Confirmation and characterization of IAU temporary meteor showers in EDMOND database

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Abstract. The European viDeo MeteOr Network Database (EDMOND) is a database of video meteor orbits resulting from cooperation and data sharing among several European national networks and the International Meteor Organization Video Meteor Network, IMO VMN, (Kornoš et al. 2013b). At present, the 4th version of the EDMOND database, which contains 83 369 video meteor orbits, has been released.

The first results of the database analysis, in which we studied minor streams, are presented. Using the radiant-geocentric velocity method we identified 267 meteor showers, among them 67 established showers and 200 from the working list of the IAU MDC. Making a more detailed examination, we clearly identified 22 showers of 65 *pro tempore* showers of the working list of the IAU MDC (updated in August 2013). The identification of 18 meteor showers was questionable, while 25 showers were not found. For all the identified temporary meteor showers, we list the weighted mean orbital elements, the radiant position and the geocentric velocity.

Keywords: meteor showers, meteor orbital databases, cluster analysis

1. Introduction

The rapid development of video techniques in recent years has resulted in the massive use of video cameras in meteor observations. The number of new meteor networks has increased, and the efficiency of those already existing has improved. In three years, the Japanese meteor network database, containing around 30 low-light level camera observations, grew to 65 000 orbits (SonotaCo 2009); SonotaCo et al. (2010). The recently established system CAMS (Cameras for Allsky Meteor Surveillance) in the United States obtained 47 000 orbits of meteors just in the first year of its operation (Jenniskens et al. 2011). In Europe, between 2000 and 2013, the IMO Video Meteor Network collected over 1.2 million single-station meteors (Molau 2014). Also, in Europe, the continuous monitoring of meteors and fireballs is conducted by the 25 stations the Spanish Meteor and Fireball Network (SPMN; Pujols et al. (2013), which has been working now for 5 years. While till mid-2011, NASA's All-Sky Fireball network, established in 2008, with its 6 video cameras, detected 1796 multi-station meteors (Cooke and Moser 2012). Another good example of well developed regional networks are the Canadian Automated Meteor Obser-

vatory (CAMO), (Brown et al. 2010) and the Croatian Meteor Network (CMN), (Andreić and Šegon 2010).

Thanks to the broad international cooperation of video meteor observers from several European countries, a multi-national network EDMONd (European viDeo-Meteor Observation Network) was created. As a result of its work, the first version of the EDMOND database, containing data from the years 2009, 2010, 2011 and half of 2012, was presented at the IMC conference in La Palma, Spain in 2012 (Kornoš et al. 2013a). In the last year, observers affiliated to the International Meteor Organization Video Meteor Network (IMO VMN) have started to share their data, whereas the data of EDMONd and IMO VMN have been merged. Nowadays, the data is collected from observers from a substantial part of Europe and, due to this international cooperation, meteor activity is monitored over almost the entire Europe. In effect, the database has accumulated 1 639 358 records of single-station meteors between 2000 and 2013 (EDMONd – 447 266 and IMO VMN – 1 192 092).

2. EDMOND database

The computation of meteor orbits is performed by the UFOOrbit software (Sono-taCo 2009). As the single-station video data are obtained and reduced using two different tools, the MetRec (Molau 1999) and UFOAnalyzer tools (SonotaCo 2009), the UFO data can be used without any changes. However, the data obtained by the MetRec software has to be first converted into the UFO format using the program INF2MCSV written by SonotaCo. The present database contains about 72 % of MetRec data. As the conversion is not fully compatible, the computation of orbits is performed in two steps. First, preliminary orbits are computed using UFOOrbit with basic parameter settings Q_o and $dt = 5$ sec (which means that all combinations of single-station meteors within 5 second intervals are computed), and with additional settings: beginning and terminal heights have to be $H_{1,2} \in (15; 200)$ km, the empirically derived quality parameter $QA > 0.3$, and the largest difference in velocity among considered stations in the orbit computation is $dV < 7$ km/s.

