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Chi-Cygnids confirmed in the EDMOND database
Detection of cm-sized P-R evolved meteoroids
Stratospheric balloon mission successful during the Perseids
Reduction and analysis of orbital data using R
September–October video meteors

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Administrative

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Preliminary results

Front cover photo

A magnitude −8 fireball captured on 2015 March 11 at 00^h00^m UT by EN95 station in Benningbroek, The Netherlands. Canon EOS 400D was used with 4.5-mm fish-eye lens at $f/3.2$ and 88 s exposure at ISO 400. Photo courtesy: Jos Nijland.

Writing for WGN This Journal welcomes papers submitted for publication. All papers are reviewed for scientific content, and edited for English and style. Instructions for authors can be found in WGN **31:4**, 124–128, and at `http://www.imo.net/docs/writingforwgn.pdf` .

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Janus

Cis Verbeeck[1]

Good-bye 2015, hello 2016!

One of the main events of 2015 was the launch of the online IMO fireball form in February. It was developed by Mike Hankey and Vincent Perlerin and with the help of numerous translators, it is currently available in 28 languages. A large fireball occurred over Germany and Switzerland on March 15, 2015, just a few weeks after the introduction of the form. This event drew 286 reports and was an excellent occasion to spread the news about the new fireball form. This form has the potential to reach a huge number of people. While indeed a large portion of public is being reached by the original AMS fireball form, the IMO fireball form currently only brings in a few percent of that number. This is not a surprise, however. The AMS fireball form has been widely publicized through the AMS website since 2005 and hence attracts a large English-speaking public. Through the IMO fireball form, local and national astronomy clubs can potentially reach many new people in their own language.

I call upon all readers to include a customized version of the IMO fireball form into their club's website. The form will be in your own language and to an outside visitor would seem to be part of your website rather than of IMO's website. It's very simple — mail Vincent Perlerin (`vperlerin@gmail.com`) for more details. In order to increase the visibility of your website, make sure to put keywords like "fireball" and "shooting star" in several elements of your website. For more details, please consult (Hankey & Perlerin, 2015). When a major fireball is spotted in your country, it can attract a lot of attention from the media. Issuing a fast press release can direct journalists towards your website and the online fireball form. Likewise, good contacts with media, weather forecasters, and science popularizers can boost the number of visitors to your website and the fireball form.

The well-organized IMC 2015 in Mistelbach was a big success, bringing together meteor enthusiasts from around the globe. As in previous years, the topics addressed were diverse and very interesting. As an IMC participant, it is very clear that we are living in an exciting age, in which meteor science is taking great strides. This can be seen in the vast number of projects, technologies, networks, data sets, and models. The most interesting aspect of any IMC, however, is seeing how eyes twinkle and new ideas take shape when people meet.

One of the traditional parts of every IMC is IMO's General Assembly Meeting (GAM). At the 2015 GAM, Vice-President Jürgen Rendtel remarked that several participants had told him that the level of the IMC was too high for them. Jürgen suggested to accommodate beginning meteor workers in next IMCs and asked the participants for ideas. There were many suggestions: an open session where people can ask questions or discuss topics, a meteor school, a hands-on session (e.g., with a WATEC camera or forward scatter setup), pro-active contacts with newcomers at the IMC, . . . Another suggestion was to provide tutorial videos, more accessible information for beginners on the IMO website, and more papers about visual observations and personal accounts of campaigns in WGN. We will take these suggestions into account. Meanwhile, we invite authors to write papers for WGN about their personal observation campaigns.

In order to better oversee the program of an IMC as a whole and to fill in voids (e.g., missing topics, accommodation of less experienced meteor workers, . . .), the IMO Council has appointed a Scientific Organizing Committee (SOC) for the IMC 2016 and will do so for every subsequent IMC as well. Since the Local Organizing Committee is now assisted by the SOC and relies on the IMO Treasurer or IMO Council for all interactions with IMO, the function of IMC Liaison Officer becomes obsolete and is abolished. Prospecting, negotiating, and deciding future IMC candidacies will be done directly by the IMO Council.

Over to 2016 now. The new year took a promising start when radio observers were treated to a higher than average Quadrantid maximum in the first days of January. In August, we expect an exciting Perseid return. Results from Mikhail Maslov and Esko Lyytinen indicate that Earth will cross a part of the Perseid stream which was shifted closer to the Earth's orbit by Jupiter in 2016. As a consequence, the background ZHR may reach a level of 150–160. You can check out IMO's Meteor Shower Calendar 2016 for details.

I am already looking forward to the IMC 2016, which will take place in June, just before the Meteoroids conference. The nice conference venue in the Dutch coast town of Egmond, the dedicated LOC and SOC, and the combination with Meteoroids look very promising. Do not miss out!

After the launch of the online fireball form, Mike Hankey and Vincent Perlerin started designing a brand new IMO website. In 2016, we intend to bring together a dedicated team of website editors who will update the

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contents regularly. Volunteers are invited to contact Cis Verbeeck. In conjunction with the work on the IMO website, Mike and Vincent will implement a visual report form and database common to IMO and AMS, which will facilitate the access to visual data.

Following the 2015 IMO Council elections, several new people joined the IMO Council for the 2016–2019 term, while Javor Kac and Paul Roggemans renewed their mandate. We are very pleased to welcome Megan Argo, Masahiro Koseki, Galina Ryabova, Damir Šegon, and Juraj Tóth to the IMO Council. I am convinced that their input and vision will benefit IMO. Meanwhile, David Asher did not renew his term in the IMO Council. David has been Council member in 2002–2009 and 2012–2015. David's original ideas and thorough and careful evaluation of proposals and situations were always much appreciated. In the name of the IMO Council, I thank David for all the good work he has done for IMO!

It's important for our organization to actively involve new and younger members, and to allow healthy organic growth. Being a Council member is not the only way in which you can help IMO. A lot of work is done by various IMO officers and members who have a passion for meteors and the organization. If you share this passion and want to join us in doing some IMO work, we would be very happy. Just let us know. There is a lot of work to be done!

Happy New Year and clear skies!

References

Hankey M. and Perlerin V. (2015). "IMO Fireball report form: results and prospects". In Rault J.-L. and Roggemans P., editors, *Proceedings of the International Meteor Conference, Mistelbach, Austria, 27–30 August 2015*. International Meteor Organization, pages 192–196.

Janus *was a Roman god with two faces, one looking to the past and one to the future, called upon at the beginning of any enterprise. Today he is often a symbol of re-appraisal at the start of the year.*

Erratum: Observation of April alpha Capricornids (IAU#752 AAC)

The WGN Editorial Team

In the 42:6 issue of WGN, Journal of the International Meteor Organization, an article was published describing the observation of the April alpha Capricornids (SonotaCo et al., 2014). The average solar longitude of the observed meteors given in abstract contained a typo. The correct value is $\lambda_\odot = 17\overset{\circ}{.}65 \pm 0\overset{\circ}{.}6$.

We sincerely apologize to our readers.

References

SonotaCo, Shimoda C., Inoue H., Masuzawa T., and Sato M. (2014). "Observation of April alpha Capricornids (IAU#752 AAC)". *WGN, Journal of the IMO*, **42:6**, 222–226.

IMO bibcode WGN-441-erratum1 NASA-ADS bibcode 2016JIMO...44....2W

Erratum: χ Cygnids observation in Japan

The WGN Editorial Team

A time error has been noted in the paper reporting the χ Cygnid observation in Japan (Shiba, 2015). The correct Date_Time data for the first meteor reported in Table 1 is 20150913_110320.

We sincerely apologize to our readers.

References

Shiba Y. (2015). "χ Cygnids observation in Japan". *WGN, Journal of the IMO*, **43:6**, 179–180.

IMO bibcode WGN-441-erratum3 NASA-ADS bibcode 2016JIMO...44Q...3W

Erratum: Results of the IMO Video Meteor Network — August 2015

The WGN Editorial Team

In the August 2015 Video Meteor Network report (Molau et al., 2015) an error occurred during typesetting of Figures 11 to 16. Correct representations of these Figures are given below.

We sincerely apologize to the authors and our readers for this error.

References

Molau S., Kac J., Crivello S., Stomeo E., Barentsen G., Goncalves R., Saraiva C., Maciejewski M., and Maslov M. (2015). "Results of the IMO Video Meteor Network — August 2015". *WGN, Journal of the IMO*, **43:6**, 188–194.

IMO bibcode WGN-441-erratum2 NASA-ADS bibcode 2016JIMO...44R...3W

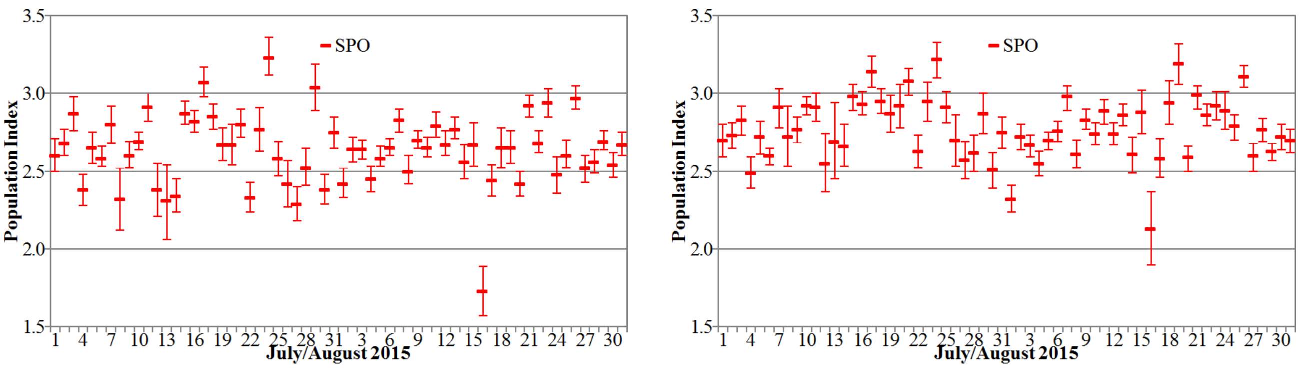

Figure 11 – Sporadic population index in July/August 2015. Left the original, right the perception coefficient corrected profile.

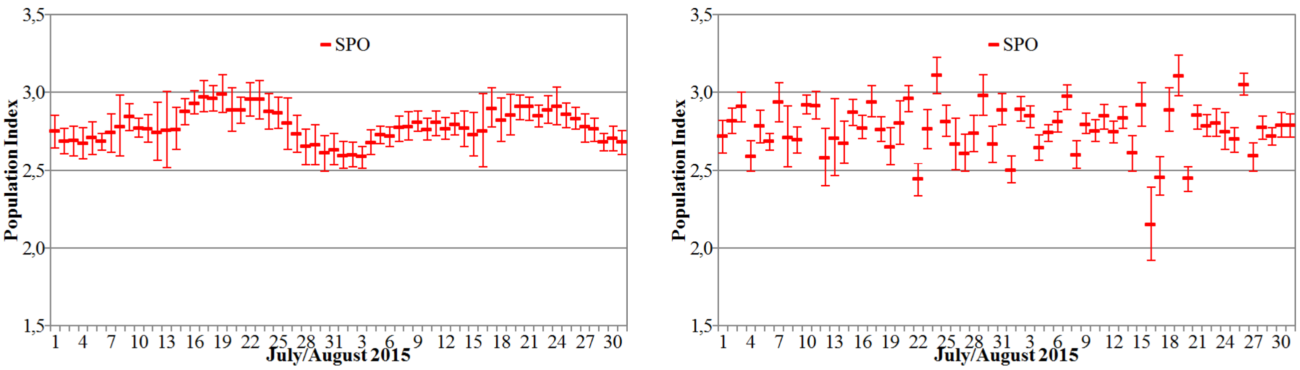

Figure 12 – With a low-pass filter smoothed sporadic population index (left) and final sporadic r-profile in July/August 2015, corrected for the perception coefficient and long-term variations.

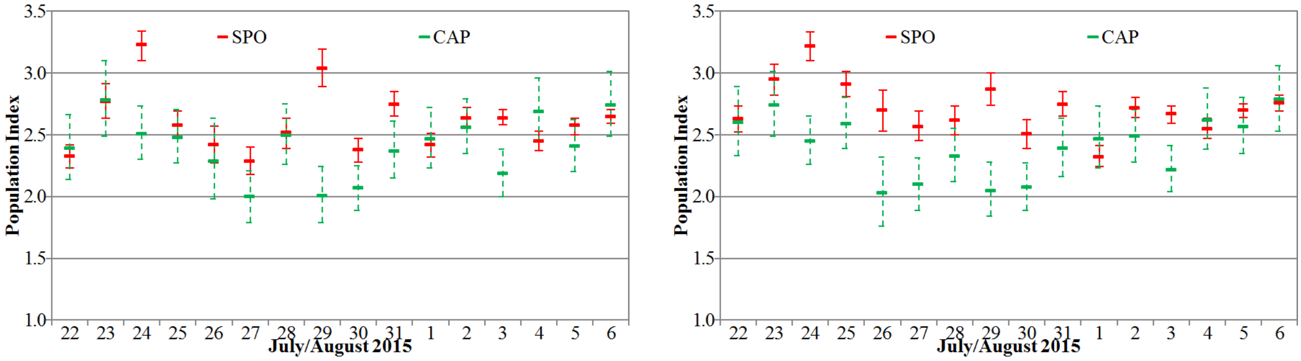

Figure 13 – Population index of the α-Capricornids and sporadic meteors in July/August 2015, derived from IMO video observations. Left the original profiles, right the profiles corrected for the perception coefficient and long-term variations.

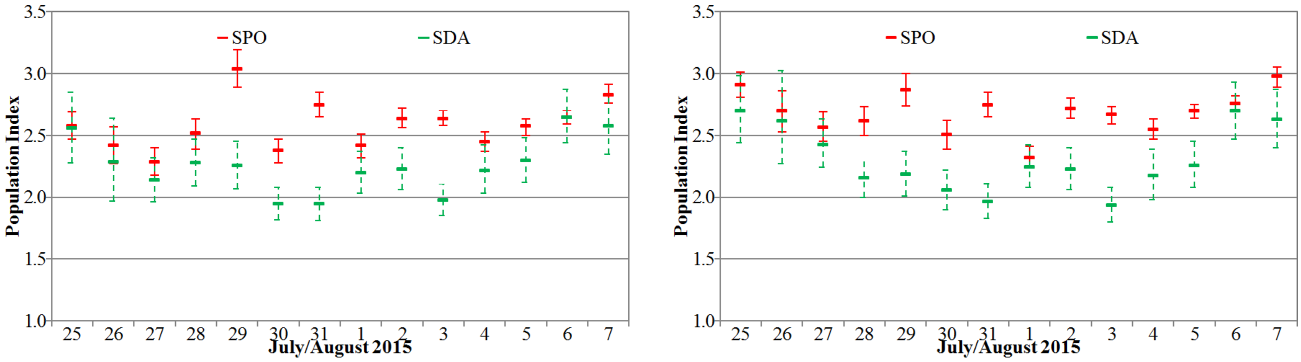

Figure 14 – Population index of the Southern δ-Aquariids and sporadic meteors in July/August 2015, derived from IMO video observations. Left the original profiles, right the profiles corrected for the perception coefficient and long-term variations.

