Meteor science

Confirmation of the χ Cygnids (CCY, IAU#757)

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In this paper we present independent confirmation of the existence of the χ Cygnid (CCY, IAU#757) meteor shower. The χ Cygnids were discovered by Peter Jenniskens within the frame of CAMS project (Cameras for Allsky Meteor Surveillance). Thanks to the cooperation between European viDeo MeteOr Network (EDMONd), International Meteor Organization Video Meteor Network (IMO VMN) and the BRAzilian Meteor Observation Network (BRAMON) the current version of the EDMOND database (v5.02) contains 189 323 multi-station meteor orbits. This large data sample allowed confirmation of the increased activity from the χ Cygnid swarm during the night of 2015 September 14/15, and also made it possible to map the activity of this newly discovered swarm during the years 2001–2014.

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1 Introduction

The χ Cygnid meteor shower (CCY, IAU#757) was discovered by Peter Jenniskens (2015) within the frame of CAMS project (Cameras for Allsky Meteor Surveillance; Jenniskens et al., 2011). M. Breukers and C. Johannink began the process by highlighting five very similar meteor orbits in the multi-station data obtained via CAMS BeNeLux in interval from $19^{h}23^{m}$ UT (2015 September 14) to $03^{h}35^{m}$ UT (2015 September 15). Partial results from CAMS California at intervals from $03^{h}10^{m}$ UT to $12^{h}45^{m}$ UT (2015 September 15) provided multi-station orbits for four more swarm members. Confirmation of the outburst was also found in the CMOR (Canadian Meteor Orbit Radar) radar data (Jenniskens, 2015), the cumulative daily map of multi-station meteor radiants showed up a concentration at the position of the mean radiant identified by video observation in interval from $05^{h}15^{m}$ UT to $20^{h}15^{m}$ UT (2015 September 15). The mean geocentric radiant of the meteor shower derived from CAMS data had equatorial coordinates RA $= 301\overset{\circ}{.}0 \pm 2\overset{\circ}{.}2$ and DEC $= 32\overset{\circ}{.}6 \pm 1\overset{\circ}{.}6$ (2000.0) and the average geocentric velocity of the meteor swarm particles was $v_g = 15.1 \pm 0.9$ km/s. Meteor shower activity was also observed from Japan (Shiba, 2015).

The working list of meteor showers IAU MDC (Jopek & Kanuchova, 2014) contains 577 meteor showers, of which 109 are considered as unconfirmed swarms (i.e. pro tempore). Due to the large amount of data, relatively long period of operation (since 2000) and the wide time zones coverage (UT−4h to UT+3h) one of the main goals of the EDMONd database has been the verification of activity and the existence of these meteor showers.

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2 European viDeo Meteor Network Database

The European viDeo Meteor Observation Network (EDMONd) was established only recently (Kornoš et al., 2013; Kornoš et al., 2014a; Kornoš et al., 2014b). The network originates from spontaneous cooperation between observers in several parts of Europe. The EDMONd Network has been enlarged in recent years and at present consists of observers from the following national networks (in alphabetical order): BOAM (Base des Observateurs Amateurs de Metéores, France); BosNet (Bosnia); CEMeNt (Central European Meteor Network, cross-border network of Czech and Slovak amateur observers); CMN (Croatian Meteor Network or Hrvatska Meteorska Mreza, Croatia); FMA (Fachgruppe Meteorastronomie, Switzerland); HMN (Hungarian Meteor Network or Magyar Hullócsillagok Egyesulet, Hungary); IMO VMN (IMO Video Meteor Network); MeteorsUA (Ukraine); IMTN (Italian amateur observers in Italian Meteor and TLE Network, Italy); NEMETODE (Network for Meteor Triangulation and Orbit Determination, United Kingdom); PFN (Polish Fireball Network or Pracownia Komet i Meteorów, PkiM, Poland); Stjerneskud (Danish all-sky fireball cameras network, Denmark); SVMN (Slovak Video Meteor Network, Slovakia); and UKMON (UK Meteor Observation Network, United Kingdom). The most recent established network (January 2014) is in the southern hemisphere – BRAMON (BRAzilian MeteOr Network). This network is independent of EDMOND database, its task is to map the activity of meteor showers in the southern hemisphere.

