An Orbital Meteoroid Stream Survey using the Southern Argentina Agile MEteor Radar (SAAMER) based on a Wavelet approach

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Abstract

Over a million individually measured meteoroid orbits were collected with the Southern Argentina Agile MEteor Radar (SAAMER) between 2012–2015. This provides a robust statistical database to perform an initial orbital survey of meteor showers in the Southern Hemisphere via the application of a 3D wavelet transform. The method results in a composite year from all 4 years of data, enabling us to obtain an undisturbed year of meteor activity with more than one thousand meteors per day. Our automated meteor shower search methodology identified 58 showers. Of these showers, 24 were associated with previously reported showers from the IAU catalogue while 34 showers are new and not listed in the catalogue. Our searching method combined with our large data sample provides unprecedented accuracy in measuring meteor shower activity and description of shower characteristics in the Southern

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Hemisphere. Using simple modeling and clustering methods we also propose potential parent bodies for the newly discovered showers.

Keywords:

meteor showers, meteoroids streams, meteors, radar

1. Introduction

The meteoroid background as measured at Earth can be broadly divided into two components: sporadic and shower meteors ([Jenniskens, 2006](#)). Sporadic meteoroids have no specific linkage to one another or to a particular parent body while shower meteoroids exhibit a common orbit suggestive of a physical linkage among stream members (variously defined by a host of possible similarity criteria, e.g. [Valsecchi et al., 1999](#)) which suggests a common parentage, though this parent body is often unknown. The fact that shower meteors may be linked to a parent makes them particularly valuable as proxy material for understanding comets and asteroids; shower meteors are small fragments of the parents and in effect, windows into the origin and evolution of these small solar system bodies. Identification of new showers may allow indirect sampling of parent bodies not previously studied and the particle distribution, shower duration, flux profile and radiant dispersion are diagnostic of the mode and timing of parent body decay. Such physical data on streams have been variously used to constrain meteoroid stream formation and evolution models (e.g. [Jenniskens et al., 2010](#); [Wiegert and Brown, 2005](#)).

Besides the study of specific showers, some analyses require that dynamical models are compared against all known showers, in the forms of shower

21 catalogs. Association between predicted showers and those observed form
 22 the basis for validation of such models. For example, Babadzhanov et al.
 23 (2008a) utilized a numerical integration method to investigate the orbital
 24 evolution of the near-Earth asteroid 2003 EH₁ and showed that its orbit in-
 25 tersects that of the Earth at eight different points with different values of
 26 argument of perihelion ω . Since the resulting orbital parameters are dif-
 27 ferent at each intersection the model explicitly predicted the existence of
 28 eight different meteor showers, presuming the complex was old enough. Us-
 29 ing published catalogs, these theoretically predicted showers were tentatively
 30 identified with observed streams. However, better information about those
 31 streams was required to prove such association and set limits to the age of
 32 the stream complex. Clearly, establishing which showers exist and which are
 33 spurious becomes critical to validating such models. In this manner, meteor
 34 shower catalogs constrain the past orbital evolution and physical character of
 35 presently detected Near-Earth Objects (NEO; Babadzhanov et al., 2008c,b).

36 Establishing the very existence of a shower is often a difficult task. Partic-
 37 ularly for weaker streams, basic physical characteristics (radiant drift, dura-
 38 tion, mass distribution) can be challenging to measure. While several dozen
 39 strong meteor showers have been known for many decades, the majority of
 40 showers are only weakly active and require large numbers of instrumentally
 41 recorded meteor radiants to separate the shower "signal" from the much
 42 stronger sporadic background "noise". Recently, optical surveys have over-
 43 come this barrier in part by using large numbers of small cameras and au-
 44 tomated meteor detection software to obtain multi-station radiants for large
 45 datasets (SonotaCo, 2009; Molau and Rendtel, 2009; Jenniskens et al., 2011)

46 and in so doing have identified several probable new minor showers. Optical
47 instruments, however, are limited to nighttime hours and clear skies - the
48 results of such surveys will tend to show large seasonal biases. Radar obser-
49 vations, in contrast, are able to record independent of weather and diurnal
50 conditions. The major limitation of radar observations in shower character-
51 ization is the lower metric precision of each measured event; however this
52 limitation is compensated through much larger datasets, with large number
53 statistics providing higher sensitivity for detection of weak showers.

54 In the last two decades several long-term optical and radar orbit survey
55 programs have been undertaken from northern hemisphere sites most notably
56 The Cameras for Allsky Meteor Surveillance (CAMS, [Jenniskens et al., 2011](#))
57 based on optical observations and a complementary survey performed with
58 the Canadian Meteor Orbit Radar (CMOR, [Brown et al., 2010](#), hereafter
59 B2010) utilizing backscatter transverse radio wave scattering. In contrast,
60 the southern hemisphere has only two recent shower surveys performed using
61 single-station radar observations ([Younger et al., 2009](#); [Janches et al., 2013](#)).
62 An effort to fill this gap utilizing optical and video observations has taken
63 place in the past few years ([Bland et al., 2012](#); [Jopek et al., 2010](#); [Molau and](#)
64 [Kerr, 2014](#); [Towner et al., 2015](#); [Jenniskens et al., 2016a](#)), focusing on larger
65 fireballs but which are limited by weather and day/night cycles. We note that
66 the Advanced Meteor Orbit Radar (AMOR) which operated in Christchurch,
67 New Zealand during the 1990s, produced some 0.5 Megaorbits, but at such
68 small particle sizes that only half a dozen of the strongest showers were visible
69 in the resulting dataset ([Galligan and Baggaley, 2004](#)).

70 In this work we report on an extension of our earlier initial single-station

71 radar study of meteor showers using the Southern Argentina Agile MEteor
72 Radar (SAAMER, [Janches et al., 2013](#), hereafter J2013). In J2013 we pro-
73 visionally identified showers using radar measurements of individual meteor
74 echoes and a statistical radiant approach which exploited the specular geom-
75 etry of meteor backscatter detection along the lines first proposed by [Jones](#)
76 ([1977](#)) and developed in detail by [Jones and Jones \(2006\)](#).

77 In this study we expand on J2013 by making use of individually measured
78 radiants/orbits (totaling ~ 1 Megaorbit) collected by the Orbital System; an
79 upgrade of SAAMER into a system capable of recording meteor orbits by
80 adding two remote receiving stations ([Janches et al., 2015](#), hereafter referred
81 as SAAMER-OS). Specifically, the orbits used in this study were collected in
82 the time period January 2012-January 2016. As first proposed by [Galligan](#)
83 [and Baggaley \(2002\)](#), we make use of the wavelet transform to extract shower
84 signals from SAAMER-OS. For this study, we apply a 3D wavelet transform
85 to identify showers, using the same general thresholds, background defini-
86 tion and shower linkage approach used by B2010 for the CMOR Northern
87 Hemisphere radar survey. However, we have developed a revised method of
88 computing background levels which includes both statistical fluctuations and
89 the physical background averaged throughout the year. This approach has
90 allowed us to improve sensitivity in both localizing 3D wavelet maxima and
91 linking them together as probable showers as compared to the original B2010
92 CMOR survey. We also compare common showers observed by CMOR and
93 SAAMER-OS in an effort to cross-validate results.

94 Finally, we have also explicitly applied our new shower linkage algorithm
95 in an attempt to confirm all showers listed in the International Astronomical

Union working list of meteor showers both on a year-to-year basis and in our composite single "virtual" year. Finally, we examine the probable origin and parent bodies of our newly detected showers.

2. Overview of SAAMER-OS Hardware and Detection Software

The SAAMER-Orbital System (OS), described in detail in [Janches et al. \(2015\)](#) is hosted by the Estacion Astronomica Rio Grande (EARG), located in Rio Grande, Tierra del Fuego, Argentina. It consists of three distinct radar stations: the central station (SAAMER-C; 53.79S, 67.75W) that hosts the transmitting and interferometry-enabled receiving antenna arrays, the northern remote station (SAAMER-N; 53.68S, 67.87W) located approximately 13 km northwest of the central station, and the western remote station (SAAMER-W; 53.83S, 67.84W) located approximately 8 km southwest of the central station. SAAMER-C has been in operation since May 2008 and utilizes high peak transmitter power (60 kW) at a frequency of 32.55 MHz. Together with a relatively narrow beam pattern provided by an eight-antenna transmitter array comprised of 3-element crossed yagi antennas ([Fritts et al., 2010](#), J2013) this allows detection of smaller meteoroids relative to most specular all-sky meteor radars (which have peak transmit powers of 6-20 kW; W. Hocking Personal Communication, 2015 and [Fritts et al., 2012](#)). The transmitting array is organized in a circular pattern of diameter 27.6 m (i.e., 3 times the radar wavelength) and the phase differences among transmitting antennas can be changed electronically, adding flexibility to the system to perform a number of transmitting and receiving modes ([Janches et al., 2014](#)). In normal operation mode each transmitting antenna transmits at a phase

120 difference of 180° from the adjoining two antennas (i.e. every other antenna
121 has the same phase), providing a gain pattern in which the majority of the
122 power is focused into eight beams at 45° azimuth increments with peak power
123 at approximately 35° zenith. The resulting transmit gain pattern results in
124 the majority of meteor echo detections to occur between zenith angles of 15°
125 and 50° . Details of the system parameters utilized for the different modes of
126 operation can be found in [Janches et al. \(2013, 2014, 2015\)](#).

127 The limiting magnitude of SAAMER-OS appears to be close to radio
128 magnitude +11 for single station observations, while the median magnitude
129 for orbital system requiring data from at least two remote stations is likely
130 closer to +9.5. Equivalent mass for orbital echoes from Verniani (1973) at 30
131 km s^{-1} is 10^{-8} kg (or 300 microns in diameter). This is an order of magnitude
132 in mass smaller than CMOR orbital masses (B2010).

133 A receiving antenna array with interferometry capability is also located at
134 SAAMER-C. The array is a typical configuration for meteor radar systems
135 consisting of 5 antennas, each of which is a 3-element vertically directed
136 crossed yagi ([Hocking et al., 1997](#)). The two remote stations, SAAMER-N
137 and SAAMER-W, were deployed in August 2010 to enable meteoroid orbit
138 determination through the time of flight method ([Baggaley et al., 1994](#)) and
139 are each equipped with a single 3-element vertically-directed crossed yagi
140 receiving antenna. The remote stations were placed in such a way that they
141 are in nearly orthogonal directions relative to SAAMER-C at a distance
142 on the order of 10 km. For common meteor echoes detected by all three
143 of the SAAMER-OS stations, the meteoroid trajectory and speed can be
144 determined using the measured time delays between the detections combined

145 with information from the interferometry from SAAMER-C ([Baggaley et al.,](#)
146 [1994](#); [Webster and Jones, 2004](#); [Brown et al., 2008](#)). The details of how
147 meteoroid orbits are measured are described in detail by [Janches et al. \(2015\)](#).

148 *2.1. Data and Results*

149 Figure 1 shows the daily count of determined meteoroid orbits observed
150 throughout the survey period (January 2012-December 2015). It can be seen
151 that the system can measure up to ~ 1800 meteoroid orbits per day. Un-
152 fortunately, due to terrestrial interference during this time there are several
153 periods in which there is lack of data preventing from the detection of weak
154 or minor showers for this initial survey (see [Janches et al., 2015](#), for more
155 details). Despite this interruption, a total of 1,001,536 meteoroid orbits were
156 measured as of December 31st, 2015 by SAAMER-OS, which represents the
157 largest sample in the Southern Hemisphere to date ([Janches et al., 2015](#)).

158 Figure 2 shows the number of the determined meteoroid orbits in each
159 one degree bin in solar longitude of an equivalent stacked or composite year.
160 Stacking data results in loss of the temporal resolution, however, this is
161 compensated by an increase in meteor counts in each solar longitude bin
162 since data with many gaps may result in artifacts in the wavelet search and
163 thus detection of non-existent meteor showers. By producing a composite
164 year through combining the four year data set we always have more than
165 1000 meteor orbits per one degree bin in solar longitude.

166 The distribution of SAAMER-OS observed meteoroid radiant is shown
167 in Fig. 3. The radiant is displayed in ecliptic coordinates in which they
168 are viewed from an Earth-centered frame of reference ([Jones and Brown,](#)
169 [1993](#)). The figure is oriented such that the center point corresponds to the

Figure 1: Number of orbits per day for the years 2012 - 2015 as recorded by SAAMER-OS. Gaps in data are due to terrestrial interference and equipment malfunctions that SAAMER experienced during this period (see [Janches et al., 2015](#), for more details).

Figure 2: The same as in Fig. 1 but now all the data stacked into one virtual year. For each day in this virtual year SAAMER-OS recorded at least 1000 meteors.

Figure 3: Raw radiant distribution of all SAAMER orbits measured over 4 consecutive years, from 2012 - 2015, with radiant density color coded in $0.5^\circ \times 0.5^\circ$ bins. We used sun-centered coordinates, where the apex of the Earth's motion is in the center of the plot, zero degrees latitude corresponds to the ecliptic plane and the sun is located at (0,0). The Helion source is to the left, the weakly visible North Apex source is in the center above the apex point, the South Apex source in the center below the ecliptic, the Antihelion source with the most prominent Southern δ Aquariids shower to the right, and the South Toroidal source at the bottom of the plot.

170 Apex of the Earth's way. For reference, the locations of the six sporadic
 171 meteoroid apparent sources are highlighted. These are the North and South
 172 Apex (NA/SA), the North and South Toroidal (NT/ST) and the Helion (H)
 173 and Antihelion (AH). Contributions from the sporadic apparent sources to
 174 the radiant distribution observed by SAAMER-OS are evident in this Figure,
 175 as well as 2 strong meteor showers, which appear as dense concentrated en-
 176 hancements in the radiant distribution (Janches et al., 2014). The strong en-
 177 hancement within the Anti Helion (AH) source corresponds to the Southern
 178 δ Aquariid (SDA) shower, which has such strong activity that it dominates
 179 the color scale in Fig. 3. The weaker enhancement to the left of the North
 180 Apex (NA) source corresponds to the Eta Aquariid shower (ETA, Campbell-
 181 Brown and Brown, 2015). As expected, the majority of meteors observed by
 182 SAAMER-OS originate from radiant locations south of the ecliptic (i.e. the
 183 ecliptic latitude of the radiant is negative), with particularly strong contri-
 184 butions from the South Apex (SA), South Toroidal (ST), Helion (H) and AH
 185 sources.

186 **3. Orbit Computation**

187 Janches et al. (2015) describes details of the meteoroid orbit measure-
 188 ment method used by SAAMER-OS. Briefly, when a meteor is detected at
 189 SAAMER-C, the location (i.e. range, azimuth, and elevation) of the specular
 190 reflection point on the meteor trail is determined using the interferometric
 191 receiving array (Hocking et al., 2001; Lau et al., 2006). The specular reflec-
 192 tion point is defined as the point on the trail that minimizes the signal travel
 193 path from the transmit array to the meteor trail. It is the point at which the

194 meteoroid is at its minimum range from the central station. At this point
195 the meteoroid's velocity is normal to the position vector from the radar. The
196 range ρ , elevation α , and azimuth ψ , to the specular point on the trail give
197 the position of the meteoroid at the specular point relative to the central
198 station using the SAAMER-C interferometric capabilities.