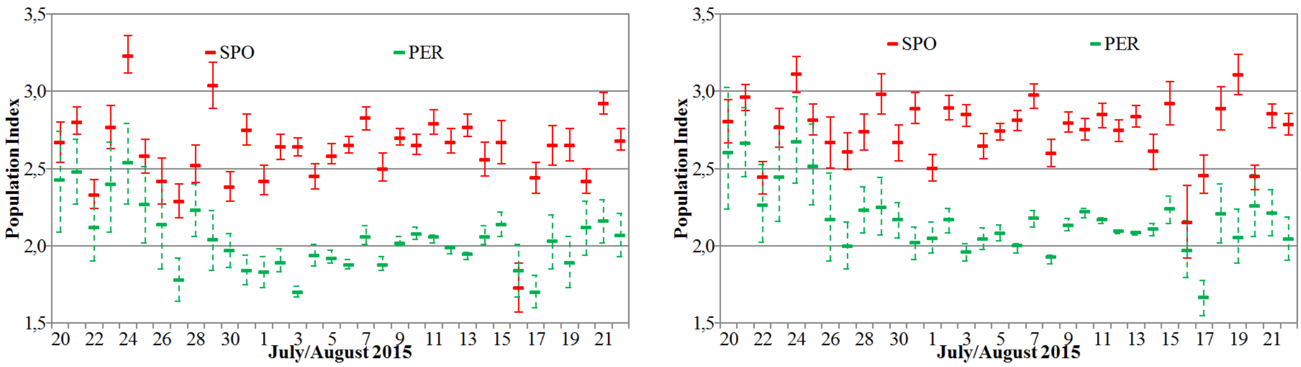

Figure 15 – Population index of the Perseids and sporadic meteors in July/August 2015, derived from IMO video observations. Left the original profiles, right the profiles corrected for the perception coefficient and long-term variations.

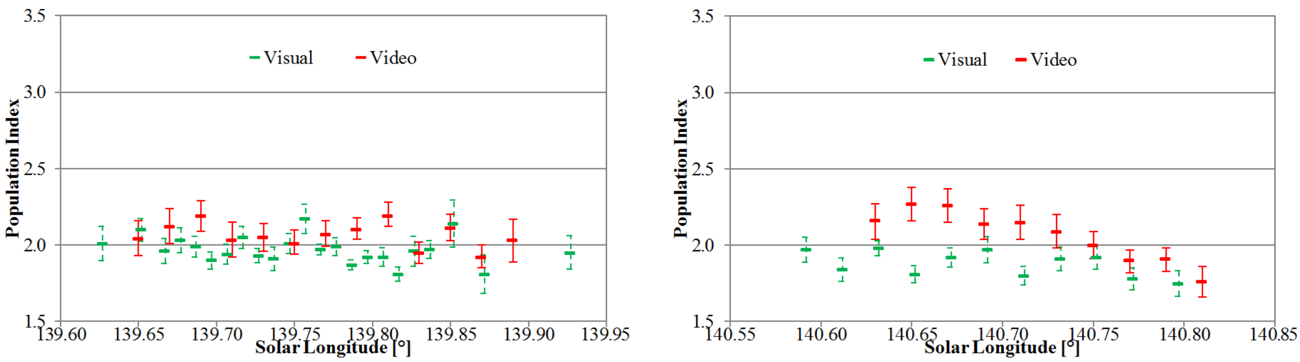

Figure 16 – r-value profile of the Perseid peak, derived from visual and video observations of IMO on 2015 August 12/13 (left) and August 13/14 (right).

Meteor science

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

Jakub Koukal[1,2], *Jiří Srba*[1,2], *and Juraj Tóth*[3]

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.

Received 2016 January 7

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^h23^m UT (2015 September 14) to 03^h35^m UT (2015 September 15). Partial results from CAMS California at intervals from 03^h10^m UT to 12^h45^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^h15^m UT to 20^h15^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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NASA-ADS bibcode 2016JIMO...44....5K

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).

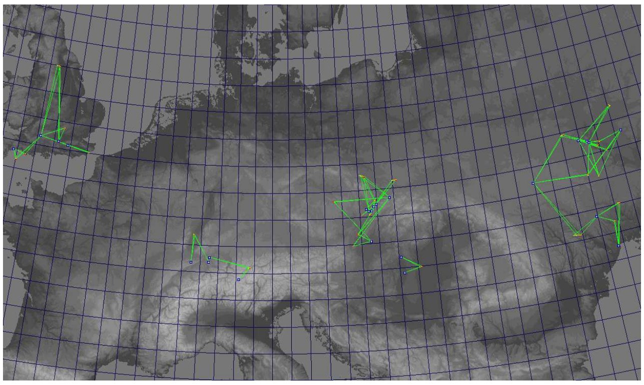

Figure 1 – Ground projection of the atmospheric trajectories of χ Cygnids meteors during enhanced shower activity in 2015.

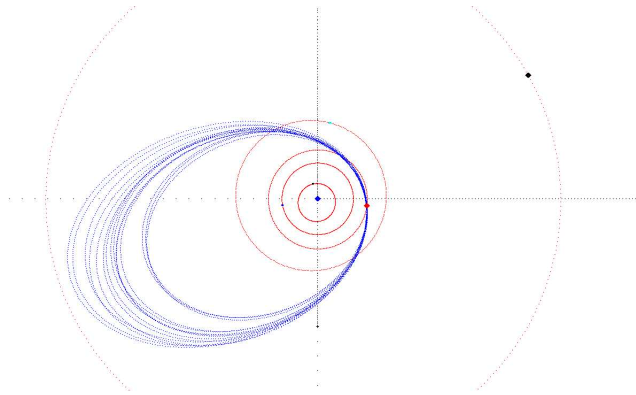

Figure 2 – View from above of the Solar system with CCY meteoroid orbits within $D_{\rm SH} < 0.1$ derived from EDMOND multi-station observations (in 2015).

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

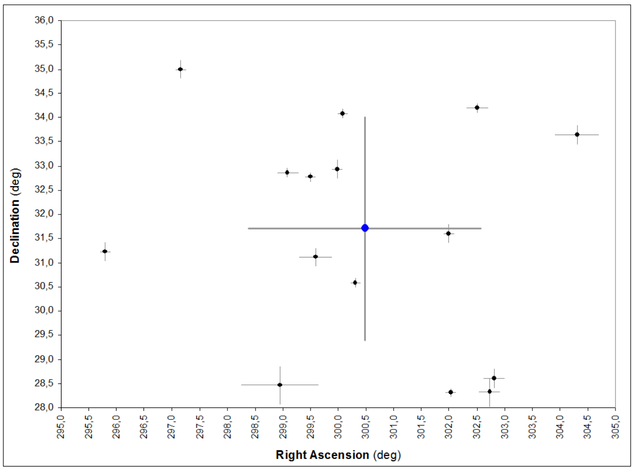

Figure 3 – Positions of the CCY mean orbit radiant (blue dot) and the individual meteoroid orbits radiants in geocentric equatorial coordinates (right ascension and declination, both in degrees) with particular error bars.

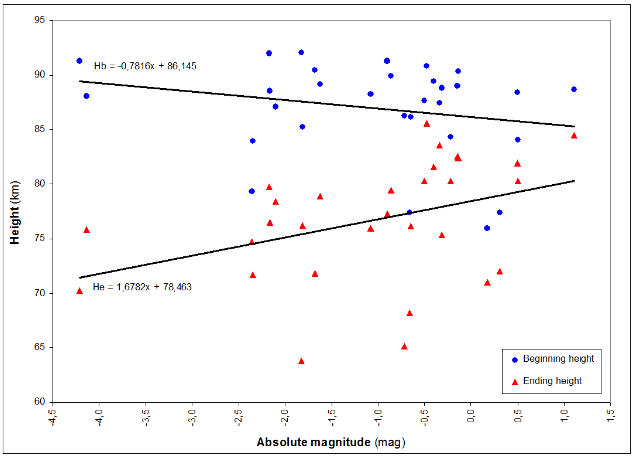

Figure 4 – Start and End altitudes of CCY meteors in relation to the absolute magnitude. The graph contains all 30 orbits of CCY meteor shower meteors from 2015 with $D_{SH} < 0.2$.

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 $165\overset{\circ}{.}6$ (September 8) and $174\overset{\circ}{.}4$ (September 17) with a flat maximum at solar longitude $170\overset{\circ}{.}8 \pm 2\overset{\circ}{.}1$ (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

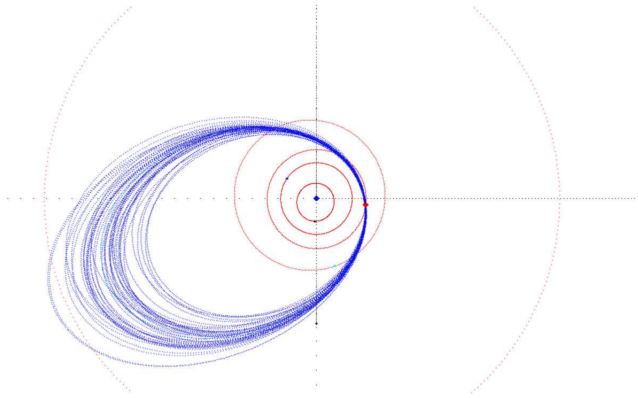

Figure 5 – View from above of the Solar system with CCY meteoroid orbits within $D_{SH} < 0.1$ derived from EDMOND multi-station observations (2007–2015).

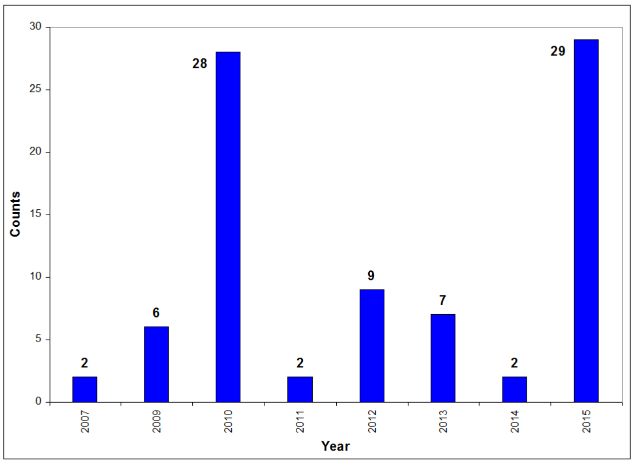

Figure 6 – The total number of CCY orbits for individual years. Increased activity with a period of approximately 5 years is possible.

orbit derived by Jenniskens (2015) using Southworth-Hawkins orbits similarity criteria. The limit value of the criterion was set $D_{SH} < 0.2$ 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 $D_{SH} < 0.1$ (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.°6 (September 8) to 174.°5 (September 17) with a flat maximum at solar longitude 170.°7 ± 2.°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 ($T_J = 3.014$; 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 YYYY MM DD	Time (UT) HH MM SS	a AU	q AU	e —	ω deg	Ω deg	i deg	v_g km/s	a_{mag} mag	RA deg	DEC deg	H_1 km	H_2 km
2015 09 10	19 19 32	2.49 ±0.19	0.938 ±0.002	0.623 ±0.029	214.9 ±0.1	167.552	16.6 ±0.6	14.3 ±0.6	−1.81	302.7 ±0.2	28.3 ±0.3	85.2	76.2
2015 09 11	01 24 24	2.92 ±0.01	0.948 ±0.001	0.676 ±0.001	211.2 ±0.1	167.798	19.3 ±0.1	15.6 ±0.1	−4.13	299.5 ±0.1	32.8 ±0.1	88.1	75.8
2015 09 12	19 53 24	2.27 ±0.12	0.953 ±0.002	0.579 ±0.025	211.1 ±0.1	169.520	17.4 ±0.4	13.8 ±0.5	−2.09	300.0 ±0.1	32.9 ±0.2	87.1	78.5
2015 09 12	22 15 13	2.55 ±0.04	0.951 ±0.001	0.627 ±0.006	211.1 ±0.1	169.616	17.1 ±0.1	14.2 ±0.1	−0.50	300.3 ±0.1	30.6 ±0.1	87.6	80.3
2015 09 12	22 45 47	2.64 ±0.04	0.945 ±0.001	0.642 ±0.006	212.6 ±0.1	169.637	16.3 ±0.1	14.2 ±0.1	0.49	302.0 ±0.1	28.0 ±0.1	88.4	81.9
2015 09 13	01 25 30	2.74 ±0.12	0.941 ±0.002	0.656 ±0.015	213.2 ±0.2	169.745	16.9 ±0.4	14.6 ±0.3	−0.90	302.8 ±0.2	28.6 ±0.2	91.3	77.2
2015 09 14	18 40 08	2.24 ±0.08	0.949 ±0.001	0.576 ±0.015	212.3 ±0.1	171.418	17.9 ±0.3	14.0 ±0.3	1.11	302.5 ±0.2	34.2 ±0.1	88.7	84.5
2015 09 14	20 22 35	2.55 ±0.11	0.949 ±0.001	0.627 ±0.016	211.4 ±0.1	171.487	17.4 ±0.3	14.4 ±0.3	−0.86	302.0 ±0.1	31.6 ±0.2	89.9	79.5
2015 09 14	22 28 52	2.15 ±0.32	0.944 ±0.004	0.561 ±0.083	214.1 ±0.2	171.573	17.5 ±1.0	13.8 ±1.2	0.85	304.3 ±0.4	33.6 ±0.2	92.6	80.6
2015 09 16	18 57 01	2.83 ±0.16	0.966 ±0.001	0.659 ±0.020	205.8 ±0.1	173.379	18.9 ±0.4	14.8 ±0.4	−0.64	297.2 ±0.1	35.0 ±0.2	86.2	76.2
2015 09 16	19 10 45	3.01 ±0.12	0.969 ±0.003	0.678 ±0.013	204.5 ±0.1	173.388	17.1 ±0.2	14.2 ±0.2	−0.14	295.8 ±0.1	31.2 ±0.2	90.3	82.4
2015 09 16	20 54 14	2.25 ±0.08	0.963 ±0.001	0.572 ±0.015	207.8 ±0.1	173.458	16.4 ±0.3	13.1 ±0.3	−0.15	299.1 ±0.2	32.9 ±0.1	89.0	82.6
2015 09 16	22 16 31	2.81 ±0.05	0.958 ±0.001	0.659 ±0.007	208.3 ±0.1	173.514	18.6 ±0.2	14.9 ±0.1	−0.32	300.1 ±0.1	34.1 ±0.1	88.8	75.3
2015 09 16	22 22 47	2.06 ±0.07	0.953 ±0.001	0.537 ±0.015	211.6 ±0.1	173.518	19.0 ±0.4	14.0 ±0.4	−0.72	302.7 ±0.2	38.5 ±0.1	86.3	65.2
2015 09 17	00 08 43	2.60 ±0.22	0.963 ±0.002	0.630 ±0.067	207.1 ±0.3	173.590	15.4 ±0.8	13.2 ±1.0	−0.34	299.0 ±0.7	28.5 ±0.4	87.5	83.6
2015 09 17	01 32 19	2.62 ±0.19	0.960 ±0.002	0.633 ±0.033	207.8 ±0.2	173.647	16.6 ±0.5	13.8 ±0.6	0.76	299.6 ±0.3	31.0 ±0.2	89.9	80.5

CAMS detection of P-R evolved cm-sized meteoroids

Peter Jenniskens[1]

The CAMS video-based meteoroid orbit survey has detected a population of cm-sized meteoroids that have the short semi-major axis $a \sim 1$ AU more typical of the much smaller Poynting-Robertson evolved meteoroids detected by radar. The discovery shows that such relatively large meteoroids can survive collisions in the interplanetary medium for several million years. That is much longer than previously assumed. Most large grains are found in orbits not much different from those of their source Jupiter-family comets and must be lost by disruptions due to processes other than collisions.