Nowadays, due to the international cooperation, meteor activity is monitored over almost the whole of Europe. Consequently, in recent years, multi-national networks of video meteor observers have contributed much new data. As a result, the latest version of EDMOND database (v5.0, January 2015) contains 3 060 250 single meteors and 189 323 orbits collected from 2001 to 2014[a].

[a]http://www.daa.fmph.uniba.sk/edmond

3 Methodology

The main part of the orbit calculations from two or more stations is performed using the UFO Orbit software (SonotaCo, 2009). Data reduction is implemented in two steps. The first step involves the calculation of the orbits via the UFO Orbit software. Meteors recorded by different stations are only processed as being identical if their time difference $\Delta t < 5$ s and all meteors with duration $dur < 0.1$ s are excluded. Multi-station trajectory qualitative criteria has to be meet as follows: maximum speed difference $\Delta v < 7$ km/s between the observations from two stations is accepted; empirically calculated multi-station trajectory quality parameter in the range $Q_A > 0.15$; height of the beginning and of the end of the meteor atmospheric trajectory $H_1 < 200$ km and $H_2 > 15$ km respectively. This first step causes unrealistic and low accurate trajectories to be excluded.

In the second step, the specific reduction criteria are applied to the previously calculated orbits. The angle of observed trajectory has to be $Q_o > 1°$, the convergence angle $Q_c > 10°$, the difference between two poles of ground trajectory $\Delta GP < 0.5°$ and the difference between unified velocity and velocity from one of the stations $\Delta v12\% < 7.07\%$ (Kornoš et al., 2013).

The assignment of the derived meteor trajectories to the mean meteor stream orbit is based on the D-criterion of orbit similarity, which compares orbital elements of the meteors (i.e. e, q, i, ω and Ω). In the case of assigning potential members of the #757 CCY meteor shower the Southworth-Hawkins criterion $D_{\rm SH}$ (Southworth & Hawkins, 1963) was used.

$$[D_{\rm SH}]^2 = (e_2 - e_1)^2 + (q_2 - q_1)^2 + (2\sin\frac{I_{21}}{2})^2 + (\frac{e_2+e_1}{2})^2(2\sin\frac{II_{21}}{2})^2 \quad (1)$$

$$I_{21} = \arccos[\cos i_1 \cos i_2 + \sin i_1 \sin i_2 \cos(\Omega_2 - \Omega_1)] \quad (2)$$

$$II_{21} = \omega_2 - \omega_1 + 2\Gamma \arcsin(\cos\frac{i_2+i_1}{2}\sin\frac{\Omega_2-\Omega_1}{2}\sec\frac{I_{21}}{2}) \quad (3)$$

with Γ being defined by

$$\Gamma = \begin{cases} +1, & |\Omega_2 - \Omega_1| \le 180° \\ -1, & |\Omega_2 - \Omega_1| > 180° \end{cases} \quad (4)$$

where e_1 and e_2 is the eccentricity, q_1 and q_2 is the perihelion distance of two orbits, ω_1 and ω_2 is the argument of perihelion of two orbits, Ω_1 and Ω_2 is the longitude of ascending node, i_1 and i_2 is the orbit inclination of two orbits, I_{21} is the angle between the orbital planes as defined in equation (2) and II_{21} is the angle between their respective perihelion points as defined in equation (3).

4 χ Cygnid activity in 2015

For the analysis of the CCY meteor shower activity in 2015, the data from 7 national networks has been used: CEMeNT (26 cameras), BRAMON (11), UKMON (19), MeteorsUA (23), ITMN (13), FMA (27) and HMN (4). The orbital elements of the derived multi-station meteor orbits (in interval September 1 to September 30) were – on the basis of the Southworth-Hawkins criterion of the orbit similarity – compared with to the CCY meteor shower mean orbit published by Jenniskens (2015). A limiting value of the orbit similarity criterion $D_{\rm SH} < 0.2$ was set together with an additional constraint of the geocentric velocity $v_g = 15.1 \pm 2.5$ km/s. Fixed v_g deviation (± 2.5 km/s) is applied in the EDMOND database for all meteor showers with a speed below 20 km/s as a first criterion for assigning a meteoroid to a meteor shower. This approach provided in total 30 multi-station meteor orbits for the newly recognized CCY swarm (Figure 1).

