Independent identification of meteor showers in EDMOND database

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Abstract

Cooperation and data sharing among national networks and International Meteor Organization Video Meteor Database (IMO VMDB) resulted in European viDeo MeteOr Network Database (EDMOND). The current version of the database (EDMOND 5.0) contains 144 751 orbits collected from 2001 to 2014. In our survey we used EDMOND database in order to identify existing and new meteor showers in the database.

In the first step of the survey, using D_{SH} criterion we found groups around each meteor within similarity threshold. Mean parameters of the groups were calculated and compared using a new function based on geocentric parameters (λ, α, δ, and V_g). Similar groups were merged into final clusters (representing meteor showers), and compared with IAU Meteor Data Center list of meteor showers. This paper presents the results obtained by the proposed methodology.

Keywords: Meteor showers, meteoroid stream identification methods, databases.

1 Introduction

Nowadays, due to the international cooperation, meteor activity is monitored over almost the entire Europe. Consequently, in recent years, multi-national networks of video meteor observers have contributed many new data. As a result, the latest version of EDMOND database contains 144 751 orbits collected from 2001 to 2014.

In this paper, we focus on determining an independent method to associate an individual meteor in the EDMOND database with a given meteor shower. The outcome of this method is confirmation of some of the previously reported meteoroid streams listed in the IAU Meteor Data Center (IAU MDC), and finding potentially new ones.

In Section 2 we provide necessary mathematical tools used in the independent identification procedure described in Section 4. Section 3 focuses on the EDMOND data preparation used in the analysis. While in Section 6 we present our conclusions and perspectives for future work.

2 Methodology

Our cluster identification procedure links two types of meteor parameters: orbital elements (e, q, i, ω, and Ω) and geocentric parameters (λ, α, δ, and V_g). The first set of parameters is applied by so called D-criteria that determine similarity between orbits of meteoroids. While the second set of parameters measure similarity between meteors on the sky in a given meteor shower activity period.

2.1 Orbital similarity functions

The similarity between two orbits is established by measuring the distance between them with D-criterion (a similarity function). Depending on the number of parameters that defines the similarity function, the distance between two orbits might be measured in a five- (Southworth & Hawkins 1963; Drummond 1981; Jopek 1993), seven- (Jopek et al. 2008), or other dimensional phase.
In our survey, we use two functions. Southworth & Hawkins (1963) criterion defined as

$$\begin{aligned} D_{SH}^2 &= [e_B - e_A]^2 + [q_B - q_A]^2 + \left[2 \cdot \sin \frac{I_{AB}}{2}\right]^2 \\ &+ \left[\frac{e_B + e_A}{2}\right]^2 \left[2 \cdot \sin \frac{\pi_{AB}}{2}\right]^2, \end{aligned} \tag{1}$$

where e_A and e_B is the eccentricity, and q_A and q_B is the perihelion distance of two orbits, I_{AB} is the angle between two orbital planes, and π_{AB} is the distance of the longitudes of perihelia measured from the intersection of the orbits.

2.2 Geocentric similarity function

The second criterion we propose a new distance function D_x involving geocentric parameters, defined as

$$\begin{aligned} D_x^2 &= w_\lambda \left(2 \cdot \sin \frac{(\lambda_A - \lambda_B)}{2}\right)^2 \\ &+ w_\alpha \left(|V_{g_A} - V_{g_B}| + 1\right) \left(2 \cdot \sin \left(\frac{\alpha_A - \alpha_B}{2} \cdot \cos \delta_A\right)\right)^2 \\ &+ w_\delta \left(|V_{g_A} - V_{g_B}| + 1\right) \left(2 \cdot \sin \left(\frac{\delta_A - \delta_B}{2}\right)\right)^2 \\ &+ w_V \left(\frac{|V_{g_A} - V_{g_B}|}{V_{g_A}}\right)^2, \end{aligned} \tag{2}$$

where λ_A and λ_B is the solar longitude, α_A and α_B is the right ascension, δ_A and δ_B is the declination, and Vg_A and Vg_B is the geocentric velocity of two meteors. The w_λ, w_α, w_δ, and w_V are suitably defined weighting factors. To normalize contribution of each term in D_x, we used values: $w_\lambda = 0.17$, $w_\alpha = 1.20$, $w_\delta = 1.20$, and $w_v = 0.20$. Moreover, the values of weighting factors fulfil assumption that compared geocentric parameters differ only 20°, 3.5°, 3.5°, and 3.5 km/s in solar longitude, right ascension, declination and velocity, respectively.

2.3 Mean parameters

The mean values of the orbital elements and other parameters of each found cluster were obtained as a weighted arithmetic mean, where the weights were determined by Welch (2001)

$$w_i = 1 - \frac{D_{SH}^2}{D_c^2}, \tag{3}$$

and where D_c is the threshold of the dynamical similarity.
The mean and standard deviation of angular elements were calculated according to Mardia (1972). The mean value of the angular element ϵ is taken as the solution of the system of equations

$$\begin{aligned} S &= r \, \sin \epsilon \, , \\ C &= r \, \cos \epsilon \, . \end{aligned} \tag{4}$$

Here

$$S = \frac{\sum_{i=1}^{N} w_i \, \sin \epsilon_i}{\sum_{i=1}^{N} w_i}, \qquad C = \frac{\sum_{i=1}^{N} w_i \, \cos \epsilon_i}{\sum_{i=1}^{N} w_i}, \qquad r = \sqrt{S^2 + C^2}. \tag{5}$$

where N is the number of members in a group/cluster, and the values of the weights w_i are given by Eq. 3.

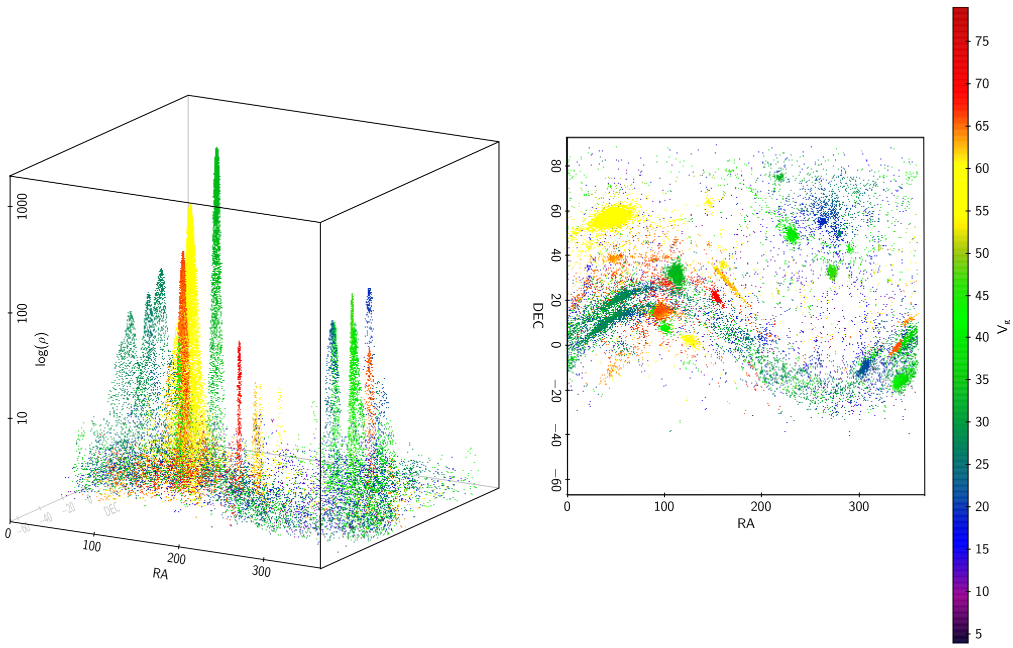

Figure 1: Found groups of orbits within assumed threshold plot in RA, DEC, V_g and $\log \rho$, where ρ represents meteor orbits concentrations in the phase space of orbital elements (Eq. 6).

