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Fireball Meteor
February 21, 20h09m UT by Tioga Gulon at Fléville (France).

Contents

Two bright fireballs over Great Britain

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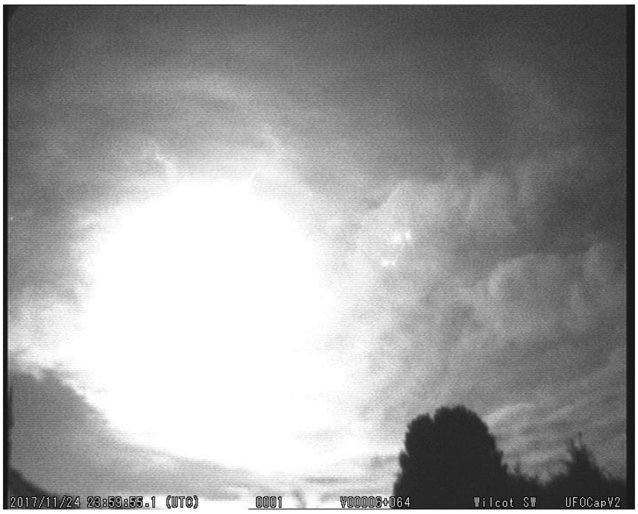
On November 24, 2017 shortly before midnight and on November 25, 2017 shortly before sunrise, two very bright fireballs lit up the sky over the United Kingdom. The UKMON (United Kingdom Meteor Observation Network) cameras and onboard cameras in the automobiles recorded their flight. The fireballs paths in the Earth´s atmosphere were calculated, as well as the orbits of bodies in the Solar System. The flight of both bodies, the absolute magnitude of which approached the brightness of the full Moon, was also observed by numerous random observers from the public in Great Britain, Ireland and France.

1 Introduction

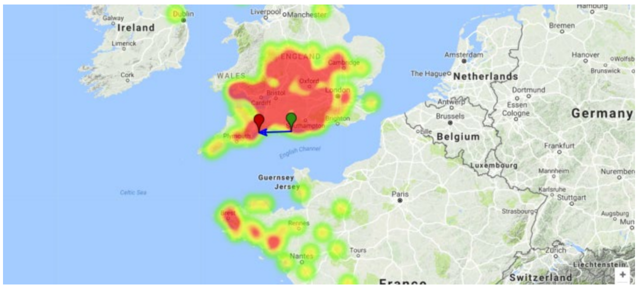
The first fireball was recorded by UKMON network cameras on November 24, 2017 at 23^{h}59^{m}55^s UT. Due to the high brightness of the fireball, both records from Wilcot SW station (*Richard Fleet*) and Church Crookham station (*Peter Campbell-Burns*) were significantly over-saturated by light. In this case, it was necessary to perform the astrometry of the recorded fireball manually from the separate segments of the sequence, omitting saturated pictures where it is not possible to reliably determine the position of the centroid. The video clips from Wilcot SW station (*Figure 1*) and from Church Crookham station (*Figure 2*) are listed below.



Fireball 20171125_071306 was recorded with just one UKMON network camera and two dashboard cameras on November 25, 2017 at 7^{h}13^{m}06^s UT. An astrometry of record from Wilcot SW station (*Richard Fleet*) was performed in the UFO Analyzer program (SonotaCo 2009), a dashboard camera record from the M4 highway near the Port Talbot (*Mark Lemon*) was used to calculate the fireball atmospheric path. The astrometry of the fireball position from this record was performed manually from the separate segments of the sequence. The position of the fireball was calculated in the horizontal coordinates system, positions of the public lighting lamps near the M4 highway were used for the calculation of the azimuth and elevation. The positions of the lamps were also used to determine the immediate position of the car on the M4 highway. The record from the dashboard camera from the M5 highway near the Churchdown (*Craig Low*) was not used for the calculation due to the small number of fixed points in the surrounding landscape that could be used for astrometry of the fireball position. The video clips from Wilcot SW station (*Figure 3*) and from onboard cameras in cars (*Figures 4 and 5*) are listed below.

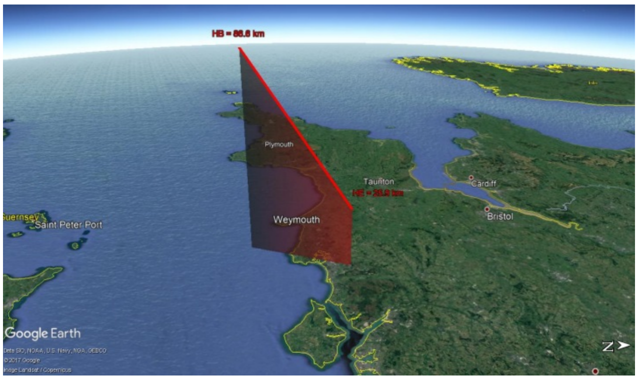
2 Visual observations

Visual observations of fireballs are collected in the IMO database a worldwide visual reports database. The report of fireball 20171124_235955 (Event 4590-2017) was sent by 113 observers from Great Britain and France. A total of 35 observers reported fragmentation during the fireball flight, 4 of them heard sound effects during the flight, and 9 observers heard sound effects after fireball flyover. The average relative brightness of the fireball from visual reports was between –10m and –15m, but many observers reported the fireball to be brighter than –20m. The position and density of the fireball 20171124_235955 observations are shown in *Figure 6*.



3 Fireball 20171124_235955 (SPO)

The recordings from the stations Wilcot (camera SW) and Church Crookham were used to calculate the atmospheric path of the fireball and the orbit of the meteoroid in the Solar system. The projection of the beginning of the atmospheric path was located at the coordinates N50.430099° W2.136627° over the English Channel, the height of the fireball at this time was 86.6 ± 0.1 kilometers above the Earth's surface. The end of the projection of the atmospheric path was located at the coordinates N50.812645° W1.914062° near the city of Ferndown (GB), the height of the fireball at this time was 25.9 ± 0.1 kilometers above the Earth's surface. The fireball reached an absolute brightness of –12.1 ± 0.2m, the initial mass of the body was 66.4 ± 14.5 kg. The 3D projection of the atmospheric path of fireball 20171124_235955 is shown in *Figure 8*.