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1 Introduction

Since October of 2010, a network of video security cameras has triangulated meteoroid orbits in California and in the BeNeLux. The network is maintained and operated largely by amateur meteor astronomers, who also assisted in the data reduction. Software for CAMS was developed by Pete Gural (Jenniskens et al., 2011).

Results have now been published. The survey detected some 230 meteor showers and shower components throughout the year. 70 of these are already in the IAU list of Established Meteor Showers, after 26 were verified by CAMS (Jenniskens et al., 2016a). An additional 55 previously known showers in need of confirmation were also validated (Jenniskens et al., 2016b). 19 new shower components were identified that are still in need of validation (Jenniskens et al., 2016b). 86 new showers were discovered (Rudawska & Jenniskens, 2014; Jenniskens et al., 2016c; Jenniskens & Nénon, 2016), 54 of which were also found present in the SonotaCo meteoroid orbit database (SonotaCo, 2009).

This short note is to share an interesting result obtained from the CAMS-detected sporadic meteoroids, reported in Jenniskens et al. (2016c).

2 Properties of the Sporadic Meteoroid Orbits

After removing all shower-assigned meteors, a sporadic component remains that makes up 73% of all CAMS-observed meteors. The Tisserand parameter with respect to Jupiter (TJ) can be used to split up this sporadic population into four groups (Figure 1). The meteoroids that come in slow (and that are relatively heavy for their brightness) are mostly from the antihelion source (TJ $\geq$ 2). They make up most matter in the zodiacal cloud and are responsible for most matter falling in on Earth.

These meteors are not from minor showers. Excluding minor meteor showers that are not yet recognized, assuming they occur at a rate following a power-law distribution with the number of detected meteors, would still leave 64% of all CAMS-detected meteors unassigned to showers.

What is the nature of these sporadic meteors arriving from the antihelion source? After correcting for observing biases, mostly due the fact that fast meteoroids are more easily detected than slow meteoroids, the resulting distribution of the semi-major axis (a) of the meteoroid orbits is shown in Figure 2.

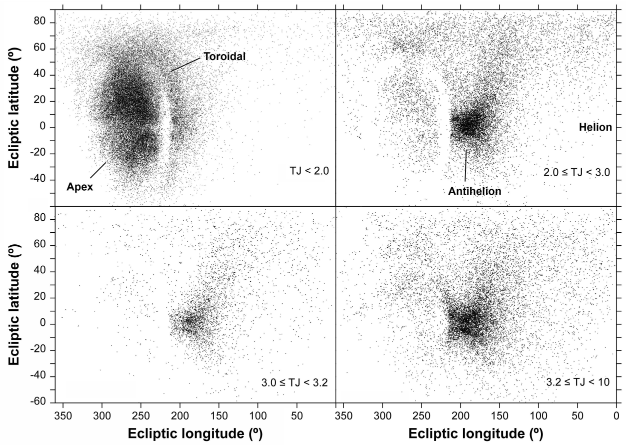

Figure 1 – The radiant distribution of sporadic meteors in four intervals of the Tisserand parameter with respect to Jupiter (TJ). From: Jenniskens et al. (2016c).

What immediately jumps out as odd is that the semi-major axis of video-detected meteors is much more similar to that of their source objects, Jupiter-family comets, than the meteoroids detected by the Canadian Meteor Orbit Radar (CMOR) and the AMOR meteoroid orbit radar in New Zealand. From CAMS data, the distribution peaks at about $a = 2.3$ AU, while both CMOR and AMOR have a peak at $a = 1.0$ AU. The most interesting result is that CAMS data do contain a component of (mostly slow-moving) relatively large meteoroids with short semi-major axis $a \sim 1$ AU (Figures 2).

At slow speeds, CAMS typically detects meteoroids of about 1 cm in size, while CMOR sees 1-mm sized meteoroids and AMOR 0.1-mm sized meteoroids.

3 Discussion

What does this all mean? The short semi-major axis of the CMOR and AMOR detected meteoroids was explained by invoking the Poynting-Robertson effect (Nesvorný et al., 2011). Because of a particle's motion, light absorbed and then re-emitted has a higher frequency (and therefore a higher energy) in forward direction of the particle's motion than in the backward direction in the reference frame of the Sun. As a result, there is a reaction force that slows the particle down. Over time, the orbit becomes shorter and less eccentric due to this Poynting-Robertson effect.

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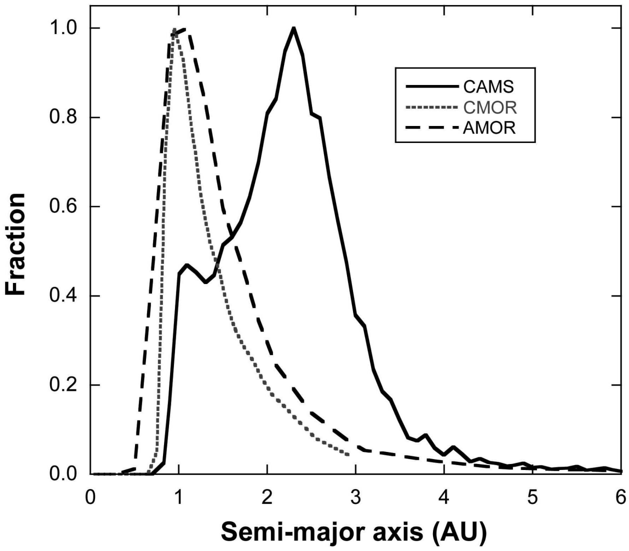

Figure 2 – The semi-major axis distribution of cm-sized meteoroids detected by CAMS and smaller radar-detected meteoroids by the CMOR (1-mm) and AMOR (0.1-mm) radars. From: Jenniskens et al. (2016c).

This effect is much stronger for smaller particles and only needs an age of about 300 000 years to explain the 0.1-mm sized AMOR-detected population (Nesvorný et al., 2011). At that age, the particle is expected to be shattered into much smaller grains due to collisions with other meteoroids, fragments of which then are blown out of the solar system.

In the past, it was assumed that larger particles would be more prone to destruction by collisions than small particles (Grün et al., 1985). This was needed to understand why there are relatively few cm-sized meteoroids compared to the much more abundant 0.1-mm meteoroids. That meant that the mm-sized grains detected by CMOR and the cm-sized grains detected by CAMS should disappear more quickly than the particles detected by AMOR, having an age much less than 300 000 years.

The new results show that they do disappear more quickly, but not from collisions. To explain the CMOR-detected population of mm-sized meteoroids, the mm-sized grains have to survive collisions at least 4–10 times longer than previously assumed (Nesvorný et al., 2011). Now, to explain the CAMS-detected population of small-a meteoroid orbits would need these grains to survive over 10 times longer than previously assumed, at least for 1–3 million years.

The bulk of CAMS-detected meteoroids disappear more quickly, however. Their age is only about 10 000 years. Something is disrupting these meteoroids other than collisions. Some evidence of that process comes also from the study of meteoroid streams, which show many streams don't survive very long. It is not clear what is responsible. Repeated heating and cooling of the grains, for example, might make them fall apart over time.

We used to think that small, less than 0.1-mm sized, meteoroids evolved rapidly by the Poynting-Robertson effect and ended up colliding with Earth or the Sun on almost circular orbits. Larger meteoroids would be lost due to collisions (Grün et al., 1985). Now, it appears that small grains are lost in collisions before they can circularize their orbits, while a small population of large grains survive collisions for a very long time. Most large grains disrupt by other processes well before they collide with another meteoroid. For more reading, please turn to the recent papers in Icarus.

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STRATO 02/2015 – The Perseids 2015 stratospheric balloon mission

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In this paper we present the first results of the MeteorCam03 experiment that allowed the observation of meteors from the stratosphere. The experiment provides a new perspective of meteor observations, mainly due to the lower extinction in these layers of the Earth's atmosphere. For the implementation of the experiment the Perseid meteor shower maximum was chosen, since the Perseids (together with the Geminid meteor shower) are one of the most active streams observable from the northern hemisphere. The MeteorCam03 experiment was part of a stratospheric balloon flight with platform JULO-X codenamed STRATO 02/2015, whose launch was carried out by the Slovak Organization for Space Activities (SOSA).

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1 Introduction

The Slovak Organization for Space Activities (SOSA) sixteenth stratospheric balloon launch, codenamed STRATO 02/2015, was scheduled to start on the night 2015 August 12/13 during the peak activity of the Perseid meteor shower. A joint experiment of Valasske Mezirici Observatory and the Society for interplanetary matter (SMPH), called MeteorCam03, was prepared for this flight in one of the three hung on gondolas. The aim of the experiment was to record meteors from the stratosphere and subsequently calculate their atmospheric trajectories (in combination with ground-based observations from European viDeo Meteor Observation Network cameras).

2 The history of meteor observations from stratospheric balloons

The pioneering observations of meteor shower activity from stratospheric balloons were carried out at the time of the predicted strong returns of the Leonid meteor shower in 1998 and 1999. The first stratospheric balloon was launched on 1998 November 17 (Noever et al., 1999) from the Marshall Space Flight Center (MSFC) at Redstone Arsenal (Huntsville, Alabama). MSFC is a leading research center for National Aeronautics and Space Administration (NASA). The maximum altitude achieved by the meteorological balloon used for this flight was 30 500 m. Most of the flights that took place were equipped with aerogel capsules whose aim was to capture small dust particles. Meteor registration during the flight was carried out by sensitive CCD cameras and recording devices. The success of the mission in 1998 led to the commissioning of further flights in 1999 and 2000[a], also during the expected returns of Leonids. In 1999, flights were also carried out to monitor the eta Aquarids (1999 May 7, start near Johnson Space Center) and Perseid (1999 August 12, the balloon reached an altitude only of 18 898 meters) activity. In later years, further flights were carried out by NASA including, for example, during the 2012 Lyrids (Moser et al., 2013). European examples included meteor observation by means of a stratospheric balloon implemented, for example, during the expected increased activity of the 2011 Draconid meteor shower and during the 2012 Geminid meteor shower (Sánchez de Miguel et al., 2013). These flights were coordinated by the Spanish Meteor Network (SPMN). These meteors were recorded by a Watec 902 H2 CCD camera and data was stored on a DVR (Digital Video Recorder). These experiments were all only designed to carry out actual meteor registration from the stratospheric balloon gondola, and/or collection of small particles (in the order of micrometers) in the stratosphere.

3 JULO-X (STRATO 02/2015) – Experiment and technical data

The STRATO-02/2015 stratospheric balloon was launched on 2015 August 13 at 00^h52^m CEST after local midnight (August 12, 23^h52^m UT) from the Malé Bielice airport (near Partizanske, Slovakia, Figure 1). The maximum height during this flight was reached at $00^h55^m40^s$ UT. After the balloon blow out at an altitude of 34 444 m the subsequent downward phase ended with a landing at 00^h34^m UT at coordinates N 48°4471 and E 18°1058 (near village Preseľany, Slovakia (Figure 1). In addition to MeteorCam03 (see Section 4) other experiments were installed to be carried out dur-

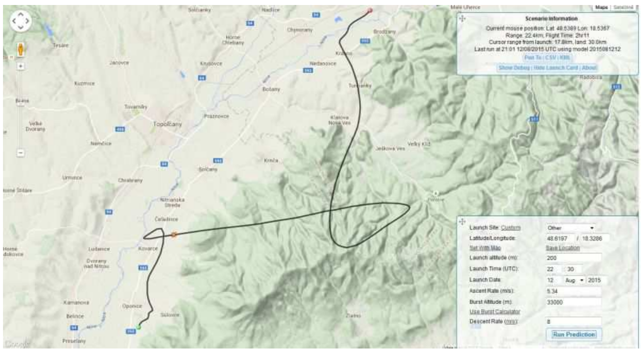

Figure 1 – Projected flight trajectory of stratospheric balloon STRATO 02/2015 to the Earth surface.

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NASA-ADS bibcode 2016JIMO...44...12K

[a]http:// http://science.nasa.gov/science-news/science-at-nasa/

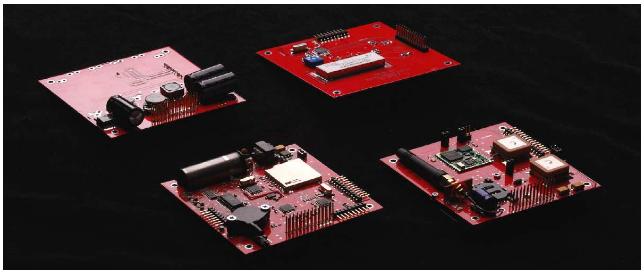

Figure 2 – Individual modules of the stratospheric platform JULO-X.

Figure 3 – Stratospheric balloon STRATO 02/2015 payload: cosmic ray particles detector (left); MeteorCam03 (middle); modules of JULO-X probe, transmitter for SkCube and Geiger-Müller tubes (right).

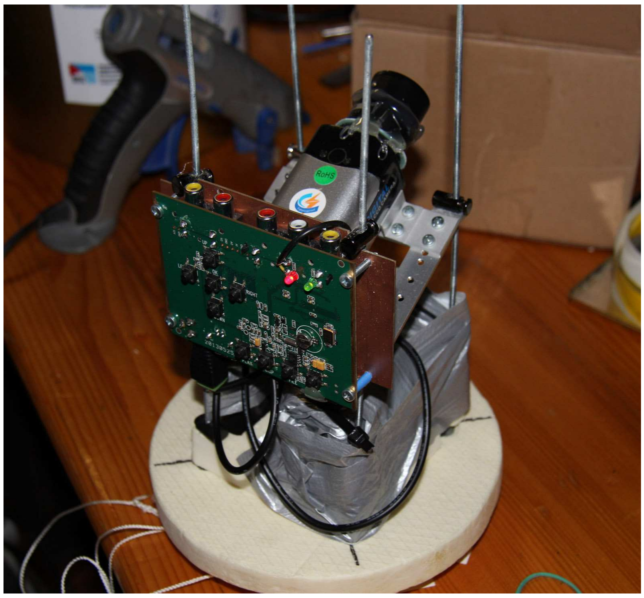

Figure 4 – Camera KPF131HR with DV recorder (MeteorCam03).

ing the flight: the detection of cosmic rays (combination of Geiger-Müller tubes and detector for charged particles via modern smartphones with special software developed by Crayfis company[b]); the testing of transmitters for the first Slovak satellite SkCube; and a student experiment ISCEAC (influence of stratospheric conditions on seed germination). The precise location of the balloon in flight was measured by two GPS modules; position and height were recorded every 30 seconds (Figure 3).