After that, to reject the less precise orbits and false orbits, another filter of parameters is applied: the angle of observed trajectory has to be $Q_o > 1$ deg, the duration of the meteor $dur > 0.1$ sec, the convergence angle $Q_c > 10$ deg, the difference between the two poles of ground trajectory $dGP < 0.5$ deg, and the difference in velocity between unified velocity and velocity from one of the stations $dv12\% < 7.07$ %. In comparison to the previous versions of the database, the most important modification is the restriction of the difference in velocities for stations used in meteor orbit computation. The definition of all parameters is in the UFO Manual. More details can be found in (Kornoš et al. 2013b).

At present, the 4th version of the EDMOND database containing 83 369 video meteor orbits, has been released. Most of them ($\sim 84\%$) are double-stations orbits. About 48 800 orbits belong to the sporadic background and 34 500 are shower meteors (59 % and 41 %, respectively).

The EDMOND database was examined in several tests and compared with other meteor orbits databases. The examination allowed us to demonstrate the characteristic features of the EDMOND, which are particularly important for future analyses based on the data.

The derivation of orbital elements, which define the shape of the orbit, is highly dependent on the uncertainty of the determination of the meteor velocity. One of the parameters used in the data reduction is dv12% (the difference in the velocities, given in percentage). The geocentric velocity is the decisive parameter in the calculation of the orbit. Thus, the dv12% parameter is an important indicator of its accuracy. The smaller the difference between velocities from different stations, the more accurate the orbit determination is. Therefore, in the distribution of dv12%, a decrease in the number of orbits with increasing values of dv12% should be the most rapid. The comparison of the distribution of dv12% parameter of the EDMOND (Kornoš et al. 2013a) and SonotaCo catalogue showed similar decrease; with a slightly slower one in the EDMOND.

The distributions of orbital parameters within several meteoroid streams from EDMOND were also analysed. In Kornoš et al. (2013a), the dispersions of orbital elements of the Lyrids from EDMOND were studied. Comparing them with the SonotaCo video orbits, the consistency of both datasets was demonstrated. Moreover, if we compare both sets of video data (Figure 1), the dispersions in $1/a$ of the meteor orbits within individual streams obtained from the EDMOND data are about 1.3 times larger than the values from the SonotaCo catalogue. Figure 1 shows the observed differences in the semi-major axes within the meteor streams compared with the orbital deviations in the streams determined from different datasets. The median semimajor axes of video meteor orbits in both the EDMOND and SonotaCo data are systematically biased, probably as a consequence of the method used to determine the orbits. In comparison with the IAU MDC photographic database (Lindblad et al. 2003), they are shifted towards the short-period side; the velocities determined in the video data are slightly underestimated.

An important indicator of the quality of data is the relative number of hyperbolic orbits, because the probability of registering real hyperbolic orbits is very small (Hajduková et al. 2014a). The apparent hyperbolicity of the orbits is, generally, caused by a high spread in velocity determination, shifting a part of the data through the parabolic limit. This, however, does not explicitly mean large measurement errors. Of the 83 369 meteor orbits collected in the EDMOND, 5.7% are determined as hyperbolic. This percentage is roughly comparable to that in the SonotaCo database. Initially, the proportion of hyperbolic meteors in the latter was 11.58%, but after the selection of quality orbits (Vereš and Tóth 2010), this was reduced to 3.28%. Of the 4712 hyperbolic meteors in the EDMOND, 43% are shower meteors. Shower meteors which have heliocentric velocities with excesses over the parabolic limit offer proof of the false hyperbolicity of their orbits. The hyperbolic orbits in our data were analysed separately in the paper Hajduková et al. (2014b).