It was a slow meteor, the geocentric velocity of the meteoroid before entering the gravitational field of the Earth was 15.58 ± 0.15 km/s (including the deceleration effect), the orbital elements of the meteoroid orbit were as follows:

- $a = 2.198 \pm 0.078$ AU,
- $q = 0.7721 \pm 0.0018$ AU,
- $e = 0.649 \pm 0.012$,
- $i = 3.02 \pm 0.03°$,
- $\omega = 63.49 \pm 0.11°$,
- $\Omega = 62.6643°$.

The fireball belonged to sporadic meteors (SPO) with a geocentric radiant RA = 47.8 ± 0.2°, Dec. = 10.9 ± 0.4°. The projection of the meteoroid orbit in the Solar System is shown in *Figure 9*, including the effect of deceleration on the geocentric velocity. Orbital heliocentric parameters of the fireball orbit are shown in *Table 1*, the geocentric orbit parameters are shown in *Table 2*.

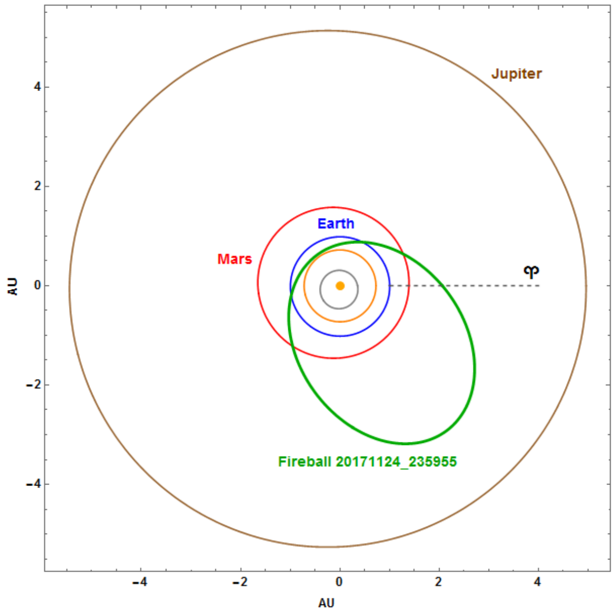


Figure 9 – Projection of the fireball 20171124_235955 orbit in the Solar System, including the effect of deceleration. Author: Jakub Koukal.

4 Fireball 20171125_071306 (SPO)

The recordings from the stations Wilcot (camera SW) and from dashboard camera from the M4 highway near the Port Talbot were used to calculate the atmospheric path of the fireball and the orbit of the meteoroid in the Solar system. The projection of the beginning of the atmospheric path was located at the coordinates N49.971264° W1.899078° over the English Channel, the height of the fireball at this time was 82.0 ± 0.2 kilometers above the Earth's surface. The end of the projection of the atmospheric path was located at the coordinates N49.68513° W3.486542° over the English Channel, the height of the fireball at this time was 38.8 ± 0.2 kilometers above the Earth's surface. Fireball reached an absolute brightness of –9.2 ± 0.3m, the initial mass of the body was 7.4 ± 2.1 kg. The 3D projection of the fireball 20171125_071306 atmospheric path is shown in *Figure 10*.

Figure 10 – 3D projection of the fireball 20171124_071306 path in the Earth's atmosphere. Author: Jakub Koukal.

It was a slow meteor, the geocentric velocity of the meteoroid before entering the gravitational field of the Earth was 20.42 ± 0.23 km/s (including the deceleration effect), the orbital elements of the meteoroid orbit were as follows:

- $a = 3.866 \pm 0.251$ AU,
- $q = 0.8534 \pm 0.0013$ AU,
- $e = 0.779 \pm 0.015$,
- $i = 22.68 \pm 0.25°$,
- $\omega = 133.71 \pm 0.05°$,
- $\Omega = 242.9665°$.

The fireball belonged to sporadic meteors (SPO) with a geocentric radiant RA = 261.9 ± 0.3°, Dec. = 21.5 ± 0.3°. The projection of the meteoroid orbit in the Solar System is shown in *Figure 11*, including the effect of deceleration on the geocentric velocity. Orbital heliocentric parameters of the fireball orbit are shown in *Table 1*, the geocentric orbit parameters are shown in *Table 2*.

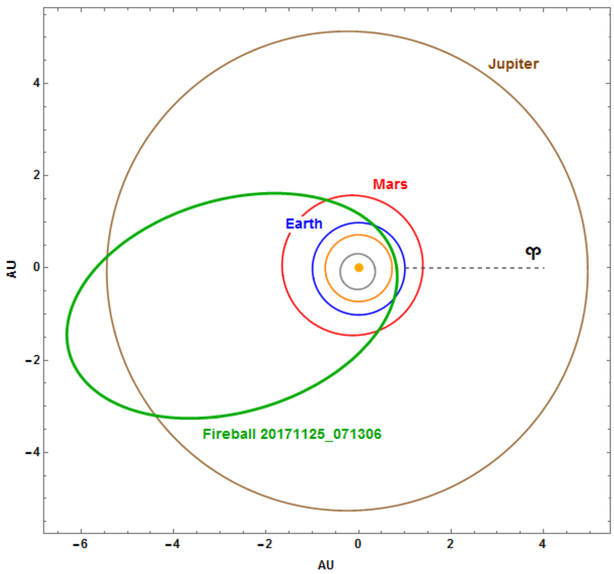


Figure 11 – Projection of the fireball 20171125_071306 orbit in the Solar System, including the effect of deceleration. Author: Jakub Koukal.