199 The meteoroid's absolute velocity is obtained from the time delay be-
200 tween the echo's appearance at the main site relative to the remote sites,
201 SAAMER-N and SAAMER-W, and the known (and fixed) vector's relat-
202 ing the position of SAAMER-C relative to SAAMER-N and SAAMER-W
203 using the geometrical technique previously employed at AMOR ([Baggaley](#)
204 [et al., 1994](#)) and CMOR ([Webster and Jones, 2004](#); [Jones et al., 2005](#)). This
205 geometrical method is applied to all meteors that are detected at all three
206 SAAMER receiving stations and relies on the assumption that the interaction
207 between the radar signal and the meteor trail is described by the specular
208 reflection condition. This constrains the possible locations of the echo points
209 along the trail as detected at the remote stations, which receive the forward
210 scattered signal transmitted by SAAMER-C from (generally) different scat-
211 tering points along the meteor trail. The measured time delay between each
212 of the detections at the remote sites and the central station allows for the
213 determination of the meteoroid velocity ([Baggaley et al., 1994](#); [Jones et al.,](#)
214 [2005](#); [Janches et al., 2015](#)). Given the position, velocity, and observation
215 time of a meteoroid relative to an observer (e.g. a radar antenna), we em-
216 ploy a patched-conics approach (a method to simplify trajectory calculations
217 for spacecraft in a multiple-body environment [Wiesel, 1997](#)) to obtain the
218 meteoroid's geocentric and heliocentric orbits. For each of the two orbits,

the central body (i.e. the Earth in our case) is assumed to provide the dominant force acting on the meteoroid and is determined by the distance of the meteoroid from the relevant celestial bodies as well as their mass properties. All other forces (e.g. atmospheric drag) are modeled as perturbation forces and are not considered in the estimation of the meteoroid’s nominal orbit.

Since SAAMER-OS is not currently using any model for the meteoroids’ deceleration in the Earth’s atmosphere, we note, that the reported geocentric speed is actually a lower limit. The deceleration in the radar observation might play a significant role for low speed meteors ($< 25 \text{ km s}^{-1}$), while for meteors with high geocentric speeds ($> 60 \text{ km s}^{-1}$) the deceleration correction is more likely to be negligible (Brown et al., 2004).

Table 1 shows comparisons of 21 showers detected both by SAAMER-OS and CMOR. For each shower we show the solar longitude of the peak λ_{max} , the sun-centered longitude $\lambda - \lambda_0$, the sun-centered latitude β , the geocentric velocity V_g in km s^{-1} , and the geocentric velocity difference ΔV_g measured by SAAMER and CMOR respectively. Note, the value of V_g is presented with the deceleration correction for CMOR while for SAAMER-OS no deceleration correction was applied. We also show a strength of the detection of the shower compared to the background activity σ_{wave} for both SAAMER and CMOR (for more details about σ_{wave} see Section 4). Comparison of common CMOR and SAAMER-OS showers shows similar speeds within uncertainties with the deceleration being a generally second order correction. We note that most of the differences where the shower peaks are observed at the same time show an overall tendency for CMOR’s speeds to be slightly higher, as expected given the deceleration correction applied to all

CMOR meteors. Interestingly, when we compare the geocentric velocities of these showers to those resulting from optical observations (Jenniskens et al., 2016b,c,d; Jenniskens and Nénon, 2016) the geocentric velocity of all comparable radar showers is systematically lower for the case of SAAMER-OS results. On average, the measured geocentric velocities by optical systems are 2 km s^{-1} higher. This shows how critical it is to accurately correct the observations for deceleration effects. In addition, since SAAMER-OS observes systematically smaller meteors than both, CMOR and CAMS, the lower geocentric velocities may be due also in part a result of different dynamics of meteoroids streams. While this issue is important, it is currently beyond the scope of this manuscript and will be addressed in later work.

4. Wavelet-based Analysis Methodology

As in B2010, we compile the data into one composite representative year for meteors with complete information about their radiant location and incident velocity. Janches et al. (2015) showed that the average error in the radiant location is close to 1° , and the spread of velocities is 10%, which are values comparable to those in B2010. This allows us to use the same method that B2010 used for CMOR, however here we modify the original method in that work based on more than 5 years of additional experience applying wavelet analysis to meteor radiant distributions.

Following B2010, we use the 3D wavelet transform to search for clusters of meteors that, after successfully passing several tests, are deemed to be shower candidates. Since the spread in radiant and velocity distributions of showers is usually best described as a Gaussian (B2010), we adopt the Mex-

Table 1: Comparison of characteristics of 21 common showers observed by CMOR and SAAMER-OS. See the main text description of presented values.

IAU	$\lambda_{\max}$	$\lambda - \lambda_0$	β	V_g	σ_{wave}	$\lambda_{\max}$	$\lambda - \lambda_0$	β	V_g	σ_{wave}	ΔV_g
	SAAMER-OS					CMOR					
ETA	46	293.7	7.2	64.2	52.2	45	294.2	7.8	63.6	257.4	0.6
OCE	47	330.4	-13.8	36.5	26.8	49	331.0	-13.1	37.0	76.3	-0.5
ARI	79	331.5	7.2	40.5	6.5	81	329.3	7.5	39.1	125.2	1.4
SZC	80	218.9	-13.5	35.9	34.6	80	219.8	-13.3	37.7	45.7	-2.2
NZC	101	210.4	13.5	36.5	19.2	101	210.6	13.6	37.5	44.9	-1.0
MIC	104	208.5	-13.3	35.9	15.1	104	209.8	-12.2	38.0	8.0	-2.1
PAU	125	215.3	-19.5	39.9	17.4	135	213.5	-18.5	44.0	14.8	-4.1
SDA	125	209.5	-7.5	39.9	141.0	126	210.1	-7.6	40.7	177.7	-1.8
CAP	127	178.6	9.7	24.4	16.3	123	179.9	9.0	22.0	24.4	2.4
NDA	136	210.3	7.7	38.1	7.0	139	208.7	7.8	37.3	12.6	0.8
DSX	187	330.8	-11.0	31.4	29.9	186	330.5	-10.9	31.3	89.3	0.1
OLP	199	236.8	-40.8	26.7	11.8	203	236.8	-36.9	25.5	70.0	1.2
ORI	207	248.3	-8.3	64.2	7.6	208	247.3	-8.1	65.4	82.5	-1.2
NOO	248	205.3	-9.0	41.7	9.8	246	204.5	-8.1	43.1	83.2	-1.4
SSE	274	326.6	18.0	42.3	14.5	275	325.4	20.5	42.3	22.2	0.0
DHY	275	230.4	-30.5	49.9	6.9	266	231.5	-28.2	54.5	18.4	-4.6
AHY	284	208.4	-25.8	42.3	13.1	286	207.4	-26.4	43.2	32.8	-0.9
XSA	288	353.1	6.7	25.5	20.9	288	353.9	6.6	25.3	12.8	0.2
DCS	299	0.8	-9.5	23.7	16.3	301	359.2	-9.3	23.8	12.9	-0.1
MHY	303	228.1	-32.3	35.4	12.4	300	224.7	-29.3	39.1	23.8	-3.7
DCS	305	356.4	-8.5	24.4	11.2	301	359.2	-9.3	23.8	12.9	0.6
MHY	310	221.1	-24	36.5	17.0	300	224.7	-29.3	39.1	23.8	-2.6
AAN	312	214.8	-19.5	41.1	16 19.1	312	215.1	-18.9	43.2	62.3	-2.1

268 ican hat mother wavelet to produce a Wavelet coefficient, described by Eq.
 269 1, at a given point $(\Lambda_0, \beta_0, V_{g0})$. For our wavelet search we use the following
 270 variables: $\Lambda = \lambda - \lambda_0$, where λ is the ecliptic longitude of the geocentric
 271 radiant, λ_0 is the solar longitude at the time of occurrence of the meteor, β
 272 is the ecliptic latitude, and V_g ; the geocentric speed. The advantages of us-
 273 ing sun-centered ecliptic coordinates is that it minimizes shower radiant drift
 274 and typically restricts the small remaining drift to be parallel to the ecliptic
 275 plane, in contrast to the large Earth-motion-induced drifts found when using
 276 right ascension and declination. B2010 did not explicitly expand the wavelet
 277 search to the fourth dimension, i.e. in time, since it provided no significant
 278 improvements compared to the 3D method. Additionally, from a single site
 279 on Earth, radiants over the entire sky are only sampled with a cadence of one
 280 day (roughly one degree in solar longitude) so shorter intervals have artificial
 281 biases. Following the same approach we divide our composite year of data
 282 into 360 bins in λ_0 , which also provides benefits in lower memory usage and
 283 higher parallelization of the wavelet search. For our dataset we apply:

$$\begin{aligned}
 W_c(\Lambda_0, \beta_0, V_{g0}) = & \frac{1}{(2\pi)^{3/2} \sqrt{\sigma_\Lambda \sigma_\beta \sigma_{V_g}}} \int_{V_{g\min}}^{V_{g\max}} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} N(\Lambda, \beta, V_g) \\
 & \left(3 - \frac{(\Lambda_0 - \Lambda)^2}{\sigma_\Lambda^2} - \frac{(\beta_0 - \beta)^2}{\sigma_\beta^2} - \frac{(V_{g0} - V_g)^2}{\sigma_{V_g}^2} \right) \times \\
 & \exp \left(-0.5 \left[\frac{(\Lambda_0 - \Lambda)^2}{\sigma_\Lambda^2} + \frac{(\beta_0 - \beta)^2}{\sigma_\beta^2} + \frac{(V_{g0} - V_g)^2}{\sigma_{V_g}^2} \right] \right) \\
 & d\Lambda d\beta dV_g
 \end{aligned} \tag{1}$$

284 where σ_Λ is the size of the probe in the ecliptic longitude direction, σ_β is the
 285 size of the probe in the ecliptic latitude direction, σ_{V_g} is the size of the velocity
 286 probe, and $N(\Lambda, \beta, V_g)$ is the number of meteor radiants at spatial coordi-

287 nates (Λ, β) with geocentric speed V_g to compute the wavelet coefficient, W_c .
 288 It is important to note that this transformation is not unit invariant, thus a
 289 change of angular units from degrees to radians will result in different values
 290 of wavelet coefficient. However, as we will see later, the number of detected
 291 showers is unit invariant. We adopt in our analysis the same unit convention
 292 utilized by B2010 (i.e., degrees for angles and km s^{-1} for velocities). Interpretation
 293 of the coefficient $N(\Lambda, \beta, V_g)$ from Eq. 1 can be challenging, since it is
 294 effectively an array of delta functions ignoring measurement uncertainty; i.e.
 295 $N(\Lambda, \beta, V_g)$ is either unity at the exact position of the meteor in (Λ, β, V_g)
 296 space or zero everywhere else. In the case of real measurements, however,
 297 each radiant is defined with some uncertainty. A better approach would be
 298 to represent each radiant as its normalized probability error density function
 299 and perform a wavelet search over this uncertainty-smeared space, but at the
 300 expense of computational speed. In this case, we might benefit from binning
 301 our dataset in the three dimensional space, which will dramatically decrease
 302 the computational demands of the wavelet search process since Eq. 1 be-
 303 comes a discrete sum. Note, the binning should be fine enough to adequately
 304 represent the distribution of meteors in the plane of the sky. B2010, however,
 305 used the continuous form of Eq. 1, which removes any potential problems
 306 with different bin sizes requiring more computational power. In this study
 307 we adopt the same settings as used in B2010.

308 To isolate local temporal maxima in W_c we determine the median value
 309 at each sun-centered radiant point throughout all 360 degree bins in solar
 310 longitude for the whole year. Thus we find W_c at each point (Λ, β, V_g) , de-
 311 termine its yearly median, and discard all points 3σ above the median. This

Figure 4: Annual time variation of W_c for the Orionids meteor shower located at $\lambda - \lambda_0 = 248.3^\circ$ $\beta = 8.3^\circ$, with the geocentric speed $V_g = 64.2 \text{ km s}^{-1}$. The angular probe size in this case is $\sigma_\Lambda = \sigma_\beta = 2.5^\circ$, while the velocity probe size $\sigma_{V_g} = 15.0\%$. The variable $\tau_{ws} = 1.0^\circ$ determines the temporal window selection, which in this case means that we bin data in integer values of the solar longitude.

312 iterative procedure continues until all values of W_c during the whole year
 313 are below the 3σ limit; i.e. we remove potential shower activity during the
 314 year (both the shower of interest and other showers which might occur in a
 315 similar radiant position) and obtain the wavelet profile of the annual average
 316 radiant background at that sun-centered radiant location. An example of the
 317 resulting annual time variation of W_c is shown in Fig 4. The annual median
 318 is the baseline from which we determine how significant is an excursion in

319 the local W_c found during the wavelet search. The number of standard devi-
 320 ations of this W_c maximum above the median is given by σ_{wave} . Our shower
 321 significance level is then stated as the σ_{wave} of the shower maximum. The
 322 interpretation of σ_{wave} is straightforward. While W_c might be for some po-
 323 tential showers quite large compared to background, these potential showers
 324 might be, in fact, fluctuations of the background and thus should be dis-
 325 carded. On the other hand, using σ_{wave} we can easily detect these artificial
 326 showers and remove them from our search. B2010 found that at their peak
 327 activity, the most prominent showers had $\sigma_{\text{wave}} > 100$. They further found
 328 (empirically) that any shower candidate with a core $\sigma_{\text{wave}} > 3$ might poten-
 329 tially be a shower, though the false positive rate increases significantly once
 330 $\sigma_{\text{wave}} < 8$. Additionally, we also require the number of individual radiants
 331 used in the calculations of W_c (which is found numerically by counting all
 332 radiants outward 3 probe sizes from the radiant of interest) to be more than
 333 30 meteors to avoid false positives in regions with low number statistics (e.g.
 334 anti-apex direction).

335 An additional modification to the B2010 method is to limit the back-
 336 ground wavelet coefficient computation throughout the year to periods when
 337 the radiant has a zenith angle less than 80° . These W_c are omitted from the
 338 annual median computation since the collecting area of such radiants varies
 339 significantly throughout the year and we found through experimentation that
 340 the resulting small number fluctuations in radiant number tend to produce
 341 an artificial contribution to the annual median value, resulting in erroneous
 342 σ_{wave} values.

343 We also must determine the increments for the search steps in (Λ, β, V_g)

344 space as well as choose angular ($\sigma_\Lambda, \sigma_\beta$) and velocity (σ_{V_g}) probe sizes. Ideally,
 345 we would use infinitesimal steps in (Λ, β, V_g) space, however, the computa-
 346 tional complexity increases as the cube of the number of bins in our 3D phase
 347 space. For our search we used 0.25° steps for angular variables (Λ, β) , and
 348 1.5% step in V_g , setting the precision bounds for the resulting shower radiants.
 349 The percentage step in V_g is used to capture characteristics of the investigated
 350 populations of meteors, in our case we investigate meteors with V_g between
 351 11 and 72 km s^{-1} . The probe size selection is complicated as different showers
 352 have distinct angular, velocity, and temporal spreads which result in differ-
 353 ent sensitivity to selected probe sizes. With potentially three different probe
 354 sizes, the time complexity increases proportional to the cube of the number of
 355 probes; here we limit the computational time by setting $\sigma_\Lambda = \sigma_\beta$. To identify
 356 the optimal probe sizes, we chose the strongest meteor shower observed by
 357 SAAMER-OS with well established orbital characteristics (B2010), namely
 358 the South δ Aquariids (SDA; $\Lambda = 210.1^\circ, \beta = -7.6^\circ, V_g = 40.7 \text{ km s}^{-1}$). We
 359 then computed $W_{c_{\max}}$ at the time and radiant location of the shower max-
 360 imum with variable probe sizes both in angular and velocity space. Since
 361 the position of $W_{c_{\max}}$ for the SDA in the SAAMER-OS data set might be
 362 different from literature values, our search was performed in a region with
 363 $205^\circ < \Lambda < 215^\circ$, $-10^\circ < \beta < -5^\circ$, and $36 < V_g < 44 \text{ km s}^{-1}$. Fig. 5
 364 shows the results of our search for an optimal probe size. From Fig. 5 we
 365 see that the best probe size settings are $\sigma_\Lambda = \sigma_\beta = 2.5^\circ$, and $\sigma_{V_g} = 15\%$.
 366 These settings were used in all of our subsequent wavelet searches. Having
 367 chosen our optimal probe sizes, the next stage in the shower search takes the
 368 array of local maxima and links them spatially and temporally. In our search

Figure 5: Contour plot showing the wavelet coefficient maxima $W_{c_{max}}$ on the date of maximum activity at the peak radiant location of the South δ Aquariids meteor shower in velocity and angular probe size phase space. The color coding represents values of $W_{c_{max}}$ normalized to unity. Here the step in the angular space was 0.1° , and the step in the velocity space was 0.5%.

linkage approach, we expanded the original idea of B2010 and perform our linking procedure in two stages.

