $+0^\circ.5$ in declination.

Independent confirmation of our results and of the existence of this shower as a separate one just came from the Polish Comets and Meteors Workshop – their results are presented in this very WGN issue (Żołądek & Wiśniewski, 2012).

Table 7 – Results of final radiant analysis for the 55 CMN and SonotaCo orbits that satisfy $D_{SH} < 0.15$. Symbols for orbital data a, $1/a$, q, e, i, Ω, ω as in Table 2. Finally, radiant position and mean daily motion are also specified. Geocentric velocity is given in km/s. The stream was active for $\lambda_\odot = 109^\circ.3 - 117^\circ.6$.

parameter	Jopek-Rudawska method	arithmetic average
a	19.6	20.3
$1/a$	0.05093±0.00807	0.04933±0.00807
q	0.9951±0.0008	0.9967±0.0008
e	0.949±0.008	0.951±0.008
i	107.5±0.3	107.5±0.3
Ω	113.2±0.2	113.2±0.2
ω	163.6±0.3	163.9±0.3
	radiant position:	mean daily motion:
α	6.9	+1.4
δ	50.7	+0.5
v_g	57.3±1.0	

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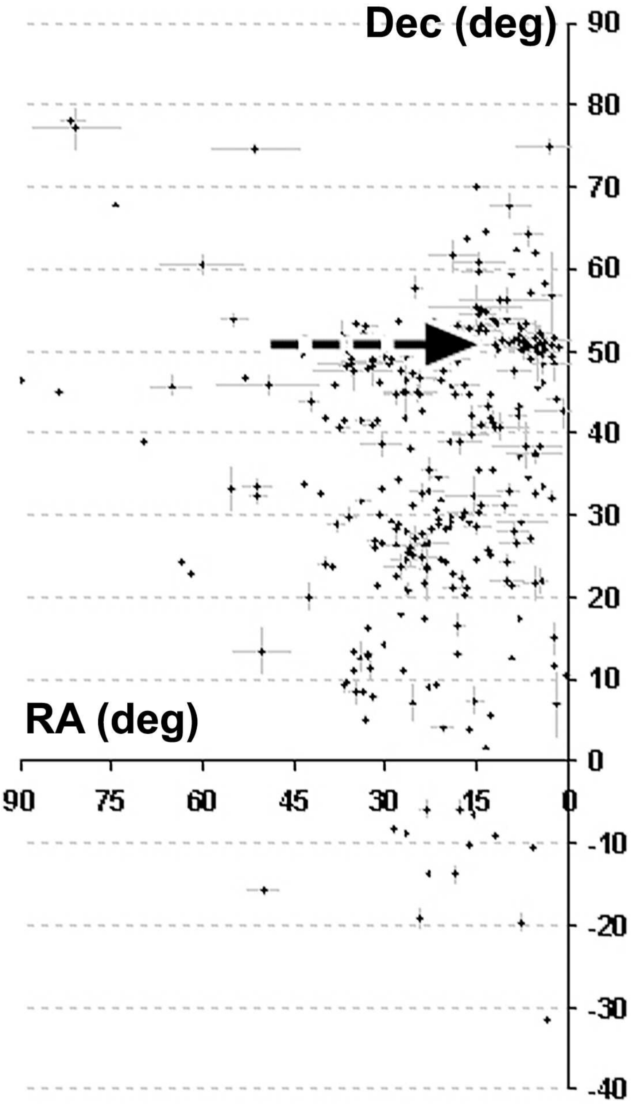

Figure 3 – Radiant plot of all radiants from CMN databases for years 2007–2010 in the part of sky where the new stream was found, for $\lambda_{\odot} = 108 - 122°$.