Table 1 – Heliocentric orbital elements (J2000.0) of the fireballs, calculated using software UFOOrbit (SonotaCo 2009), the effect of deceleration is considered in the calculation. Author: Jakub Koukal.

Heliocentric orbital elements		Fireball 20171124_235955 Sporadic	Fireball 20171125_071306 Sporadic
Semi major axis	*a*	2.198 ± 0.078 AU	3.866 ± 0.251 AU
Eccentricity	*e*	0.649 ± 0.012	0.779 ± 0.015
Perihelion distance	*q*	0.7721 ± 0.0018 AU	0.8534 ± 0.0013 AU
Aphelion distance	*Q*	3.623 ± 0.156 AU	6.879 ± 0.502 AU
Argument of perihelion	*ω*	63.49 ± 0.11°	133.71 ± 0.05°
Longitude of ascending node	*Ω*	62.6643°	242.9665°
Inclination	*i*	3.02 ± 0.03°	22.68 ± 0.25°
Orbital period	*P*	3.26 ± 0.17 y	7.60 ± 0.74 y
Tisserand's parameter	TB_J	3.35 ± 0.09	2.34 ± 0.08

Table 2 – Geocentric radiant, geocentric velocity, beginning and terminal height of fireballs, calculated using software UFOOrbit (SonotaCo 2009), the effect of deceleration is considered in the calculation. Author: Jakub Koukal.

Geocentric orbital elements		Fireball 20171124_235955 Sporadic	Fireball 20171125_071306 Sporadic
Geocentric velocity	v_g	15.58 ± 0.15 km/s	20.42 ± 0.23 km/s
Radiant right ascension	*RA*	47.8 ± 0.2°	261.9 ± 0.3°
Radiant declination	*Dec.*	10.9 ± 0.4°	21.5 ± 0.3°
Beginning height of the atmospheric path projection	H_B	86.6 ± 0.1 km	82.0 ± 0.2 km
Terminal height of the atmospheric path projection	H_E	25.9 ± 0.1 km	38.8 ± 0.2 km
Absolute magnitude	a_{mag}	–12.1 ± 0.2 mag	–9.2 ± 0.3 mag
Initial mass	m_i	66.4 ± 14.5 kg	7.4 ± 2.1 kg

5 Conclusions

The bright fireballs recorded during the night of November 24–25, 2017 did not have a common origin. Fireball 20171124_235955, due to the Tisserand's parameter (TP_J = 3.35 ± 0.09), has an asteroidal origin (A-C type). The probable parent body is the asteroid 2015 WZ1, the value of the orbit similarity criterion D_D = 0.023. Fireball 20171125_071306, due to the Tisserand's parameter (TP_J = 2.34 ± 0.08), has a cometary origin (JFC type). The parent body is probably an unknown comet of Jupiter's family. Due to the atmospheric path of the fireball 20171124_235955 and due to its initial mass, it is very likely that a fragment (or fragments) fell on the Earth's surface.

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Orbit analysis of a bright Southern sigma Sagittariids fireball

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During twilight on June 14, 2017, CEMeNt network cameras recorded a long and bright fireball with an absolute magnitude of -7.9 ± 0.2m, whose atmospheric path began over the northwest of Romania and ended up above southern Poland. This fireball belongs to the Southern sigma Sagittariids meteor shower and was recorded from 9 cameras of the CEMeNt network. The atmospheric path of the fireball as well as the heliocentric orbit of the meteoroid are analyzed in this article.

6 Introduction

During twilight on June 14, 2017, a bright fireball with an absolute magnitude of –7.9 ± 0.2m flew over four European countries (Romania, Hungary, Slovakia and Poland). The fireball was visually observed from several locations in the Czech Republic (Nýdek, Brno, Uherský Brod), most of the observers reported a relative brightness between –6 and –12m. At the time of the event the sky was cloudless above the territory of the Czech Republic, Poland and Slovakia, which was also reflected in the number of records from the CEMeNt network stations as well as in the number of visual observations. The flight of this fireball, which belongs to the Southern sigma Sagittariids meteor shower, was confirmed by CEMeNt network cameras, which recorded it at $20^h07^m07.2 \pm 0.1^s$ UT. The fireball was included in the EDMOND database (Kornoš et al., 2014a) with the designation 20170614_200707, which accurately identifies the observation time in the YYYYMMDD_HHMMSS format.

The Southern sigma Sagittariids meteor shower (168 SSS) is one of the weaker and less known showers. In the IAU MDC meteor showers database (Jopek et al., 2014), there is only one mean orbit of this shower (Sekanina 1976) that was taken from radar observations. This meteor shower is very poorly explored; the mean orbit of the shower is based on radar observations from 1968 and 1969. The orbital elements of the shower mean orbit are as follows:

- v_g = 29.3 km/s,
- a = 2.594 AU,
- q = 0.361 AU,
- e = 0.861,
- i = 2.8°,
- ω = 113.6°,
- Ω = 267.4°,

The coordinates of the geocentric radiant (J2000.0) are:

- RA = 278.6°,
- DEC = –25.3°.

The mean orbit was calculated from the 29 individual orbits belonging to the shower. The asteroid 2001 MEW1 is assumed to be the parent body, but the relationship of the Scutid meteor shower and this asteroid has not yet been established.

7 Instrumentation and methodology

Wide field systems

Video systems used in the CEMeNt network (*Figure 1*) are generally based on various types of sensitive CCTV cameras with CCD sensors (Sony Ex-View HAD, Sony Super HAD II, Sony Super HAD 960 H Effio) of size 1/3" or 1/2" with fast (~ f / 1.0) varifocal lenses with PAL B image resolution (720 × 576 px). Most of the stations have a field of view within the range of 60° – 90° in the horizontal direction.