In the first stage we considered identified points as part of a single linked stream if the location of the W_c was separated by less than 2° in angular coordinates and less than 10% in geocentric velocity V_g and if the separation in solar longitude was below 2° . This first stage works particularly well for finding stream cores. All linked showers from this first stage analysis, together with their characteristics, wave profiles, and orbital elements can be found in the Supplementary Material¹.

During this first stage, we observed that different linked chains of maxima were associated with the same shower. This is due to the very strict linkage constraints whereby the maximal angular and velocity linkage values are too low. This results in slicing one longer duration shower into several separate chains. To determine if the linked chains are truly separate showers we performed a second more permissive linkage cycle using slightly wider constraints increasing the maximum angular radiant spatial separation to 3° and the maximum difference in V_g to 15%. All linked showers found in the second stage, with their characteristics, σ_{wave} profiles, and orbital elements can also be found in the Supplementary Material.

In total, the first stage of our linking procedure resulted in 133 shower candidates, while the second step using looser criteria provided an additional two candidates for a total of 135 potential showers (see Supplementary Material for more details). From this initial set of potential showers, we applied

¹See ftp://aquarid.physics.uwo.ca/pub/peter/SAAMER_paper/supplementary.pdf

several further filtering procedures. The reason for these additional filters is simple: we seek only high-quality showers which will be likely confirmed by independent observers in the future. All candidates were required to have a duration of at least 4 days (or 4 degrees in solar longitude). Furthermore, we required that the core (the maximum of the linked chain with the highest value of σ_{wave}) of the candidate must have $\sigma_{\text{wave}} > 6$. Note, that these additional filter conditions were not used in B2010 and would have resulted in the removal of 29 of the 117 identified meteor streams in that earlier work. Of those 29 streams only 5 have been confirmed by other surveys, suggesting that some may be spurious.

5. Results and Analysis

After applying these previously mentioned association techniques and filters, our survey resulted in the identification of 52 meteor streams, 26 of which have not been previously identified according to the IAU Meteor shower list. It is important to note that, although we performed two stages of linking, some streams might actually be part of a larger complex. In this manuscript, we report our findings in two sections: Section 5.1 will describe the showers that are listed in the IAU Meteor Shower Catalogue at the time this work was been conducted, independent of whether they are considered established or not. In Section 5.2 we describe the showers that were not listed in the IAU Meteor Shower Catalogue and thus we consider them as new showers. For more details regarding our shower selection process and the raw results from our shower search the reader can refer to the Supplementary Material accessible online.

416 5.1. IAU Catalogue Showers

417 In this Section we describe our results for showers identified by our search
418 method that we can associate with showers listed in the IAU Meteor Shower
419 Catalogue as of February, 2016 (Jopek and Kaňuchová, 2014). We compared
420 the solar longitude, radiant location in sun-centered coordinates, and the
421 geocentric velocity of all IAU MDC showers with those resulting from our
422 search. We consider a positive association when: 1) the value of the solar
423 longitude reported in the IAU list falls within the duration of the shower
424 period during which SAAMER-OS detected it, 2) the radiant location was
425 within 3° of that reported in the IAU list, and 3) the geocentric velocity
426 was within 10% difference. Numerous showers in the IAU list have more
427 than one reported set of parameters. In those cases we treated all reports
428 with equal weight. We considered the IAU MDC showers the same as our
429 detected showers as long as one set from the IAU MDC matched our associ-
430 ation criteria. Several showers were associated with more than one reported
431 IAU MDC shower. These cases were treated separately, taking into account
432 whether the IAU MDC lists the reported shower as established and has a
433 well supported set of parameters. Table 2 summarizes the results described
434 in this section where the showers are sorted according to their solar longitude
435 at which highest wavelet coefficient W_c occurs.

436 In the following paragraphs we provide specific comments about showers
437 listed in Table 2. We will provide comments only for selected showers.

438 η Aquariids (ETA)

439 ETA is the second strongest shower observed by SAAMER-OS with a
440 strength over 50σ above the annual median. The timing and radiant position

are in good agreement with the IAU database, while our reported geocentric velocity $V_g = 64.2 \text{ km s}^{-1}$ is on the lower end of all reported values being slightly lower than that reported by [Brown et al. \(2008\)](#) and B2010, possibly reflecting deceleration in the SAAMER-OS measurements.

Southern Daytime ω Cetids (OCE)

OCE is a strong shower in our sample with $\sigma_{\text{wave}} = 26.8$ lasting for more than 40 days. This gives us strong confidence that the shower is real. OCE is an established shower that has been reported numerous times in the IAU MDC database. The solar longitude of the peak in our search falls between values reported by [Brown et al. \(2008\)](#) and B2010. Different timing of the peak also changes RA and Dec, however the sun-centered coordinates are independent of such a drift. Our reported values are in agreement with [Brown et al. \(2008\)](#) and B2010.

Daytime Arietids (ARI)

ARI is located within the Helion source, and thus it is a daytime shower, observations of which are almost exclusive to radars. SAAMER-OS observation of this shower places the maximum later than other reported values (B2010, [Jenniskens et al., 2016b](#)), however the position and the geocentric velocity are almost identical to the values reported by B2010. While the activity of this shower is quite weak as seen by SAAMER-OS (just barely above our minimum 6σ threshold due to the high northern declination of the radiant) at the time of maximum we determined the semimajor axis $a = 2.48 \text{ au}$, which is a higher value than previously reported by other radars ([Bruzzone et al., 2015](#)) but closer to optical observations ([Jenniskens et al., 2016b](#)).

Days on either side of the peak, however, are comparable to the speeds and mean orbits reported in [Bruzzone et al. \(2015\)](#).

Southern June Aquilids (SZC)

SZC is the third strongest shower in the SAAMER-OS sample. This established shower has less than 150 reported meteors according to the IAU database; this number increases up to 500 when we include results of B2010. SAAMER has measured SZC meteors with position and timing almost identical to B2010. The geocentric velocity of SZC from SAAMER-OS observations is approximately 10% lower than previously reported. We note that [Jenniskens et al. \(2016b\)](#) reports the shower peak at the solar longitude $\lambda = 104^\circ$ which disagrees with our findings and with those of B2010. One potential source explanation is that [Jenniskens et al. \(2016b\)](#) mistakenly exchanged SZC for MIC (Microscopiids), which has similar radiant/speed values.

Southern May Ophiuchids (SOP)

SOP is not currently an established IAU MDC shower having only a handful of reported meteors since it is not easily observable from the Northern hemisphere, where most of the surveys to date have taken place. SAAMER-OS, however, detected SOP as a stronger shower with $\sigma_{\text{wave}} = 15$, duration of 33° in the solar longitude, and positive drift in both RA and Dec. The peak of SOP ($\lambda = 81^\circ$) appears later than previously reported ($\lambda = 65.2^\circ$ [Jopek et al., 2010](#)), however, the orbital elements for this shower are similar to those determined by [Jopek et al. \(2010\)](#).

488 *Northern June Aquilids (NZC)*

489 NZC is a shower of medium strength lasting for more than 30 days from
490 SAAMER measurements. This shower is not considered established in the
491 IAU meteor database despite many reports with significant numbers of me-
492 teors (B2010, [Jenniskens et al., 2016b](#)). The characteristics of the NZC in
493 our survey agree with previously reported values with one exception in the
494 geocentric velocity $V_g = 36.5 \text{ km s}^{-1}$, where our value is 5% smaller, possibly
495 due to lack of deceleration correction.

496 *Microscopiids (MIC)*

497 MIC is one of the stronger showers in the southern hemisphere, and was
498 previously reported only by B2010. There is a possibility also that this
499 shower may have been misidentified by [Jenniskens et al. \(2016b\)](#) as SZC.
500 Our reported timing, radiant location are almost identical to those reported
501 by B2010, while our geocentric velocity is approximately 6% smaller.

502 *Piscis Austrinids (PAU)*

503 PAU is another strong shower in the southern hemisphere, that is difficult
504 to observe by facilities in the northern hemisphere. This shower is considered
505 established by IAU despite having less than 200 reported meteors. Interest-
506 ingly, the timing of the peak of PAU is 10° earlier and the speed 10% smaller
507 than the value reported by B2010. However, the radiant location is almost
508 identical. The activity is broad and the peak not well defined so this differ-
509 ence may reflect the broadness of the shower profile. The velocity difference
510 is also the reason why the reported orbital elements are different to those we
511 found in this work.

512 *South δ Aquariids (SDA)*

513 SDA is the strongest ($\sigma_{\text{wave}} = 141$) and the longest lasting (more than
514 50 days) shower in our sample. This shower is well established. The char-
515 acteristics we determined and report here agree well with published values,
516 though our geocentric velocity $V_g = 39.9 \text{ km s}^{-1}$ falls into the slower end of
517 reported values, again possibly due to the fact that we are not correcting for
518 deceleration.

519 *October Leporids (OLP)*

520 OLP is a stronger shower in the southern hemisphere previously reported
521 only by B2010. Due to its far southern radiant location, B2010 did not
522 see as many meteors as for other showers, however, its significance level in
523 CMOR data of $\sigma_{\text{wave}} = 70$ makes this shower one of the strongest southern
524 hemisphere showers observed by CMOR. Our results are in good agreement
525 with those reported by B2010. An outstanding feature of this shower from
526 both CMOR and SAAMER measurements is its high inclination, Aten-like
527 orbit and its unknown parent body.

528 *β Canis Majorids (MCB)*

529 MCB is a weak shower lasting for only 5 days in SAAMER data. It
530 was previously reported by Andreić et al. (2014) with only 20 meteors. Our
531 reported values agree well with Andreić et al. (2014) however, due to the
532 low significance level with $\sigma_{\text{wave}} = 7$, the activity profile is not completely
533 convincing (see the Supplementary Material) and it is unclear whether this
534 is a real shower or just a fluctuation in the background.

535 *November Orionids (NOO)*

536 NOO is an established shower in the southern hemisphere that has been
537 widely reported according to the IAU MDC. SAAMER detects NOO as a
538 weaker shower ($\sigma_{\text{wave}} = 9.8$) with characteristics very similar to reported
539 values. Interestingly, NOO is very strong when observed by optical systems
540 [Jenniskens et al. \(2016b\)](#). While the parent body for NOO remains unknown,
541 its orbital elements suggest a cometary origin. Even though our measured
542 geocentric velocity is slightly lower than previously reported values, and thus
543 so is the semimajor axis $a = 4.68$ au, we confirm its probable Halley-type
544 comet (HTC) or Oort Cloud comet (OCC) origin.

545 *e Velids (EVE) / Puppis-Velid I Complex (PUV) / b Puppids (PVE)*

546 Our search resulted in provisional detection of a shower that can be asso-
547 ciated with three non established IAU MDC showers, namely the EVE, PUV,
548 PVE. Since the timing, radiant location and the geocentric velocity are only
549 available for EVE ([Jenniskens et al., 2016b](#)), we identify our results with
550 this shower. This shower is located at a high southern hemisphere latitude,
551 presumably the main reason it remained unknown until 2016. In comparison
552 with [Jenniskens et al. \(2016b\)](#) our shower has an earlier peak activity occur-
553 ring at $\lambda = 250^\circ$, slightly different radiant location, and a lower geocentric
554 velocity $V_g = 39.9$ km s $^{-1}$. However, this shower is one of the strongest in
555 our dataset with $\sigma_{\text{wave}} = 13.6$. It is active for a period of 21 days, and is
556 peculiar because of its very highly inclined orbit $I = 71.9^\circ$, typical for the
557 South Toroidal source region.

558 *December Hydrids (DHY)*

559 DHY is the second weakest shower in Table 2 even though its observing
560 geometry is good for SAAMER. This shower was exclusively reported by
561 B2010 with more than 600 meteors and very good significance level, but has
562 not yet been categorized as established. The timing and radiant location
563 are in good agreement with B2010, while our reported speed is 10% lower.
564 However, we must again remain cautious in this case, since our search method
565 resulted in a rather weak activity. The shower duration from SAAMER-OS
566 observations is 5 days, which is shorter than reported by B2010 (20 days).

567 *Daytime Capricornids-Sagittariids (DCS)*

568 DCS is a minor not established shower in the southern hemisphere that
569 was repeatedly reported in the 70's by Sekanina (1973, 1976) and then re-
570 discovered 30 years later by B2010. Although the timing, radiant location,
571 and geocentric speed determined from our survey are different from earlier
572 reports, it is in a good agreement with B2010. The shower is listed twice in
573 Table 2 since our search code interpreted this shower as two separate show-
574 ers with very similar, though spatially separated enough, radiant locations
575 and geocentric velocities. However, their durations do not overlap, with an
576 approximate 3 day gap.

577 *μ Hydrids (MHY)*

578 MHY is a shower first reported by B2010. It is a southern hemisphere
579 shower not yet established by the IAU MDC ($\beta = -32.3^\circ$). MHY is one
580 of the weaker showers in SAAMER-OS survey ($\sigma_{\text{wave}} = 12.4$) with slightly
581 different timing of the peak, radiant location and geocentric velocity than

582 those reported by B2010. Since the shower is located significantly below the
 583 ecliptic plane, the observation geometry of B2010 might play a significant
 584 role in CMOR’s ability to observe it, and thus the exact position may need
 585 to be refined. Interestingly, our searching code detected another shower with
 586 similar peak timing, radiant location, and geocentric speed, that was actually
 587 much stronger than the shower reported by B2010. We also associated this
 588 shower with MHY (the second record in Table 2). The radiant separation of
 589 these showers is quite significant, and it would be very rare that two different
 590 showers appear at the same time in a very similar place with comparable
 591 geocentric velocities. Nevertheless, we are confident that this shower is real
 592 and supporting the findings of B2010, who reported a very peculiar orbit (
 593 $a = 1.08$ au, $e = 0.77$, and $I = 71.8^\circ$). Such orbits are unique in the Solar
 594 System given the fact that currently there is no known body with similar
 595 orbital elements.

596 5.2. *New Showers*

597 In this section we describe new showers that, to the best of our knowledge,
 598 are not associated with any shower listed in the IAU Meteor Shower list at
 599 the time of this investigation. The results are listed in Table 3.

600 30 *Ophiuchids (THO)*

601 THO is a weaker north apex meteor stream lasting for 5 days, which ap-
 602 pears to have been undetected in north-hemisphere surveys. Its significance
 603 level ($\sigma_{\text{wave}} = 6.5$) is very near the limit of our linking criteria, and thus more
 604 data is required to confirm this shower candidate as an established shower.
 605 THP has a retrograde ($I = 138.1^\circ$) and eccentric orbit ($e = 0.615$), which

606 suggests cometary origin, probably from a Halley-type comet.