3 Data preparation

The current version of the database, EDMOND 5.0, which contains 144 751 orbits collected from 2001 to 2014, has been split between particular years of observations. At first, we pre-ordered dataset of each year in a way that the starting orbit is with the highest orbits concentrations in the phase space of orbital elements. For this purpose we calculated ρ, as defined by Eq. 6. As a result, for each year our input data is ordered from the highest to the lowest density ρ (Figure 1).

4 Identification procedure

Our method may be summarised by following steps:

Step 1: We probe database using D_{SH} with a low threshold value $D_c = 0.05$. Around a meteoroid orbit is created a sphere of orbital parameters and radius D_c. A set of orbits within the sphere creates a group, which members are excluded from following search around another meteoroid orbit. In this way, we have independent groups around each reference meteoroid orbit. Next, for each group a weighted mean of parameters is calculated (Eq. 3).

Step 2: Using D_x we are merging groups into clusters of similar weighted means of geocentric parameters found in Step 1. Groups are associated if $D_x \leq D'_c$, where $D'_c = 0.15$.

To calculate mean of parameters of a new cluster, first we search for an orbit within the cluster with the highest density at a point in orbital elements space (Welch 2001)

$$\rho = \sum_{i=1}^{N} \left(1 - \frac{D_i^2}{D_c^2}\right), \tag{6}$$

where D_i is the value of D_{SH} obtained for the i-th meteor in the cluster by comparing its orbit with orbits of each member of the cluster, and D_c is the threshold value adjust to a studied cluster. The orbit with the highest ρ is a reference to calculate the new weighted mean of parameters for cluster found in Step 2.

We repeat Step 2 using new means till groups are no longer linked into clusters.

Step 3: We compare parameters of known meteor showers in the IAU MDC with the final mean values of the same parameters of found clusters. For this purpose we use D_{SH} criterion with $D_c = 0.15$. We merge clusters of the same identified meteor shower. Although, a cluster must have 5 or more members to be considered as a representation of a meteor shower.

5 Results

The results of our survey are given in Table 1 and Figure 2-7. It contains 257 meteoroid streams identified by described earlier procedure. It summarizes the mean geocentric parameters and mean orbital parameters of the detected showers (clusters), ranked according to the IAU MDC coding. In addition, in the last column, is given value of D_{SH} that determines the similarity between the mean orbit of a cluster and the orbit of a given meteoroid stream from the IAU MDC. Additionally, we visualise results separately for each seasons in Figures 4-7, where colours represent amount of meteors within an identified meteor shower, while the size of points corresponds to D_{SH} value.

To show efficiency of the procedure we present here results for selected cases. Figure 2 shows meteor concentrations of Geminids, Perseids, and Orionids on the sky. Those meteor showers are the most prominent showers in the EDMOND database, including over 5 000 members. Those showers have been correctly identified by our procedure. Their activity period lasts about 25-35 days. As should be expected, Geminids and Orionids are more compact in comparison to Perseids meteor shower. But in contrast, Perseids is more prominent than the other two showers.

A given identification method may fail in separation of branches of the same meteor shower. Moreover, if two meteor showers are located in close distance to each other on the sky, an identification method based on geocentric parameters may fail and link those two showers into one. However, our identification procedure succeeds in correct separation of meteor showers in such cases. Figure 3 presents example of such pairs as: Southern & Northern Taurids, December Monocerotids & November Orionids, and Northern & Southern October δ Arietids. The second listed shower of a given pair is marked in blue. As shown in Figure 3 our identification procedure correctly separates meteor showers.

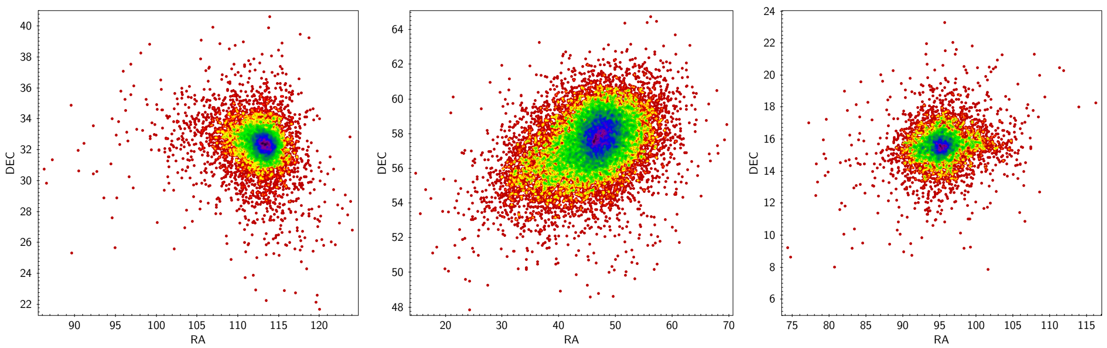

Figure 2: Identified meteor showers: Geminids (left), Perseids (centre), and Orionids (right). Colours represent meteor concentrations on the sky.

6 Conclusion

In order to apply D_{SH} criterion in Step 3 for identification of clusters, we selected meteor showers for which their orbital elements are provided by the IAU MDC (as of June 2014). In total we used 488 meteor showers.

We identified 257 meteor showers. The list includes 42 already established streams, 152 from the working list and 63 *pro-tempore* meteor showers. For a higher threshold ($D_c'' = 0.20$), we found 284 meteor shower in total (44, 173, and 67, respectively). However, with such threshold value

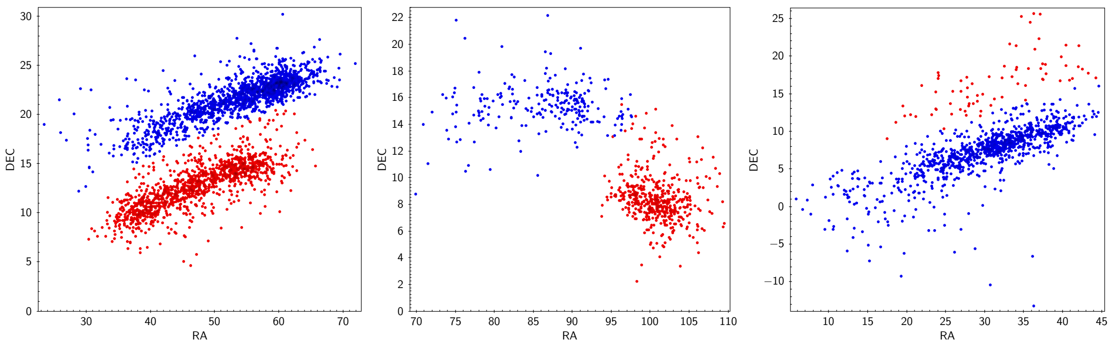

Figure 3: Identified meteor showers: Southern & Northern Taurids (left), December Monocerotids & November Orionids (centre), and Northern & Southern October δ Arietids (right). Colours indicated different showers of the pair – respectively red & blue.

some of the showers are more contaminated by the sporadic background.

There are several clusters that require further investigation. Some of them are those meteor showers for which orbital elements are not given at the IAU MDC. We plan to identify them using D_x criterion, calculate their orbital elements which will be provided to the IAU MDC subsequently. Of course, not identified yet clusters may represents also possible new meteor showers, which need our additional, detailed analysis before they will be submitted to the IAU MDC as well.