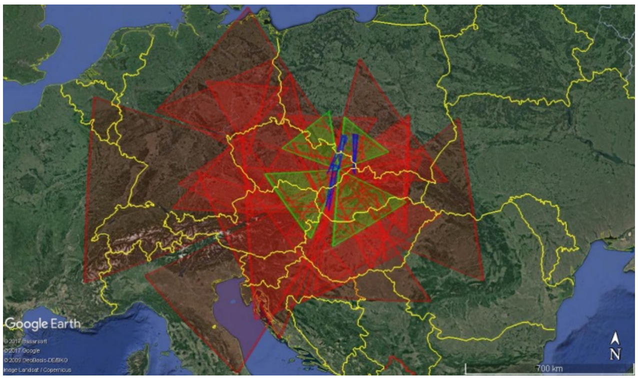

Figure 1 – 2D projection of videocameras FOV in the CEMeNt network. Wide field systems are marked in red. Author: Jakub Koukal.

Detection software, processing

The detection of meteors is done by UFOCaptureV2 software (SonotaCo, 2009), and for astrometric and photometric processing UFOAnalyzerV2 software (SonotaCo, 2009) is used. Orbits of meteoroids in the solar system are calculated using the software UFOOrbitV2 (SonotaCo, 2009). Deceleration is derived out of this software as an exponential fit of the actual speed of the meteor for each frame. The Drummond´s orbit similarity criterion (Drummond, 1981) is used to assign a meteor to the meteor shower, the limit value of this criterion is set at $D_D < 0.1$. An empirical equation was used to estimate the initial meteoroids weight (Jacchia et al., 1967), based on the observations of 413 bright meteors. The equation defines the dependence of the initial meteoroids weight on the photometric absolute magnitude, meteoroids geocentric speed and zenithal angle of the observed meteors radiant.

8 EDMOND database

At present, there are 4655640 individual meteor records (from 2000 to 2016) in the EDMOND database, of which 592699 multi-station orbits (so-called *Q0* orbits or raw orbits) have been created. The database itself is understood to be multiplatform, therefore combines outputs from systems with different parameters as well as from systems with different recording and evaluation methodology (UFO Capture, MetRec, CMN). Because of the inhomogeneity of the input data, it is necessary to establish reduction criteria within the EDMOND database (Kornoš et al. 2014a,b), which makes it possible to exclude orbits from the database that do not meet the required geometric conditions or due to inhomogeneity they are not compatible. The result of applying the reduction criteria is a significant reduction to 326823 multi-station orbits that are stored in the output version of the EDMOND database. The multi-station orbits are necessary to determine the origin of the body and due to the knowledge of the heliocentric parameters of the meteoroid orbit and the complementary parameters (e.g. the Tisserand´s parameter T_J in relation to the Jupiter) it is possible to determine whether the body is of cometary or asteroid origin or belongs to one of the known meteor showers.

9 Atmospheric path, radiant and heliocentric orbit of the fireball

Figure 2 – Summary image of the fireball 20170614_200707, station Kroměříž ENE. Author: Jakub Koukal.

Records were taken from the stations Kroměříž ENE (*Figure 2*), Vsetín E (*Figure 5*), Těrlicko NE (*Figure 6*), Blahová E (*Figure 8*) and Kráčany N (*Figure 9*) to calculate the atmospheric path of the fireball 20170614_200707 and the meteoroids orbit in the Solar System. The records taken from stations Kroměříž SE (*Figure 3*), Maruška SE (*Figure 4*) and Vartovka NE (*Figure 7*) were not used for the calculation of the meteoroids orbit.

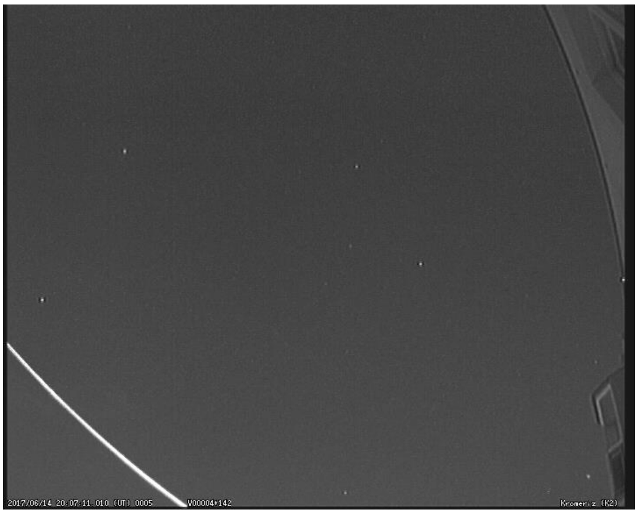

Figure 3 – Summary image of the fireball 20170614_200707, station Kroměříž SE. Author: Jakub Koukal.

Figure 4 – Summary image of the fireball 20170614_200707, station Maruška SE. Author: Jakub Koukal.

Figure 5 – Summary image of the fireball 20170614_200707, station Vsetín E. Author: Hvězdárna Vsetín.

Figure 6 – Summary image of the fireball 20170614_200707, station Těrlicko NE. Author: Jan Kondziolka.

Figure 7 – Summary image of the fireball 20170614_200707, station Vartovka NE. Author: Hvezdáreň Banská Bystrica.

Figure 8 – Summary image of the fireball 20170614_200707, station Blahová E. Author: UMa Astronomy.

The projection of the beginning of the atmospheric path was located at coordinates N47.519745° E23.235519° near the village of Rodina (Romania), the height of the fireball at this time was 94.4 ± 0.1 kilometers above the Earth's surface. The end of the projection of the atmospheric path was located at coordinates N50.032967° E19.378588° near the village of Balusie (Poland), the height of the fireball at this time was 85.3 ± 0.1 kilometers above the Earth's surface (*Figure 10*). The fireball reached an absolute brightness –7.9 ± 0.3m (*Figure 11*), an estimated initial mass of the body is 3.11 ± 0.49 kg (Jacchia et al., 1967).