The stratospheric balloon platform JULO-X, on which all experiments were accommodated, was developed within the scope of the SkBalloon project (started in 2008). The first flight of the experimental platform JULO1 took place in October 2010. Based on the knowledge gained from the launch of the first series, the second generation of the platforms has been developed (called JULO2). The first start of stratospheric balloon with this platform took place in April 2012. JULO-X is the 3rd generation platform, which was developed for multi-start usage and reliability for scientific experiments. Stratospheric probe JULO-X consists of five modules: the transceiver module, radio-beacon module (short range tracking), power supply module (PSU board), sensors board (also carrying the main processor/computer) and the system for real time positioning (GPS module). Bus hardware is based on CubeSat microsatellites (Figure 2).

The transceiver module is a HX1 transmitter with frequency 144.800 MHz. Transmitted packets are compatible with APRS (Automatic Packet Reporting System). The HX1 transmitter has a power of 500 mW and a data packet is generated every 23 seconds. The module for the close range tracking (radio-beacon) is used to locate the balloon on the ground from distances of several hundred meters. This system is able to work for several weeks regardless of the other systems performance, and is used for close tracking in difficult terrain. The module transmits in the 70 cm band at a frequency of 434 MHz, its output is 10 mW, which is sufficient for detecting until distances of 2 km. The power system of stratospheric platform JULO-X consists of six lithium cells with a capacity of approximately 5 000 mAh and is able to power the probe for 12 hours (without additional experiments). To power the sensor electronics, DC-DC converters (3.3 V and 5 V) are used. The sensor board carries sensors for measuring the basic atmospheric parameters (ambient temperature, relative humidity and atmospheric pressure). The module also includes a sensor for measuring acceleration in all axes (accelerometer) and a digital compass (magnetometer). All recorded data, including battery status, are stored on the internal SD card. The module hosts the main processor which manages the communication and data storage. Up to 8 analog differential signals with voltage range 0–2.5 V can be linked into this module. A system for determining position includes a pair of GPS receivers with an accuracy of approximately 2 m. The system also includes a GSM module for sending SMS messages with the coordinates of the probe, this module is usable only to an altitude of approximately 1 500 m.

The complete stratospheric probe is launched by a meteorological weather balloon filled with helium with an uplift about 6 kg. The diameter of the full-filled balloon on the ground is around 2 m (with total volume about 4 m^3), and 12 m before its break at high altitude. Aerodynamic braking of the payload after the burst is achieved using a parachute with a diameter of 80 cm, the effective aerodynamic braking starts downwards of heights of around 10 kilometers above

[b] http://crayfis.io

Figure 5 – Stacked image of meteor 20150813_005041 from MeteorCam03.

Figure 6 – Stacked image of meteor 20150813_005041 from ground station Maruska SE.

the Earth's surface. The impact speed of the payload is about 20 km/h.

4 MeteorCam03 – equipment

The MeteorCam03 experiment consists of a sensitive CCD camera KPF131HR (1/3" chip Sony Super HAD II CCD, sensitivity 0.002 lx in BW mode and resolution 582 × 500 px) and 4 mm fixed focal length lens Computar (maximum aperture $F/1.2$) (Figure 4). Meteor registration was carried out via a DVR (Digital Video Recorder) with two channels, data saving on the mini-iSD memory card with a capacity of 32 GB. For the experiment a frame rate of 25 fps/s was used. Continuous video recording was divided into one-minute long sequences and saved in format `*.avi` with MJPEG codec compression. Elevation of the camera was set at 30 degrees, also for monitoring of the light pollution. This value corresponds to the normal elevation of the ground-based stations in EDMONd (usually around 45 degrees). The camera was installed without a gyroscopic stabilization.

5 Results – Two-station meteor orbits

During the flight total amount of 45 meteors were registered, 23 of them were also identified in ground station data from the EDMONd network (Kornoš et al., 2014a; Kornoš et al., 2014b). Due to significant gondola instability during the flight it was not possible to process data in a conventional way via the commonly used UFOAnalyzer software (SonotaCo, 2007a; SonotaCo, 2009). It was necessary to perform individual astrometric calibration of each recorded meteor, this being based on still image (frame) analysis in the AstroRecord software (De Lignie, 1997) (Figures 5 and 6).

Measured equatorial coordinates (Ra, Dec) of the beginning (first frame) and end (last frame) of each meteor were inserted into the calculation procedure of the UFOOrbit software (SonotaCo, 2007b; SonotaCo, 2009) in photographic format (with the known time of the meteor event, equatorial coordinates of the beginning and end of the meteor, geographical coordinates and altitude of stratospheric balloon gondola at the time of event and duration of the phenomenon as determined from the recorded video of the meteor). Due to the large amount of data collected during the MeteorCam03 experiment, only 3 meteors have now been fully analyzed. For these, two-station orbits were calculated, using the mobile station located in the stratospheric balloon gondola and the ground station Maruska SE (Figures 7 and 8). In all three cases meteors were members of the Perseid stream. The orbital elements are shown in Table 1, including the position of the geocentric radiant of the meteor and the initial and end height of the meteor atmospheric trajectory.

6 Summary and conclusions

In presenting these initial results from the MeteorCam03 experiment we demonstrate the possibility of using sensitive CCD cameras located in a stratospheric balloon gondola for the calculation of two-station (or more stations) orbits of meteors in combination with ground based data. In the event of unfavorable weather conditions during interesting events (for example predicted outburst of meteor showers) the stratospheric balloon based observation can provide valuable data. We consider this experiment to have been very successful, due to the recorded number of meteors on MeteorCam03 camera and also due to a successful calculation of two-station orbits in collaboration with ground based stations organized in the EDMONd network.

Acknowledgement

The experiment was in part funded by a special grant of the Czech Astronomical Society (ČAS), by the Observatory Valasske Mezirici (CZ) and by the Society for Interplanetary Matter (SMPH). We would like to thank to Observatory Partizanske (SK) for organization of the stratospheric balloon launch at Male Bielice Airport.

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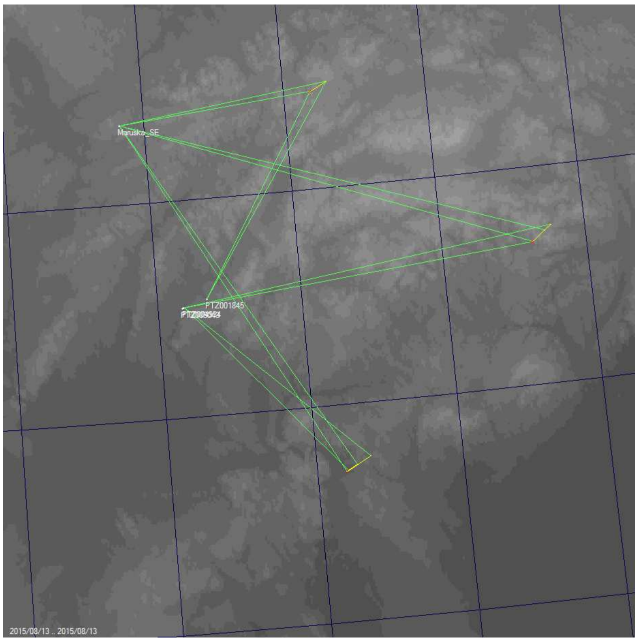

Figure 7 – Ground projection of the meteoroids atmospheric trajectories, two-station calculation from MeteorCam03 and Maruska SE (ground based).

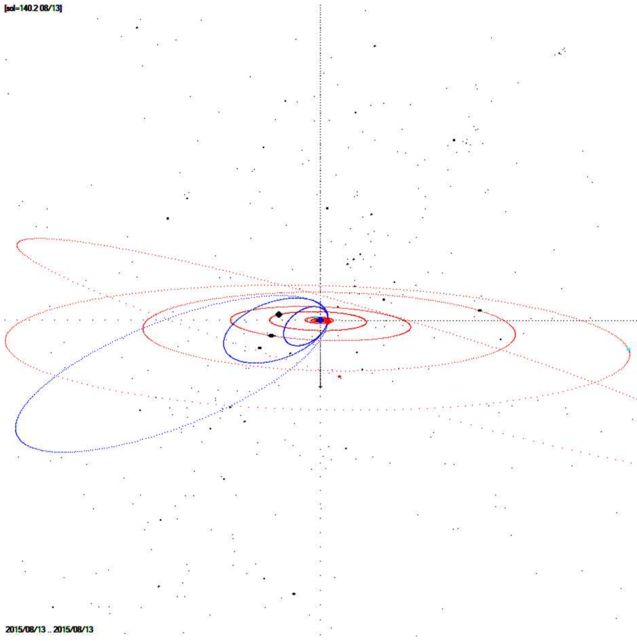

Figure 8 – Orbits of the meteoroids in the Solar System, two-station calculation from MeteorCam03 and Maruska SE (ground based).

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Table 1 – Orbital elements and radiant data of analyzed meteors. The following parameters for each meteor are listed: a – semi-major axis, q – perihelion distance, e – eccentricity, peri – argument of perihelion, node – 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	UT	a	q	e	peri	node	i	v_g	a_{mag}	RA	DEC	H_1	H_2
YYYY MM DD	HH MM SS	AU	AU		deg	deg	deg	km/s		deg	deg	km	km
2015 08 13	00 18 44	2.95	0.9663	0.672	152.213	139.755	120.51	58.60	−1.67	45.19	52.01	108.3	95.1
			±0.0031	±0.061	±1.720		±0.55	±0.83		±0.14	±0.10		
2015 08 13	00 49 32	20.15	0.9881	0.868	161.193	139.775	119.39	60.44	−2.51	42.26	53.29	103.4	92.7
			±0.0017	±0.087	±1.165		±0.66	±1.08		±0.19	±0.26		
2015 08 13	00 50 41	30.74	0.9695	0.968	155.811	139.776	112.73	59.28	−3.37	44.45	58.10	110.1	87.4
			±0.0015	±0.053	±0.787		±0.44	±0.66		±0.12	±0.14		

Preliminary results

R suite for the Reduction and Analysis of UFO Orbit Data

Peter Campbell-Burns[1] *and Richard Kacerek*[1]

This paper presents work undertaken by UKMON to compile a suite of simple R scripts for the reduction and analysis of meteor data. The application of R in this context is by no means an original idea and there is no doubt that it has been used already in many reports to the IMO. However, we are unaware of any common libraries or shared resources available to the meteor community. By sharing our work we hope to stimulate interest and discussion. Graphs shown in this paper are illustrative and are based on current data from both EDMOND and UKMON.

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1 Background

Faced with increasing numbers of meteor observations from an expanding network, we looked at alternatives to Excel to process our data. Microsoft Excel is easy to use (up to a point) and it is familiar to almost everyone, but very large datasets can be difficult to manage. A more general disadvantage with spreadsheets is that the method of analysis and the data itself are bound together in one entity; when changing datasets or refreshing data care is needed to ensure formulae continue to be applied correctly and are not lost altogether. Mistakes are made too easily.

A brief trawl of the internet led us to R which satisfied two key criteria: (1) the ability to handle large datasets easily and efficiently, and (2) affordability (in fact R freely is distributed). It has a large following and its range of application gave the immediate impression of a powerful and well established solution.

2 What is R?

R is a highly extensible software environment for statistical computing which has been growing in popularity over recent years. It is used by academics and in many industries. It has its own interpreted programming language, an extensive graphics capability and supports wide range of statistical techniques. Its graphics and statistics capabilities can be augmented by add-on libraries and packages which include statistical methods, enhanced graphics and interactive 3D graphics. There is even a web presentation layer. R runs on a wide variety of UNIX platforms and similar systems (including FreeBSD and Linux), and also on Windows and MacOS.

R's data types include data frames, matrices, tables, vectors and lists. Of these, it is the data frame that makes R particularly adept at handling large comma separated datasets (such as the output from UFO Orbit). A data frame is simply a two dimensional representation of data in which each column contains a measurement and each row contains case, but unlike conventional arrays or matrices, each column can be of a different type.

The potential of R for the reduction and analysis of meteor data is demonstrated by the ease with which an entire UFO Orbit dataset can be ingested, filtered and manipulated. Ingestion of an entire dataset into a data frame (maintaining column names) is done in one simple statement, as follows:

```
dataset1 <- read.csv(<filepath>, header=TRUE).
```

Once the file is ingested operations such as filtering, extraction, and statistical / mathematical operations, can be performed on individual cells within the data frame, on single rows and columns, and on multiple rows and columns. The simplicity of manipulating data frames is demonstrated by a few examples in Table 1.

Several third party IDEs (Integrated Development Environments) are available which improve productivity around code development and debugging, and which make management of the R environment easier. Perhaps the most well known is RStudio which is available in open source as well as in commercial editions and, like R itself, runs on Windows, MacOS and Linux platforms.

The main disadvantage with R is that it is not widely understood and requires users to learn a new (and slightly unconventional) language. Its capability to process large datasets is limited by platform on which it runs as datasets are stored and processed in memory. In practice, this is unlikely to be a problem. Even with datasets as large as Edmond we have yet to encounter problems on a computer with only 2 Gb of memory.

3 Developing a library of scripts

To evaluate R's potential for the reduction, statistical analysis and visualisation of meteor data, we developed a number of R scripts which produced summary tables and graphs that were frequently used by UKMON (and which were previously generated using Excel). These included various predefined plots and graphs showing observation numbers for each station, velocity and magnitude distributions for the Perseids, along with shower activity patterns. This significantly reduced the time taken to produce reports and summaries of meteor activity. As confidence in using R increased, and as further ideas came forward, more and different types of

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IMO bibcode WGN-441-campbell-burns-r
NASA-ADS bibcode 2016JIMO...44...16C

Table 1 – Examples of simple operations on a data frame containing variables X_stream, X_vo, X_amag, X_H1, X_H2.

Action	R statement
Create a new dataset containing only those meteors with stream ID "_J5_PER".	`pers=dataset1[mt$X_stream=="PER",]`
Create a new dataset containing only the velocities of meteors with stream ID "_J5_PER".	`pvel<-dataset1[dataset1$X_stream=="_J5_PER","X_vo"]`
Create a new dataset containing meteors with absolute magnitude ≤ -4	`fballs <- dataset1[dataset1$X_amag <= -4, ]`
Add a new calculated column to dataset1 holding the height difference $H1 - H2$ for each meteor	`dataset1$H_diff <- dataset1$X_H2 - dataset1$X_H1`
Sort the dataset into order of increasing magnitude	`dsort <- dataset1[sort(dataset1$X_amag),]`

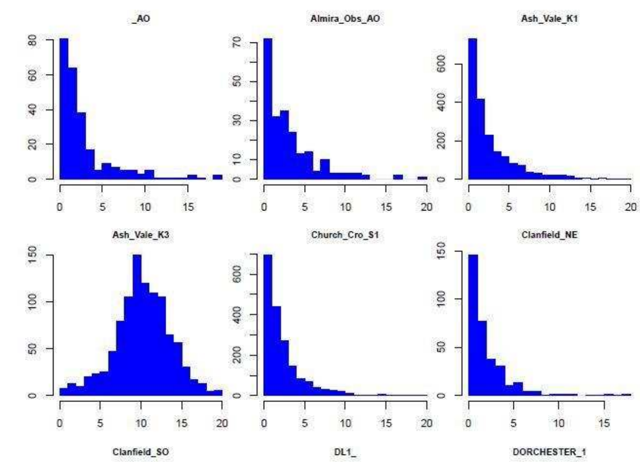

Figure 1 – Delta Vo plot with Ash Vale K3 camera showing an anomalous profile (Data: UKMON).