7 Acknowledgement

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IAU	Code	$\lambda_\odot$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
001	CAP	127.2	305.8	-9.3	21.84	0.748	0.601	7.1	267.5	127.2	807	0.03
002	STA	215.3	47.1	12.9	27.62	0.816	0.347	5.3	116.7	35.3	1155	0.02
004	GEM	261.7	113.1	32.4	33.51	0.885	0.147	22.5	324.3	261.7	8268	0.03
005	SDA	127.5	340.3	-16.4	40.14	0.967	0.080	26.8	151.0	307.5	1252	0.06
006	LYR	32.2	272.1	33.3	46.17	0.922	0.918	79.0	215.0	32.2	1045	0.06
007	PER	139.5	46.8	57.6	58.27	0.886	0.947	112.5	149.2	139.5	17265	0.10
008	ORI	208.1	95.2	15.6	65.49	0.907	0.568	163.5	84.7	28.1	4835	0.04
009	DRA	195.0	262.9	55.8	20.02	0.650	0.996	30.8	173.3	195.0	496	0.03
010	QUA	283.1	229.4	50.0	40.03	0.624	0.980	70.4	173.0	283.1	1381	0.07
012	KCG	136.7	283.1	52.6	23.33	0.704	0.982	36.5	202.4	136.7	112	0.11

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Table 1 – *Continued from previous page*

IAU	Code	$\lambda_{\odot}$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
013	LEO	235.7	153.6	21.9	69.91	0.851	0.984	162.1	171.7	235.7	332	0.08
015	URS	270.4	218.6	75.9	32.63	0.798	0.937	52.1	206.8	270.4	316	0.01
016	HYD	255.0	124.4	2.9	58.28	0.974	0.248	128.5	121.3	75.0	976	0.17
017	NTA	225.8	55.3	22.1	27.90	0.825	0.354	2.9	294.9	225.8	1403	0.01
018	AND	226.4	20.9	30.5	16.71	0.692	0.781	9.3	241.0	226.4	115	0.05
019	MON	258.8	100.7	8.2	40.98	0.979	0.188	34.9	129.4	78.8	467	0.03
020	COM	273.8	167.2	27.7	62.61	0.922	0.540	134.9	266.5	273.8	435	0.16
021	AVB	19.0	194.5	3.0	19.32	0.709	0.693	4.5	254.8	19.0	109	0.13
022	LMI	208.2	159.2	36.7	60.76	0.930	0.599	124.7	100.1	208.2	201	0.07
023	EGE	205.1	101.8	27.8	67.80	0.885	0.765	170.7	239.9	205.1	330	0.07
025	NOA	195.7	31.0	16.5	33.31	0.909	0.193	5.8	314.1	195.7	74	0.13
026	NDA	137.9	343.0	0.5	38.06	0.954	0.102	21.4	328.4	137.9	344	0.05
027	KSE	6.3	224.9	21.7	41.28	0.951	0.494	59.4	272.4	6.3	6	0.21
028	SOA	195.0	30.8	7.8	28.06	0.821	0.307	5.5	122.8	15.6	903	0.08
031	ETA	46.0	338.1	-0.7	65.35	0.933	0.576	163.4	96.1	46.0	645	0.04
033	NIA	148.2	339.5	-0.9	28.04	0.828	0.366	8.2	294.8	148.2	79	0.04
034	DSE	318.8	231.9	13.5	63.18	0.839	0.962	126.3	193.9	318.8	13	0.13
038	CUR	350.6	167.3	31.7	17.60	0.642	0.762	12.1	243.9	350.6	5	0.11
039	NAL	342.4	132.7	1.4	11.43	0.576	0.919	4.6	38.1	162.4	15	0.11
040	ZCY	12.7	297.1	42.3	41.26	0.807	0.916	70.4	144.5	12.7	49	0.15
047	DLI	30.5	221.8	-9.5	29.75	0.849	0.349	7.7	294.9	30.5	8	0.10
049	LVI	2.5	191.9	-0.1	26.65	0.796	0.432	5.2	284.9	2.5	22	0.20
052	OUM	68.0	206.3	57.5	12.07	0.550	1.013	16.6	182.6	68.0	7	0.10
055	ASC	37.8	229.0	-21.7	32.36	0.892	0.285	5.2	122.0	217.8	5	0.19
061	TAH	75.1	230.9	34.1	14.71	0.622	0.965	19.3	208.9	75.1	24	0.03
083	OCG	193.4	300.9	58.1	19.71	0.646	0.977	29.4	198.6	193.4	70	0.08
088	ODR	109.8	282.7	62.7	27.84	0.711	1.011	45.6	188.7	109.8	66	0.10
089	PVI	286.0	172.2	10.8	63.52	0.887	0.423	161.4	282.4	286.0	42	0.13
090	JCO	290.1	181.4	21.2	61.60	0.892	0.500	135.2	272.4	290.1	94	0.18
096	NCC	292.9	125.2	22.0	27.32	0.815	0.405	2.7	287.5	292.9	113	0.07
097	SCC	291.8	117.9	14.5	25.51	0.791	0.469	5.2	100.3	111.8	96	0.14
112	NDL	334.3	155.0	19.2	21.50	0.739	0.638	5.6	260.6	334.3	62	0.04
113	SDL	327.5	139.2	30.5	16.78	0.708	0.796	7.1	238.3	327.5	6	0.15
124	SVI	350.6	169.1	-1.0	22.58	0.753	0.575	2.8	88.5	170.6	34	0.12
125	SAL	349.6	150.5	29.3	13.77	0.649	0.873	5.1	226.1	349.6	5	0.14
133	PUM	24.8	142.7	59.4	9.56	0.563	1.003	9.9	181.8	24.8	5	0.06
134	NGV	12.2	183.9	19.0	15.67	0.665	0.826	8.4	237.5	12.2	8	0.16
136	SLE	12.5	195.1	0.3	22.78	0.747	0.552	4.9	273.5	12.5	22	0.04
145	ELY	49.5	290.4	43.5	43.51	0.910	1.001	74.1	191.1	49.5	157	0.14
164	NZC	93.9	304.3	-5.0	37.05	0.921	0.123	40.7	328.4	93.9	11	0.11
168	SSS	82.5	276.0	-25.6	29.74	0.857	0.332	2.8	117.2	262.5	6	0.05
171	ARI	82.0	46.2	25.0	40.16	0.967	0.062	30.4	25.3	82.0	11	0.11
177	BCA	115.6	336.5	52.5	47.62	0.880	0.986	85.4	199.9	115.6	27	0.21
179	SCA	101.1	300.5	-19.7	32.78	0.898	0.234	1.6	309.3	101.1	6	0.15
186	EUM	100.6	204.0	64.8	15.80	0.607	1.002	21.9	164.0	100.6	41	0.09
187	PCA	115.3	27.5	70.7	40.53	0.717	0.842	71.9	125.0	115.3	18	0.06
191	ERI	135.3	42.8	-13.1	63.40	0.893	0.948	130.7	30.5	315.3	12	0.07
193	ZAR	138.4	39.6	11.7	69.60	0.915	0.949	174.0	29.8	318.4	18	0.09
194	UCE	148.0	41.3	-2.6	62.23	0.801	0.650	142.8	78.4	328.0	13	0.06
199	ADC	146.5	327.9	-18.5	20.93	0.739	0.619	2.8	85.1	326.5	5	0.03
205	XAU	152.1	71.0	65.8	54.61	0.872	0.934	103.1	146.9	152.1	21	0.15
206	AUR	158.6	91.4	38.7	64.75	0.925	0.652	148.6	105.5	158.6	184	0.07
207	SCS	158.7	65.1	32.4	69.31	0.881	1.003	162.4	179.3	158.7	47	0.16
208	SPE	167.2	47.1	39.4	63.43	0.910	0.705	138.5	248.2	167.2	568	0.10
215	NPI	171.8	9.7	7.0	29.41	0.853	0.285	4.7	304.4	171.8	206	0.10
216	SPI	176.8	14.7	1.4	30.07	0.861	0.266	5.3	126.9	351.3	160	0.12
217	OPC	186.4	3.9	-2.0	20.57	0.752	0.610	2.3	84.8	6.5	11	0.09
219	SAR	167.6	8.5	12.3	37.87	0.955	0.124	19.1	324.0	167.6	120	0.15
220	NDR	158.5	255.8	56.1	19.22	0.627	1.000	29.5	175.7	158.5	174	0.07