Figure 9 – Summary image of the fireball 20170614_200707, station Kráčany N. Author: UMa Astronomy.

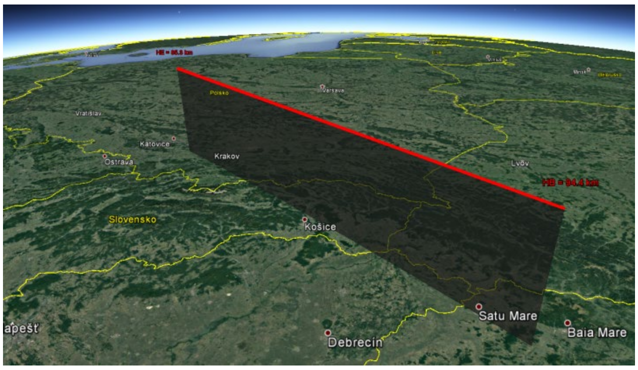

Figure 10 – 3D projection of the atmospheric path of the fireball 20170614_200707 on the Earth´s surface. Author: Jakub Koukal.

It was a relatively slow meteor; its geocentric velocity before entering the Earth's gravitational field (v_g) was 30.89 ± 0.41 km/s (including the effect of the deceleration). Velocity before entering the Earth's atmosphere (v_i) was 33.09 ± 0.39 km/s. The orbital elements of the meteoroid orbit in the Solar System were as follows:

- a = 2.064 ± 0.130 AU (semi-major axis),
- q = 0.2831 ± 0.0025 AU (perihelion distance),
- e = 0.863 ± 0.007 (eccentricity),
- i = 9.32 ± 0.05° (inclination),
- ω = 123.86 ± 0.06° (argument of the perihelion),
- Ω = 263.7059° (longitude of the ascending node).

The bolide was a member of the Southern sigma Sagittariids meteor shower (IAU MDC #168 SSS) with the geocentric radiant RA = 280.73 ± 0.09° (right ascension), DEC = -29.49 ± 0.13° (declination). The projection of the meteoroid orbit in the Solar system is shown in *Figure 12*, including the effect of the deceleration on the geocentric

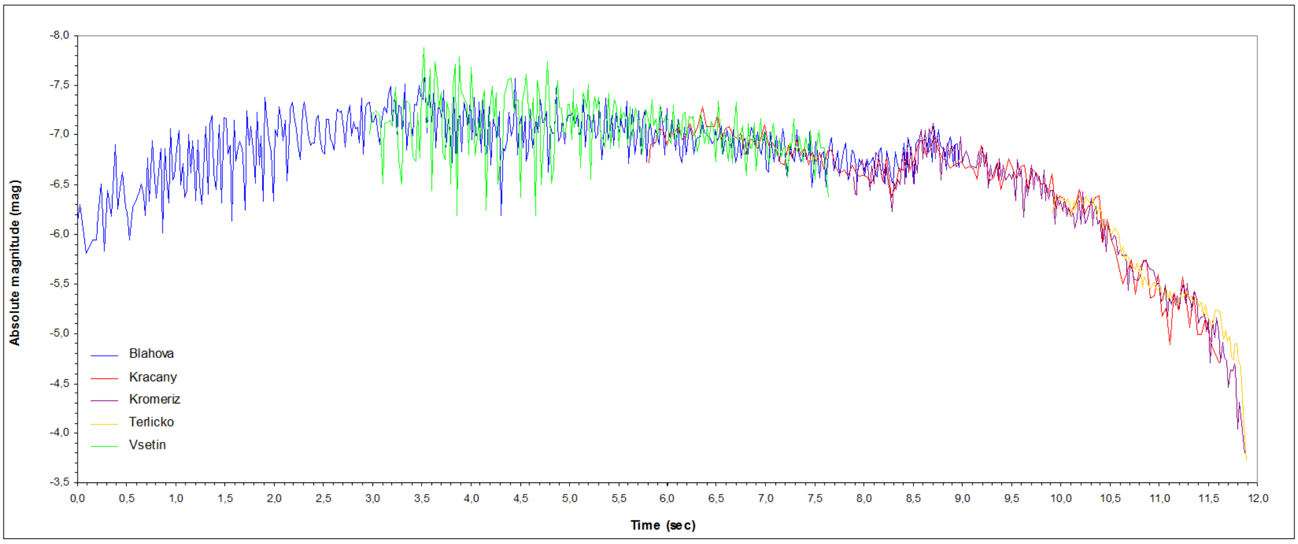

Figure 11 – The course of the absolute magnitude of the fireball 20170614_200707 from individual stations. Author: Jakub Koukal.

velocity v_g. The orbital heliocentric parameters of the meteoroid orbit are shown in *Table 1*, the geocentric orbit parameters then in *Table 2*.

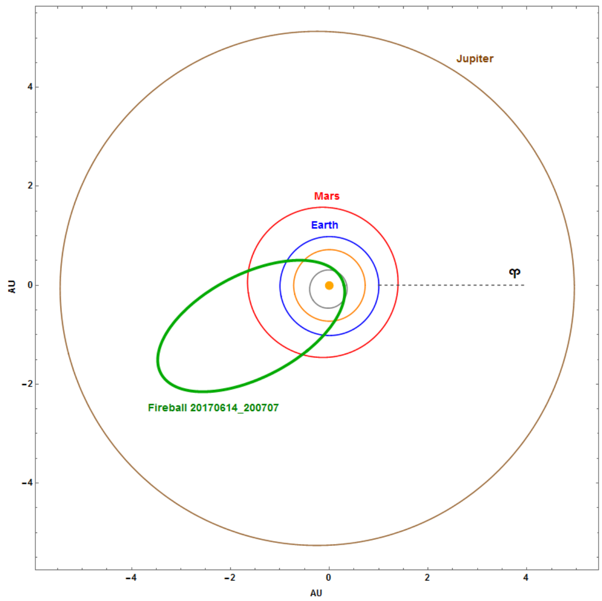

Figure 12 – Orbit of the bolide 20170614_200707 in the Solar System, the effect of deceleration is considered in the calculation. Author: Jakub Koukal.