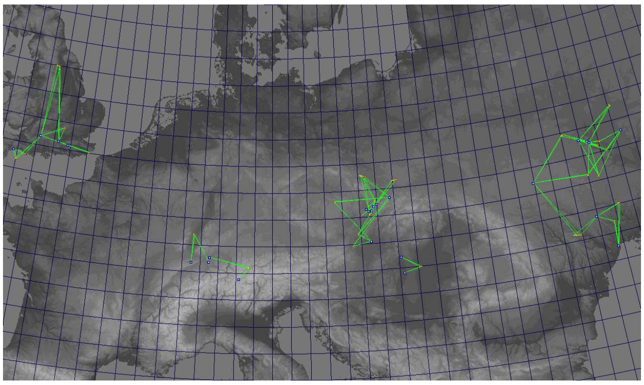

Figure 1 – Ground projection of the atmospheric trajectories of χ Cygnids meteors during enhanced shower activity in 2015.

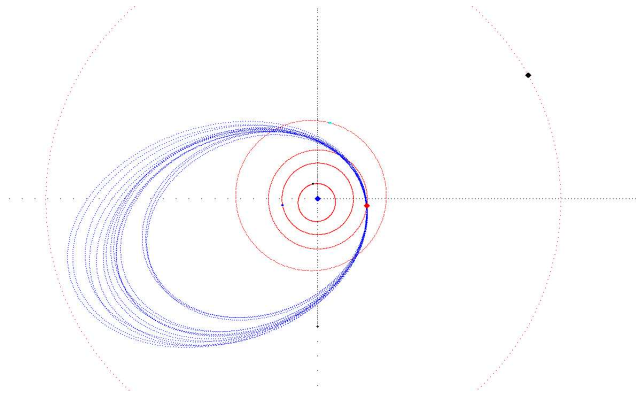

Figure 2 – View from above of the Solar system with CCY meteoroid orbits within $D_{\rm SH} < 0.1$ derived from EDMOND multi-station observations (in 2015).

In the next step, the mean orbit derived from these 30 multi-stations trajectories was used as a reference orbit. The total number of meteor trajectories for the final calculation of the CCY shower mean orbit was reduced again, with an upper limit of $D_{\rm SH} < 0.1$ being used for the criteria of orbit similarity (Figure 2). Reduction resulted in 16 precise and most reliable orbits of meteors forming part of the CCY swarm (Table 2). The final derived CCY stream orbital elements and radiant position details and their comparison with those derived by P. Jenniskens are listed below (Table 1).

The CCY meteoroid stream particles' low geocentric velocity ($v_g = 14.23 \pm 0.63$ km/s) leads to the shower's

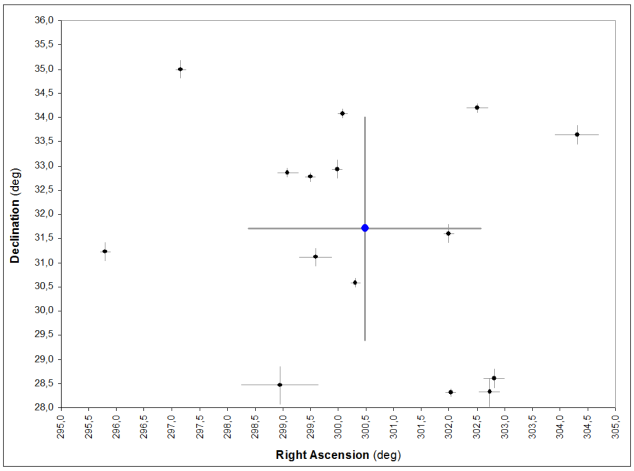

Figure 3 – Positions of the CCY mean orbit radiant (blue dot) and the individual meteoroid orbits radiants in geocentric equatorial coordinates (right ascension and declination, both in degrees) with particular error bars.