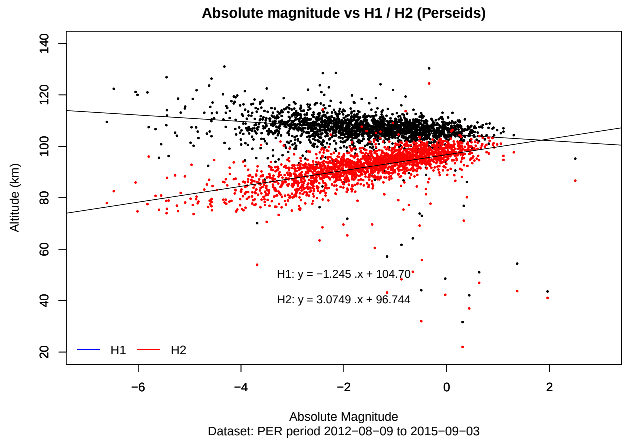

Figure 2 – Variation of magnitudes with H1 and H2 (also showing a least squares line fit) (Data: EDMOND).

analyses were added. Recently developed scripts use more advanced graphical features of R (e.g. 3D scatter plots and line fitting).

Having developed a rather loose collection of analysis and reporting scripts, the logical next step was to standardize and 'package' in a way that made them easier to use. A 'wrapper' or 'master script' was then written which looks after:

1. Setting up the user environment (pointers to working directories, etc.),
2. User dialogues to select the input dataset and filter criteria (currently only filtering by stream and / or year is supported),
3. Data reduction (common to all scripts so that these are performed once only),
4. Analysis and reporting (directing graphical output to jpeg or PDF according to a configuration setting, the latter offering best image quality).

The analysis scripts are executed by the master script using a source statement which runs the script as if it was embedded in the master script. One of many possible code improvements would be to present scripts as functions within a single R library or package. However, the source approach is preferred at this time as it makes customisation a little easier.

A full catalogue of the currently available analyses is presented in Table 2. Example outputs are presented in Figures 2 to 6. These analyses produce predefined plots can be tailored to meet the needs of individual users (for example changing a frequency distribution to show heliocentric rather than observed velocities). R may look a little daunting to the beginner but there is plenty of help on the Internet.

4 Next steps

This is very much a "work in progress". It is acknowledged that the types of analysis implemented to date are summaries based on the available 'raw' data from the UFO Orbit `csv` output file, and are therefore basic in nature. Stream analysis uses only categorisations derived by UFO Orbit, but a key method in the meteor scientist's is to use orbital similarities using D-criterion. This is well within the capabilities of R and is a planned addition.

Other applications we wish to explore include:

- Visualisation of orbits using the R's 3D graphing (maybe even an interactive 3D display) with the

Table 2 – Catalogue of R analysis scripts.

Analysis Type	Summary	R file
Simple counts	Counts by stream (ten highest counts)	`streamcounts.r`
	Meteor counts by solar longitude	`counts_by_sol.r`
	Number of matched observation (UNIFIED_2, UNIFIED_3, etc)	`stream_plot_by_correlation.r`
	Number of matched meteor observations by stream	`stream_counts.r`
	Number of matched meteor observations by station	`streamcounts_plot_by_station.r`
	Table of matched observations (count of Station A / Station B pairs)	`station_match_tab_correlation.r`
	List of meteors brighter than amag < -4	`fireball_detect.r`
Stream analysis	Number of meteors by solar longitude (sol) over stream duration	`stream_plot_timeline_solar.r`
	Scatter-plot showing radiant (Right ascension v Declination) for individual meteors	`stream_plot_radiant.r`
	Multi-chart plot showing movement of radiant (2SD and 3D plots)	`stream_plot_radiant_movement.r`
	Table of matched observations (counts by stream and by year)	`stream_counts_by_year.r`
	Table of matched observations (counts by stream and by station)	`stream_counts_by_station.r`
Magnitude	Frequency distribution of absolute magnitudes (amag)	`stream_plot_mag.r`
	Scatter plot of absolute magnitude (amag) against start height (H1) and amag against end height (H2) for individual meteors.	`abs_magnitude_vs_h1_h2.r`
	Scatter plot of absolute magnitude (amag) against start height (H1) and amag against end height (H2) for individual meteors with a least squares line fit.	`abs_magnitude_vs_h1_h2_reg.r`
	Scatter plot of absolute magnitude (amag) against height difference (H1 – H2) for individual meteors with a least squares line fit.	`abs_magnitude_vs_h_diff_reg.r`
	Count of stream meteors with magnitudes less than or equal to -4 (all streams)	`fireball_by_month.r`
	Count of meteors with magnitudes less than or equal to -4 (by stream)	`fireball_by_stream.r`
Velocity	Frequency distribution of Observed velocities (vo)	`stream_plot_vel.r`
	Frequency distribution of Helio-centric Velocity (vs)	`heliocentric_velocity.r`
Orbital	Scatter plot of semi-major axis (a) vs ascending node (node)	`semimajor_v_ascending.r`
	Scatter plot of semi-major axis (a) vs inclination (incl)	`semimajor_v_inclination.r`
	Frequency distribution of Semi-major axis (a)	`semimajoraxisfreq.r`
	Frequency distribution of semi-major axis (A) with a range of bin sizes.	`a_binned_multi.r`
	Frequency distribution of semi-major axis (A) with a fixed (configurable) bin size.	`a_binned.r`
Ablation	Line plot of start height (H1) to end height (H2) for individual meteors. This plot provides a simple visualisation of where in the atmosphere ablation is taking place.	`stream_ablation.r`
Quality	Plot of difference in Vo between station and unified data (all stations)	`delta_v0_overall.r`
	Plot of difference in Vo between station and unified data by station	`delta_v0_by_station.r`
	Distribution of quality metric QA (all stations)	`qa_overall.r`
	Distribution of quality metric QA by station	`qa_by_station.r`
	Summary of Delta Vo by station (min, max, mean, sd)	`delta_vo_by_station.r`

potential to overlay orbits of potential progenitor bodies.

- Using R to measure data quality and to highlight problems in data acquisition and in the data processing pipeline (a simple summary using R has already to highlight a problem with the setup of the Ash Vale K3 camera, see Figure 1).

Obtaining R and the Report Suite

The R scripts which make up the analysis suite can be downloaded from the UKMON website (UKMON, 2016). The distribution (`zip` file) also includes a README file which provides instructions for installation and use. These scripts are shared under the Creative Commons Non Commercial Sharealike License V4.

R is available as Free Software from the R Project for Statistical Computing website (The R Foundation,

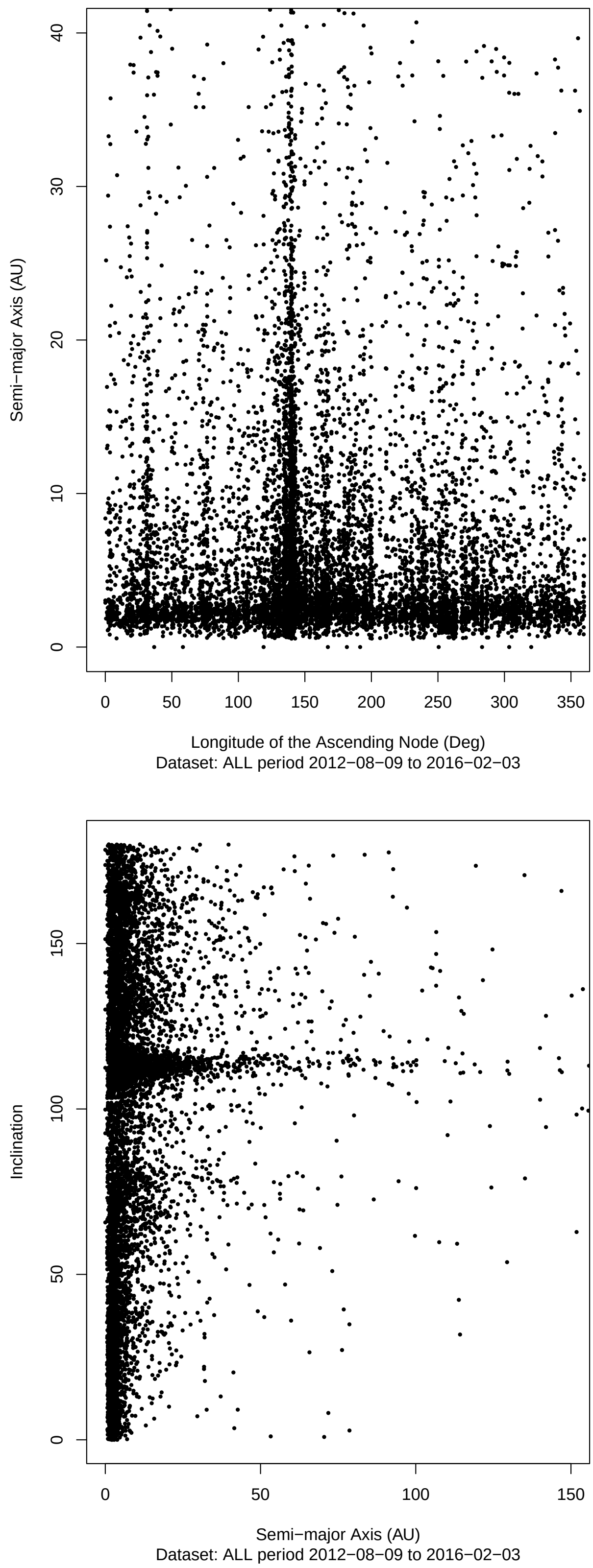

Figure 3 – Semi-major axis plotted against longitude of the ascending node (top) and inclination plotted against semi-major axis (bottom) for all streams and sporadics (Data: EDMOND).

2016). It is distributed under the terms of the Free Software Foundation's GNU General Public License.

RStudio is obtainable available in open source and commercial editions from the RStudio website (RStudio, 2016).

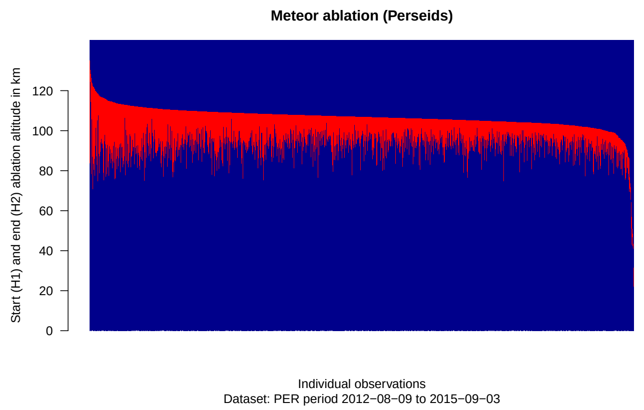

Figure 4 – Meteor Ablation Plot for the Perseids (Data: UKMON).

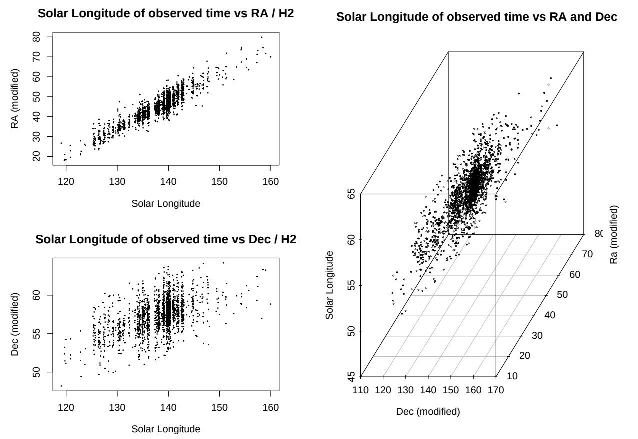

Figure 5 – Motion of the radiant (also demonstrating R's 3D capability) (Data: EDMOND).

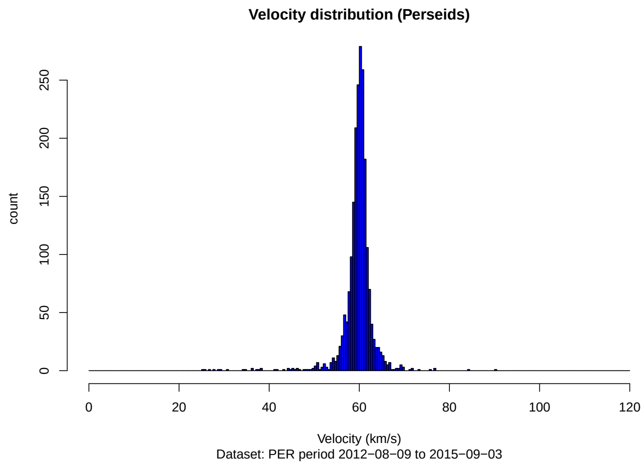

Figure 6 – Velocity distribution of the Perseids (Data: UKMON).

5 Learning R

There are many useful online resources available on the Internet. Possibly one of the best is a distance learning module which is part of the Data Science Specialisation course run by the John Hopkins University which is available through Coursera (John Hopkins University, 2016).

6 Summary

R has proved itself to be highly adept at handling the types of data generated by the Sonotaco suite and, once the hurdle of familiarity with R has been overcome, it makes data reduction and data analysis a far more manageable task compared with Excel. It is more powerful and the extensible graphics capability makes it a particularly useful tool. Furthermore, its following is such that there are many active user groups where questions can be asked and often receive quick responses.

To date, our R scripts provide only simplistic analyses based on raw UFO Orbit output, but these are the types of summarisations that are most frequently used in reports and papers by UKMON (and others). Our aim is to continue adding to the suite with examples of different statistical methods and, by sharing our work at this early stage of development, it is hoped to stimulate interest and discussion. We also hope that others will be willing to contribute ideas and analytical methods so that a more complete collection of scripts can be developed.

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Results of the IMO Video Meteor Network — September 2015

Sirko Molau[1], Stefano Crivello[2], Rui Goncalves[3], Carlos Saraiva[4], Enrico Stomeo[5], and Javor Kac[6]

The September 2015 report of IMO Video Meteor Network observations is presented, covering more than 11 000 hours of observations with over 53 000 meteors being recorded. A recently discovered minor shower of the κ-Cepheids cannot be identified in the 2015 Network data. The χ-Cygnids, a minor shower discovered in 2015, is confirmed based on the 2015 data, and data going back to 1999. The flux density profiles are shown for the shower for the period 2012–2015. The peak in 2015 is reached between September 14 and 17.

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1 Introduction

2015 confirmed its reputation as an unusually productive year for meteor observers. Even though a first glimpse shows larger gaps in the observing statistics, the weather was quite cooperative, in particular in Germany. Three out of four cameras obtained twenty or more observing nights. In the greater Berlin area, three Remo cameras of Sirko Molau and Ludwig2 of Rainer Arlt could even operate without any break. For this reason, the output of these cameras was particularly high with over a thousand meteors each. Only two Italian wide-angle cameras and the image-intensified systems in Bavaria and on the Canary Islands were similarly successful. In fact, Sirko Molau could for the first time record over 10 000 meteors in a single month with all his cameras combined. That has not even been achieved in August so far.