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Table 1 – *Continued from previous page*

IAU	Code	$\lambda_{\odot}$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
221	DSX	188.0	155.1	-1.9	31.28	0.857	0.150	23.3	212.5	8.0	14	0.02
224	DAU	185.4	79.2	52.1	62.36	0.889	0.888	127.4	221.2	185.4	37	0.13
226	ZTA	194.8	86.5	14.2	66.30	0.871	0.704	161.8	68.5	14.8	305	0.10
227	OMO	196.6	95.4	0.6	64.39	0.818	0.916	139.1	35.5	17.7	132	0.15
228	OLY	205.7	109.0	47.1	64.13	0.864	0.893	134.9	218.6	205.7	79	0.06
229	NAU	198.6	66.3	35.3	56.58	0.966	0.196	133.1	308.8	198.6	9	0.24
230	ICS	204.2	150.7	38.9	61.46	0.923	0.643	126.7	104.5	204.2	24	0.10
234	EPC	189.4	10.8	10.0	21.50	0.745	0.586	4.6	268.8	189.4	150	0.02
235	LCY	188.2	334.0	30.3	17.12	0.696	0.832	17.3	232.8	188.2	35	0.02
237	SSA	192.8	39.2	10.9	38.13	0.956	0.084	16.4	150.7	12.8	14	0.19
241	OUI	204.2	256.8	75.8	31.03	0.685	0.991	51.9	183.0	204.2	152	0.10
243	ZCN	216.3	102.2	15.7	64.05	0.889	0.491	164.0	94.4	36.3	547	0.20
244	PAR	222.5	97.4	53.9	54.16	0.944	0.520	107.7	267.9	222.5	8	0.14
245	NHD	225.9	124.3	-2.7	65.84	0.840	0.928	139.8	31.0	46.2	41	0.13
250	NOO	243.4	88.1	15.4	42.54	0.986	0.105	25.3	143.0	63.4	233	0.05
256	ORN	251.7	75.8	25.5	25.25	0.783	0.450	2.6	284.2	251.7	439	0.05
257	ORS	254.5	74.8	15.5	21.95	0.729	0.562	5.1	91.9	74.5	208	0.06
258	DAR	265.0	75.6	29.6	18.57	0.709	0.689	3.8	253.3	265.0	41	0.08
260	GTI	260.1	41.4	32.7	12.83	0.647	0.890	5.6	220.3	260.1	6	0.12
267	JNO	291.4	83.7	1.3	14.24	0.634	0.862	8.1	46.2	111.4	14	0.12
268	BCD	318.2	124.4	9.1	16.68	0.655	0.774	5.4	62.1	138.2	54	0.06
269	OCS	318.7	348.2	69.8	12.80	0.577	0.984	17.3	178.7	318.7	5	0.14
273	PBO	45.8	221.9	67.0	15.23	0.523	1.006	23.0	186.9	45.8	13	0.14
278	MSR	107.3	236.9	24.3	11.46	0.582	1.005	11.9	194.3	107.3	21	0.11
279	ZED	107.5	257.2	62.2	20.77	0.617	1.014	33.1	182.4	107.5	121	0.11
281	OCT	192.6	166.7	78.6	45.01	0.935	0.991	77.5	168.8	192.6	23	0.06
282	DCY	189.1	301.3	44.5	15.50	0.639	0.984	21.6	197.4	189.1	36	0.13
286	FTA	232.1	59.0	14.7	24.52	0.767	0.460	5.1	103.8	52.1	469	0.12
288	DSA	252.7	61.8	9.6	18.78	0.666	0.684	6.5	75.6	72.7	28	0.13
289	DNA	244.6	43.0	24.4	15.26	0.665	0.792	2.9	239.8	244.6	11	0.11
323	XCB	293.3	250.2	28.7	43.11	0.697	0.743	74.5	112.4	293.3	5	0.13
327	BEQ	95.5	309.3	0.3	32.31	0.858	0.161	45.3	330.4	95.5	19	0.19
333	OCU	202.3	145.4	64.1	54.34	0.858	0.977	100.3	163.1	202.3	220	0.02
348	ARC	33.3	317.1	46.6	40.94	0.872	0.857	68.8	133.9	33.3	87	0.08
362	JMC	73.9	16.2	54.1	42.92	0.925	0.611	68.4	99.0	73.9	7	0.07
365	BCM	103.8	49.6	58.7	43.45	0.936	0.554	69.6	91.9	103.8	5	0.14
386	OBC	202.9	52.5	56.6	49.31	0.921	0.494	84.5	272.9	202.9	17	0.24
388	CTA	217.7	60.5	26.0	39.76	0.974	0.097	16.3	326.1	217.7	141	0.08
390	THA	235.0	88.3	35.8	31.48	0.859	0.133	27.7	329.8	235.0	5	0.05
391	NDD	234.9	258.6	64.2	26.28	0.655	0.988	42.3	176.7	234.9	13	0.16
392	NID	232.9	200.2	65.1	42.28	0.742	0.985	74.9	173.4	232.9	32	0.15
401	BSX	286.0	159.1	1.2	54.13	0.931	0.099	147.4	149.8	106.0	7	0.10
403	CVN	286.4	199.5	44.0	52.87	0.885	0.860	94.3	223.1	286.4	12	0.13
404	GUM	283.7	240.6	60.9	33.21	0.718	0.982	55.2	182.5	283.7	18	0.27
427	FED	315.0	237.1	60.7	34.59	0.874	0.971	55.3	194.6	315.0	7	0.13
428	DSV	267.0	203.9	4.9	65.24	0.916	0.574	150.7	96.8	267.0	78	0.07
430	POR	173.5	72.5	6.6	65.88	0.857	0.860	151.1	47.2	349.8	184	0.13
431	JIP	93.9	331.1	29.0	57.70	0.883	0.886	111.9	224.7	93.9	32	0.11
432	NBO	296.4	200.6	12.3	65.89	0.811	0.837	144.4	232.4	296.4	11	0.15
434	BAR	136.4	29.4	26.2	66.13	0.765	0.912	155.4	222.4	136.4	43	0.11
435	MPR	140.1	70.3	51.2	56.29	0.827	0.607	119.4	91.1	140.1	28	0.14
436	GCP	227.8	52.6	82.4	35.34	0.856	0.836	55.3	227.3	227.8	18	0.14
437	NLY	228.7	135.0	41.2	62.55	0.708	0.818	135.6	234.8	228.7	13	0.17
438	MLE	231.1	138.8	32.7	66.77	0.789	0.911	151.2	218.4	231.1	40	0.10
439	ASX	235.0	155.4	1.2	69.64	0.866	0.914	164.8	325.7	55.0	7	0.18
440	NLM	230.7	154.6	34.6	65.98	0.797	0.980	140.0	168.9	230.7	105	0.11
441	NLD	232.3	185.6	73.2	40.54	0.651	0.969	70.8	199.1	232.3	50	0.10
442	RLE	263.9	154.8	3.0	66.26	0.793	0.691	165.6	67.7	83.9	8	0.09
443	DCL	253.5	146.4	26.9	64.43	0.875	0.576	153.8	264.4	253.5	84	0.14