607 *Octantids (OCD)*

608 OCD is a new stronger shower ($\sigma_{\text{wave}} = 10.8$) with a very high southern
609 ecliptic latitude. This shower lasts for 20 days and is one of the prominent
610 showers of the southern toroidal sporadic source. Its very distinctive Aten-
611 like orbital elements ($a = 0.96$ au, $e = 0.174$, $I = 65.1^\circ$) and duration suggest
612 that OCD is a product of cometary activity of a Halley-type comet, that has
613 been evolving for several thousand years.

614 ρ *Phoenicids (RPH)*

615 As the third strongest new shower ($\sigma_{\text{wave}} = 20.9$), RPH is highly visible
616 in our dataset even without the use of any complex processing techniques.
617 This shower lasts for 10 days and is part of the south toroidal source being
618 again most probably associated with one of the Halley-type comets due to
619 its peculiar highly-inclined orbit.

620 *o Pavonids (OPA)*

621 OPA is a weak shower located in the south toroidal region lasting for 5
622 days. It has an orbit with a very high Tisserand's parameter with respect to
623 Jupiter ($T_J = 6.3$), Aten-like orbit, and very high inclination. This shower
624 is very peculiar, potentially originating from the population of Near-Earth
625 Asteroids (NEAs) or highly evolved from an HTC-parent.

626 *v Pavonids (UPA)*

627 At first this shower appeared to be a continuation of OPA, however,
628 a large gap between these two showers and a noticeably different radiant

location led us to consider these to be different showers. Accordingly, the resulting σ_{wave} makes this shower the weakest in this survey, and thus more observations are required to determine whether this shower is real or just a fluctuation of the background. Having very similar properties to OPA this shower is also a candidate for either a NEA origin or highly evolved HTC.

634 *Telescopiids (TEL)*

TEL is a shower at the bottom edge of the anti-helion source lasting for 10 days. Although the significance level ($\sigma_{\text{wave}} = 6.4$) is low, this shower has a very distinctive activity profile (see Supplementary Material) giving us confidence that this shower is indeed real.

639 α *Sagittariids (ASG)*

ASG is one of showers that are at the very limit of our acceptance criteria with a very short duration of 5 days and limiting significance level $\sigma_{\text{wave}} = 6.2$. Nevertheless, if real, this anti-helion shower might be one of the showers caused by Jupiter Family comets due to its favorable inclination and highly eccentric orbit.

645 β *Aquilids (BAD)*

BAD is one of the few new showers in the northern hemisphere, more precisely in the northern part of the anti-helion source. The fact that this shower has not been observed by northern hemisphere radar surveys raises question about its validity. Lasting for 8 days, this shower is another candidate for a possible NEA origin.

651 α *Phoenicids* (APH)

652 Another from the group of new south toroidal showers, APH is a weaker
653 shower lasting for 6 days that is very peculiar for its orbit with the semimajor
654 axis ($a = 0.7$ au) lower than Venus. Though this part of the sky is not
655 significantly populated by meteors in the SAAMER-OS sample, the activity
656 of this shower stands out, which gives us considerable confidence that this
657 shower is real.

658 ζ *Phoenicids* (ZPH)

659 ZPH is one of the stronger showers detected by our survey in the south
660 toroidal source ($\sigma_{\text{wave}} = 13.1$). ZPH lasts for 13 days, has a highly-inclined
661 orbit ($I = 76.9^\circ$) and $T_J = 2$, with high e suggestive of a cometary origin,
662 the most probable being from a Halley-type comet.

663 ψ *Phoenicids* (PPH)

664 PPH is the strongest new shower ($\sigma_{\text{wave}} = 26.2$) discovered in the SAAMER-
665 OS dataset by our searching method. Lasting for 23 days PPH is one of the
666 most prominent showers in July observable from the southern hemisphere.
667 With its location in the south toroidal source resulting in its intrinsically
668 highly-inclined orbit ($I = 74.8^\circ$), this shower most probably originates from
669 one of the Halley-type comets. Though its small semi-major axis and modest
670 eccentricity produces $T_J = 4.4$ suggestive of an asteroidal origin, the dura-
671 tion of PPH and its high inclination is clearly the result of long dynamical
672 evolution, with Poynting-Robertson drag perhaps producing the small a, e
673 combination.

674 λ *Caelumids* (*LCA*)

675 After a period of almost three months in which showers were not detected
676 by SAAMER in the south toroidal sporadic source, LCA was observed in
677 October. LCA is a weaker shower lasting only 4 days - it is very close to
678 the detection limit set by our search criteria. Its orbit is typical of showers
679 found in the toroidal source with very high inclination and the semimajor
680 axis placing its aphelion just below the orbit of Jupiter.

681 σ *Columbids* (*SCO*)

682 SCO is a shower in the south toroidal source that lasts for 6 days. Since
683 its sun-centered coordinates and geocentric velocity are very similar to PPH,
684 the strongest shower in the south toroidal source, the significance level for
685 this shower is quite low ($\sigma_{\text{wave}} = 7.9$). The potential linkage between SCO
686 and PPH will be discussed in the next Section,

687 γ *Sextantids* (*GSE*)

688 GSE belongs to the southern part of the helion source. Its duration (4
689 days) and significance level ($\sigma_{\text{wave}} = 6.2$) is at the limit of our searching
690 criteria. GSE has an Aten-type orbit with an extreme value of the Tisserand
691 parameter ($T_J = 7.4$).

692 *Puppids-Pyxidids Complex* (*PPC*)

693 This complex consists of 8 showers (THP, ECM, OBP, OAP, OPU, OLV,
694 NPU, NLV) that, utilizing a looser linking criteria, forms a south toroidal
695 shower that lasts for more than 40 days. It is the southern counterpart of
696 the Coronae Borelid complex first reported in the North Toroidal source
697 by CMOR in B2010. All showers have very similar orbits with semimajor

698 axes close to 1 au, low eccentricities, and very high inclinations ($I \sim 67^\circ$).
 699 We consider NPU as the core of this complex due to its significance level
 700 $\sigma_{\text{wave}} = 9.6$. This complex is similar to NID/QUA/TCB complex (B2010)
 701 that is observed in the north toroidal source with one exception - a much
 702 lower geocentric velocity. South toroidal showers in this complex are system-
 703 atically 8-10 km s⁻¹ slower, which is more than expected for a deceleration
 704 correction alone and makes any genetic association with its north hemisphere
 705 counterpart difficult.

706 ζ *Antliids* (ZAN)

707 ZAN is a weaker shower at the edge of the south toroidal source that
 708 might be also associated with PPC. However, its location in the sky, shower
 709 profile, and higher eccentricity lead us to exclude this shower from PPC.

710 ι *Arids* (IAD)

711 This shower is located near the far edge of the helion source. Its activity
 712 lasts 5 days and it is characterized by a very eccentric orbit ($e = 0.86$),
 713 and low inclination ($I = 14.5^\circ$). This shower is, most likely, a product of a
 714 Jupiter-family comet.

715 ι *Lupids* (ILU)

716 ILU is also a shower located within the helion source, even though its
 717 position is very close to the south apex source. Its activity lasts for 6 days
 718 with the significance level comfortably above the limits ($\sigma_{\text{wave}} = 9.3$). ILU
 719 has very similar orbital elements to MHY $a = 1.05$ au, $e = 0.744$, $I = 66.2^\circ$,
 720 and also NHR introduced later in the text. Without further modeling it is
 721 difficult to determine whether these showers have the same parent body. Also

722 a very high inclination suggests that this shower may have its counterparts
723 located in, either the North or South Toroidal source.

724 κ *Velids* (*KVE*)

725 KVE is the second strongest shower in our survey occurring in the south
726 toroidal source and lasting for more than 15 days. KVE is almost identical
727 to the α Puppids reported by [Younger et al. \(2009\)](#). Because the authors
728 did not reported their findings to the IAU working list, we excluded their
729 listing from our association code. Our findings suggest that this stream is
730 one of the streams evolved from Halley-type comets ([Pokorný et al., 2014](#))
731 and may be linked to the complex of showers associated with 96P/Machholz
732 ([Babadzhanov and Obruchov, 1992](#)).

733 θ *Carinids* (*TCD*)

734 TCD is a strong shower within the south toroidal source region lasting
735 for 7 days. Its significance level ($\sigma_{\text{wave}} = 9.8$) is not particularly high because
736 it shares the radiant location, and geocentric velocity with the stronger and
737 long lasting shower EVE. Similar to EVE and other southern toroidal showers
738 TCD is characteristic for its high inclination ($I = 74.5^\circ$) and $T_J < 3$.

739 *6 Puppids* (*SXP*)

740 SXP is a minor shower in the southern part of the anti-helion source.
741 SXP is quite a short shower lasting for 5 days. The orbital characteristics of
742 this shower are quite peculiar for a shower originating from the anti-helion
743 source, believed to be mainly populated by Jupiter-family comets ([Nesvorný
744 et al., 2011](#)). The high inclination of the SXP meteors ($I = 58.6^\circ$) suggests
745 that this shower is more likely a product of a Halley-type comet.

746 *Volantids (VOL)*

747 VOL is one of the strongest showers with a duration of 10 days impacting
748 the Earth almost from the south pole ($\beta = -72.7^\circ$). With a geocentric speed
749 almost identical to the Earth's orbital speed ($V_g = 29.6 \text{ km s}^{-1}$), this shower
750 clearly exhibits a cometary origin, with a high inclination ($I = 49.1^\circ$) which
751 suggests a Halley-type comet as possible parent bodies. This shower was also
752 recently independently discovered by [Jenniskens et al. \(2016a\)](#).

753 *9 Herculids (NHR)*

754 NHR is a very peculiar shower in this survey since its radiant location is
755 well within the northern hemisphere and thus, it should have been observed
756 by previous surveys. Because of this we cannot discount the possibility that
757 this shower may be the result of an artifact of our searching methodology.
758 NHR is located between the north apex and the helion sources. It has an
759 orbit with high eccentricity and inclination ($e = 0.826, I = 65.5^\circ$), while its
760 semimajor axis is very close to unity. To determine whether this shower is
761 real, or if it was a strong outburst, a longer survey with uniform data coverage
762 is required. As mentioned before, this meteor shower has very similar orbital
763 elements to MHY and ILU.

764 *January μ Velids (JMV)*

765 JMV is a stronger ($\sigma_{\text{wave}} = 9.8$), long lasting shower (15 days) in the south
766 toroidal source. With one of the highest values of the Tisserand parameter
767 ($T_J = 6.1$), JMV appears to be another promising candidate for a high-
768 inclination NEO parent or an evolved shower from an HTC source.

769 *ψ Velids (PVL)*

770 PVL is one of the stronger showers in the south toroidal source lasting
771 for 21 days. PVL has almost exactly the same radiant location, and identical
772 geocentric velocity as ZPH, however, their peak activity differs in solar longi-
773 tude by $\sim 180^\circ$. This suggests that these showers are actually twin showers
774 and thus a product of the same parent body, most probably a Halley-type
775 comet.

776 *ι Antliids (IAN)*

777 IAN is a weaker shower at the southern edge of the anti-helion source
778 that lasts for 6 days. Although its significance level is not high, both the
779 consistent rise and fall of the activity level about the maximum date and
780 its orbital characteristics provide confidence that it is a real shower. Its
781 Aten-type highly inclined orbit suggests a possible NEO origin.

782 *March β Equuleids (MBE)*

783 MBE is a weaker helion-source shower that lasts for 9 days. Its signif-
784 icance level $\sigma_{\text{wave}} = 6.3$ is decreased by the presence of the SSE, which is
785 active for 22 days approximately 3 months earlier and has very similar radi-
786 ant position in the sun-centered coordinates and similar geocentric velocity.
787 MBE is certainly of cometary origin, having a highly eccentric ($e = 0.965$),
788 and a highly inclined ($I = 68.8^\circ$) orbit.

789 *5.3. Newly identified Meteor Showers - population characteristics*

790 Here we focus on a more global overview of the common characteristics
791 of the new showers identified during the SAAMER-OS survey. The radiant
792 location of the new showers is shown in sun-centered coordinates in Figs. 6

793 and 7. In these figures the radiant locations are color coded according to the
 794 solar longitude where the maximum activity occurred for the IAU list meteor
 795 showers (Fig. 6) and for the newly discovered showers (Fig. 7). In comparing
 796 these figures, it can be seen that the new showers exhibit a half ring-like
 797 structure located about 55° away south of the apex direction. This result
 798 is very similar to the northern hemisphere ring identified during the CMOR
 799 survey reported by B2010. Showers having radiants within this structure
 800 occur during a broad range of solar longitudes, implying that different parent
 801 bodies are required to create the observed features. The northern part of this
 802 ring is also known for its distinctive distribution of sporadic radiants first
 803 reported as a ring-like structure by [Campbell-Brown \(2008\)](#). This sporadic
 804 population is believed to be caused by dust released by Halley-type comets
 805 ([Pokorný et al., 2014](#)). A dynamical model that would reproduce all the
 806 observed features along with the temporal variations has yet to be developed.

807 Figures 8 and 9 are color coded according to each shower's geocentric
 808 velocities. The survey resulted in only three showers, two known (ETA, ORI)
 809 and one new (THO), with very high geocentric velocities ($v_g > 60 \text{ km s}^{-1}$).
 810 This is less than expected if we compare our results with those from B2010
 811 who found 10 showers at high geocentric velocities. Since, in principle, both
 812 radars should be able to detect very fast meteors, this result suggests that
 813 either the south apex source is poorer in meteor showers, or an unknown bias
 814 at higher geocentric speeds is present in the SAAMER-OS sample.

815 An interesting result is found when we combine our search results with
 816 those from B2010. The ring structure is almost exclusively populated by
 817 showers with geocentric velocities in the $35 - 40 \text{ km s}^{-1}$ range. The conser-

Figure 9: The same as in Fig. 8 but for newly discovered showers.

830 km s^{-1} compared to 20 km s^{-1} . Figure 10 shows the orbital eccentricity dis-
 831 tribution vs. the semimajor axis of detected showers from our survey color
 832 coded by their Tisserand parameter with respect to Jupiter. Most of the
 833 newly discovered showers (triangles in Fig. 10) have semimajor axes close
 834 to 1 and low eccentricities. This combination of orbital elements directly
 835 influences the distribution of T_J producing the very high values $T_J > 4$ for
 836 many of the SAAMER showers. No showers with the semimajor axis larger
 837 than 5 au were reported, and only two new showers have the semimajor axis
 838 larger than 3 au.

839 Figure 11 displays the distribution of inclinations with respect to the
 840 semimajor axis, showing that most of the new showers cluster at $a = 1 \text{ au}$
 841 and $I \sim 65^\circ$, formed mostly by the showers within the south toroidal source
 842 region. There were no new showers discovered below $I < 30^\circ$. This is
 843 somewhat expected since this region has been covered by many different

Figure 10: Distribution of eccentricities with respect to semimajor axes of all meteor showers found by our survey. The symbols in this figure are color coded by their Tisserand parameter T_J . Black solid lines denote the region of (a, e) phase-space inside of which impacts on the Earth are possible. The lines denote (a, e) combinations for orbits with perihelion (right hand line) and aphelion distance (left hand line) equal to the Earth's orbit. Newly discovered showers are represented by triangles, while previously known showers by filled circles.

Figure 11: Distribution of inclinations with respect to semimajor axes of all meteor showers found in our survey. As for Figure 10, the symbols are color coded by their Tisserand parameter T_J . Newly discovered showers are represented by triangles, previously known showers by filled circles.

844 surveys (e.g. B2010 [Jenniskens et al., 2016b](#)). Interestingly, only one new
 845 retrograde meteor shower was found (THO). It is interesting to note the
 846 large number of such high - I , small- e , a showers which mirrors a similar
 847 population first reported by CMOR in B2010 for which no immediate parent
 848 body population is known.