10 Conclusions

The length of the fireball 201710614_200707 path in the Earth's atmosphere was 403.6 km, it is one of the longest meteors in the EDMOND database. It was not an Earth-grazer, the body disappeared in the atmosphere of the Earth. Given the Tisserand´s parameter (TP_J = 3.15 ± 0.11), the asteroid origin of the body (A-C type) can be assumed.

Acknowledgments

Acknowledgment belongs to all station owners, operators and observers for their long-term and precise work, which enabled the establishment and development of the CEMeNt network. Acknowledgment also belongs to all interested institutions in support of activities and network growth. The KOSOAP (Cooperating Network of Astronomic Observational Projects, in Czech: Kooperující síť v oblasti astronomických odborně-pozorovatelských programů) and RPKS (Evolvement of the Cross Border Network for Scientific Work and Education, in Czech: Rozvoj přeshraniční kooperující sítě pro odbornou práci a vzdělávání) projects were realized by the Valašské Meziříčí Observatory (CZ) and Kysucké Nové Město Observatory (SR) in cooperation with the Society for Interplanetary Matter. Projects were co-funded by European Union (Cross-border Cooperation Programme Slovak Republic – Czech Republic 2007-2013).

Table 1 – Heliocentric orbital elements (J2000.0) of the fireball 20170614_200707, calculated using software UFOOrbit (SonotaCo 2009), the effect of deceleration is considered in the calculation. Author: Jakub Koukal.

Heliocentric orbital element		Fireball 20170614_200707 Southern sigma Sagittariids (168 SSS)
Semimajor axis	*a*	2.064 ± 0.130AU
Eccentricity	*e*	0.863 ± 0.007
Perihelion distance	*q*	0.2831 ± 0.0025 AU
Aphelion distance	*Q*	3.845 ± 0.259 AU
Argument of perihelion	*ω*	123.86 ± 0.06°
Longitude of ascending node	*Ω*	263.7059°
Inclination	*i*	9.32 ± 0.05°
Orbital period	*P*	2.97 ± 0.28 y
Heliocentric velocity	v_s	36.29 ± 0.26 km/s
Tiserand's parameter	TP_J	3.15 ± 0.11

Table 2 – Geocentric radiant, geocentric velocity, beginning and terminal height of the fireball 20170614_200707, calculated using software UFOOrbit (SonotaCo 2009), the effect of deceleration is considered in the calculation. Author: Jakub Koukal.

Geocentric element Atmospheric path		Fireball 20170614_200707 Southern sigma Sagittariids (168 SSS)
Geocentric velocity	v_g	30.89 ± 0.41 km/s
Initial velocity	v_i	33.09 ± 0.39 km/s
Initial mass	m_i	3.11 ± 0.49 kg
Radiant right ascension	*RA*	280.73 ± 0.09°
Radiant declination	*Dec.*	–29.49 ± 0.13°
Beginning height of the atmospheric path projection	H_b	94.4 ± 0.1 km
Terminal height of the atmospheric path projection	H_e	85.3 ± 0.1 km
Absolute magnitude	a_{mag}	–7.9 ± 0.2 m

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The Gamma Lyrids (GLY-794) did it again

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Like in 2015 significant activity has been detected from the Gamma Lyrids (794) by CMOR in 2018, but thus far no orbits could be found in the CAMS BeNeLux data (until 6 February 2018) although clear sky allowed collecting a large number of orbits.

1 Introduction

A search on 2013–2016 CMOR orbits resulted in the detection of the Gamma Lyrids (GLY–794) at $\lambda_{\odot} = 316°$ in 2015. No earlier evidence for this shower has been found in any year from 2002–2014 in CMOR data (Brown, 2016). A spread in v_g of 2 km/s in velocity and 2.7° on the radiant position was found with an activity lasting less than 2 days. The orbit is typical for a Halley type comet but no parent body could be associated yet.

On 2015 February 5, 10^h–11^h UT amateur radio observers reported an outburst, one of them the Belgian amateur Lucas Pellens (Steyaert, 2015). CAMS BeNeLux had 38 cameras collecting orbits in the nights of 2015 February 4–5, 5–6 and 6–7 but not any single orbit matches with the GLY-794 orbit (Roggemans, 2015).

Table 1 – The available orbits for the Gamma Lyrids (794), all data referring to J2000.0.

	Brown (2016)	Jenniskens et al. (2017)	EDMOND #2854
$\lambda_{\odot}$ (°)	316.5	317	316.6
α (°)	285	287	287.1
δ (°)	33.7	35.5	32.8
v_g (km/s)	37	33.5	35.7
a	–	5.99	16.6
q	0.78	0.795	0.766
e	0.992	0.867	0.954
ω (°)	125.7	125.6	122.9
Ω (°)	316.5	317	316.6
i (°)	54.6	49.9	52.1
N	32	2	

2 And again in 2018

The GLY-794 appeared to be an annual shower in the radar data, but did not come forward in any orbit search on meteors in the visual range. Also 2018 data for CAMS BeNeLux revealed no orbits for this shower.