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IAU	Code	$\lambda_\odot$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
444	ZCS	112.5	9.8	50.3	56.08	0.891	0.999	106.2	164.3	112.5	258	0.06
450	AED	20.5	308.4	11.4	59.93	0.935	0.710	120.7	113.0	20.5	25	0.08
451	CAM	25.3	222.9	74.8	16.06	0.574	1.001	25.0	180.6	25.3	28	0.17
452	TVI	32.3	203.1	4.1	16.17	0.649	0.793	6.0	242.3	32.3	54	0.11
454	MPV	30.7	206.8	2.4	20.18	0.721	0.694	7.8	254.8	30.7	62	0.12
455	MAC	41.6	209.1	6.4	15.53	0.654	0.848	7.8	233.4	41.6	24	0.08
456	MPS	68.1	251.3	-14.2	24.63	0.790	0.517	6.8	275.9	68.1	12	0.08
458	JEC	82.6	314.8	33.2	51.85	0.889	0.909	95.3	219.1	82.6	51	0.11
459	JEO	91.7	250.8	-1.2	14.88	0.631	0.877	7.7	229.8	91.7	25	0.09
460	LOP	85.1	255.3	-2.9	18.86	0.708	0.743	11.0	249.0	85.1	67	0.03
463	JRH	119.6	262.2	38.0	14.76	0.606	0.978	20.0	206.7	119.6	37	0.06
464	KLY	125.8	271.4	37.5	18.00	0.675	0.966	24.3	208.8	125.8	78	0.04
465	AXC	134.5	10.3	47.6	55.10	0.873	0.886	105.4	223.3	134.5	144	0.04
466	AOC	142.4	34.2	2.6	65.63	0.912	0.707	158.4	69.3	322.4	51	0.11
468	AAH	133.7	272.1	23.8	13.55	0.649	0.963	15.1	210.1	133.7	33	0.11
469	AUS	144.0	287.6	0.1	10.83	0.603	0.947	6.3	213.2	144.0	24	0.06
470	AMD	145.5	268.4	59.9	20.61	0.621	1.008	32.8	184.9	145.5	657	0.05
472	ATA	145.8	313.2	0.3	18.19	0.694	0.749	9.5	248.1	145.8	131	0.07
473	LAQ	155.4	351.3	1.0	31.06	0.876	0.252	6.5	308.9	155.4	162	0.10
474	ABA	147.1	301.1	7.3	15.70	0.682	0.861	11.7	230.5	147.1	93	0.04
476	ICE	170.3	5.5	-2.3	26.27	0.786	0.360	2.3	117.1	350.3	5	0.10
477	SRP	169.3	341.1	3.6	18.28	0.709	0.709	6.0	253.4	169.3	196	0.08
479	SOO	177.4	67.9	11.8	67.08	0.879	0.789	160.3	58.0	344.4	102	0.23
480	TCA	202.2	132.4	29.6	66.62	0.795	0.809	158.6	124.8	202.2	127	0.10
481	OML	215.6	145.0	31.2	66.90	0.813	0.889	150.7	140.2	215.6	83	0.04
485	NZT	233.2	71.3	19.7	33.50	0.915	0.217	5.4	130.0	53.2	59	0.08
486	NZP	231.1	57.4	29.7	27.87	0.844	0.380	10.9	292.7	231.1	45	0.10
488	NSU	238.6	145.6	60.0	54.58	0.894	0.816	99.4	231.4	238.6	22	0.10
490	DGE	258.5	75.9	-5.4	23.25	0.792	0.656	19.7	75.4	78.5	11	0.14
491	DCC	249.7	129.7	11.6	62.35	0.917	0.390	165.3	107.1	69.7	87	0.05
495	DMT	258.5	65.5	9.1	15.81	0.656	0.788	5.2	60.4	78.5	49	0.07
497	DAB	262.0	210.8	22.1	59.54	0.964	0.684	114.2	112.2	262.0	5	0.06
500	JPV	285.7	219.7	1.4	65.13	0.882	0.646	147.3	105.4	285.7	51	0.08
501	FPL	317.7	149.4	7.9	28.53	0.829	0.363	5.2	114.1	137.7	97	0.03
502	DRV	254.5	185.0	12.9	67.93	0.889	0.784	153.7	125.4	254.5	63	0.04
505	AIC	133.8	344.6	-14.8	38.64	0.956	0.104	22.6	147.1	313.8	577	0.13
506	FEV	308.7	196.4	13.1	62.00	0.896	0.471	137.9	275.2	308.7	65	0.12
510	JRC	84.7	321.4	44.4	49.13	0.886	1.007	87.6	190.9	84.7	79	0.06
511	FLY	197.7	92.6	53.6	60.19	0.817	0.862	123.0	226.2	197.7	175	0.10
513	EPV	253.0	192.6	8.8	65.23	0.935	0.538	150.4	93.6	253.0	30	0.08
515	OLE	290.9	137.5	8.0	37.80	0.942	0.086	21.3	151.6	110.9	26	0.07
516	FMV	322.2	218.6	4.2	65.49	0.852	0.718	143.8	245.2	322.2	44	0.12
517	ALO	10.7	242.8	1.6	55.76	0.942	0.300	111.7	293.5	10.7	13	0.11
518	AHE	32.4	271.1	20.6	51.80	0.878	0.780	93.9	239.8	32.4	14	0.09
519	BAQ	45.0	322.7	0.1	67.84	0.886	0.921	155.4	144.8	45.0	10	0.04
522	SAP	110.4	349.9	11.1	63.27	0.932	0.555	148.7	267.0	110.4	260	0.04
523	AGC	155.4	344.1	75.9	43.47	0.843	1.004	75.0	188.7	155.4	198	0.05
524	LUM	214.4	156.1	49.5	59.90	0.863	0.918	116.2	147.5	214.4	83	0.07
525	ICY	223.6	286.5	56.8	18.64	0.654	0.989	28.2	183.9	223.6	31	0.10
526	SLD	218.2	159.1	69.3	49.20	0.801	0.984	88.6	191.2	218.2	85	0.09
528	JZD	275.9	241.2	69.4	29.34	0.614	0.973	47.1	191.6	275.9	32	0.13
529	EHY	261.9	136.8	0.6	61.25	0.950	0.359	140.7	108.1	81.9	91	0.09
531	GAQ	37.0	296.8	15.1	60.54	0.867	0.990	117.7	194.4	37.0	13	0.19
532	MLD	50.9	202.9	81.3	15.48	0.605	1.000	22.5	168.2	50.9	12	0.08
533	JXA	110.4	33.9	8.9	68.53	0.916	0.835	171.9	309.8	290.4	71	0.10
534	FOA	135.3	24.2	47.1	60.65	0.839	1.003	121.3	192.2	135.3	79	0.04
537	KAU	195.3	78.6	33.0	64.87	0.953	0.539	157.3	267.3	195.3	66	0.14
538	FFA	212.6	51.2	28.8	36.79	0.942	0.216	21.0	308.0	212.6	50	0.06
539	ACP	270.7	317.1	63.2	16.81	0.620	0.981	24.4	187.1	270.7	18	0.12

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Table 1 – *Continued from previous page*