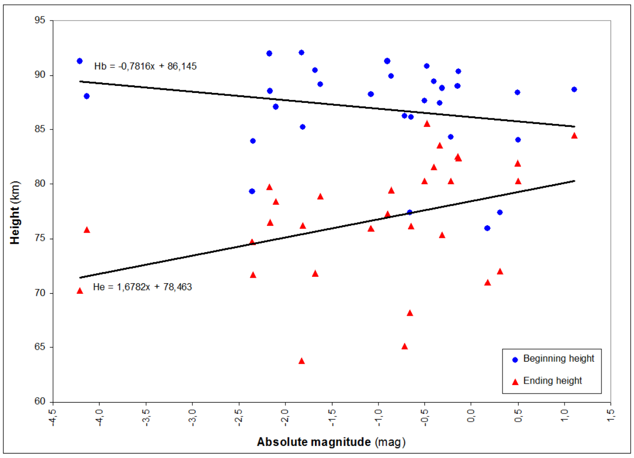

Figure 4 – Start and End altitudes of CCY meteors in relation to the absolute magnitude. The graph contains all 30 orbits of CCY meteor shower meteors from 2015 with $D_{\mathrm{SH}} < 0.2$.

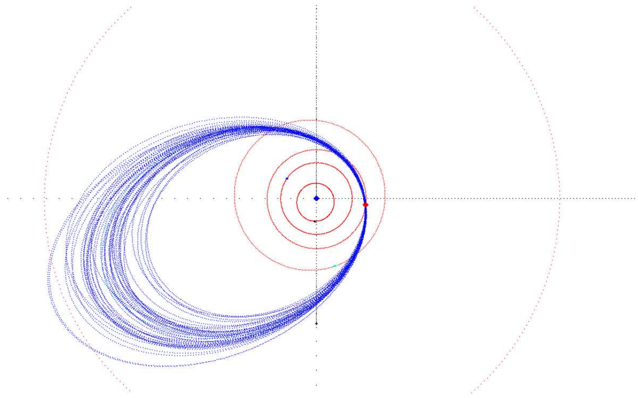

Figure 5 – View from above of the Solar system with CCY meteoroid orbits within $D_{\mathrm{SH}} < 0.1$ derived from EDMOND multi-station observations (2007–2015).

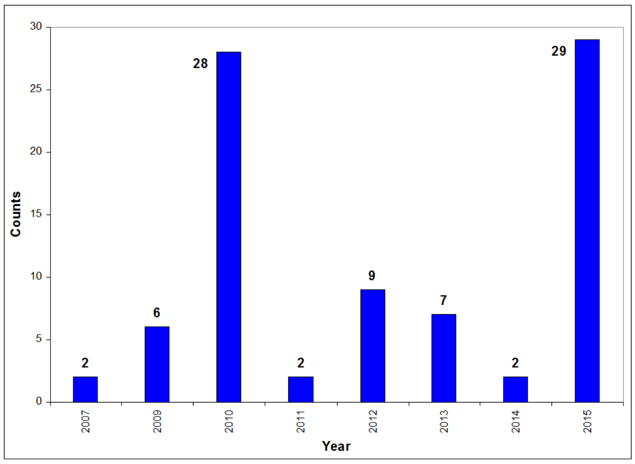

Figure 6 – The total number of CCY orbits for individual years. Increased activity with a period of approximately 5 years is possible.

radiant covering a large area of sky. The radiant has an elliptical shape with the major axis around 10° aligned with right ascension and the minor axis around 7° in the declination (Figure 3).

The initial heights of individual meteors are mostly between 85 to 95 kilometers above the Earth's surface. Despite the low geocentric velocity of the meteoroids the final heights of most meteors are predominantly in the range of 70 to 85 kilometers above the Earth's surface (Figure 4).

Based on our data the CCY meteor shower was active in 2015 between solar longitudes 165°.6 (September 8) and 174°.4 (September 17) with a flat maximum at solar longitude 170°.8 ± 2°.1 (September 13).