The remarkable absence in the visual range stands in great contrast to the strong appearance as radiant source for the orbits detected by CMOR (*Figure 1*). I checked the available datasets and I could not find any single resembling orbit in the SonotaCo data sets, nothing in the Croatian Meteor Network (CMN) datasets, nothing in the Photographic orbit catalogue and nothing in the Harvard radar meteor orbit list 1961–1965 and 1968–1969. One single orbit which qualifies for the GLY-794 shower was found in EDMOND (Kornos et al., 2014). A single meteor recorded on 6 February 2012 compares well to the reference orbit, but indeed a single meteor doesn't prove a meteor stream.

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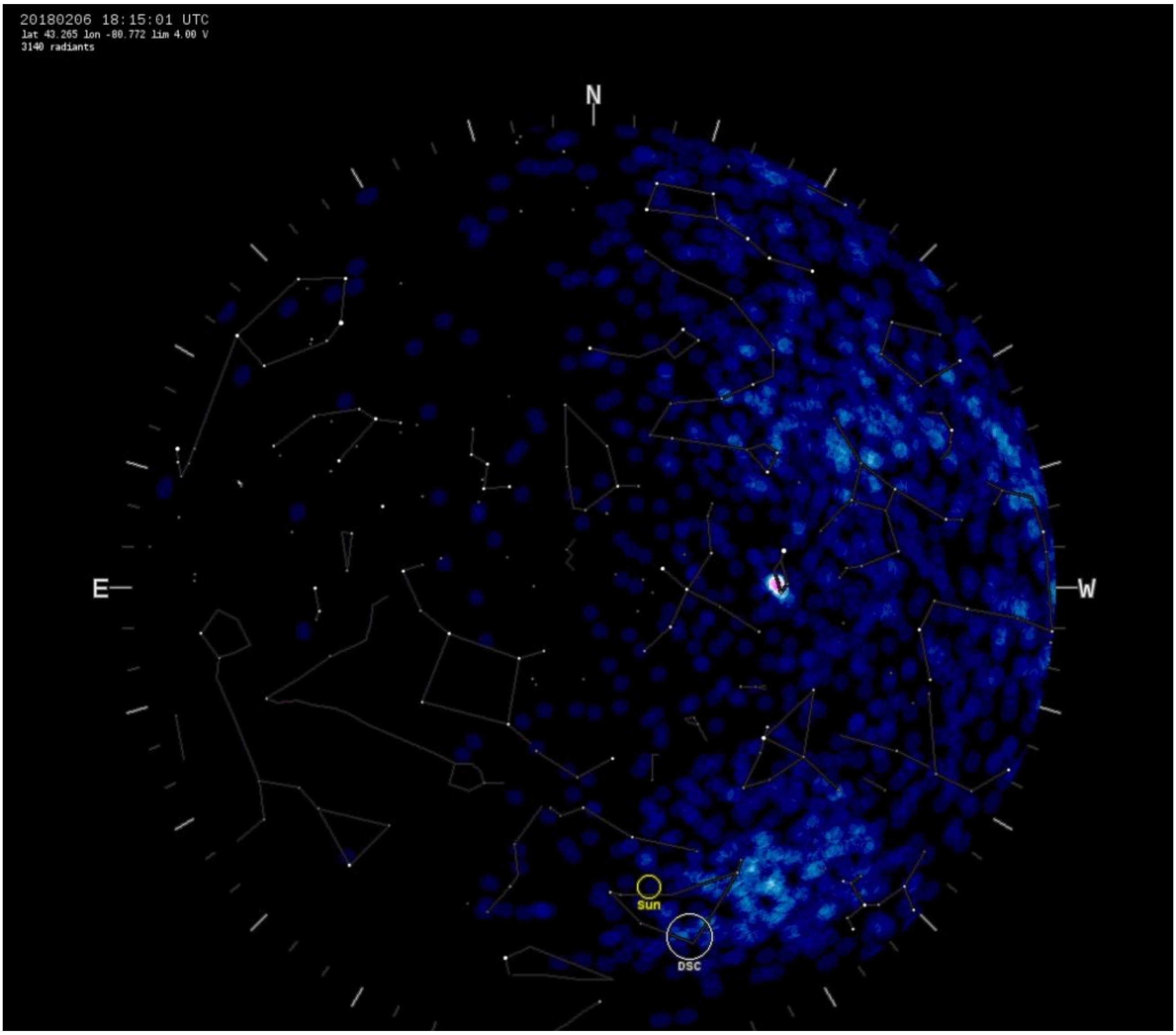

Figure – 1 CMOR image at 2018 February 06 at 18h15m UT showing one concentrated radiant activity at the position of the GLY-794 shower.

January 2018 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month January 2018 is presented. This month was characterized by exceptional poor weather, lowest amount of sunshine since January 1935 during daylight, mostly overcast during the night. Thanks to the dedication of the network team still 11986 meteors were recorded, 4859 of which proved multiple station, or 41%. In total 1878 orbits were collected during this month.

1 Introduction

December 2017 was the worst December month in the short 6 years of CAMS BeNeLux history. When compared on a longer term this month had the lowest number of sunshine hours since December 1934. We all hoped to get somehow better weather for January 2018, but nature has no mercy, January 2018 became about as bad as December 2017. January 2018 had the lowest number of sunshine hours since 1935. The network got another month with long nights and rich meteor activity spoiled by bad weather.

2 January 2018 statistics

Motivation of volunteers depends a lot on an efficient system to collect the results, providing frequent feedback. The BeNeLux CAMS network is coordinated by *Carl Johannink* who provides all participants on a weekly basis with status updates, showing which CAMS stations reported their results. When any unusual activity or any peculiar event occurred, a summary is shared with all participants. Data is being reported on a daily bases, but since the CAMS team works with volunteers who have other commitments as well, some people report their data only every few days. Once all data has been collected for a month, *Carl Johannink* sends a report to all participants with a final list of multiple station meteors and some statistics. This summary report is based on the data provided by Carl.