A comparison of both the EDMOND and the SonotaCo catalogue, in terms of orbital parameters, showed an equivalence of the data.
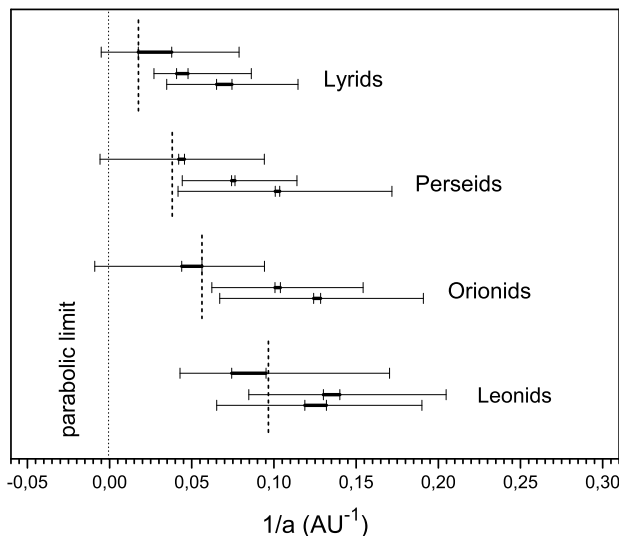
Figure 1. Comparison of the observed dispersion for the chosen meteoroid streams from different databases (upper line – photographic meteors from the IAU MDC, middle line – video meteors from the SonotaCo catalogue (2007–2009), lower line – the EDMOND data) described by absolute median deviation in terms of $1/a$: Thin line – the interval between two limiting values of $(1/a)_{1/2}$, which includes 50 percent of all orbits. Bold line – the interval between two limiting values of the uncertainty $(1/a)_L$ of the resulting values of median $(1/a)_M$. Dotted vertical line – the parabolic limit. Dashed vertical lines – parent comets (the figure is taken from the paper (Hajduková 2014)).

3. Identification of streams in EDMOND

Meteor showers in the EDMOND database were identified using the IAU Meteor Data Center Database (IAU MDC; (Jopek and Kaňuchová 2014)). At the end of August 2013, the IAU MDC list of showers contained 461 showers, 95 of them established and 366 in the working list.

In the first search, the radiant position-geocentric velocity method was used (we hereafter call it *radiant-V_g* method). Meteors were selected according to the peaks activity of meteor showers (± 15 deg) given in the IAU MDC list, and fulfilling the conditions for radiant position (± 5 deg) and geocentric velocity ($\pm 10\% \cdot V_g$). A shower was considered only if at least 5 orbits had been identified. In this way, 267 meteor showers were identified, where 200 of them are meteor showers from the working list and 67 are the established showers.

We focused on *pro tempore* showers from the IAU MDC working list. Of 65 *pro tempore* showers in the list, 61 were identified using the *radiant-V_g* method. To determine their fundamental parameters more precisely, the first part of the Welch method (Welch 2001) with Southworth-Hawkins D criterion (Southworth and Hawkins 1963) was used. According to the equation (4) in Welch (2001) paper

$$\rho = \sum_{i=1}^{N} \left(1 - \frac{D_i^2}{D_c^2} \right) \ ; \qquad D_i \leqslant D_c \ , \tag{3.1}$$

where ρ is a density at a point in orbital elements space, N is the number of meteors of a *pro tempore* shower found in the first step, D_i is the value obtained for the i-th meteor in the *pro tempore* shower by comparing its orbit with orbits of each member of the identified shower, and D_c is the threshold value that determines the dynamical similarity among meteor orbits. We searched for the core of each *pro tempore* shower identified in the first step of the analysis (i.e. by *radiant-V_g* method).

The procedure creates a group of meteors around each meteor orbit from the examined shower, which fulfil the condition of the limiting value of Southworth and Hawkins criterion $D_c = 0.12$. On the basis of the equation (3.1), the value of the density (ρ) is determined for each group. The higher the density value, the more important the group in the examined shower is. However, the highest value of ρ does not always mean it is the core of the stream because the initial set could be contaminated by a nearby separate small shower; or because the MDC data are not yet accurate enough.

We therefore compared all the available parameters of each *pro tempore* shower at the IAU MDC with the mean values of the same parameters of each found group. We compared as well the mean orbits, radiant positions and geocentric velocities with newly meteor showers found in the SonotaCo (2007-2009) and CAMS (2010-2011) databases (Rudawska and Jenniskens 2014). The mean values of the orbital elements and other parameters of each group were obtained as a weighted arithmetic mean, where the weight was determined by $(1 - D_i^2/D_c^2)$ (Welch 2001).