IAU	Code	$\lambda_\odot$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
540	TCR	271.7	166.6	0.9	69.35	0.892	0.802	171.3	52.5	91.7	6	0.18
541	SSD	248.2	285.3	63.5	21.61	0.652	0.983	32.2	182.4	248.2	39	0.12
542	DES	255.5	154.3	1.8	68.37	0.863	0.910	162.3	35.7	75.5	13	0.13
544	JNH	273.6	148.1	-5.1	61.59	0.985	0.338	137.5	107.9	93.6	7	0.25
545	XCA	155.1	8.2	49.0	50.60	0.914	0.695	93.9	250.3	155.1	15	0.09
546	FTC	139.3	23.5	66.8	51.32	0.880	1.007	93.5	173.0	139.3	142	0.07
548	FAQ	112.4	319.5	-2.0	37.04	0.926	0.129	35.0	325.3	112.4	174	0.01
549	FAN	111.6	17.9	44.8	59.63	0.865	0.907	118.8	140.0	111.6	214	0.08
550	KPC	114.4	26.0	59.4	51.16	0.881	0.993	92.4	161.2	114.4	53	0.10
551	FSA	139.3	24.9	38.0	62.72	0.859	0.899	132.6	221.1	139.3	134	0.07
552	PSO	161.0	71.2	-0.6	65.63	0.854	1.002	140.5	19.3	341.0	103	0.12
553	DPE	164.8	54.2	44.0	63.74	0.854	0.888	135.5	221.9	164.8	36	0.09
554	APE	160.9	39.1	45.5	60.98	0.883	0.798	126.0	236.2	160.9	104	0.19
555	OCP	187.9	66.2	72.4	50.85	0.869	0.916	90.9	215.1	187.9	35	0.11
556	PTA	186.5	57.4	28.3	59.60	0.960	0.251	156.8	303.3	186.5	90	0.08
557	SFD	216.1	300.7	64.8	24.67	0.918	0.977	36.2	194.3	216.1	53	0.06
560	SES	246.3	140.6	2.0	67.49	0.952	0.767	156.2	57.5	66.3	10	0.25
561	SSX	254.9	139.0	0.9	65.48	0.930	0.616	149.9	77.5	74.9	68	0.10
562	BCT	259.8	181.3	28.8	64.89	0.787	0.976	132.4	182.7	259.8	31	0.13
563	DOU	267.8	159.7	42.9	56.36	0.937	0.542	106.6	266.0	267.8	60	0.04
564	SUM	275.9	175.3	37.4	58.03	0.877	0.675	114.3	250.3	275.9	8	0.15
565	FUM	273.5	169.8	43.5	56.21	0.944	0.631	105.1	254.3	273.5	21	0.11
566	BCF	271.9	180.0	23.6	66.00	0.852	0.868	141.6	223.6	271.9	38	0.12
568	FCV	306.4	196.4	30.7	55.12	0.919	0.594	102.0	262.1	306.4	25	0.08
570	FBH	313.0	245.0	23.5	55.04	0.867	0.914	100.9	148.5	313.0	30	0.07
571	TSB	343.1	216.2	24.3	49.18	0.956	0.502	82.4	270.4	343.1	44	0.03
572	TOH	335.0	233.5	9.3	64.03	0.923	0.862	129.2	225.4	335.0	5	0.25
573	TLM	250.0	164.0	38.6	63.26	0.826	0.929	127.8	209.3	250.0	62	0.11
574	GMA	250.8	163.8	54.4	54.68	0.871	0.848	100.9	226.2	250.8	44	0.08
575	SAU	233.0	105.4	38.7	55.27	0.969	0.190	119.6	310.8	233.0	10	0.05
576	FOB	281.2	202.3	20.5	63.83	0.705	0.981	131.6	176.9	281.2	10	0.18
577	FPI	128.7	9.1	12.4	63.74	0.954	0.483	161.9	275.4	128.7	34	0.06
578	TUM	251.8	137.5	51.1	53.33	0.917	0.472	100.5	274.6	251.8	29	0.08
579	TCV	278.6	208.7	29.5	59.79	0.791	0.963	114.0	161.6	278.6	25	0.09
580	CHA	147.4	18.4	43.9	57.77	0.890	0.767	114.5	241.3	147.4	118	0.13
581	NHE	30.2	261.2	39.4	39.51	0.906	0.899	64.4	216.9	30.2	90	0.14
583	TTA	163.5	55.2	2.8	63.28	0.867	0.692	146.8	71.1	343.5	39	0.09
584	GCE	137.4	24.9	74.6	45.84	0.849	0.976	81.1	156.1	137.4	160	0.08
586	TLA	130.5	333.7	43.4	45.17	0.916	0.783	77.6	240.4	130.5	85	0.08
587	FNC	130.5	313.3	45.5	35.88	0.893	0.840	57.4	230.3	130.5	33	0.13
588	TTL	213.3	106.7	50.8	60.46	0.854	0.720	124.7	247.0	213.3	37	0.12
590	VCT	277.3	180.6	45.1	53.72	0.900	0.771	98.2	238.3	277.3	15	0.27
591	ZBO	319.4	215.1	17.4	61.30	0.904	0.741	121.6	244.0	319.4	21	0.15
592	PON	135.5	16.7	28.2	64.12	0.895	0.771	142.1	240.4	135.5	102	0.05
593	TOL	220.8	116.7	42.8	63.29	0.904	0.691	138.2	248.9	220.8	48	0.06
594	RSE	290.7	230.0	21.7	57.36	0.951	0.816	106.1	130.4	290.7	10	0.18
595	TTT	177.0	58.6	17.0	63.51	0.917	0.445	172.9	100.0	346.9	77	0.09
596	MUS	276.7	190.7	59.2	44.47	0.874	0.847	76.2	226.8	276.7	23	0.18
599	POS	16.8	283.6	7.2	63.88	0.948	0.998	128.4	186.3	16.8	5	0.11
600	FAU	202.4	89.8	42.7	62.90	0.885	0.621	140.3	257.8	202.4	75	0.13
603	FCR	225.7	116.5	32.4	64.51	0.895	0.547	155.1	269.8	225.7	53	0.10
604	ACZ	278.1	118.2	16.9	33.28	0.897	0.195	4.8	131.7	98.1	39	0.04
605	FHR	8.8	260.0	45.8	39.33	0.887	0.962	63.8	203.3	8.8	11	0.10
606	JAU	276.9	170.1	63.6	40.10	0.844	0.751	64.7	241.8	276.9	16	0.20
607	TBO	296.3	215.0	25.2	60.10	0.800	0.976	117.2	190.4	296.3	37	0.08
608	FAR	180.8	60.7	29.7	63.47	0.909	0.487	159.4	272.7	180.8	34	0.16
609	BOT	277.5	185.7	34.2	60.46	0.866	0.863	118.6	221.7	277.5	42	0.23
610	SGM	251.1	94.0	14.8	41.47	0.985	0.132	23.4	138.6	71.1	310	0.17
611	VCF	261.8	187.0	44.0	55.42	0.805	0.931	103.6	208.1	261.8	17	0.15

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Table 1 – *Continued from previous page*

IAU	Code	$\lambda_\odot$	α	δ	V_g	e	q	i	ω	Ω	No	D_{SH}
612	NCA	250.9	192.1	49.3	53.15	0.789	0.981	96.7	171.2	250.9	28	0.08
613	TLY	197.7	122.6	43.5	64.63	0.788	0.960	138.7	156.0	197.7	67	0.10
615	TOR	285.6	186.8	24.6	62.78	0.871	0.791	129.6	234.4	285.6	47	0.13
616	TOB	291.1	183.2	26.4	57.49	0.919	0.502	122.4	273.2	291.1	5	0.18
617	IUM	223.9	132.3	50.6	60.67	0.787	0.888	122.5	220.0	223.9	35	0.15
619	SLM	253.3	136.3	33.1	59.75	0.949	0.369	134.2	286.4	253.3	26	0.10
620	SBO	295.3	204.9	31.5	56.65	0.815	0.883	109.4	219.7	295.3	7	0.25
621	SUA	298.1	181.6	58.0	37.25	0.886	0.727	57.3	244.3	298.1	37	0.16
622	PUA	231.7	129.0	55.0	57.23	0.895	0.774	110.7	237.1	231.7	16	0.27