849 Figure 12 shows the distribution of inclinations of all showers result-
 850 ing from this survey with respect to their eccentricity. The majority of
 851 SAAMER-OS showers, even those with rather high eccentricities ($e < 0.7$),

852 have inclinations which exceed the Kozai angle ($I \approx 39.2^\circ$) and thus are
 853 affected by Kozai oscillations. This may reflect an observational selection
 854 effect as showers affected by the Kozai oscillation will typically have much
 855 longer dynamical coherence and collisional lifetimes compared to lower in-
 856 clination streams. Thus we may be able to see backward in time to much
 857 older streams in the toroidal sources as a result. In this view, the low- a and
 858 e of these streams are simply the result of the Poynting-Robertson circu-
 859 larization of the orbits, having removed the orbits from their original HTC
 860 parent orbits, but with the streams remaining in the Kozai due to their high
 861 inclination.

862 *5.4. Potential parent body candidates: shower branches, twins and stream* 863 *complexes*

864 Knowledge of a shower parent body enables modeling of the meteor
 865 shower activity through time and allows the connection of properties of
 866 shower meteoroids (chemistry, strength, etc.) with a specific object. There
 867 is no robust method that enables unequivocal identification of the parent
 868 body of all meteor showers. Radiative forces acting on small meteoroids in
 869 the mass range observable by radar systems [Burns et al. \(1979\)](#) should lead
 870 to a mass dependent segregation in meteoroid orbits relative to the orbit of
 871 the parent body over time. This change in orbit size, together with plane-
 872 tary perturbations will produce a meteor shower having a duration directly
 873 dependant on its age of ejection from the parent. From [Tables 2 and 3](#), we
 874 know that the duration of the meteor showers we measure in our survey range
 875 from several to as much as 50 days (as is the case of SDA). For example, the
 876 Orionid meteoroid stream (ORI), which lasts for 11 days, is believed to be

Figure 12: Distribution of inclinations as a function of eccentricities of all meteor showers found in our survey. Symbols are color coded by their Tisserand parameter T_J . Newly discovered showers are represented by triangles, previously known showers by filled circles.

877 2 500 to 62 000 years old, with the most probable age being 23 000 years
878 (Jones et al., 1989). However, while the shower duration provides a power-
879 ful constraint on stream age, such detailed study and modeling of particular
880 meteor showers is beyond the scope of this work.

881 For this work we use a simpler, but effective approach that considers
882 the orbital dis-similarity criterion developed by Valsecchi et al. (1999). This
883 method uses quantities directly observable by Earth-bound instruments, i.e.
884 the geocentric speed, the right ascension, the declination of the radiant and
885 the solar longitude of the peak of the meteor showers. The applicability of
886 this approach to long lasting showers is more uncertain. However, for many
887 meteor showers this method helps narrow the number of candidate parent
888 bodies efficiently enough to highlight the most possible candidates from a
889 myriad of possible parent objects.

890 In this work, we calculate D_N , the orbital dis-similarity criterion (Valsec-
891 chi et al., 1999), for all showers found in our survey with respect to all objects
892 in the Minor Planet Center Orbit Database². Since the number of potential
893 parent bodies is extremely large, we focus on the three most promising can-
894 didates, i.e. objects with the lowest D_N , since showing only the very best
895 candidate on the basis of orbit alone is misleading due to different object
896 sizes. We expect, a priori, that larger parent bodies and comets are more
897 likely to have spawned meteoroid streams now visible at the Earth, every-
898 thing else being equal. Additionally, we searched for the comet or the object
899 with the lowest absolute magnitude with $D_N < 1$, choosing all comets as

²<http://www.minorplanetcenter.net/iau/MPCORB.html>

900 more probable parents over Near Earth Asteroids (NEAs) in the final tabu-
 901 lation. Results of our search are shown in Tables 4 and 5.

902 Examination of Tables 4 shows that the method, while simple, is limited
 903 in its utility when applied to more evolved stream-parent body linkages. For
 904 example, for the ETAs the known parent body is 1P/Halley (Babadzhanov,
 905 1987), which agrees with what our method produces. In contrast, 1P/Halley
 906 is also known to be the parent body for the ORI, which our method did
 907 not capture. Thus the results reported in this section must be treated with
 908 caution, the main purpose being to provide a series of potential parent bodies
 909 which require follow-up simulations to confirm or refute. Through the rest
 910 of this section we will focus on the few most promising parent bodies and
 911 their possible showers based on this analysis. Since the physical size of these
 912 parent bodies is mostly unknown we use a simple relation (Chesley et al.,
 913 2002)

$$D = \frac{1329}{\sqrt{p}} 10^{-0.2H} \quad (2)$$

914 to convert the absolute magnitude H to the body diameter D assuming the
 915 albedo p is known (hereafter we use a typical albedo $p = 0.15$ for all parent
 916 bodies in this paper).

917 2003 UL9 is one of the smaller NEO's with an absolute magnitude of 22.5,
 918 which translates to an approximate radius of 50 m. Its size is probably too
 919 small to be a shower parent body. However, it might be the product of a
 920 recent breakup of a larger parent that lead to the formation of the Puppids-
 921 Pixidids Complex (PPC).

922 2009 VQ25, an Apollo asteroid, is also related to PPC according to the
 923 orbital dis-similarity criterion, however the similarity with the shower com-

924 plex is smaller than for the case of 2003 UL9. On the other hand, it's size is
925 approximately 5 times larger than 2003 UL9.

926 2007 HX4, another NEO with an absolute magnitude of 17.7 (1 km di-
927 ameter), is another body related to PPC, mostly to its later part being a
928 potential parent body for OPU, OLV, NPU, and NLV.

929 (2102) Tantalus, based on the latest observations, is a probable binary
930 ([Warner, 2015](#)), and has been previously suspected to be a parent body of
931 known meteor streams ([Kostolansky, 1998](#)). Its absolute magnitude 16.0 (2-
932 4 km in diameter) and uncommon Q spectral type ([Bus and Binzel, 2002](#))
933 make it an attractive candidate for several newly discovered meteor showers
934 (KVE, TCD, VOL, PLV). Alternatively, this may be part of the broader
935 96P/Machholz complex of bodies/showers.

936 2010 BG2 is an asteroid on a peculiar orbit. Although small in size
937 ($H = 19.9$), its comet-like orbit and higher inclination ($I = 42.9^\circ$) may lead
938 to the discovery of a possible progenitor. Its orbit similarity to previously
939 established meteor showers AHY, MHY, and AAN is a promising result.

940 2009 FG1 is another asteroid from a growing suite of NEOs. With its
941 highly inclined orbit ($I = 69.8^\circ$) it is a potential parent body for four newly
942 discovered showers (LCA, SCO, THP, ECM). However, since its size is rather
943 small ($H = 18.8$) it's unlikely that this particular body is the real parent body
944 of all mentioned showers, but may be genetically related as a sibling from an
945 earlier breakup.

946 C/2015 P3 (Swan) is a new comet discovered in Australia, reported by
947 [Mattiazzo et al. \(2015\)](#). Due to its high inclination $I = 58.2^\circ$, C/2015 P3
948 (Swan) is a promising candidate for many newly discovered showers. How-

949 ever, its orbital period of more than 3500 years makes further observations
950 quite challenging.

951 C/2013 R1 (Lovejoy) is very similar to C/2015 P3 (Swan). Its incli-
952 nation is very promising as a candidate for north/south toroidal showers,
953 however the orbital period of this comet is even longer, more than 6000 years
954 ([Wirström et al., 2016](#)).

955 P/2010 H3 (SOHO) is another designation for P/2004 V9 or P/1999 J6
956 and is believed to be a parent body of ARI ([Jenniskens et al., 2012](#)), al-
957 though recent modeling of meteor streams suggests that these objects alone
958 cannot explain the ARI activity profile ([Abedin et al., 2017](#)). Our method in-
959 deed shows a reasonable linking between this comet and ARI, however, more
960 streams like SZC or newly discovered ASG show a very good match, consis-
961 tent with broader identification with the 96P Machholz group ([Jenniskens,](#)
962 [2006](#)).

963 C/1995 O1 (Hale-Bopp), one of the brightest comets recently observed
964 at Earth, is a very promising candidate for four newly discovered showers,
965 namely KVE, TCD, PVL and IAN. With a high level of dust production
966 during its passage through the Solar System in the late 90's, it poses as a
967 promising candidate, though more detailed modeling casts some doubt as to
968 its potential as an immediate parent body for Earth-intersecting meteoroids
969 ([Beech et al. \(1996\)](#)).

970 6. Conclusions

971 Using more than one million individual orbits measured in the southern
972 hemisphere during 2012–2015 by SAAMER-OS radar we found 58 meteor

973 showers through an algorithm based on a 3D wavelet searching method. We
 974 performed a detailed analysis of the ideal wavelet probe size using the SDA
 975 shower as a calibration source (Fig. 5) resulting in different settings than
 976 those used by B2010. The ideal angular probe size for SAAMER, $\sigma_\Lambda = \sigma_\beta =$
 977 2.5° , is significantly smaller than for CMOR (4° , c.f. B2010), while the ideal
 978 velocity probe size for SAAMER $\sigma_{v_g} = 15\%$ is 50% larger than for CMOR
 979 (10% , c.f. B2010). With more than 20 showers observable by both SAAMER
 980 and CMOR, we will investigate this discrepancy in the future.

981 All meteor streams last for at least four days and were required to satisfy
 982 several criteria described in Section 4. In our study we found 34 new streams
 983 (see Table 2) and 24 streams (see Table 3) that were listed previous to this
 984 work on the IAU Meteor Shower Working list. Our approach is very sim-
 985 ilar to that used by B2010, although, somewhat more restrictive in several
 986 parameters.

987 Most of the 34 new meteor showers were found within the south toroidal
 988 source region, which is a less studied counterpart of the north toroidal source
 989 (Campbell-Brown and Wiegert, 2009; Janches et al., 2015). We also recog-
 990 nized one shower complex- Puppids-Pixidids Complex -in the south toroidal
 991 source containing 7 newly discovered showers. We also confirmed a Toroidal-
 992 Helion-Anti-helion linked radiant ring structure similar to that reported by
 993 B2010, extending it for the southern part thus completing the shower list for
 994 this ring for both hemispheres.

995 The majority of previously observed and new meteor showers have un-
 996 known parent bodies. We performed a simple parent body search using the
 997 method developed by Valsecchi et al. (1999) which provides a list of potential

parent bodies for our showers (Tables 4 and 5). While several parent bodies have very promising orbital similarity with our meteor showers, to confirm their connection requires full-fledged modeling that is far beyond the scope of this manuscript.

We note that the geocentric velocities presented in this paper are not corrected for atmospheric deceleration, which can potentially change the value of the geocentric velocity for a significant fraction of the showers presented. Based on the experience gained with CMOR, this correction will tend to increase the geocentric velocity by a few percent (see Table 1). This change will result in a shift towards orbits with higher semimajor axes and eccentricities. A future focus for these streams will include measurement of their mass distribution indices (?).

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1022 **References**

- 1023 Abedin, A., Wiegert, P., Pokorný, P., Brown, P., Jan. 2017. The age and the
1024 probable parent body of the daytime arietid meteor shower. *Icarus*, 281,
1025 417–443.
- 1026 Andreić, Ž., Gural, P., Šegon, D., Skokić, I., Korlević, K., Vida, D., Novosel-
1027 nik, F., Gostinski, D., Jun. 2014. Results of CMN 2013 search for new
1028 showers across CMN and SonotaCo databases I-0.5mm. *WGN, Journal of*
1029 *the International Meteor Organization* 42, 90–97.
- 1030 Babadzhhanov, P. B., Obrubov, I. V., Mar. 1992. Evolution of short-period
1031 meteoroid streams. *Celestial Mechanics and Dynamical Astronomy* 54,
1032 111–127.
- 1033 Babadzhhanov, P. B., Williams, I. P., Kokhirova, G. I., Jun. 2008a. Meteor
1034 showers associated with 2003EH1. *Monthly Notices of the RAS*, 386, 2271–
1035 2277.
- 1036 Babadzhhanov, P. B., Williams, I. P., Kokhirova, G. I., Feb. 2008b. Near-
1037 Earth asteroids among the Piscids meteoroid stream. *Astronomy and As-*
1038 *trophysics*, 479, 249–255.
- 1039 Babadzhhanov, P. B., Williams, I. P., Kokhirova, G. I., May 2008c. Near-
1040 Earth Objects in the Taurid complex. *Monthly Notices of the RAS*, 386,
1041 1436–1442.
- 1042 Baggaley, W. J., Bennett, R. G. T., Steel, D. I., Taylor, A. D., Sep. 1994.
1043 The Advanced Meteor Orbit Radar Facility - AMOR. *Quarterly Journal*
1044 *of the RAS*, 35, 293.

1045 Beech, M., Brown, P., Jones, J., Nov. 1996. On the non-observability of me-
1046 teors from Comet C/1995 01 Hale-Bopp. *Monthly Notices of the RAS*, 283,
1047 137–140.

1048 Bland, P. A., Spurný, P., Bevan, A. W. R., Howard, K. T., Towner, M. C.,
1049 Benedix, G. K., Greenwood, R. C., Shrbený, L., Franchi, I. A., Deacon,
1050 G., Borovička, J., Ceplecha, Z., Vaughan, D., Hough, R. M., Mar. 2012.
1051 The Australian Desert Fireball Network: a new era for planetary science.
1052 *Australian Journal of Earth Sciences* 59, 177–187.

1053 Brown, P., Jones, J., Weryk, R. J., Campbell-Brown, M. D., Dec. 2004.
1054 The Velocity Distribution of Meteoroids at the Earth as Measured by the
1055 Canadian Meteor Orbit Radar (CMOR). *Earth Moon and Planets* 95, 617–
1056 626.

1057 Brown, P., Weryk, R. J., Wong, D. K., Jones, J., May 2008. A meteoroid
1058 stream survey using the Canadian Meteor Orbit Radar. I. Methodology
1059 and radiant catalogue. *Icarus*, 195, 317–339.

1060 Brown, P., Wong, D. K., Weryk, R. J., Wiegert, P., May 2010. A meteoroid
1061 stream survey using the Canadian Meteor Orbit Radar. II: Identification
1062 of minor showers using a 3D wavelet transform. *Icarus*, 207, 66–81.

1063 Bruzzone, J. S., Brown, P., Weryk, R. J., Campbell-Brown, M. D., Jan. 2015.
1064 A decadal survey of the Daytime Arietid meteor shower using the Canadian
1065 Meteor Orbit Radar. *Monthly Notices of the RAS*, 446, 1625–1640.

1066 Burns, J. A., Lamy, P. L., Soter, S., Oct. 1979. Radiation forces on small
1067 particles in the solar system. *Icarus*, 40, 1–48.

1068 Bus, S. J., Binzel, R. P., Jul. 2002. Phase II of the Small Main-Belt Asteroid
1069 Spectroscopic Survey. A Feature-Based Taxonomy. *Icarus*, 158, 146–177.

1070 Campbell-Brown, M., Brown, P. G., Feb. 2015. A 13-year radar study of the
1071 η -Aquariid meteor shower. *Monthly Notices of the RAS*, 446, 3669–3675.

1072 Campbell-Brown, M., Wiegert, P., Jan. 2009. Seasonal variations in the north
1073 toroidal sporadic meteor source. *Meteoritics and Planetary Science* 44,
1074 1837–1848.

1075 Campbell-Brown, M. D., Jul. 2008. High resolution radiant distribution and
1076 orbits of sporadic radar meteoroids. *Icarus*, 196, 144–163.