5 The χ Cygnid shower overall activity

The overall activity analysis for the CCY meteor shower during the years 2000–2015 was performed using the entire EDMOND database. Orbital elements of the multi-station meteors in the time range (September 1 to September 30) were compared to the mean CCY orbit derived by Jenniskens (2015) using Southworth-Hawkins orbits similarity criteria. The limit value of the criterion was set $D_{\mathrm{SH}} < 0.2$ with an additional constraint of $v_g = 15.1 \pm 2.5$ km/s. Fixed v_g deviation (±2.5 km/s) is applied in EDMOND database for all meteor showers with a speed below 20 km/s as a first criterion for assigning the meteoroid into meteor shower. This approach provided in total 85 CCY shower multi-station meteor orbits. In the next step, the mean orbit obtained from the EDMOND database based on 29 multi-station orbits from 2015 was used as a reference orbit. The number of orbits for the final calculation of the mean CCY stream orbit was reduced again using the orbits similarity criteria with an upper limit $D_{\mathrm{SH}} < 0.1$ (Figure 5). Based on this reduction, 49 precise CCY meteoroid stream orbits were obtained in total. The final derived CCY stream orbital elements and radiant position details are compared with those derived by P. Jenniskens are listed below (Table 1).

The earliest orbits of the CCY meteor stream in the EDMOND database were found from 2007. Based on this data it is possible to conclude, that CCY meteor shower is active on the regular basis and is probably undergoing a periodic activity enhancement with period of about 5 years (increased activity was also recorded in 2010). In other years, the CCY stream activity is very low but detectable (Figure 6).

Table 1 – Orbital elements and radiant data of CCY meteor shower mean orbits from different sources. Individual parameters are described in Table 2. Other parameters: N_{tot} – the total number of meteors, N – the number of meteors after reduction using orbit similarity criteria.

Source	CAMS	EDMOND	EDMOND
Elements	2015	2015	2007 – 2015
a	2.75	2.56	2.64
[AU]	±0.40	±0.25	±0.24
q	0.949	0.953	0.951
[AU]	±0.003	±0.009	±0.011
e	0.655	0.627	0.640
	±0.041	±0.036	±0.032
ω	209.9	210.1	210.6
[deg]	±1.9	±2.9	±3.2
Ω	171.64	171.43	170.71
[deg]	±0.23	±2.11	±2.44
i	18.6	17.4	17.6
[deg]	±1.6	±1.0	±1.4
v_g	15.1	14.2	14.5
[km/s]	±0.9	±0.6	±0.8
RA	301.0	300.5	300.6
[deg]	±2.2	±2.1	±2.9
ΔRA	0.68	0.59	0.74
DEC	32.6	31.7	31.5
[deg]	±1.6	±2.3	±3.1
ΔDEC	0.20	0.12	0.18
N (N_{tot})	9 (9)	16 (30)	49 (85)

The overall activity of the CCY meteor shower as documented in the entire EDMOND database shows periodic enhancement in a range of solar longitudes from $165\overset{\circ}{.}6$ (September 8) to $174\overset{\circ}{.}5$ (September 17) with a flat maximum at solar longitude $170\overset{\circ}{.}7 \pm 2\overset{\circ}{.}6$ (September 13).

6 Summary and conclusions

Based on the data from the EDMOND database, we have confirmed the enhanced activity of the χ Cygnid meteor shower in 2015. In addition we have found that this meteor shower is active on a regular basis with increased activity occurring at intervals of about 5 years. In other years the activity of the CCY swarm is very low, at the detection limit of sporadic background. Based on the Tisserand's parameter of the meteor shower mean orbit ($T_{\mathrm{J}} = 3.014$; EDMOND 2007–2015) we assume the parent body of the CCY swarm is probably unknown Jupiter family comet (JFC), but the value of Tisserand's parameter is approaching the upper limit of JFC group. Swarm activity starts annually around September 8 and ends around September 17, with a very flat maximum on September 13, the FWHM of the activity profile is 5.2 days. In addition to enhanced activity in 2015, enhanced activity in 2010 was also found. For the years 2000–2006, no orbits related to the CCY stream were found, but this may be a consequence of low number of observations in EDMOND database from these years.

Acknowledgement

We would like to thank to all operators of all national networks and independent databases that are listed in the "European Video Meteor Network Database" whose long term and precise work enabled compilation of the EDMOND database.

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Table 2 – Orbital elements and radiant data of 16 analyzed meteors from 2015 activity ($D_{SH} < 0.1$). Following parameters for each meteor are listed: a – semi-major axis, q – perihelion distance, e – eccentricity, ω – argument of perihelion, Ω – ascending node, i – inclination, v_g – geocentric velocity, a_{mag} – absolute magnitude, RA, DEC – geocentric radiant position, H_1 – beginning height, H_2 – terminal height.