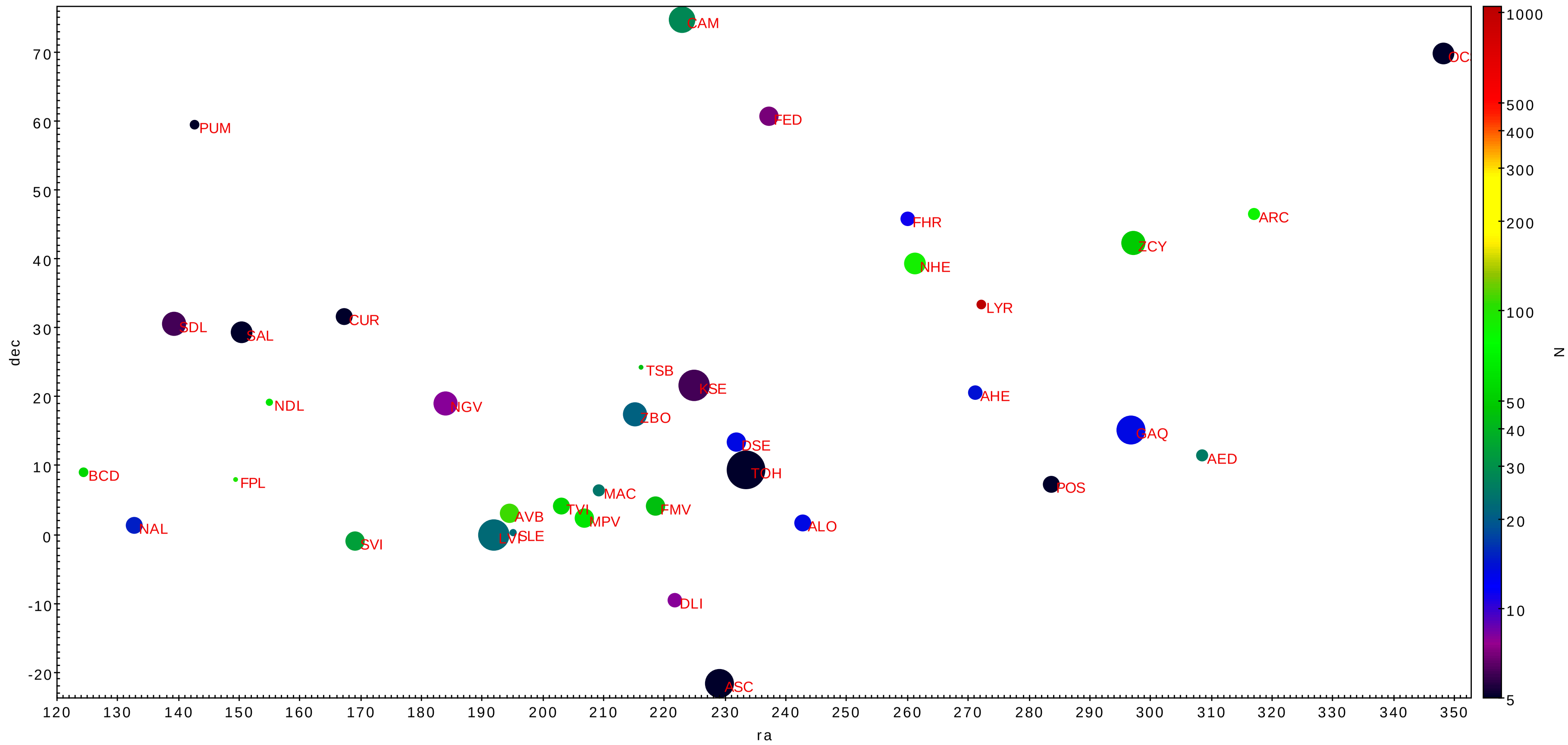

Figure 4: Identified spring meteor showers. Colour represents number of members of a shower, while the size represents D value based on the similarity measure between the mean orbital parameters of a cluster and linked with it the IAU MDC meteor shower (column 12 and 13 in Table 1, respectively).

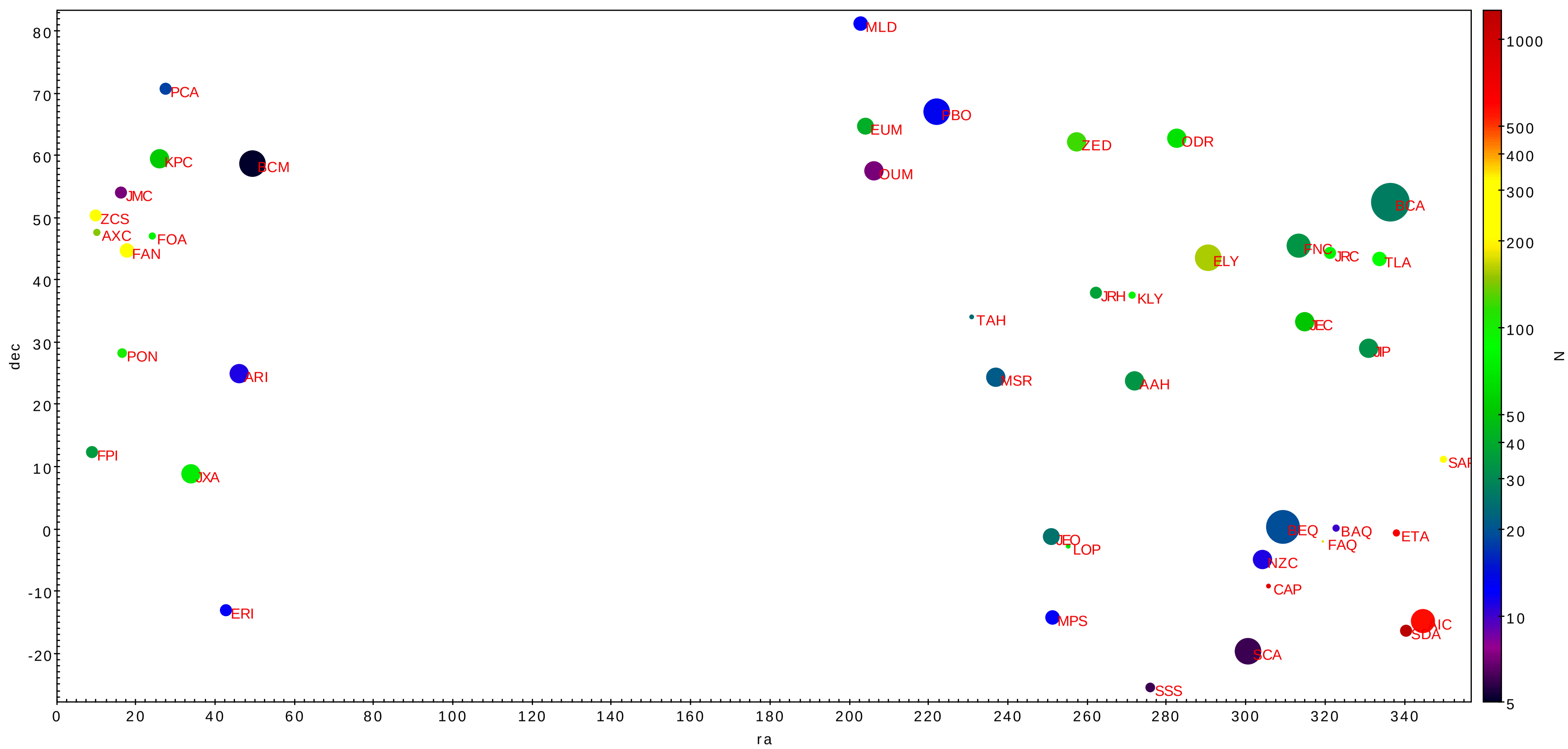

Figure 5: Identified summer meteor showers. Colour represents number of members of a shower, while the size represents D value based on the similarity measure between the mean orbital parameters of a cluster and linked with it the IAU MDC meteor shower (column 12 and 13 in Table 1, respectively).