1077 Chesley, S. R., Chodas, P. W., Milani, A., Valsecchi, G. B., Yeomans,
1078 D. K., Oct. 2002. Quantifying the Risk Posed by Potential Earth Impacts.
1079 *Icarus*, 159, 423–432.

1080 Fritts, D. C., Janches, D., Hocking, W. K., Oct. 2010. Southern Argentina
1081 Agile Meteor Radar: Initial assessment of gravity wave momentum fluxes.
1082 *Journal of Geophysical Research (Atmospheres)* 115, D19123.

1083 Fritts, D. C., Janches, D., Hocking, W. K., Mitchell, N. J., Taylor, M. J., May
1084 2012. Assessment of gravity wave momentum flux measurement capabili-
1085 ties by meteor radars having different transmitter power and antenna con-
1086 figurations. *Journal of Geophysical Research (Atmospheres)* 117, D10108.

1087 Galligan, D. P., Baggaley, W. J., 2002. Wavelet enhancement for detecting
1088 shower structure in radar meteoroid data II. Application to the AMOR
1089 data. In: Green, S. F., Williams, I. P., McDonnell, J. A. M., McBride, N.

1090 (Eds.), IAU Colloq. 181: Dust in the Solar System and Other Planetary
1091 Systems. Vol. 15. p. 48.

1092 Galligan, D. P., Baggaley, W. J., Sep. 2004. The orbital distribution of radar-
1093 detected meteoroids of the Solar system dust cloud. Monthly Notices of the
1094 RAS, 353, 422–446.

1095 Hocking, W. K., Fuller, B., Vandepeer, B., Jan. 2001. Real-time determi-
1096 nation of meteor-related parameters utilizing modern digital technology.
1097 Journal of Atmospheric and Solar-Terrestrial Physics 63, 155–169.

1098 Hocking, W. K., Thayaparan, T., Jones, J., 1997. Meteor decay times and
1099 their use in determining a diagnostic mesospheric Temperature-pressure
1100 parameter: Methodology and one year of data. Geophysics Research Let-
1101 ters, 24, 2977–2980.

1102 Janches, D., Close, S., Hormaechea, J. L., Swarnalingam, N., Murphy,
1103 A., O’Connor, D., Vandepeer, B., Fuller, B., Fritts, D. C., Brunini, C.,
1104 Aug. 2015. The Southern Argentina Agile MEteor Radar Orbital Sys-
1105 tem (SAAMER-OS): An Initial Sporadic Meteoroid Orbital Survey in the
1106 Southern Sky. Astrophysical Journal, 809, 36.

1107 Janches, D., Hocking, W., Pifko, S., Hormaechea, J. L., Fritts, D. C., Brunini,
1108 C., Michell, R., Samara, M., Mar. 2014. Interferometric meteor head echo
1109 observations using the Southern Argentina Agile Meteor Radar. Journal
1110 of Geophysical Research (Space Physics) 119, 2269–2287.

1111 Janches, D., Hormaechea, J. L., Brunini, C., Hocking, W., Fritts, D. C., Apr.
1112 2013. An initial meteoroid stream survey in the southern hemisphere using

1113 the Southern Argentina Agile Meteor Radar (SAAMER). *Icarus*, 223, 677–
 1114 683.

1115 Jenniskens, J., Baggaley, J., Crumpton, I., Aldous, P., Gural, P. S., Samuels,
 1116 D., Albers, J., Soja, R., Apr. 2016a. A surprise southern hemisphere meteor
 1117 shower on New-Year’s Eve 2015: the Volantids (IAU#758, VOL). *WGN*,
 1118 *Journal of the International Meteor Organization* 44, 35–41.

1119 Jenniskens, P., 2006. *Meteor Showers and Their Parent Comets*. Cambridge
 1120 University Press.

1121 Jenniskens, P., Duckworth, H., Grigsby, B., Jun. 2012. Daytime Arietids and
 1122 Marsden Sunskirters (ARI, IAU #171). *WGN*, *Journal of the International*
 1123 *Meteor Organization* 40, 98–100.

1124 Jenniskens, P., Gural, P. S., Dynneson, L., Grigsby, B. J., Newman, K. E.,
 1125 Borden, M., Koop, M., Holman, D., Nov. 2011. CAMS: Cameras for Allsky
 1126 Meteor Surveillance to establish minor meteor showers. *Icarus*, 216, 40–61.

1127 Jenniskens, P., Nnon, Q., Mar. 2016. CAMS verification of single-linked
 1128 high-threshold D-criterion detected meteor showers. *Icarus*, 266, 371–383.

1129 Jenniskens, P., Nnon, Q., Albers, J., Gural, P. S., Haberman, B., Holman,
 1130 D., Morales, R., Grigsby, B. J., Samuels, D., Johannink, C., Mar. 2016b.
 1131 The established meteor showers as observed by CAMS. *Icarus*, 266, 331–
 1132 354.

1133 Jenniskens, P., Nnon, Q., Gural, P. S., Albers, J., Haberman, B., Johnson,
 1134 B., Holman, D., Morales, R., Grigsby, B. J., Samuels, D., Johannink, C.,

1135 Mar. 2016c. CAMS confirmation of previously reported meteor showers.
1136 Icarus, 266, 355–370.

1137 Jenniskens, P., Nénon, Q., Gural, P. S., Albers, J., Haberman, B., John-
1138 son, B., Morales, R., Grigsby, B. J., Samuels, D., Johannink, C., Mar.
1139 2016d. CAMS newly detected meteor showers and the sporadic back-
1140 ground. Icarus, 266, 384–409.

1141 Jenniskens, P., Vaubaillon, J., Binzel, R. P., DeMeo, F. E., Nesvorný, D.,
1142 Bottke, W. F., Fitzsimmons, A., Hiroi, T., Marchis, F., Bishop, J. L., Ver-
1143 nazza, P., Zolensky, M. E., Herrin, J. S., Welten, K. C., Meier, M. M. M.,
1144 Shaddad, M. H., Oct. 2010. Almahata Sitta (=asteroid 2008 TC₃) and the
1145 search for the ureilite parent body. Meteoritics and Planetary Science 45,
1146 1590–1617.

1147 Jones, J., 1977. Meteor Radiant Distribution Using Spherical Harmonic Anal-
1148 ysis. Bulletin of the Astronomical Institutes of Czechoslovakia 28, 272.

1149 Jones, J., Brown, P., Dec. 1993. Sporadic meteor radiant distributions -
1150 Orbital survey results. Monthly Notices of the RAS, 265, 524.

1151 Jones, J., Brown, P., Ellis, K. J., Webster, A. R., Campbell-Brown, M., Krze-
1152 menski, Z., Weryk, R. J., Apr. 2005. The Canadian Meteor Orbit Radar:
1153 system overview and preliminary results. Planetary Space Science, 53, 413–
1154 421.

1155 Jones, J., Jones, W., Apr. 2006. Meteor radiant activity mapping using single-
1156 station radar observations. Monthly Notices of the RAS, 367, 1050–1056.

1157 Jones, J., McIntosh, B. A., Hawkes, R. L., May 1989. The age of the Orionid
1158 meteoroid stream. *Monthly Notices of the RAS*, 238, 179–191.

1159 Jones, W., Jul. 1997. Theoretical and observational determinations of the
1160 ionization coefficient of meteors. *Monthly Notices of the RAS*, 288, 995–
1161 1003.

1162 Jopek, T. J., Kaňuchová, Z., Jul. 2014. Current status of the IAU MDC
1163 Meteor Showers Database. *Meteoroids 2013*, 353–364.

1164 Jopek, T. J., Koten, P., Pecina, P., May 2010. Meteoroid streams identifica-
1165 tion amongst 231 Southern hemisphere video meteors. *Monthly Notices of*
1166 *the RAS*, 404, 867–875.

1167 Kostolansky, E., Apr. 1998. On asteroidal meteoroid streams detection. *Con-*
1168 *tributions of the Astronomical Observatory Skalnaté Pleso* 28, 22–30.

1169 Lau, E. M., Avery, S. K., Avery, J. P., Janches, D., Palo, S. E., Schafer, R.,
1170 Makarov, N. A., Jul. 2006. Statistical characterization of the meteor trail
1171 distribution at the South Pole as seen by a VHF interferometric meteor
1172 radar. *Radio Science* 41, RS4007.

1173 Mattiazzo, M., Maury, A., Soulier, J.-F., Sato, H., Weryk, R., Guido, E.,
1174 Howes, N., Jacques, C., Pimentel, E., Barros, J., Aug. 2015. Comet C/2015
1175 P3 (Swan). *Central Bureau Electronic Telegrams* 4136.

1176 Molau, S., Kerr, S., Apr. 2014. Meteor showers of the southern hemisphere.
1177 *WGN, Journal of the International Meteor Organization* 42, 68–75.

1178 Molau, S., Rendtel, J., Aug. 2009. A Comprehensive List of Meteor Showers
1179 Obtained from 10 Years of Observations with the IMO Video Meteor Net-
1180 work. WGN, Journal of the International Meteor Organization 37, 98–121.

1181 Nesvorný, D., Janches, D., Vokrouhlický, D., Pokorný, P., Bottke, W. F.,
1182 Jenniskens, P., Dec. 2011. Dynamical Model for the Zodiacal Cloud and
1183 Sporadic Meteors. *Astrophysical Journal*, 743, 129.

1184 Pokorný, P., Vokrouhlický, D., Nesvorný, D., Campbell-Brown, M., Brown,
1185 P., Jul. 2014. Dynamical Model for the Toroidal Sporadic Meteors. *Astro-*
1186 *physical Journal*, 789, 25.

1187 Sekanina, Z., Feb. 1973. Statistical Model of Meteor Streams. III. Stream
1188 Search Among 19303 Radio Meteors. *Icarus*, 18, 253–284.

1189 Sekanina, Z., Feb. 1976. Statistical model of meteor streams. IV - A study of
1190 radio streams from the synoptic year. *Icarus*, 27, 265–321.

1191 SonotaCo, Apr. 2009. A meteor shower catalog based on video observations
1192 in 2007-2008. WGN, Journal of the International Meteor Organization 37,
1193 55–62.

1194 Towner, M. C., Bland, P. A., Cupak, M. C., Howie, R. M., Sansom, E. K.,
1195 Paxman, J. P., Inie, M., Galloway, M., Deacon, G., Dyl, K. A., Benedix,
1196 G. K., Tingay, S. J., Harrison, J. A., Bevan, A. W. R., Mar. 2015. Initial
1197 Results from the Desert Fireball Network. In: Lunar and Planetary Science
1198 Conference. Vol. 46 of Lunar and Planetary Science Conference. p. 1693.

1199 Valsecchi, G. B., Jopek, T. J., Froeschle, C., Apr. 1999. Meteoroid stream

1200 identification: a new approach - I. Theory. Monthly Notices of the
1201 RAS, 304, 743–750.

1202 Warner, B. D., Jan. 2015. A Quartet of Near-Earth Asteroid Binary
1203 Candidates. Minor Planet Bulletin 42, 79–83.

1204 Webster, A. R., Jones, J., Dec. 2004. Single and Multi-Station Radar Ob-
1205 servations of the Geminid/sextantid Meteor Stream System. Earth Moon
1206 and Planets 95, 713–721.

1207 Wiegert, P., Brown, P., Dec. 2005. The Quadrantid meteoroid complex.
1208 Icarus, 179, 139–157.

1209 Wiesel, W., 1997. Spaceflight Dynamics. McGraw-Hill series in aeronautical
1210 and aerospace engineering. McGraw-Hill.

1211 Wirström, E. S., Lerner, M. S., Källström, P., Levinsson, A., Olivefors, A.,
1212 Tegehall, E., Apr. 2016. HCN observations of comets C/2013 R1 (Lovejoy)
1213 and C/2014 Q2 (Lovejoy). Astronomy and Astrophysics, 588, A72.

1214 Younger, J. P., Reid, I. M., Vincent, R. A., Holdsworth, D. A., Murphy, D. J.,
1215 Sep. 2009. A southern hemisphere survey of meteor shower radiants and
1216 associated stream orbits using single station radar observations. Monthly
1217 Notices of the RAS, 398, 350–356.

Table 2: Showers found using our search algorithm associated with showers in IAU Meteor Shower list sorted by the time of the solar longitude of their peak activity $\lambda_{\max}$. Note that two showers, MHY and DCS, have two entries in this table. Both showers exhibit two distinctive peaks in activity separated by several days and by several degrees in the angular space. For each shower we provide the solar longitude of the beginning of the shower (λ_{beg}), the solar longitude of the peak ($\lambda_{\max}$), the solar longitude of the end of the shower (λ_{end}), the duration of the shower in degrees, the sun-centered longitude ($\lambda - \lambda_0$), the sun-centered latitude (β), the geocentric right ascension (RA), the geocentric declination (Dec), the geocentric velocity (V_g), the wavelet coefficient at the peak (W_{cmax}), the number of σ values above the annual median (σ_{wave}), the number of radiants used for determination of the wavelet coefficient (r_{cnt}), the drift in RA per degree of the solar longitude (RA_{dr}), the error of the drift in RA, the correlation coefficient of the linear fit to the drift (r_{RA}), the drift in Dec per degree of the solar longitude (Dec_{dr}), the error of the drift in Dec, the correlation coefficient of the linear fit to the drift (r_{Dec}), the semimajor axis (a) with its uncertainty, the eccentricity (e) with its uncertainty, the inclination (I) with its uncertainty, the argument of pericenter (ω) with its uncertainty, the longitude of the ascending node (Ω) with its uncertainty, the perihelion distance (q) with its uncertainty, and the Tisserand parameter with respect to the Jupiter (T_J).