September 1/2 and 9/10 were the best nights with 75 active cameras each. Already for the fifth time in 2015, the overall effective observing time in a single month was a 5-digit figure. With over 11 000 hours (Table 3 and Figure 1), 2015 September ranks fourth in the IMO Network long-term statistics. Also the output of over 53 000 meteors is unique; more meteors than that were only recorded in 2011 October (with particularly strong Orionids) and in August 2011–2015. Compared to the previously best September result, we achieved an increase of 40% in meteor detections.

Already in August Detlef Koschny activated a second image-intensified camera Lic1 on Tenerife. The camera is identical to Lic4, which Detlef operates at his Dutch home in Noordwijk, however, a different lens stop is used. Data from this camera are reported here for the first time, the August data will be submitted later.

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IMO bibcode WGN-441-molau-vidsep
NASA-ADS bibcode 2016JIMO...44...21M

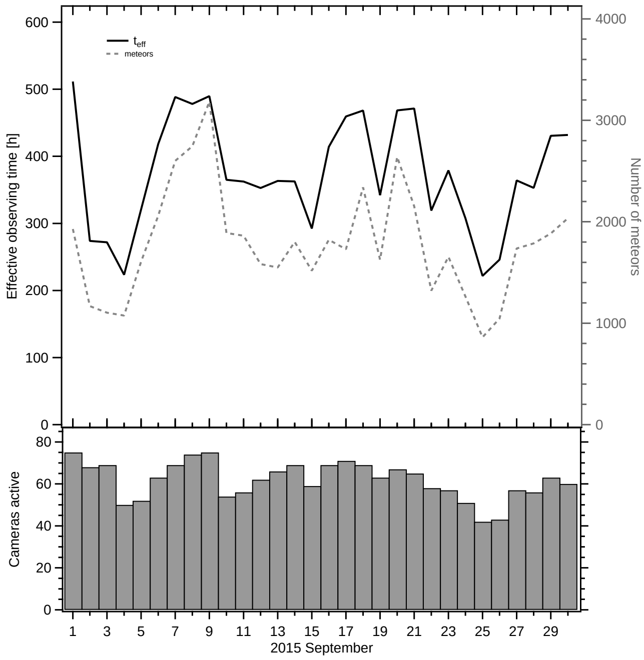

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2015 September.

2 Minor showers of September

September is renowned for a number of minor showers or "streamlets" which often show irregular activity. In some years a few radiants are active, in other years different radiants. Maybe that is not even a special characteristic of September, but at least there is a growing suspicion here, because meteor shower analyses often reveal different results. Three minor meteor shower candidates shall be analysed in more detail now.

2.1 κ-Cepheids

The first shower is the κ-Cepheids (751 KCE). This shower was recently detected by Croatian meteor observers (Šegon et al., 2015b) and has "working" status in the MDC list.[a] Showers are first marked like this, before they are taken over into the ordinary working list after an independent check. In this case, there was even a possible parent body identified: 2009 SG_{18}.

At the 2015 IMC, Damir Šegon pointed to possible enhanced activity in the morning hours (UT) of 2015 September 21 (Šegon et al., 2015a). Indeed, Jürgen

[a]http://www.astro.amu.edu.pl/~jopek/MDC2007/Roje/pojedynczy_obiekt.php?kodstrumienia=00751&colecimy=0&kodmin=00001&kodmax=00792

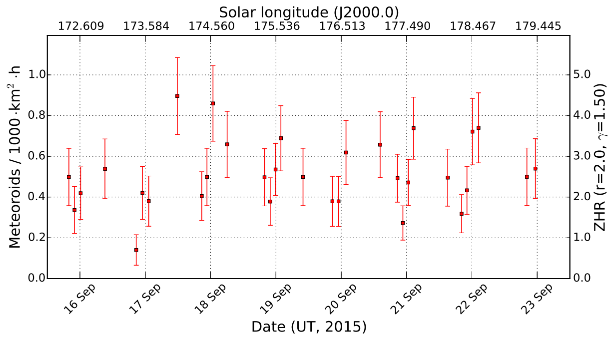

Figure 2 – Flux density profile of the 2015 κ-Cepheids, derived from observations of the IMO Video Network. The shower does not stand out from the sporadic background.

Rendtel visually spotted a handful of shower meteors in the relevant interval, but significance was low because of the small sample size (Rendtel, 2015).

After we re-calculated the shower assignment of all meteors, we could not confirm this observation. The shower does not stand out of the sporadic background at any time (Figure 2). Depending on the parameter choice, different peaks can be seen at different times, but they are of no significance. In addition we checked which radiants could be detected in the video data of September 20/21 (177°–178° solar longitude). None of the intersection areas matched even remotely to the given position.

The analysis of a million video meteors in 2012 showed some individual radiants between 174° and 180° solar longitude (Molau, 2014). All of them are farther north with a declination beyond 80°, their rank is partly beyond 20 and the shower parameters (α, δ, v_{geo}, rank) vary strongly from one night to the next. Hence, also in this data set we cannot identify the κ-Cepheids.

2.2 Suspect shower dismissed

Beyond that, Jürgen reported "suspicious activity" from a radiant near $\alpha = 95°$, $\delta = 67°$ on the morning of September 17 (174° solar longitude). Once more we re-calculated the radiants in that particular night, but there was no hit. Only in the following night we found one reasonable candidate with $\alpha = 97°$, $\delta = 63°$ and $v_{geo} = 59$ km/s. However, that one was at the bottom of the list and, thus, rather a chance alignment.

Also the 2012 analysis (Molau, 2014) yielded a radiant in close temporal (173° solar longitude) and spatial ($\alpha = 100°$, $\delta = 66°$, $v_{geo} = 58$ km/s) vicinity. However, also that one had a rank of 44 and must be rather rated as statistical fluctuation.

2.3 χ-Cygnids

The third meteor shower candidate are the χ-Cygnids (757 CCY) which were announced in an IAU telegram (Green, 2015). There Peter Jenniskens reported an "outburst" of a new cometary meteor shower. In the night of September 14/15, five similar orbits were obtained by the CAMS Benelux network. In the same night, CAMS California could provide an additional four orbits. At 172° solar longitude, the radiant was located at $\alpha = 301.^\circ0$ and $\delta = 32.^\circ6$ with $v_{geo} = 15.1$ km/s. Also Yasuo Shiba from the SonotaCo Network pointed by email to an unknown meteor shower that was observed between September 20 and 22. At 177° solar longitude, the average radiant position was about $\alpha = 298°$, $\delta = 36°$ with $v_{geo} = 15.5$ km/s. According to Shiba, the shower had not been detected in Japan between 2007 and 2014.

But was it indeed a new meteor shower?

Once more, we first turned to the analysis of 2012 (Molau, 2014). To ease the search for unknown meteor showers, Sirko Molau prepared an Excel file with macros two years ago.[b] There one only has to enter the observed radiant position, and Excel will calculate if there are similar radiants in our list. In addition one can check if there is a hit in the MDC list or the CMOR data. Indeed, we found immediately a number of matches in close spatial and temporal vicinity (Table 1, left column).

The radiant becomes visible at about 165° to 166° solar longitude, peaks around 171° to 172° and disappears at 173° solar longitude. Between 175° and 179° solar longitude it re-occurs, but with a position 5° more north. It remains an open question whether it is in fact one or two meteor showers.

Did we miss this meteor shower in our 2012 analysis? Not at all. The unknown shower was automatically recognized by our search routine, and we reported about this candidate in the September 2012 report (Molau et al., 2012; second shower in Table 9). At the IMC 2013, when the full list of IMO Network meteor showers was presented (Molau, 2014), we listed this shower candidate with number C8. The position given there matched perfectly to the data given in the telegram (Table 2).

Thus, we could identify this shower in our 1999–2011 data set. But was there indeed an "outburst" on 2015 September 14/15? We took the meteor shower parameters of 2012 (see Table 2), re-calculated the meteor shower assignment for 2012 till 2015 and determined the flux density profile (Figure 3). In 2015, the flux density was poor with a rate of about 0.5 meteoroids per 1 000 km^2 per hour. Still, this activity level was higher than in the three previous years, which probably just reflects the sporadic background. There was no particular peak on September 14/15.

Next we re-calculated the radiants per night for 2012 till 2015. The data sets are only one third to one half of the 1999–2011 data set. The shower can hardly be detected in the years 2012–2014, only sometimes we find radiants with similar parameters, but also a large rank. In 2015, however, the χ-Cygnids are the strongest meteor source in the sky between solar longitude 173° and 177°. The analysis had to be extended several times, because the activity interval was much larger than expected. In the end, we confirmed activity of the shower between 162° and 181° solar longitude without any doubt. The meteor shower was stronger and active longer than in the years before. That was probably

[b] `http://www.imonet.org/imc13/search_shower.xlsm`

Table 1 – Individual radiants from the χ-Cygnids, derived from observations of 1999–2011 as well as 2012 to 2015. *Rk* is the rank of the radiant.

	1999–2011 (76 000 meteors)			2012 (25 500 meteors)			2013 (25 000 meteors)			2014 (22 500 meteors)			2015 (39 000 meteors)		
$\lambda_\odot$	α / δ	v_{geo}	*Rk*	α / δ	v_{geo}	*Rk*	α / δ	v_{geo}	*Rk*	α / δ	v_{geo}	*Rk*	α / δ	v_{geo}	*Rk*
162													303 / 21	13	10
163				310 / 33	15	48							303 / 25	14	4
164													305 / 22	10	6
165	295 / 33	19	25				308 / 25	14	31				303 / 25	15	6
166	297 / 34	19	20							298 / 35	13	26	303 / 26	13	5
167													304 / 27	14	3
168	303 / 29	18	11				294 / 33	13	26				303 / 27	14	2
169	302 / 31	17	8	298 / 39	19	29							304 / 30	14	2
170	302 / 31	17	7				302 / 29	10	46				302 / 29	14	2
171	302 / 32	18	6	307 / 38	15	43	300 / 36	18	24	302 / 29	15	13	301 / 31	13	2
172	302 / 32	19	6				302 / 30	14	42				302 / 35	13	3
173	303 / 34	17	11	309 / 37	19	18				299 / 30	14	27	302 / 33	13	1
174													300 / 34	13	1
175	299 / 38	18	9										300 / 36	14	1
176	300 / 39	18	9				303 / 25	15	46	305 / 34	14	22	300 / 37	14	1
177	296 / 40	19	20	310 / 39	17	27	305 / 29	17	41	309 / 34	15	12	298 / 37	13	1
178	298 / 38	18	10				299 / 25	13	36				296 / 39	13	4
179	300 / 39	19	25										298 / 39	13	2
180													296 / 42	13	4
181													296 / 41	13	4

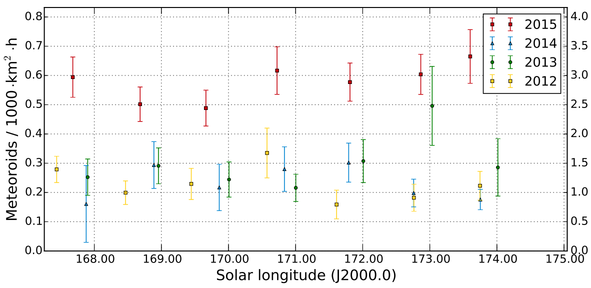

Figure 3 – Flux density profile of the χ-Cygnids 2012–2015, derived from observations of the IMO Video Network with the shower parameters of 2012.

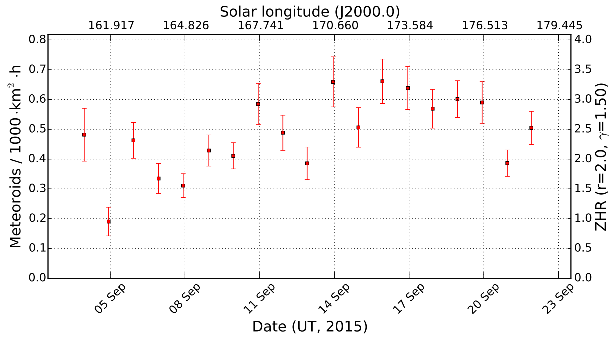

Figure 4 – Flux density profile of the χ-Cygnids 2015, derived from observations of the IMO Video Network with the new shower parameters of 2015.

the reason why it was detected both in the CAMS and SonotaCo network data of 2015.

The 2015 data set confirms that we are dealing here with a single shower, not two. Also the radiant drift can be determined precisely now thanks to the long activity interval. The drift in right ascension has a different sign than given by MDC. The difference in the radiant position of Jenniskens and Shiba confirm our value, though.

Last but not least we re-calculated the flux density of 2015 once more with the new parameters of Table 2. The result is given in Figure 4. The activity shows significant fluctuations and the peak occurred between September 14 and 17.

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Table 2 – Parameters of the χ-Cygnids from the MDC Working List and the analyses of the IMO Network in 2012 (Molau, 2014) and 2015 (this work).

	Solar Longitude		Right Ascension		Declination		v_{inf}	
Source	Mean [°]	Interval [°]	Mean [°]	Drift [°]	Mean [°]	Drift [°]	Mean [km/s]	Drift [km/s]
MDC	170.5	—	300.5	+0.68	+31.1	+0.2	14.65	—
IMO 2012	171	168–173	302	−0.0	+32.0	+0.9	14	—
IMO 2015	173	162–181	300.3	−0.4	+33.4	+1.1	13.3	—

ence, Mistelbach, Austria, 27–30 August 2015. International Meteor Organization, pages 51–57.

Šegon D., Gural P., Andreić Ž., Vida D., Skokić I., and Novoselnik F. (2015b). “Four possible new high-declination showers”. *WGN, Journal of the IMO*, **43:5**, 147–150.

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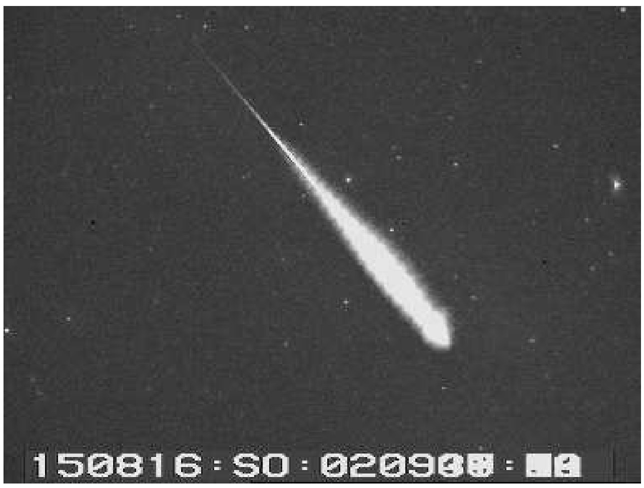
– A −1 magnitude sporadic meteor, recorded by Jenni camera on 2015 May 19 at $20^h15^m06^s$ UT.

– A −1 magnitude sporadic meteor, recorded by Jenni camera on 2015 June 13 at $20^h31^m08^s$ UT.

– A −4 magnitude sporadic meteor, recorded by Nowatec camera on 2015 June 19 at $18^h05^m04^s$ UT.