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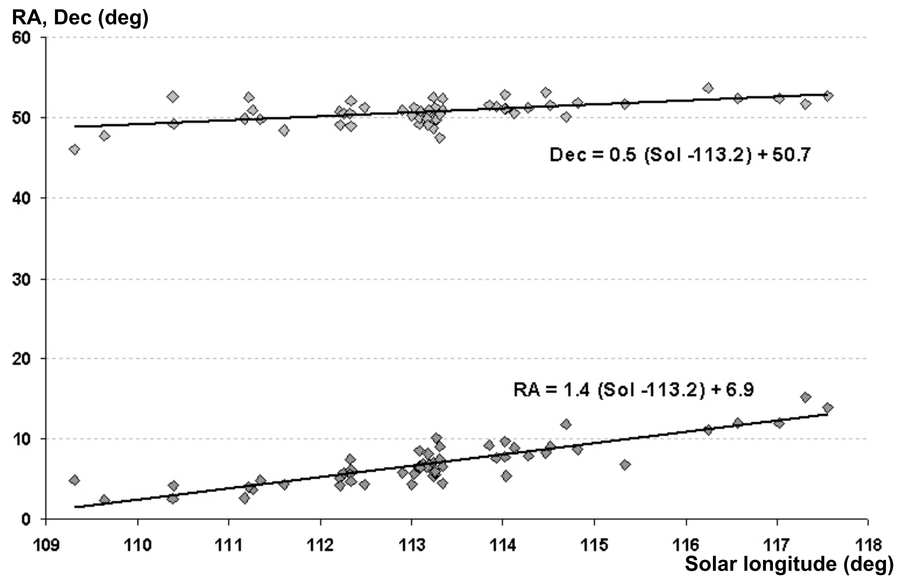

Figure 4 – Determination of radiant mean daily motion from all datasets available (CMN+SonotaCo).

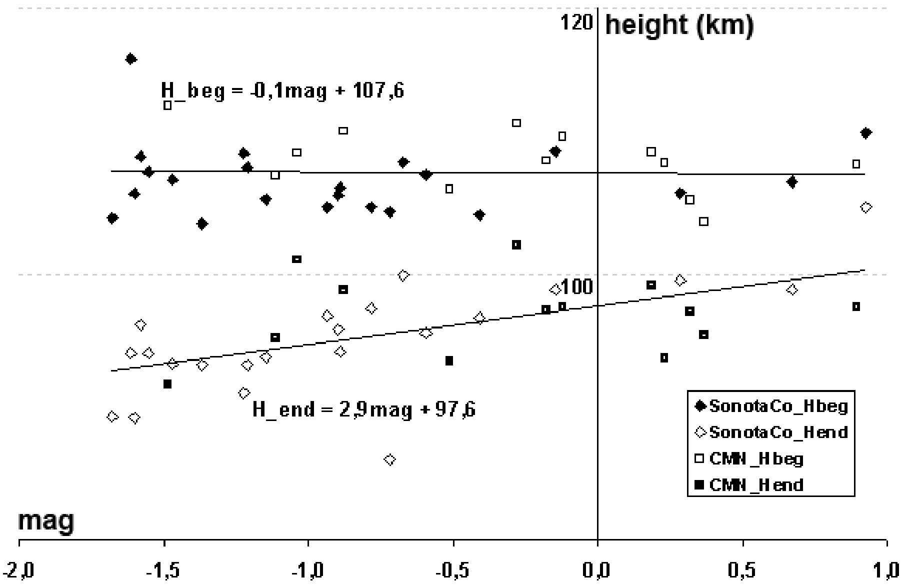

Figure 5 – Beginning and ending heights of ZCS meteors as a function of their magnitude.

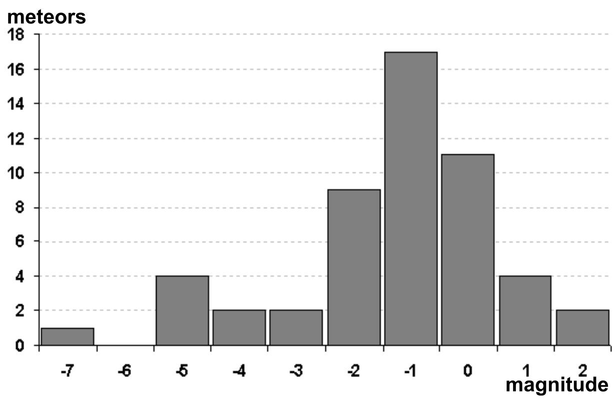

Figure 6 – Magnitude distribution of ZCS meteors.

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