Name	IAU	λ_{start}	λ_{max}	λ_{end}	Dur.	$\lambda - \lambda_0$	β	RA	Dec	V_g	W_{cmax}	σ_{wave}	r_{cut}	RA_{dr}	r_{RA}	Dec_{dr}	r_{Dec}	a	e	I	ω	Ω	q	T_J							
η Aquarids	ETA	33	46	60	28	293.7	7.2	338.5	-1.2	64.2	475.0	52.2	433	0.70	0.02	0.989	0.34	0.01	0.993	4.78	6.26	0.886	164.3	2.3	91.3	12.8	46	0.545	0.071	0.2	
Southern Daytime ω -Cetids	OCE	21	47	61	41	330.4	-13.8	21.3	-5.9	36.5	334.9	26.8	331	0.91	0.02	0.992	0.48	0.01	0.989	1.57	0.25	0.916	0.019	35.8	4.0	215.0	2.0	227	0.132	0.015	3.7
Daytime Arietids	ARI	73	79	81	9	331.5	7.2	46.0	24.9	40.5	64.0	6.5	55	0.89	0.04	0.996	0.05	0.08	0.263	2.48	0.79	0.969	0.014	26.7	4.7	28.5	2.2	79	0.077	0.014	2.4
Southern June Aquilids	SZC	76	80	82	7	218.9	-13.5	304.3	-33.6	35.9	446.1	34.6	463	0.17	0.03	0.926	0.40	0.05	0.964	1.00	0.08	0.924	0.014	48.6	6.2	158.0	1.6	260	0.076	0.010	5.5
Southern May Ophiuchids	SOP	63	81	96	34	188.3	-6.3	269.2	-29.7	25.9	221.7	15.0	261	0.91	0.02	0.995	-0.11	0.01	0.829	2.00	0.28	0.784	0.035	6.3	1.1	107.9	2.2	261	0.432	0.020	3.4
Northern June Aquilids	NZC	84	101	116	33	210.4	13.5	310.1	-4.4	36.5	189.5	19.2	258	0.78	0.02	0.994	0.19	0.02	0.894	1.46	0.21	0.916	0.018	36.8	4.2	327.1	2.0	101	0.123	0.014	3.9
Microscopids	MIC	83	104	120	38	208.5	-13.3	319.3	-29.7	35.9	212.2	15.1	332	0.92	0.01	0.998	0.26	0.01	0.969	1.55	0.23	0.911	0.019	33.2	3.7	144.4	2.0	284	0.138	0.015	3.7
Piscis Austrinids	PAU	122	125	134	13	215.3	-19.5	349.9	-25.6	39.9	252.6	17.4	703	0.72	0.06	0.973	0.39	0.06	0.905	1.58	0.29	0.910	0.017	60.3	5.2	143.5	2.6	305	0.143	0.013	3.5
Southern δ Aquarids	SDA	111	125	161	51	209.5	-7.5	339.2	-16.8	39.9	329.6	141	2180	0.79	0.01	0.996	0.29	0.01	0.972	2.08	0.53	0.965	0.014	27.8	4.9	152.8	2.2	305	0.074	0.013	2.8
α Capricornids	CAP	105	127	131	27	178.6	9.7	305.6	-9.4	24.4	139.6	16.3	106	0.60	0.02	0.988	0.21	0.01	0.959	3.59	0.97	0.840	0.045	7.9	0.9	266.9	2.0	127	0.377	0.017	2.3
Northern δ Aquarids	NDA	131	136	142	12	210.3	7.7	344.4	1.7	38.1	80.7	7.0	142	0.69	0.02	0.998	0.08	0.06	0.429	1.66	0.30	0.953	0.015	26.5	4.5	332.9	2.0	136	0.079	0.014	3.4
Daytime Sextantids	DSX	175	187	197	23	330.8	-11.0	155.4	-1.6	31.4	369.7	29.9	271	0.52	0.04	0.954	-0.54	0.02	0.989	1.08	0.08	0.858	0.022	22.2	2.7	213.6	1.8	7	0.154	0.017	5.2
October Leporids	OLP	192	199	204	13	236.8	-40.8	78.7	-17.9	26.7	101.2	11.8	161	1.13	0.08	0.981	0.32	0.06	0.886	0.76	0.02	0.549	0.017	53.4	3.2	149.0	2.7	19	0.341	0.019	7.3
Orionids	ORI	204	207	214	11	248.3	-8.3	95.5	15.1	64.2	61.7	7.6	50	0.77	0.05	0.983	-0.09	0.05	0.512	3.24	2.83	0.823	0.134	162.5	2.2	86.5	13.8	27	0.574	0.073	0.7
β Canis Majorids	MCB	234	236	239	6	217.7	-44.8	92.8	-21.3	42.3	77.8	7.2	193	2.07	0.23	0.977	-0.46	0.30	0.611	4.75	3.34	0.873	0.086	68.5	2.7	80.6	5.0	56	0.603	0.024	1.4
November ω Orionids	NOO	241	248	252	12	205.3	-9.0	93.4	14.4	41.7	96.6	9.8	129	0.90	0.09	0.951	-0.06	0.03	0.501	4.68	3.17	0.976	0.018	27.4	3.9	142.7	2.4	68	0.112	0.015	1.5
ϵ Velids	EVE	240	250	261	22	269.9	-62.0	131.4	-48.2	39.9	280.3	13.6	739	0.67	0.06	0.931	-0.38	0.04	0.892	2.08	0.53	0.525	0.121	71.9	2.3	1.4	3.1	70	0.986	0.000	2.8
σ Serpentids	SSE	259	274	295	37	326.6	18.0	242.1	-2.6	42.3	103.2	14.5	200	0.89	0.03	0.987	-0.22	0.03	0.815	2.01	0.54	0.933	0.019	58.1	5.3	37.8	2.7	274	0.134	0.013	2.8
December Hydrids	DHY	272	275	277	6	230.4	-30.5	137.4	-15.7	49.9	40.0	6.9	108	0.61	0.14	0.905	-0.85	0.11	0.969	2.22	0.85	0.825	0.053	96.3	3.7	109.9	7.8	95	0.387	0.04	2.3
α Hydrids	AHY	272	284	294	23	208.4	-25.8	127.8	-7.7	42.3	100.3	13.1	138	0.58	0.02	0.986	-0.08	0.04	0.439	4.56	3.06	0.94	0.039	56.6	3.6	119.4	3.5	104	0.273	0.018	1.5
Daytime ξ Sagittarids	XSA	270	288	297	28	353.1	6.7	281.5	-16.2	25.5	313.6	20.9	419	0.89	0.02	0.995	0.06	0.01	0.669	2.13	0.32	0.784	0.036	6.3	1.0	77.8	2.1	288	0.460	0.019	3.2
Daytime χ Capricornids	DCS	281	299	299	19	0.8	-9.5	304.2	-29.5	23.7	202.2	16.3	176	1.10	0.04	0.990	0.19	0.03	0.829	2.94	0.61	0.805	0.043	7.3	0.8	273.8	2.0	119	0.574	0.016	2.7
μ Hydrids	MHY	298	303	309	12	228.1	-32.3	158.3	-25.9	35.4	118.3	12.4	268	0.83	0.07	0.988	-0.46	0.28	0.634	0.9	0.06	0.699	0.016	67.1	4.0	139.8	3.8	123	0.270	0.021	6.0
Daytime χ Capricornids	DCS	302	305	316	15	356.4	-8.5	305.7	-28.1	24.4	180.1	11.2	265	0.70	0.05	0.968	0.29	0.02	0.971	2.37	0.39	0.783	0.039	7.2	0.9	264.9	2.1	125	0.513	0.018	3.0
μ Hydrids	MHY	300	310	310	11	221.1	-24.0	162.1	-18.5	36.5	166.6	17.0	287	0.66	0.14	0.866	0.03	0.09	0.127	0.99	0.08	0.825	0.016	60.7	4.7	145.3	2.6	130	0.173	0.014	5.5
α Antilids	AAN	301	312	324	24	214.8	-19.5	160.2	-12.7	41.1	210.6	19.1	328	0.60	0.03	0.981	-0.36	0.06	0.851	1.61	0.31	0.91	0.018	59.4	5.1	142.1	2.7	132	0.146	0.013	3.5

Table 3: The same as Table 2 but now for new showers found using our search algorithm sorted by the time of the solar longitude of their peak activity $\lambda_{\max}$.

Name	IAU	λ_{start}	λ_{mid}	Dur.	$\lambda - \lambda_0$	β	RA	Dec	V_g	W_{max}	σ_{wave}	r_{cut}	R_{dir}	r_{RA}	Dec _{dir}	r_{Dec}	a	e	I	ω	q	$\pm$									
30 Ophiuchids	THO	5	8	5	248.5	18.7	257.2	-4.1	57.0	26.0	6.5	62	0.90	0.23	0.916	1.57	0.16	0.985	1.36	0.37	0.615	0.051	138.1	2.9	284.5	16.0	8	0.523	0.084	3.2	
Octantids	OCN	21	26	40	252.9	-54.8	294.1	-77.4	31.9	133.4	10.8	257	2.61	0.18	0.963	0.41	0.04	0.925	0.97	0.06	0.174	0.021	65.1	2.8	112.7	20.2	206	0.797	0.062	5.7	
ρ Phoenicids	RPH	34	38	43	10	308.2	-49.3	14.0	-49.2	43.0	191.5	20.9	233	0.89	0.04	0.990	0.50	0.11	0.854	2.70	1.04	0.726	0.008	77.0	2.6	291.6	6.6	218	0.739	0.028	2.2
σ Pavonids	OPA	45	46	49	5	246.4	-50.0	315.5	-69.9	31.0	79.3	7.1	220	0.21	0.55	0.212	-0.02	0.34	0.032	0.88	0.04	0.312	0.026	64.5	3.0	133.6	8.9	226	0.604	0.049	6.3
ν Pavonids	UPA	54	54	61	8	237.8	-44.8	309.0	-65.3	31.0	58.7	6.1	155	1.02	0.20	0.933	0.69	0.17	0.896	0.86	0.04	0.452	0.020	63.5	3.2	135.8	5.8	234	0.470	0.035	6.4
Telescopids	TEL	57	63	66	10	221.4	-31.3	291.0	-53.6	31.9	59.8	6.4	146	2.51	0.26	0.965	-0.27	0.11	0.657	0.94	0.05	0.710	0.018	55.5	3.6	139.5	3.0	243	0.273	0.017	5.9
α Sagittarids	ASG	78	78	82	5	212.2	-19.5	295.6	-41.2	30.5	80.3	6.2	345	2.38	0.38	0.975	-0.01	0.14	0.058	1.03	0.07	0.812	0.021	36.0	3.2	143.8	1.8	258	0.193	0.015	5.5
β Aquilids	BAD	80	81	87	8	220.7	25.0	298.5	4.6	31.0	30.3	6.5	58	0.90	0.16	0.940	0.05	0.15	0.149	0.88	0.04	0.783	0.017	49.9	4.0	328.1	2.0	81	0.191	0.014	6.2
α Phoenicids	APH	97	101	102	6	243.8	-38.3	4.3	-40.5	27.1	55.2	7.2	121	0.66	0.09	0.974	0.66	0.08	0.977	0.70	0.01	0.597	0.019	58.6	3.7	159.3	2.1	281	0.281	0.018	7.8
ζ Phoenicids	ZPH	96	105	108	13	237.5	-52.0	13.7	-52.8	41.7	168.8	13.1	361	0.84	0.09	0.946	0.42	0.05	0.939	2.14	0.60	0.616	0.099	76.9	2.6	60.3	7.2	285	0.821	0.027	2.7
ψ Phoenicids	PPH	98	111	120	23	251.3	-53.8	30.1	-46.9	37.6	432.7	26.2	673	0.84	0.03	0.990	0.59	0.02	0.987	1.26	0.15	0.291	0.064	74.8	2.7	63.3	14.7	291	0.890	0.035	4.4
λ Caelids	LCA	193	195	196	4	232.9	-55.3	75.2	-32.9	40.5	101.8	7.0	304	-0.02	0.50	0.031	0.73	0.39	0.798	2.67	0.93	0.693	0.102	71.1	2.4	55.5	5.6	15	0.822	0.021	2.3
σ Columbids	SCO	198	199	203	6	250.0	-53.8	89.3	-30.3	39.3	108.7	7.9	350	0.11	0.08	0.590	0.42	0.27	0.615	1.39	0.21	0.370	0.079	75.8	2.7	57.0	11.2	19	0.875	0.029	4.0
γ Sextantids	GSE	196	199	199	4	316.9	-20.8	150.1	-10.0	27.5	45.4	6.2	95	1.00	0.40	0.867	-0.60	0.21	0.896	0.74	0.02	0.792	0.019	38.4	3.6	204.0	1.3	19	0.154	0.013	7.4
3 Puppids	THP	192	200	205	14	287.2	-53.8	115.4	-33.5	32.9	82.8	7.8	281	1.08	0.10	0.959	0.03	0.06	0.157	0.96	0.06	0.183	0.021	67.0	2.8	248.5	20.2	20	0.787	0.063	5.7
η Canis Majorids	ECM	200	201	206	7	276.8	-55.8	108.4	-34.1	33.9	100.7	7.0	381	0.11	0.13	0.354	0.03	0.31	0.048	1.02	0.08	0.061	0.030	68.7	2.7	284.1	65.2	21	0.954	0.051	5.4
October β Pyxidids	OBP	203	207	208	6	295.5	-51.8	126.8	-34.8	33.4	68.6	6.9	225	0.53	0.19	0.851	-0.10	0.05	0.753	0.99	0.07	0.284	0.019	66.7	2.8	252.1	13.3	27	0.708	0.050	5.6
October α Pyxidids	OAP	206	211	221	16	301.3	-48.8	135.2	-34.6	32.4	72.5	7.4	211	0.60	0.20	0.660	0.08	0.06	0.347	0.94	0.06	0.369	0.019	64.3	2.9	240.5	8.9	31	0.594	0.042	5.9
October Puppids	OPU	208	212	216	9	289.3	-53.8	125.0	-36.4	31.9	73.2	7.0	273	-0.16	0.19	0.325	-0.13	0.11	0.431	0.94	0.06	0.206	0.022	64.7	2.8	243.4	16.4	32	0.748	0.058	5.9
ζ Antlids	ZAN	207	212	214	8	307.1	-42.5	143.5	-31.0	32.4	56.3	6.8	180	0.89	0.12	0.955	-0.27	0.20	0.519	0.89	0.05	0.505	0.018	63.5	3.2	229.2	5.6	32	0.443	0.031	6.1
October λ Velids	OLV	217	221	222	6	291.0	-52.8	132.8	-38.1	33.9	65.1	7.0	163	1.39	0.33	0.905	-0.45	0.12	0.873	0.99	0.07	0.231	0.020	68.0	2.8	256.3	17.1	41	0.762	0.054	5.6
November Puppids	NPU	220	224	225	6	280.4	-57.5	125.1	-40.5	35.4	137.3	9.6	451	1.41	0.13	0.987	-0.51	0.10	0.951	1.17	0.12	0.176	0.073	69.2	2.6	322.6	15.4	44	0.961	0.016	4.8
November λ Velids	NLV	226	232	237	12	284.9	-57.8	132.9	-43.8	36.5	96.3	6.8	256	-0.01	0.09	0.022	-0.29	0.08	0.787	1.28	0.15	0.265	0.080	69.9	2.6	320.2	11.0	52	0.941	0.017	4.4
ι Arids	IAD	247	250	251	5	13.8	-25.0	261.5	-48.3	21.3	44.7	8.0	47	1.24	0.76	0.758	-0.30	0.28	0.607	5.44	2.10	0.860	0.055	14.5	0.8	300.6	1.5	70	0.762	0.011	2.0
ι Lupids	ILL	267	271	272	6	316.5	-30.8	213.0	-46.1	37.0	71.8	9.3	185	1.58	0.35	0.912	-0.36	0.13	0.820	1.05	0.10	0.744	0.018	66.2	4.0	225.1	3.9	91	0.268	0.020	5.2
θ Carinids	TCD	274	276	280	7	282.3	-60.3	156.8	-59.2	41.7	172.4	9.8	581	2.13	0.26	0.964	-0.13	0.10	0.475	2.38	0.76	0.595	0.129	74.5	2.4	342.2	3.7	96	0.966	0.006	2.5
κ Velids	KVE	272	276	286	15	257.8	-60.5	141.1	-51.0	40.5	440.7	23.5	806	1.24	0.13	0.952	-0.48	0.07	0.905	2.08	0.54	0.536	0.120	72.9	2.4	19.1	4.1	96	0.965	0.007	2.8
6 Puppids	SXP	275	277	279	5	209.4	-37.0	119.7	-17.2	39.9	67.4	7.2	167	0.47	0.37	0.597	-0.22	0.18	0.584	3.72	1.85	0.876	0.059	58.6	2.8	98.0	4.2	97	0.460	0.021	1.8
Volantids	VOL	274	280	283	10	303.7	-77.8	121.1	-72.7	29.6	280.4	19.7	398	-1.42	0.39	0.787	-0.64	0.08	0.944	2.72	0.65	0.642	0.086	49.1	1.8	346.7	2.1	100	0.973	0.003	2.6
9 Herculids	NHR	281	282	285	5	318.3	25.0	243.2	4.3	38.1	51.8	9.9	105	0.04	0.12	0.215	-0.34	0.14	0.821	1.08	0.11	0.826	0.016	65.6	4.7	37.8	3.1	282	0.187	0.016	5.0
January μ Velids	JMV	282	287	296	15	268.6	-50.8	166.0	-51.1	34.9	145.5	9.8	339	0.92	0.09	0.945	-0.13	0.04	0.663	0.88	0.05	0.117	0.068	73.1	3.0	172.4	10.6	107	0.779	0.108	6.1
ψ Velids	PVL	278	288	298	21	238.4	-53.0	142.6	-42.6	41.7	170.0	12.5	383	1.05	0.04	0.986	-0.45	0.03	0.969	2.00	0.52	0.594	0.098	75.0	2.6	57.6	7.0	108	0.813	0.024	2.9
ι Antlids	IAN	299	302	304	6	239.3	-39.5	162.9	-36.2	36.5	63.2	6.8	265	0.06	0.2	0.169	-0.73	0.20	0.901	0.86	0.06	0.523	0.021	75.4	3.6	133.8	6.6	122	0.412	0.039	6.2
March β Equuleids	MBE	354	359	2	9	326.0	19.2	320.9	5.0	45.6	30.2	6.3	61	-0.01	0.00	0.868	-0.01	0.00	0.875	4.17	2.81	0.965	0.023	68.8	5.4	42.8	3.4	359	0.148	0.015	1.4

Table 4: Previously recognized showers found using our search algorithm sorted by the time of the solar longitude of their peak activity $\lambda_{\max}$.