Date	Time (UT)	a	q	e	ω	Ω	i	v_g	a_{mag}	RA	DEC	H_1	H_2
YYYY MM DD	HH MM SS	AU	AU	—	deg	deg	deg	km/s	mag	deg	deg	km	km
2015 09 10	19 19 32	2.49	0.938	0.623	214.9	167.552	16.6	14.3	−1.81	302.7	28.3	85.2	76.2
		0.19	0.002	0.029	0.1		0.6	0.6		0.2	0.3		
2015 09 11	01 24 24	2.92	0.948	0.676	211.2	167.798	19.3	15.6	−4.13	299.5	32.8	88.1	75.8
		0.01	0.001	0.001	0.1		0.1	0.1		0.1	0.1		
2015 09 12	19 53 24	2.27	0.953	0.579	211.1	169.520	17.4	13.8	−2.09	300.0	32.9	87.1	78.5
		0.12	0.002	0.025	0.1		0.4	0.5		0.1	0.2		
2015 09 12	22 15 13	2.55	0.951	0.627	211.1	169.616	17.1	14.2	−0.50	300.3	30.6	87.6	80.3
		0.04	0.001	0.006	0.1		0.1	0.1		0.1	0.1		
2015 09 12	22 45 47	2.64	0.945	0.642	212.6	169.637	16.3	14.2	0.49	302.0	28.0	88.4	81.9
		0.04	0.001	0.006	0.1		0.1	0.1		0.1	0.1		
2015 09 13	01 25 30	2.74	0.941	0.656	213.2	169.745	16.9	14.6	−0.90	302.8	28.6	91.3	77.2
		0.12	0.002	0.015	0.2		0.4	0.3		0.2	0.2		
2015 09 14	18 40 08	2.24	0.949	0.576	212.3	171.418	17.9	14.0	1.11	302.5	34.2	88.7	84.5
		0.08	0.001	0.015	0.1		0.3	0.3		0.2	0.1		
2015 09 14	20 22 35	2.55	0.949	0.627	211.4	171.487	17.4	14.4	−0.86	302.0	31.6	89.9	79.5
		0.11	0.001	0.016	0.1		0.3	0.3		0.1	0.2		
2015 09 14	22 28 52	2.15	0.944	0.561	214.1	171.573	17.5	13.8	0.85	304.3	33.6	92.6	80.6
		0.32	0.004	0.083	0.2		1.0	1.2		0.4	0.2		
2015 09 16	18 57 01	2.83	0.966	0.659	205.8	173.379	18.9	14.8	−0.64	297.2	35.0	86.2	76.2
		0.16	0.001	0.020	0.1		0.4	0.4		0.1	0.2		
2015 09 16	19 10 45	3.01	0.969	0.678	204.5	173.388	17.1	14.2	−0.14	295.8	31.2	90.3	82.4
		0.12	0.003	0.013	0.1		0.2	0.2		0.1	0.2		
2015 09 16	20 54 14	2.25	0.963	0.572	207.8	173.458	16.4	13.1	−0.15	299.1	32.9	89.0	82.6
		0.08	0.001	0.015	0.1		0.3	0.3		0.2	0.1		
2015 09 16	22 16 31	2.81	0.958	0.659	208.3	173.514	18.6	14.9	−0.32	300.1	34.1	88.8	75.3
		0.05	0.001	0.007	0.1		0.2	0.1		0.1	0.1		
2015 09 16	22 22 47	2.06	0.953	0.537	211.6	173.518	19.0	14.0	−0.72	302.7	38.5	86.3	65.2
		0.07	0.001	0.015	0.1		0.4	0.4		0.2	0.1		
2015 09 17	00 08 43	2.60	0.963	0.630	207.1	173.590	15.4	13.2	−0.34	299.0	28.5	87.5	83.6
		0.22	0.002	0.067	0.3		0.8	1.0		0.7	0.4		
2015 09 17	01 32 19	2.62	0.960	0.633	207.8	173.647	16.6	13.8	0.76	299.6	31.0	89.9	80.5
		0.19	0.002	0.033	0.2		0.5	0.6		0.3	0.2		