The results obtained from this procedure are given in Table 1 and Table 2. Table 1 contains 22 showers for which the identification was certain, i.e. the parameters of which agree well with those from the IAU MDC list. Another 18 showers, for which the comparison showed quite considerable differences in some parameters, and thus making their identification questionable, are shown in Table 2. For instance, the difference in solar longitude or right ascension of radiant position reaches $10°$, while the difference in eccentricities and perihelion distances, probably due to their high geocentric velocity, is greater than 0.1. In the EDMOND database (as of August 2013) we could not identify 25 *pro tempore* meteor showers. The reason is either the number of orbits in the particular showers was insufficient (less than 5) or the differences between some of the compared parameters were too big (larger than in Table 2).

A few low inclined meteor showers (#449, #467, #473, #475, #476, #478) seem to be represented as separate branches, where one (or both) of the branch includes from 1 to 3 members. However, as the amount of meteors in the Northern and/or Southern branch is small (<5), and there is no evident splitting, in those cases we considered such shower as one meteor shower. Therefore, we added (or subtracted) 180 degrees to the angular elements (ω, Ω) of the smaller branch, and then the weighted mean of ω and Ω of the shower was calculated.

Table 1. Mean values of the parameters: solar longitude (L_S), radiant position $(RA, Dc)_{2000}$, geocentric velocity (V_g), orbital elements and (D) – Southworth-Hawkins criterion of reliably identified *pro tempore* showers from the IAU MDC in the database EDMOND. N – number of meteors. In the second line of each shower, there are standard deviations.

Shower	L_S	RA	Dec	V_g	q [AU]	e	ω [°]	Ω [°]	i [°]	N	D_{SH}
448 AAL	14.4	219.7	-13.0	37.70	0.097	0.945	329.6	14.4	6.7	8	0.05
	6.0	3.2	1.6	2.35	0.028	0.025	5.4	6.0	3.5		0.04
449 ABS	7.3	166.5	5.5	14.65	0.844	0.658	52.4	187.3	0.7	5	0.04
	5.1	2.4	2.7	0.82	0.023	0.050	4.6	5.1	0.8		0.04
456 MPS	61.7	243.7	-10.5	24.63	0.541	0.790	273.2	61.7	9.0	26	0.05
	4.4	2.9	1.4	1.12	0.040	0.025	4.8	4.4	1.2		0.03