Shower Name	IAU	Parent 1	H	D_N	Parent 2	H	D_N	Parent 3	H	D_N	Largest Parent	H	D_N	U	$\cos(\theta)$
η Aquarids	ETA	1P/Halley	5.5	0.0517	P/2010 H3 (SOHO)	—	1.0449	2015 DU180	20.8	1.3317	1P/Halley	5.5	0.0517	2.1778	-0.9073
Southern Daytime ω -Cetids	OCE	2013 KN6	18.5	0.0393	2015 DU180	20.8	0.0721	2014 JO25	18.1	0.1077	P/2010 H3 (SOHO)	—	0.3665	1.2440	-0.4761
Daytime Arietids	ARI	P/2010 H3 (SOHO)	—	0.0085	1998 Q552	14.3	0.1642	(1566) Icarus	16.9	0.1830	P/2010 H3 (SOHO)	—	0.0085	1.3790	-0.4731
Southern June Aquilids	SZC	(329015) 2005 MB	17.1	0.0926	(1566) Icarus	16.9	0.0937	P/2010 H3 (SOHO)	—	0.1092	P/2010 H3 (SOHO)	—	0.1092	1.2224	-0.6112
Southern May Ophiuchids	SOP	2008 XM1	22.0	0.0114	2009 XT6	20.2	0.0137	2004 LC2	18.5	0.0212	300P/Catalina	18.3	0.4425	0.8688	-0.1467
Northern June Aquilids	NZC	2015 NF	19.6	0.0786	2013 LC7	19.4	0.0962	2003 NC	19.4	0.1002	P/2010 H3 (SOHO)	—	0.2308	1.2405	-0.4932
Microscopids	MIC	2015 NF	19.6	0.0570	2003 NC	19.4	0.0740	2013 LC7	19.4	0.1071	P/2010 H3 (SOHO)	—	0.2791	1.2229	-0.4664
Piscis Austrinids	PAU	2009 OG	16.2	0.0878	2014 LJ21	16.0	0.1423	2002 PM6	17.7	0.1570	C/2015 D4 (Borisov)	9.4	0.6133	1.3604	-0.5453
Southern δ Aquarids	SDA	2002 PM6	17.7	0.1098	2001 VB	18.4	0.1159	2004 QX2	21.7	0.1183	P/2010 H3 (SOHO)	—	0.6393	1.3602	-0.4892
α Capricornids	CAP	2015 PU228	20.3	0.0237	2014 OW3	22.4	0.0279	2008 BC15	26.6	0.0312	C/2007 W1 (Boattini)	12.0	0.4635	0.8276	0.0221
Northern δ Aquarids	NDA	2004 QX2	21.7	0.0326	2011 GS60	19.0	0.0731	2014 QO390	21.1	0.0851	C/2012 F6 (Lemmon)	5.5	0.8990	1.3034	-0.4992
Daytime Sextantids	DSX	2006 SO198	23.9	0.0490	2008 SC	21.7	0.0739	2006 KK21	20.4	0.0828	35/P Herschel	8.3	0.7615	1.0419	-0.4854
October Leporids	OLP	2009 UY17	20.9	0.1151	2015 TD323	19.9	0.1249	2009 HE	21.3	0.1267	35/P Herschel	8.3	0.4692	0.9030	-0.6263
Orionids	ORI	C/2010 L5 (WISE)	17.4	0.2049	53P/Tempel-Tuttle	10.0	0.7275	2004 UL	18.8	1.1655	C/2010 L5 (WISE)	17.4	0.2049	2.1545	-0.9168
β Canis Majorids	MCB	1998 KO3	19.5	0.0838	2010 US7	19.0	0.1169	C/2013 R1 (Lovejoy)	11.6	0.1177	C/2013 R1 (Lovejoy)	11.6	0.1177	1.4179	-0.4305
November ω Orionids	NOO	2013 WM	23.8	0.0974	2008 XM	20.0	0.1107	2011 WN15	19.6	0.1265	C/2013 R1 (Lovejoy)	11.6	0.7808	1.3964	-0.4166
ϵ Velids	EVE	2006 BZ7	17.5	0.0696	2015 XG261	23.1	0.0926	2010 XA68	21.9	0.1345	C/2013 R1 (Lovejoy)	11.6	0.1779	1.3253	-0.4668
σ Serpentids	SSE	2011 XA3	20.4	0.0597	(3200) Phaethon	14.6	0.1336	2011 WN15	19.6	0.1913	C/2013 R1 (Lovejoy)	11.6	0.6857	1.4012	-0.5213
December Hydrids	DHY	2012 MS4	18.7	0.2186	C/1995 OP (Hale-Bopp)	2.3	0.3568	C/2013 R1 (Lovejoy)	11.6	0.4861	C/1995 O1 (Hale-Bopp)	2.3	0.3568	1.6536	-0.6606
α Hydrids	AHY	2011 XA3	20.4	0.1562	2010 BG2	19.9	0.2074	2004 XK50	19.3	0.2488	C/2013 R1 (Lovejoy)	11.6	0.6691	1.4066	-0.4258
Daytime ξ Sagittariids	XSA	2013 AB65	27.6	0.0171	2005 AD13	17.9	0.0216	2015 AR45	19.8	0.0307	141P/Machholz	15.0	0.7390	0.8541	-0.1165
Daytime χ Capricornids	DCS	2011 OF26	24.8	0.0115	2012 BL14	28.2	0.0190	2016 BN14	26.5	0.0287	141P/Machholz	15.0	0.9158	0.8012	0.0112
μ Hydrids	MHY	2009 AE16	18.7	0.1101	2005 AC	18.2	0.1621	2010 BG2	19.9	0.1848	C/2009 O2 (Catalina)	12.3	0.6501	1.1666	-0.6309
Daytime χ Capricornids	DCS	2011 OF26	24.8	0.0119	2011 CT4	20.5	0.0138	2011 BW10	25.2	0.0147	(1685) Toro	14.2	0.5164	0.8294	-0.0607
μ Hydrids	MHY	2010 BG2	19.9	0.0764	2010 CC19	22.3	0.0914	2009 AE16	18.7	0.1063	C/2009 O2 (Catalina)	12.3	0.7319	1.1998	-0.6041
α Antilids	AAN	2010 BG2	19.9	0.0567	2006 AL8	18.4	0.1154	2002 AJ129	18.7	0.1337	C/2009 O2 (Catalina)	12.3	0.6708	1.3577	-0.5393

Table 5: New showers found using our search algorithm sorted by the time of the solar longitude of their peak activity $\lambda_{\max}$.

Shower Name	IAU	Parent 1	H	D_N	Parent 2	H	D_N	Parent 3	H	D_N	Largest Parent	H	D_N	U	$\cos(\theta)$
30 Ophiuchids	THO	2012 US136	15.9	0.6771	2012 FZ23	18.2	0.8639	2010 EF44	20.2	0.9269	2012 US136	15.9	0.6771	1.9062	-0.8837
Oetanids	OKD	2015 TT178	20.7	0.0934	2004 HC2	19.5	0.1168	2002 TE66	18.4	0.1459	1998 XM4	15.5	0.2909	1.0735	-0.5511
ρ Phoenicids	RPH	2002 TW55	18.0	0.0994	2001 TZ44	17.4	0.1823	2007 VG	21.0	0.2091	C/2015 P3 (Swan)	12.5	0.8117	1.4564	-0.5121
ν Pavonids	OPA	1998 XM4	15.5	0.0986	2007 TD71	18.4	0.1003	(5381) Sekhmet	16.6	0.1079	C/2015 P3 (Swan)	12.5	0.7877	1.0470	-0.5886
ν Pavonids	UPA	(5381) Sekhmet	16.6	0.0764	2001 TZ44	17.4	0.1393	2005 NX4	19.8	0.1503	C/2015 P3 (Swan)	12.5	0.5433	1.0483	-0.6018
Telescopiids	TEL	2010 SG13	18.3	0.1170	2003 HA	16.5	0.1296	2005 LX36	20.8	0.1439	C/2015 P3 (Swan)	12.5	0.3894	1.0783	-0.5688
α Sagittariids	ASG	2010 SG13	18.3	0.0285	(329915) 2005 MB	17.1	0.0399	(1566) Icarus	16.9	0.0533	P/2010 H3 (SOHO)	—	0.2668	1.0347	-0.5033
β Aquilids	BAD	(329915) 2005 MB	17.1	0.0292	2003 OS13	17.4	0.0713	2010 SG13	18.3	0.0716	C/2015 P3 (Swan)	12.5	0.3238	1.0545	-0.5919
α Phoenicids	APH	2006 AD	16.7	0.1679	2012 XT134	19.0	0.1683	2010 JU39	19.6	0.1732	C/2015 P3 (Swan)	12.5	0.3786	0.9338	-0.6964
ζ Phoenicids	ZPH	(5496) 1973 NA	16.0	0.0323	2012 XT134	19.0	0.1041	C/2015 D4 (Borisov)	9.4	0.1525	C/2015 D4 (Borisov)	9.4	0.1525	1.4179	-0.5211
ψ Phoenicids	PPH	(5496) 1973 NA	16.0	0.0600	C/2015 D4 (Borisov)	9.4	0.1793	2012 XT134	19.0	0.1884	C/2015 D4 (Borisov)	9.4	0.1793	1.2819	-0.5605
λ Caelids	LCA	2009 VQ25	18.6	0.0445	2010 QE2	17.2	0.0684	2009 FG1	18.8	0.0945	C/2015 P3 (Swan)	12.5	0.1044	1.3647	-0.4532
σ Columbiids	SCO	2003 UL9	22.4	0.0713	2009 VQ25	18.6	0.0743	2009 FG1	18.8	0.0750	C/2015 P3 (Swan)	12.5	0.1295	1.3203	-0.5539
γ Sextantids	GSE	2001 TD45	19.9	0.0658	1999 VO6	17.0	0.0721	2004 VG64	18.3	0.0786	35/P Herschel	8.3	0.7429	0.9086	-0.6476
3 Puppiids	THP	2003 UL9	22.4	0.0098	2009 FG1	18.8	0.0811	2009 VQ25	18.6	0.0832	C/2015 P3 (Swan)	12.5	0.2842	1.0980	-0.5080
η Canis Majorids	ECM	2003 UL9	22.4	0.0442	2009 FG1	18.8	0.1126	2003 QQ47	17.4	0.1479	C/2015 P3 (Swan)	12.5	0.3264	1.1346	-0.5586
October β Pyxidids	OBP	2003 UL9	22.4	0.0109	2009 VQ25	18.6	0.0856	2011 BJ2	18.2	0.1006	C/2015 P3 (Swan)	12.5	0.1944	1.1114	-0.5602
October α Pyxidids	OAP	2003 UL9	22.4	0.0440	2011 BJ2	18.2	0.0803	2008 HD3	19.8	0.0809	C/2015 P3 (Swan)	12.5	0.2057	1.0745	-0.5670
October Puppiids	OPU	2003 UL9	22.4	0.0256	2007 HX4	17.7	0.0617	2014 HM129	20.3	0.0814	C/2015 P3 (Swan)	12.5	0.2619	1.0608	-0.5605
ζ Antliids	ZAN	2000 JE5	19.1	0.1005	2008 HD3	19.8	0.1097	2003 UL9	22.4	0.1238	C/2015 P3 (Swan)	12.5	0.2324	1.0723	-0.5938
October λ Velids	OLV	2007 HX4	17.7	0.0412	2011 WO4	19.2	0.0440	(10563) Izhutubar	16.8	0.0801	C/2015 P3 (Swan)	12.5	0.2250	1.1245	-0.5668
November Puppiids	NPU	2011 WO4	19.2	0.0697	2007 HX4	17.7	0.0738	(10563) Izhutubar	16.8	0.0967	C/2015 P3 (Swan)	12.5	0.2691	1.1786	-0.5277
November λ Velids	NIV	(10563) Izhutubar	16.8	0.0455	2011 WO4	19.2	0.0619	2007 HX4	17.7	0.0966	C/2013 R1 (Lovejoy)	11.6	0.2748	1.2120	-0.5158
ι Arids	IAD	141P/Machholz	XXX	0.0105	2013 WS67	23.3	0.0303	2015 FH120	18.7	0.0334	141P/Machholz	15.0	0.0105	0.7153	0.2129
ι Lupids	ILU	2012 MS4	18.7	0.1077	2002 AB29	17.9	0.1396	2004 XK50	19.3	0.1427	C/2013 R1 (Lovejoy)	11.6	0.3701	1.2227	-0.5919
κ Velids	KVE	(2102) Tantalus	16.0	0.0506	2006 BZ7	17.5	0.0666	C/1995 O1 (Hale-Bopp)	2.3	0.1731	C/1995 O1 (Hale-Bopp)	2.3	0.1731	1.3428	-0.4781
θ Carinids	TCD	(2102) Tantalus	16.0	0.0695	2006 BZ7	17.5	0.0782	C/1995 O1 (Hale-Bopp)	2.3	0.1410	C/1995 O1 (Hale-Bopp)	2.3	0.1410	1.3846	-0.4829
6 Puppiids	SXP	2002 AB29	17.9	0.0989	2012 MS4	18.7	0.1025	2004 XK50	19.3	0.1409	C/2013 R1 (Lovejoy)	11.6	0.3512	1.3273	-0.3882
Volantids	VOL	2011 AL1	19.6	0.0912	2008 CM	17.2	0.1013	(2102) Tantalus	16.0	0.1154	C/2013 R1 (Lovejoy)	11.6	0.5155	0.9882	-0.1741
9 Herculids	NHR	2011 XA3	20.4	0.1624	2004 XK50	19.3	0.1860	2002 AB29	17.9	0.2491	C/2013 R1 (Lovejoy)	11.6	0.6475	1.2610	-0.6011
January μ Velids	JMV	—	—	—	—	—	—	—	—	—	—	—	—	1.1498	-0.6342
ψ Velids	PVL	2008 AH4	21.6	0.0431	C/1995 O1 (Hale-Bopp)	2.3	0.1488	(2102) Tantalus	16.0	0.1498	C/1995 O1 (Hale-Bopp)	2.3	0.1488	1.3824	-0.5104
ι Antliids	IAN	2008 AH4	21.6	0.0922	2005 AC	18.2	0.2109	2005 OU2	19.1	0.2108	C/1995 O1 (Hale-Bopp)	2.3	0.4828	1.1995	-0.6676
March β Equuleids	MBE	2012 US136	15.9	0.1158	2010 EF44	20.2	0.1341	2015 EV	22.5	0.1882	2012 US136	15.9	0.1158	1.5404	-0.5235