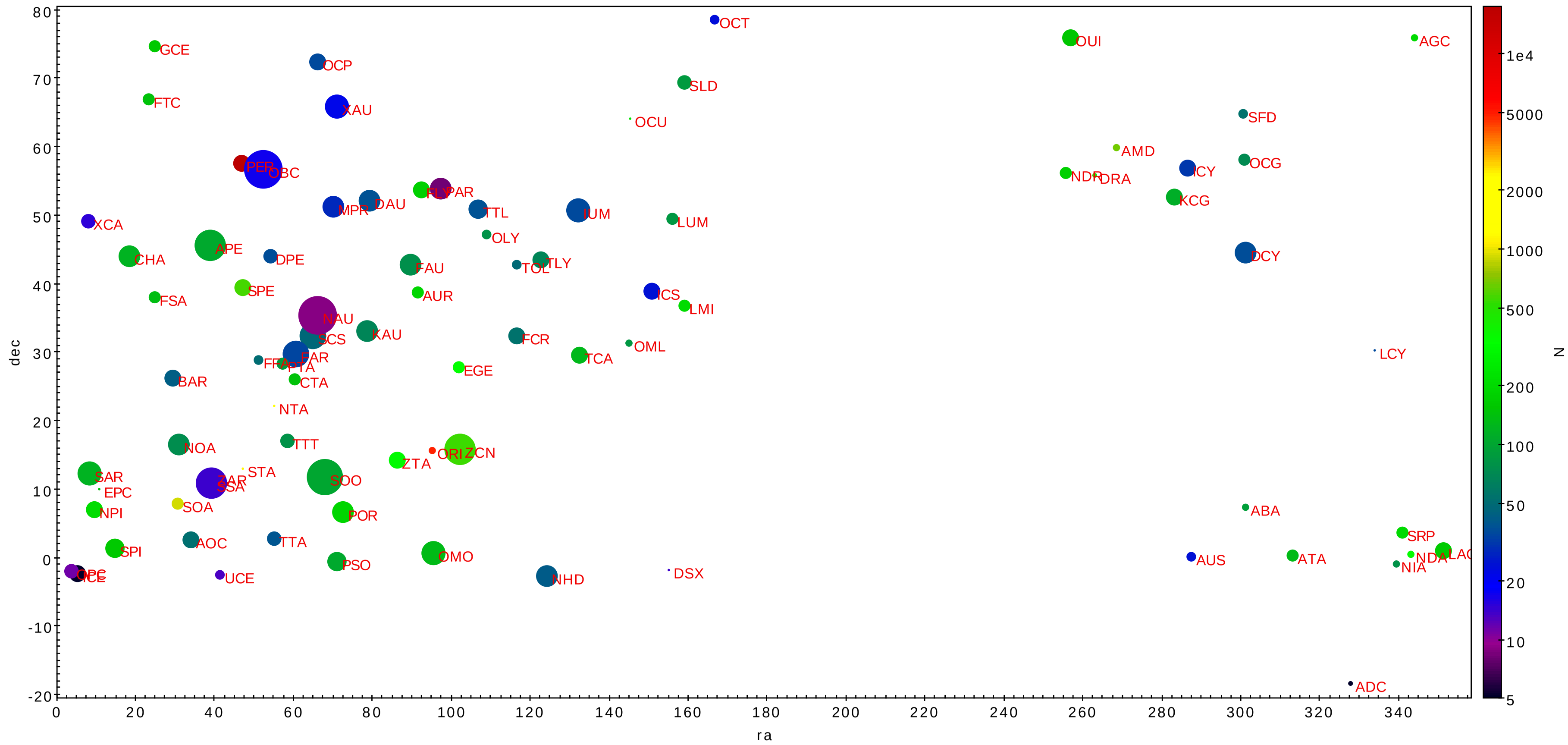

Figure 6: Identified autumn meteor showers. Colour represents number of members of a shower, while the size represents D value based on the similarity measure between the mean orbital parameters of a cluster and linked with it the IAU MDC meteor shower (column 12 and 13 in Table 1, respectively).

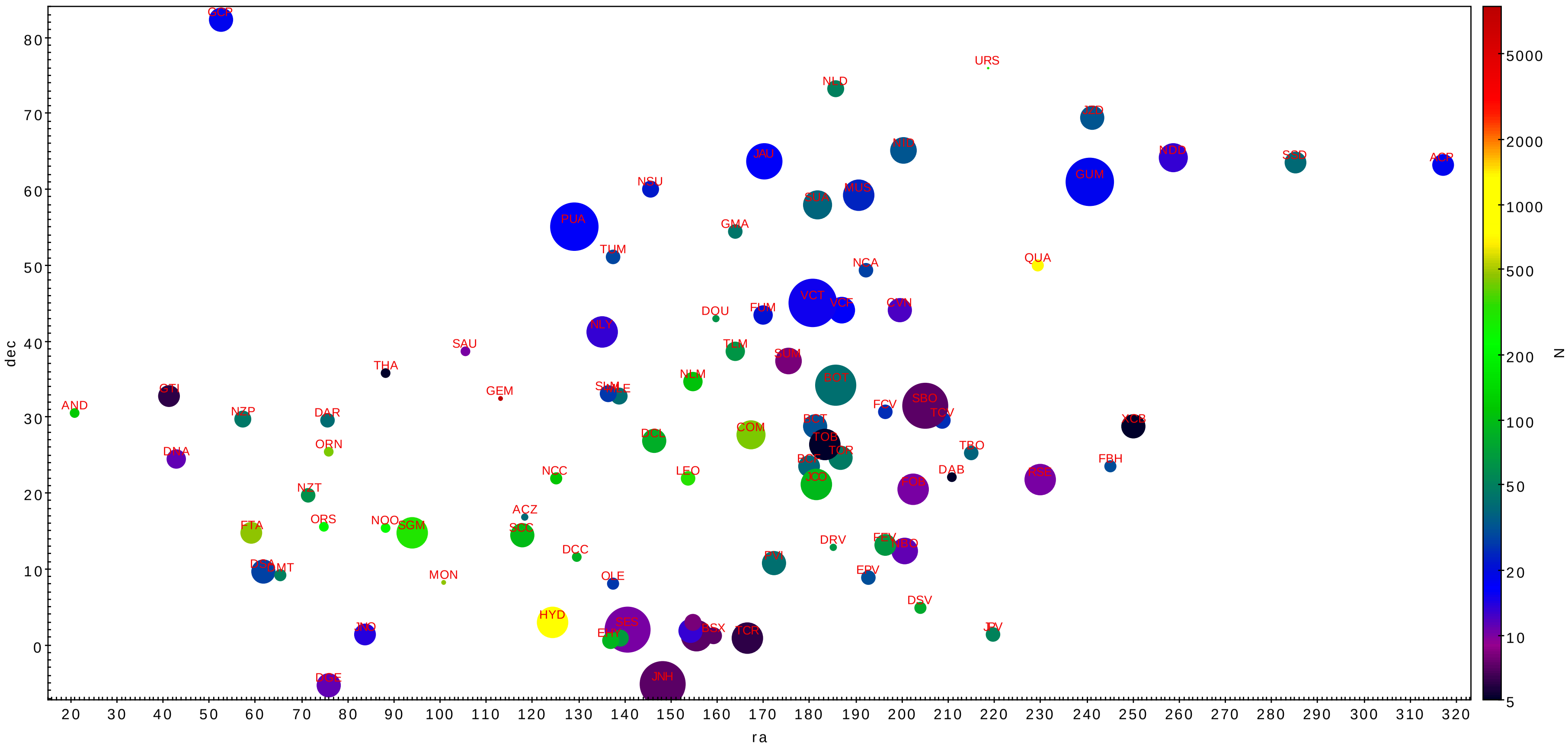

Figure 7: Identified winter meteor showers. Colour represents number of members of a shower, while the size represents D value based on the similarity measure between the mean orbital parameters of a cluster and linked with it the IAU MDC meteor shower (column 12 and 13 in Table 1, respectively).