– A −2 magnitude sporadic meteor, recorded by Templar1 camera on 2015 August 16 at $00^h09^m37^s$ UT.

Table 3 – Observers contributing to 2015 September data of the IMO Video Meteor Network. Eff.CA designates the effective collection area; the overall number of nights is the number of nights with at least one camera operating, the overall observing time and number of meteors are sums over all cameras.

Code	Name	Location	Camera	FOV [$^{\circ 2}$]	Stellar LM [mag]	Eff.CA [km^2]	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	Ludwig2 (0.8/8)	1475	6.2	3779	30	189.5	1561
BANPE	Bánfalvi	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	12	27.2	202
BERER	Berkó	Ludányhalászi/HU	Hulud1 (0.8/3.8)	5542	4.8	3847	11	92.1	535
			Hulud3 (0.95/4)	4357	3.8	876	1	8.8	18
BOMMA	Bombardini	Faenza/IT	Mario (1.2/4.0)	5794	3.3	739	29	173.8	898
BREMA	Breukers	Hengelo/NL	Mbb3 (0.75/6)	2399	4.2	699	22	133.0	444
BRIBE	Klemt	Herne/DE	Hermine (0.8/6)	2374	4.2	678	26	144.6	594
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	23	117.2	431
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	5.0	1611	25	140.1	522
			Bmh2 (1.5/4.5)*	4243	3.0	371	23	123.1	438
CRIST	Crivello	Valbrevenna/IT	Bilbo (0.8/3.8)	5458	4.2	1772	28	180.4	813
			C3P8 (0.8/3.8)	5455	4.2	1586	26	135.6	497
			Stg38 (0.8/3.8)	5614	4.4	2007	29	199.4	1418
CSISZ	Csizmadia	Baja/HU	Huvcse02 (0.95/5)	1606	3.8	390	16	112.1	225
DONJE	Donani	Faenza/IT	Jenni (1.2/4)	5886	3.9	1222	26	168.7	1001
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	24	147.7	587
FORKE	Förster	Carlsfeld/DE	Akm3 (0.75/6)	2375	5.1	2154	24	133.5	726
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	28	209.6	915
			Templar2 (0.8/6)	2080	5.0	1508	28	204.5	696
			Templar3 (0.8/8)	1438	4.3	571	28	190.7	352
			Templar4 (0.8/3.8)	4475	3.0	442	27	205.3	734
			Templar5 (0.75/6)	2312	5.0	2259	26	171.2	746
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	19	125.4	567
			Orion3 (0.95/5)	2665	4.9	2069	18	95.7	248
			Orion4 (0.95/5)	2662	4.3	1043	13	74.3	187
HERCA	Hergenrother	Tucson/US	Salsa3 (0.8/3.8)	2336	4.1	544	26	192.1	526
HINWO	Hinz	Schwarzenberg/DE	Hinwo1 (0.75/6)	2291	5.1	1819	26	152.3	826
IGAAN	Igaz	Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	20	134.3	263
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	21	113.2	269
		Budapest/HU	Hupol (1.2/4)	3790	3.3	475	4	32.0	25
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	20	132.6	238
			Husor2 (0.95/3.5)	2465	3.9	715	20	140.1	255
KACJA	Kac	Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	22	100.3	250
		Kamnik/SI	Cvetka (0.8/3.8)*	4914	4.3	1842	16	84.4	596
			Rezika (0.8/6)	2270	4.4	840	15	85.5	878
			Stefka (0.8/3.8)	5471	2.8	379	10	60.1	327
KOSDE	Koschny	Izana Obs./ES	Icc7 (0.85/25)*	714	5.9	1464	27	222.9	2141
			Lic1 (2.8/50)*	2255	6.2	5670	26	182.8	1564
		La Palma/ES	Icc9 (0.85/25)*	683	6.7	2951	29	174.9	2891
		Noordwijkerhout/NL	Lic4 (1.4/50)*	2027	6.0	4509	20	106.9	194
LOJTO	Łojek	Grabniak/PL	Pav57 (1.0/5)	1631	3.5	269	5	26.6	34
LOPAL	Lopes	Lisbon/PT	Naso1 (0.75/6)	2377	3.8	506	28	87.5	346

Table 3 – Observers contributing to 2015 September data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Location	Camera	FOV [°2]	Stellar LM [mag]	Eff.CA [km2]	Nights	Time [h]	Meteors
MACMA	Maciejewski	Chełm/PL	Pav35 (0.8/3.8)	5495	4.0	1584	24	135.6	731
			Pav36 (0.8/3.8)*	5668	4.0	1573	22	123.7	647
			Pav43 (0.75/4.5)*	3132	3.1	319	21	134.5	488
			Pav60 (0.75/4.5)	2250	3.1	281	23	139.3	781
MARGR	Maravelias	Lofoupoli-Crete/GR	Loomecon (0.8/12)	738	6.3	2698	11	102.4	243
MARRU	Marques	Lisbon/PT	Cab1 (0.8/3.8)	5291	3.1	467	28	200.1	734
			Ran1 (1.4/4.5)	4405	4.0	1241	28	207.4	601
MASMI	Maslov	Novosibirsk/RU	Nowatec (0.8/3.8)	5574	3.6	773	14	69.7	344
MOLSI	Molau	Seysdorf/DE	Avis2 (1.4/50)*	1230	6.9	6152	24	161.2	1921
			Escimo2 (0.85/25)	155	8.1	3415	22	146.7	310
			Mincam1 (0.8/8)	1477	4.9	1084	22	139.1	980
		Ketzür/DE	Remo1 (0.8/8)	1467	6.5	5491	30	207.4	2106
			Remo2 (0.8/8)	1478	6.4	4778	30	214.3	1765
			Remo3 (0.8/8)	1420	5.6	1967	26	174.9	1084
			Remo4 (0.8/8)	1478	6.5	5358	30	218.4	1889
MORJO	Morvai	Fülöpszállás/HU	Huful (1.4/5)	2522	3.5	532	18	134.8	255
MOSFA	Moschini	Rovereto/IT	Rover (1.4/4.5)	3896	4.2	1292	22	23.3	150
OCHPA	Ochner	Albiano/IT	Albiano (1.2/4.5)	2944	3.5	358	8	16.9	128
OTTMI	Otte	Pearl City/US	Orie1 (1.4/5.7)	3837	3.8	460	26	145.2	313
PERZS	Perkó	Becsehely/HU	Hubec (0.8/3.8)*	5498	2.9	460	20	135.0	785
ROTEC	Rothenberg	Berlin/DE	Armefa (0.8/6)	2366	4.5	911	27	192.0	436
SARAN	Saraiva	Carnaxide/PT	Ro1 (0.75/6)	2362	3.7	381	28	201.3	411
			Ro2 (0.75/6)	2381	3.8	459	27	209.4	614
			Ro3 (0.8/12)	710	5.2	619	26	208.8	628
			Sofia (0.8/12)	738	5.3	907	28	216.2	462
SCALE	Scarpa	Alberoni/IT	Leo (1.2/4.5)*	4152	4.5	2052	24	129.4	280
SCHHA	Schremmer	Niederkrüchten/DE	Doraemon (0.8/3.8)	4900	3.0	409	22	114.8	555
SLAST	Slavec	Ljubljana/SI	Kayak1 (1.8/28)	563	6.2	1294	20	96.0	369
			Kayak2 (0.8/12)	741	5.5	920	18	94.6	115
STOEN	Stomeo	Scorze/IT	Min38 (0.8/3.8)	5566	4.8	3270	25	129.6	843
			Noa38 (0.8/3.8)	5609	4.2	1911	26	128.5	663
			Sco38 (0.8/3.8)	5598	4.8	3306	25	126.5	847
STRJO	Strunk	Herford/DE	Mincam2 (0.8/6)	2354	5.4	2751	27	148.0	810
			Mincam3 (0.8/6)	2338	5.5	3590	27	121.2	663
			Mincam4 (1.0/2.6)	9791	2.7	552	24	78.0	135
			Mincam5 (0.8/6)	2349	5.0	1896	29	142.8	532
			Mincam6 (0.8/6)	2395	5.1	2178	25	127.5	491
TEPIS	Tepliczky	Agostyán/HU	Huago (0.75/4.5)	2427	4.4	1036	23	138.5	371
			Humob (0.8/6)	2388	4.8	1607	22	138.9	646
TRIMI	Triglav	Velenje/SI	Sraka (0.8/6)*	2222	4.0	546	14	52.0	148
YRJIL	Yrjölä	Kuusankoski/FI	Finexcam (0.8/6)	2337	5.5	3574	19	94.6	318
						Overall	30	11 250.5	53 569

* active field of view smaller than video frame

Results of the IMO Video Meteor Network — October 2015

Sirko Molau[1], Stefano Crivello[2], Rui Goncalves[3], Carlos Saraiva[4], Enrico Stomeo[5], and Javor Kac[6]

The October 2015 overview of IMO Video Meteor Network observations is presented, covering more than 9 600 hours of observations with almost 55 000 recorded meteors. The flux density profile is presented for the October Ursae Majorids for the years 2011 to 2015. The flux density profiles for Orionids are presented for years 2012 to 2015, showing a broad maximum between October 20 and 27.

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1 Introduction

The unusually attractive observing conditions of the previous months finally terminated in October. Often the pleasant Indian summer days extend well into October, but this year the observing statistics has as many holes as Swiss cheese. Only 38 cameras, i.e. less than half of the 82 active cameras, managed to record meteors in twenty or more nights. Most cameras (67) were active in the night of October 30/31 (Table 1 and Figure 1).

With respect to the number of observing hours, October 2015 falls 15% short of the outcome from the previous year. However, the average of 5.7 meteors per hour was well beyond the value of the previous three years (4.6 to 4.9) and comparable to the values of 2009 and 2011. Only October 2010, when the Orionids were particularly active, is out of reach with an average of 7.0 meteors per hour.

2 Minor showers of October

The narrow peak of the October Camelopardalids at 192.6° solar longitude occurred in the daytime hours UT of 2015 October 6 and was not covered by European video cameras. Our two American observers together caught just one shower member.

The Draconids two nights later did not emerge noticeably from the sporadic background either.

The October Ursae Majorids peaked in the night of October 15/16. Unfortunately the observing conditions were particularly poor that night. Still, the activity profile fits nicely to the values of the previous years with a maximum flux density of about 6 meteoroids per 1 000 km^2 per hour (Figure 2).

Similarly to the ε-Geminids, the Leonis Minorids show no distinct activity profile in the last third of October. Their flux density varies between 6 and 7 meteoroids per 1 000 km^2 per hour.

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IMO bibcode WGN-441-molau-vidoct
NASA-ADS bibcode 2016JIMO...44...27M

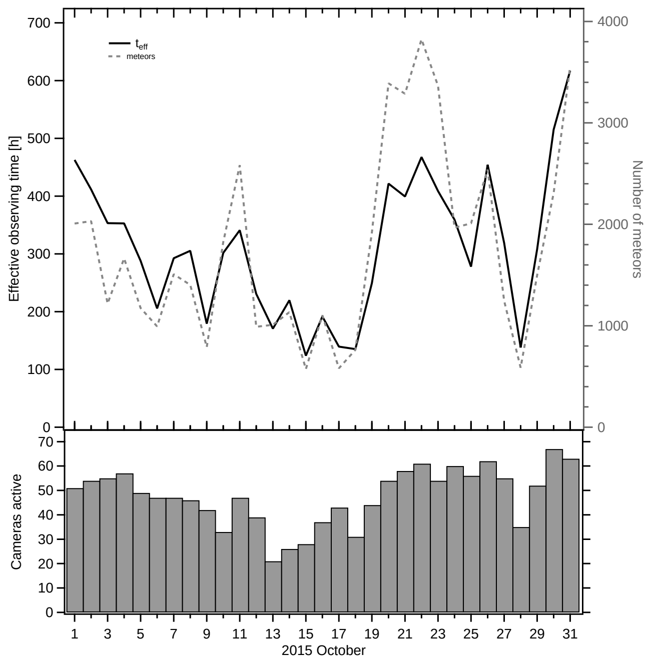

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2015 October.

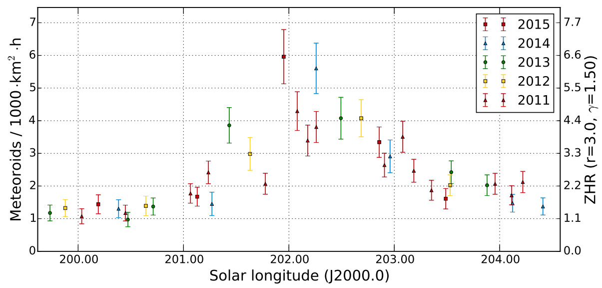

Figure 2 – Flux density profiles of the October Ursae Majorids, derived from observations of the IMO Video Network between 2011 and 2015.

As in the years before, the ε-Geminids showed an activity profile with a roughly constant flux density and no distinct peak.

2.1 Orionids

The Orionids have a well-defined activity profile. Contrary to other large showers, their peak is not spiky but rather curved (Figure 3). The flux density between October 20 and 27 is above 10 meteoroids per 1 000 km^2 per hour.

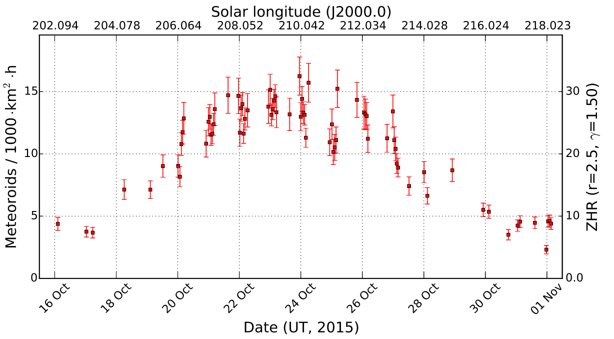

Figure 3 – Flux density profile of the Orionids 2015, derived from observations of the IMO Video Network.

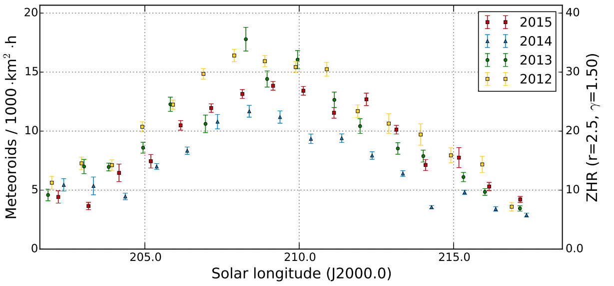

Figure 4 – Comparison of the flux density profiles of the Orionids 2012–2015.

The flux density does not differ significantly between 2015 and the three preceding years, after Orionid activity had come back to the typical level in 2012 (Figure 4). The lowest values were observed in 2014 and the highest in 2012. The two years of 2013 and 2015 are somewhere in-between. After we learned in the July analysis (Molau et al., 2015) that our current flux density measurements are systematically affected by the Moon, these variations may solely result from different lunar phases.