458 JEC	83.0	315.5	33.1	52.11	0.911	0.888	218.7	83.0	95.4	10	0.05
	1.9	1.4	1.0	0.80	0.008	0.047	1.4	1.9	1.1		0.03
460 LOP	85.9	257.6	-5.4	19.62	0.722	0.724	251.8	85.9	10.3	27	0.05
	3.7	2.2	2.4	1.13	0.037	0.032	5.0	3.7	1.0		0.03
462 JGP	120.5	263.5	13.3	62.31	0.484	0.922	275.2	120.5	149.4	12	0.06
	3.5	161.1	1.1	0.57	0.040	0.034	4.2	3.5	1.7		0.03
463 JRH	125.8	265.9	36.2	14.18	0.982	0.553	204.5	125.8	19.7	8	0.05
	5.2	2.8	2.3	0.97	0.012	0.046	5.4	5.2	1.5		0.03
465 AXC	136.1	4.7	48.9	54.72	0.898	0.843	221.4	136.1	104.2	14	0.06
	2.1	3.0	1.3	0.63	0.015	0.049	2.7	2.1	1.2		0.03
466 AOC	136.8	29.0	0.9	65.84	0.696	0.901	70.2	316.8	159.8	6	0.05
	4.5	3.5	2.1	0.56	0.025	0.048	2.9	4.5	3.6		0.05
467 ANA	139.5	318.1	-12.2	21.35	0.612	0.752	265.6	139.5	2.6	23	0.06
	3.2	2.1	2.1	1.39	0.037	0.037	4.2	3.2	1.6		0.03
474 ABA	147.9	301.3	4.5	15.07	0.860	0.676	230.9	147.9	10.1	11	0.05
	6.6	1.9	2.4	1.49	0.041	0.053	7.4	6.6	1.0		0.03
477 SRP	177.1	345.9	5.1	18.41	0.699	0.699	254.8	177.1	5.8	15	0.06
	4.2	1.8	2.0	1.51	0.046	0.043	6.6	4.1	1.1		0.03
478 STC	170.7	315.3	-13.3	10.19	0.927	0.561	218.3	170.7	1.1	6	0.05
	8.1	1.9	3.5	1.17	0.024	0.041	6.6	8.1	0.9		0.03
479 SOO	185.7	80.4	10.6	66.87	0.792	0.876	56.5	5.7	156.5	20	0.07
	3.1	2.2	1.6	0.69	0.031	0.049	4.6	3.1	2.9		0.03
480 TCA	204.1	135.1	29.2	67.31	0.808	0.839	125.9	204.1	158.0	18	0.06
	3.5	3.1	1.2	0.52	0.023	0.044	3.8	3.5	2.2		0.03
497 DAB	261.8	210.6	22.9	59.47	0.690	0.967	113.1	261.8	113.6	5	0.03
	0.7	1.1	1.2	0.31	0.025	0.021	3.3	0.7	0.5		0.05
500 JPV	288.2	221.9	1.2	65.05	0.657	0.866	106.6	288.2	146.5	8	0.05
	3.4	2.4	1.4	0.92	0.028	0.056	3.1	3.4	2.6		0.04
502 DRV	253.2	185.1	12.3	68.18	0.776	0.920	123.8	253.2	154.8	7	0.05
	4.0	3.2	1.7	0.82	0.024	0.051	4.1	4.0	2.6		0.04
508 TPI	146.5	351.5	4.0	38.01	0.102	0.951	328.0	146.5	21.1	143	0.06
	4.7	3.3	2.0	1.49	0.021	0.014	3.9	4.7	3.0		0.03
529 EHY	258.2	134.1	2.4	61.72	0.362	0.951	107.4	78.2	143.0	18	0.07
	3.1	2.6	1.0	0.97	0.029	0.031	4.0	3.1	1.8		0.03
530 ECV	304.9	193.9	-18.6	67.39	0.790	0.813	56.0	124.9	157.9	6	0.05
	3.7	3.2	1.7	0.49	0.038	0.026	5.8	3.7	3.9		0.04
546 FTC	144.1	30.2	67.4	52.20	1.009	0.868	173.0	144.1	95.4	14	0.06
	2.8	4.3	1.5	1.10	0.002	0.058	2.3	2.8	2.2		0.04