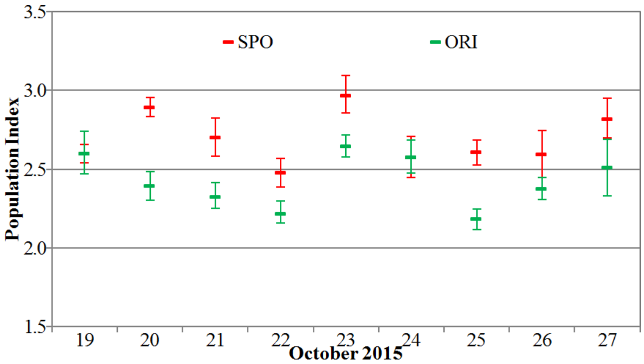

Figure 5 – Population index of the Orionids and sporadic meteors in October 2015.

The calculated population index is given in Figure 5. Unfortunately it shows significant scatter even after the correction of the perception coefficient and long-term variations. All we can say is that the r-value of the Orionids was about 0.3 lower than the sporadic r-value. Only in the night of October 24/25, when the rates also showed a little dip, both population indices were identical.

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Molau S., Kac J., Crivello S., Stomeo E., Barentsen G., Goncalves R., Saraiva C., Maciejewski M., and Maslov M. (2015). "Results of the IMO Video Meteor Network – July 2015". *WGN, Journal of the IMO*, **43:6**, 181–187.

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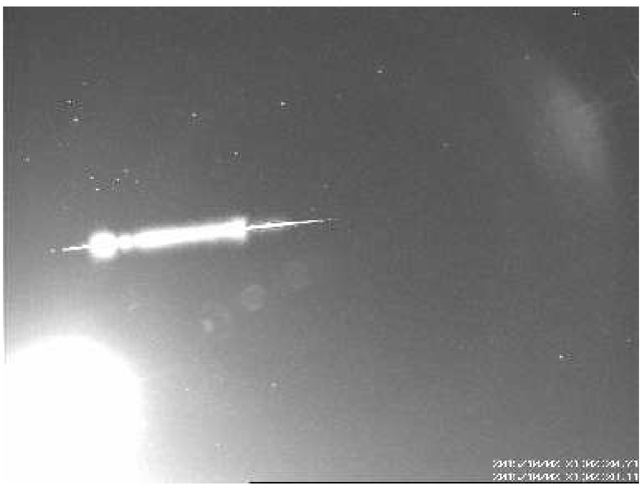

– A −4 magnitude sporadic meteor, recorded by HUBEC camera on 2015 October 2 at $21^h02^m20^s$ UT.

– A −3 magnitude sporadic meteor, recorded by HUDEB camera on 2015 October 31 at $02^h57^m16^s$ UT.

Table 1 – Observers contributing to 2015 October data of the IMO Video Meteor Network. Eff.CA designates the effective collection area; the overall number of nights is the number of nights with at least one camera operating, the overall observing time and number of meteors are sums over all cameras.

Code	Name	Location	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Meteors
ARLRA	Arlt	Ludwigsfelde/DE	Ludwig2 (0.8/8)	1475	6.2	3779	21	126.4	1082
BANPE	Bánfalvi	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	14	34.4	279
BERER	Berkó	Ludányhalászi/HU	Hulud1 (0.8/3.8)	5542	4.8	3847	11	86.1	597
BOMMA	Bombardini	Faenza/IT	Mario (1.2/4.0)	5794	3.3	739	19	136.2	845
BREMA	Breukers	Hengelo/NL	Mbb3 (0.75/6)	2399	4.2	699	20	142.9	432
BRIBE	Klemt	Herne/DE	Hermine (0.8/6)	2374	4.2	678	18	147.9	656
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	20	132.9	548
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	5.0	1611	18	142.8	906
			Bmh2 (1.5/4.5)*	4243	3.0	371	19	136.6	732
CRIST	Crivello	Valbrevenna/IT	Bilbo (0.8/3.8)	5458	4.2	1772	22	166.0	1212
			C3P8 (0.8/3.8)	5455	4.2	1586	23	165.8	874
			Stg38 (0.8/3.8)	5614	4.4	2007	23	151.2	898
CSISZ	Csizmadia	Baja/HU	Huvcse02 (0.95/5)	1606	3.8	390	22	129.3	272
DONJE	Donani	Faenza/IT	Jenni (1.2/4)	5886	3.9	1222	20	143.7	941
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	19	140.0	963
FORKE	Förster	Carlsfeld/DE	Akm3 (0.75/6)	2375	5.1	2154	16	119.6	768
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	20	137.3	913
			Templar2 (0.8/6)	2080	5.0	1508	18	139.2	682
			Templar3 (0.8/8)	1438	4.3	571	21	133.2	417
			Templar4 (0.8/3.8)	4475	3.0	442	19	128.8	683
			Templar5 (0.75/6)	2312	5.0	2259	22	129.9	882
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	15	99.4	593
			Orion3 (0.95/5)	2665	4.9	2069	16	83.9	243
			Orion4 (0.95/5)	2662	4.3	1043	1	8.4	22
HERCA	Hergenrother	Tucson/US	Salsa3 (0.8/3.8)	2336	4.1	544	28	224.6	812
HINWO	Hinz	Schwarzenberg/DE	Hinwo1 (0.75/6)	2291	5.1	1819	15	120.3	726
IGAAN	Igaz	Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	15	119.5	371
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	22	93.2	350
		Budapest/HU	Hupol (1.2/4)	3790	3.3	475	9	53.8	56
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	19	168.6	473
			Husor2 (0.95/3.5)	2465	3.9	715	20	169.0	412
KACJA	Kac	Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	16	54.0	158
		Kamnik/SI	Cvetka (0.8/3.8)*	4914	4.3	1842	16	87.8	694
			Rezika (0.8/6)	2270	4.4	840	16	101.7	1252
			Stefka (0.8/3.8)	5471	2.8	379	15	86.8	508
		Kostanjevec/SI	Metka (0.8/12)*	715	6.4	640	2	18.1	73
KOSDE	Koschny	Izana Obs./ES	Icc7 (0.85/25)*	714	5.9	1464	24	160.0	1723
			Lic1 (2.8/50)*	2255	6.2	5670	20	131.3	1195
		La Palma/ES	Icc9 (0.85/25)*	683	6.7	2951	26	143.2	2213
		Noordwijkerhout/NL	Lic4 (1.4/50)*	2027	6.0	4509	19	130.7	235
LOJTO	Łojek	Grabniak/PL	Pav57 (1.0/5)	1631	3.5	269	2	19.7	57

Table 1 – Observers contributing to 2015 October data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Location	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Meteors
LOPAL	Lopes	Lisboa/PT	Naso1 (0.75/6)	2377	3.8	506	7	24.0	132
MACMA	Maciejewski	Chełm/PL	Pav35 (0.8/3.8)	5495	4.0	1584	22	171.8	1276
			Pav36 (0.8/3.8)*	5668	4.0	1573	20	170.4	1041
			Pav43 (0.75/4.5)*	3132	3.1	319	21	166.4	701
			Pav60 (0.75/4.5)	2250	3.1	281	20	166.3	1119
MARGR	Maravelias	Lofoupoli-Crete/GR	Loomecon (0.8/12)	738	6.3	2698	24	177.0	595
MARRU	Marques	Lisbon/PT	Cab1 (0.8/3.8)	5291	3.1	467	19	96.7	396
			Ran1 (1.4/4.5)	4405	4.0	1241	15	91.1	431
MASMI	Maslov	Novosibirsk/RU	Nowatec (0.8/3.8)	5574	3.6	773	2	16.3	121
MOLSI	Molau	Seysdorf/DE	Avis2 (1.4/50)*	1230	6.9	6152	19	129.3	1272
			Escimo2 (0.85/25)	155	8.1	3415	16	105.6	223
			Mincam1 (0.8/8)	1477	4.9	1084	19	104.3	624
		Ketzür/DE	Remo1 (0.8/8)	1467	6.5	5491	21	150.7	1453
			Remo2 (0.8/8)	1478	6.4	4778	21	152.8	1271
			Remo3 (0.8/8)	1420	5.6	1967	15	80.0	473
			Remo4 (0.8/8)	1478	6.5	5358	21	161.0	1192
MORJO	Morvai	Fülöpszállás/HU	Huful (1.4/5)	2522	3.5	532	20	170.7	429
MOSFA	Moschini	Rovereto/IT	Rover (1.4/4.5)	3896	4.2	1292	15	38.3	263
OTTMI	Otte	Pearl City/US	Orie1 (1.4/5.7)	3837	3.8	460	23	132.1	349
PERZS	Perkó	Becsehely/HU	Hubec (0.8/3.8)*	5498	2.9	460	20	109.1	677
ROTEC	Rothenberg	Berlin/DE	Armefa (0.8/6)	2366	4.5	911	19	135.5	369
SARAN	Saraiva	Carnaxide/PT	Ro1 (0.75/6)	2362	3.7	381	19	99.8	307
			Ro2 (0.75/6)	2381	3.8	459	18	90.2	344
			Ro3 (0.8/12)	710	5.2	619	17	84.0	372
			Sofia (0.8/12)	738	5.3	907	19	105.9	384
SCALE	Scarpa	Alberoni/IT	Leo (1.2/4.5)*	4152	4.5	2052	17	91.1	343
SCHHA	Schremmer	Niederkrüchten/DE	Doraemon (0.8/3.8)	4900	3.0	409	21	125.6	628
SLAST	Slavec	Ljubljana/SI	Kayak1 (1.8/28)	563	6.2	1294	17	66.3	257
			Kayak2 (0.8/12)	741	5.5	920	13	66.6	120
STOEN	Stomeo	Scorze/IT	Min38 (0.8/3.8)	5566	4.8	3270	22	150.3	1713
			Noa38 (0.8/3.8)	5609	4.2	1911	20	153.1	1492
			Sco38 (0.8/3.8)	5598	4.8	3306	21	160.0	1821
STRJO	Strunk	Herford/DE	Mincam2 (0.8/6)	2354	5.4	2751	23	143.2	905
			Mincam3 (0.8/6)	2338	5.5	3590	23	149.5	727
			Mincam4 (1.0/2.6)	9791	2.7	552	15	13.4	83
			Mincam5 (0.8/6)	2349	5.0	1896	19	102.2	530
			Mincam6 (0.8/6)	2395	5.1	2178	22	144.0	503
TEPIS	Tepliczky	Agostyán/HU	Huago (0.75/4.5)	2427	4.4	1036	20	151.7	493
			Humob (0.8/6)	2388	4.8	1607	19	154.0	848
TRIMI	Triglav	Velenje/SI	Sraka (0.8/6)*	2222	4.0	546	7	26.7	67
YRJIL	Yrjölä	Kuusankoski/FI	Finexcam (0.8/6)	2337	5.5	3574	22	169.6	756
* active field of view smaller than video frame						Overall	31	9 640.8	54 848

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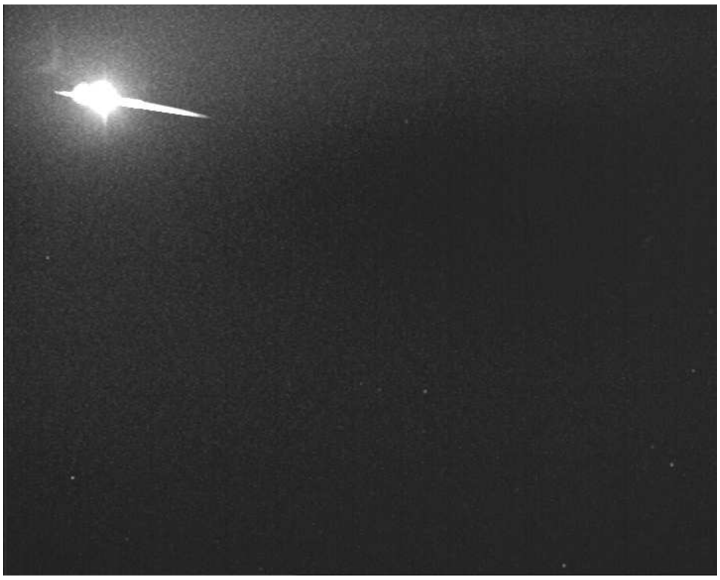
2015 Taurids from Croatia

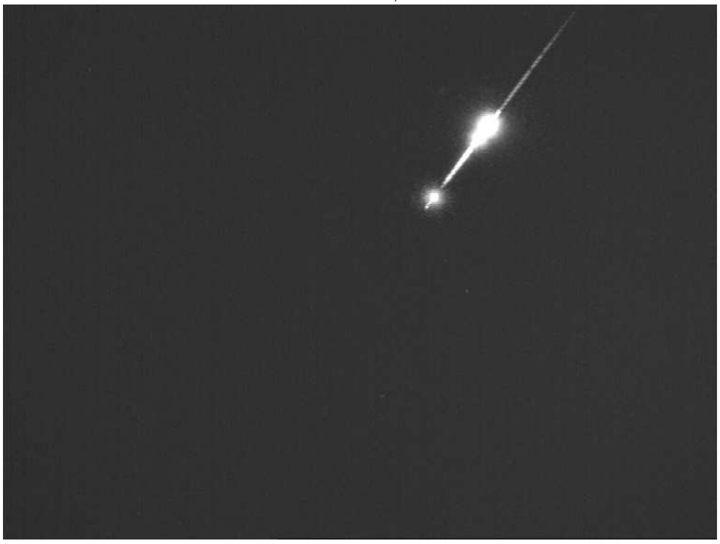
2015 November 5, $19^{h}05^{m}$ UT



CMN camera Višnjan_B, courtesy of Denis Vida and Korado Korlević

CMN camera Rijeka_B, courtesy of Ivica Ćiković

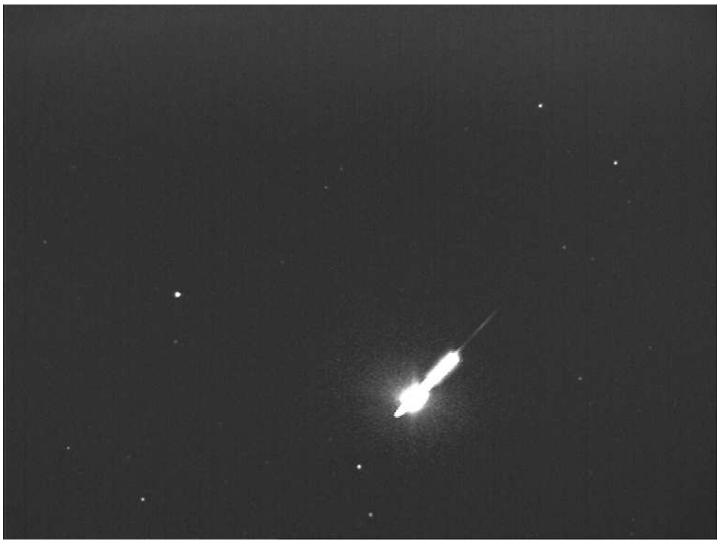
2015 November 12, $01^{h}15^{m}$ UT



CMN camera Višnjan_D, courtesy of Denis Vida and Korado Korlević

The 2015 Taurids put on a spectacular display. The Croatian Meteor Network has recorded a number of fireballs from that shower, using 1004X cameras and CAMS software. Some of the detected fireballs are presented here.

2015 November 24, $00^{h}10^{m}$ UT



CMN camera Višnjan_B, courtesy of Denis Vida and Korado Korlević

CMN camera Rijeka_A, courtesy of Ivica Ćiković