Table 2. Mean values of the parameters: solar longitude (L_S), radiant position $(RA, Dc)_{2000}$, geocentric velocity (V_g), orbital elements and (D) – Southworth-Hawkins criterion of questionably identified *pro tempore* showers from the IAU MDC in the database EDMOND. N – number of meteors. In the second line of each shower, there are standard deviations.

Shower	L_S	RA	Dec	V_g	q [AU]	e	ω [°]	Ω [°]	i [°]	N	D_{SH}
451 CAM	40.6	182.7	83.2	13.02	1.000	0.517	167.9	40.6	19.0	4	0.04
±	5.8	7.8	2.6	0.69	0.003	0.033	3.5	5.8	1.2		0.04
464 KLY	125.9	276.3	34.8	18.61	0.945	0.695	213.6	125.9	25.1	6	0.06
	6.8	2.2	1.9	1.32	0.018	0.043	4.3	6.8	1.5		0.04
468 AAH	136.3	267.8	20.6	12.47	0.977	0.631	204.4	136.3	13.5	7	0.05
	7.4	2.6	2.2	1.05	0.013	0.047	5.4	7.4	1.2		0.04
470 AMD	144.4	254.8	58.2	18.98	1.012	0.631	178.4	144.4	29.5	17	0.07
	4.2	4.2	2.6	1.12	0.002	0.041	3.6	4.2	2.0		0.03
471 ABC	137.8	306.3	-12.5	16.95	0.752	0.676	248.9	137.8	3.4	9	0.05
	3.8	2.2	2.4	1.42	0.035	0.043	4.6	3.8	1.5		0.03
472 ATA	143.8	310.3	-1.8	18.66	0.742	0.735	248.3	143.8	8.8	10	0.06
	6.3	1.9	3.6	1.29	0.046	0.044	7.1	6.3	1.5		0.04
473 LAQ	145.3	341.0	-5.1	31.12	0.279	0.881	303.2	145.3	4.1	20	0.07
	2.8	2.4	1.8	1.09	0.026	0.023	3.8	2.8	2.4		0.04
475 SAQ	157.1	330.6	-10.7	21.02	0.669	0.810	255.7	157.1	0.8	8	0.06
	4.0	1.6	1.4	1.22	0.033	0.060	5.1	4.0	0.7		0.05
476 ICE	175.5	4.6	-0.7	26.23	0.419	0.811	107.7	355.5	2.6	21	0.07
	5.0	2.9	2.1	1.39	0.043	0.032	5.7	5.0	1.7		0.03
481 OML	219.7	148.5	29.1	67.13	0.892	0.793	140.7	219.7	152.1	6	0.06
	3.7	3.2	1.7	1.00	0.024	0.048	5.2	3.7	2.6		0.04
484 IOA	233.6	28.5	15.6	14.51	0.824	0.677	233.9	233.6	1.5	5	0.05
	4.5	1.7	2.5	1.34	0.037	0.038	6.2	4.5	1.0		0.05
499 DDL	277.4	169.5	26.6	63.06	0.536	0.955	266.1	277.4	135.3	62	0.06
	2.8	2.5	1.4	0.85	0.022	0.044	3.0	2.8	1.6		0.03
531 GAQ	49.8	305.8	14.1	60.78	0.980	0.781	201.2	49.8	123.3	6	0.04
	2.7	1.9	0.5	0.30	0.012	0.048	3.7	2.7	0.9		0.04
533 JXA	112.6	35.0	9.2	68.85	0.863	0.939	313.8	292.6	171.8	19	0.06
	6.6	4.7	2.0	0.55	0.038	0.032	6.5	6.6	2.3		0.03
537 KAU	207.4	90.7	32.0	64.98	0.483	0.965	272.9	207.4	160.4	10	0.06
	4.6	4.4	1.1	1.01	0.045	0.040	5.6	4.6	2.5		0.04
538 FFA	215.1	50.9	30.2	38.12	0.187	0.957	311.3	215.1	24.1	5	0.05
	5.8	4.8	2.7	1.87	0.021	0.029	4.0	5.8	3.3		0.05
545 KCA	156.4	8.6	49.4	51.36	0.685	0.925	250.7	156.4	93.6	4	0.05
	1.9	2.5	1.4	0.94	0.019	0.049	2.0	1.9	1.3		0.04
547 KAP	137.6	43.9	45.6	63.53	0.976	0.852	157.0	137.6	132.0	11	0.06
	2.1	2.6	1.4	0.50	0.009	0.040	3.0	2.1	2.2		0.03

4. Conclusions

In the work, the European viDeo MeteOr Network Database (EDMOND) is introduced. Its 4th version contains 83 369 video meteor orbits. The Database was created thanks to the broad international cooperation of several European national networks and the International Meteor Organization Video Meteor Network, with the aim of connecting observers within a wide area. This has made it possible to

combine those observations which otherwise would have stayed as single-station data.

We expect to use this expanding database, particularly to study minor streams. The first results are here presented. Using the *radiant-V_g* method we identified 267 meteor showers of the IAU MDC, where 67 of them are established showers and 200 are showers from the working list.

Making a more detailed analysis of *pro tempore* showers from the IAU MDC working list, we determined their orbital elements, radiant positions, geocentric velocities and solar longitudes. The results were divided into two groups, based on a comparison of the mean values with those available in the IAU MDC. Table 1 contains 22 showers of the 65 *pro tempore* showers in the working list of the IAU MDC (August 2013), identification of which was clear and reliable. Identification of 18 meteor showers listed in Table 2 is questionable, as some their parameters differ considerably from those at the IAU MDC.

This work showed that the EDMOND database is able to provide relevant data convenient for the confirmation of meteor showers from the working list of the IAU MDC, which can improve their orbital and geophysical parameters.

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