In spite of the unfavorable weather, CAMS BeNeLux managed to collect 11986 meteors with 93 operational cameras at 22 participating stations, with 4859 or 41% multistation meteors good for 1878 orbits. These results are not bad, on the contrary, taking into account the extraordinary bad weather it is a surprise that still such good result is obtained. This proves the remarkable efficiency of the CAMS BeNeLux system.

At best 86 of the 93 operational cameras were active during some nights in January 2018. On average 72.1 cameras were capturing per night. Only 6 nights did not yield any orbit, but even during these nights some meteors were registered. Thanks to AutoCAMS the surveillance of the BeNeLux sky was guaranteed with a minimum of 53 active cameras on all nights. On as many as 25 nights orbits have been collected. The long winter nights may often start with an overcast sky looking hopeless to get anything like clear sky, but nights of 13 to 14 hours may surprise with some unexpected clear sky. Casual observers often remain unaware of such clear periods, while the AutoCAMS observers get happily surprised when confirming unexpected meteors. A substantial part of the January 2018 orbits comes from this permanent alertness provided by AutoCAMS. *Figure 1* shows the enormous increase in camera capacity, although that the number of orbits remained well below the number of 2017.

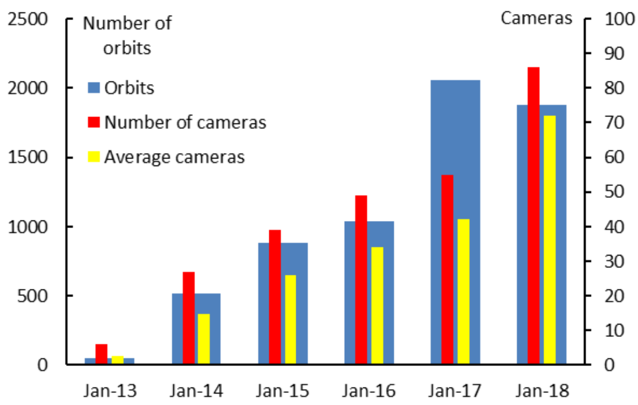

Figure 1 – Comparing January 2018 to previous months of January in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bar the average number of cameras running per night.

Table 1 – January 2018 compared to previous months of January.

Year	Nights	Orbits	Stations	Max. Cams	Min Camas	Mean Cams
2013	7	49	6	6		2.6
2014	21	514	11	27		14.8
2015	22	880	14	39		26.1
2016	25	1037	15	49	10	34.0
2017	23	2058	18	55	18	42.3
2018	25	1878	22	86	53	72.0

Beyond the bad weather, many technical problems encountered by several CAMS participants definitely costed the network a number of orbits. The rapid expansion of the CAMS network, which got 50% more cameras during 2017, suffered some hardware and software issues. The number of camera faillures or CAMS PC drop-outs, failing synchronization of the PC clock, etc., accounts for a loss of at least 10% in number of orbits. The hardware and software challenges definitely require attention in the near future.

3 Conclusion

The team members spent a lot of efforts to get some results out of mostly cloudy nights. In spite of the bad weather still a very nice result has been obtained. Because of the exceptional bad weather the result is not in proportion to the amount of effort and equipment used, any normal weather January month may yield about the double of the 2018 scores. Technical issues with CAMS hardware need attention in the near future.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. Thanks to *Carl Johannink* for providing all the data on which this report is based. The CAMS BeNeLux team is operated by the following volunteers:

Hans Betlem (Leiden, CAMS 371, 372 and 373), *Felix Bettonvil* (Utrecht, CAMS 376 and 377) , *Jean-Marie Biets* (Wilderen, CAMS 380, 381 and 382), *Martin Breukers* (Hengelo, CAMS 320, 321, 322, 323, 324, 325, 326 and 327), *Bart Dessoy* (Zoersel, CAMS 397, 398, 804, 805 and 806), *Franky Dubois* (Langemark, CAMS 386), *Luc Gobin* (Mechelen, CAMS 390, 391, 807 and 808), *Robert Haas* (Alphen aan de Rijn, CAMS 360, 361, 362, 363, 364, 365, 367 and 368), *Robert Haas / Edwin van Dijk* (Burlage, CAMS 801, 802, 821 and 822), *Klaas Jobse* (Oostkapelle, CAMS 330, 331, 332, 333, 334, 337, 338 and 339) , *Carl Johannink* (Gronau, CAMS 311, 312, 313, 314, 315, 316, 317 and 318), *Hervé Lamy* (Dourbes / Ukkel, CAMS 394 and 395/ 393), *Koen Miskotte* (Ermelo, CAMS 351, 352, 353 and 354), *Piet Neels* (Ooltgensplaat, CAMS 340, 341, 342, 343, 344 and 345, 349, 840), *Tim Polfliet* (Gent, CAMS 396), *Steve Rau* (Zillebeke, CAMS 385 and 387), *Paul Roggemans* (Mechelen, CAMS 383, 384, 388, 389, 399 and 809), *Hans Schremmer* (Niederkruechten, CAMS 803) and *Erwin van Ballegoij* (CAMS 347 and 348).

A search for December alpha Bootids (497)

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The registration of a bright multiple station meteor that proved to belong to the December alpha Bootids (DAB – 497) resulted in a search for earlier orbits of this minor shower registered by the CAMS BeNeLux network as well as all major video networks. A cluster with 78 similar orbits was identified, radiating from RA 212.3° and Decl. +22.0° with a geocentric velocity of 59.6 km/s in a time lapse from 257° to 273° in solar longitude with best activity at ~263.9°. The orbital elements match perfectly with previously published results. There is no indication for any periodicity in the shower displays which is remarkably rich in bright meteors and rather deficient in faint meteors. Being detected independently from orbital data collected by different video networks, confirmed by 78 orbits with a medium threshold D criterion $D_D < 0.08$ and 43 orbits with a high threshold of $D_D < 0.04$, this minor shower could be considered to be listed as an established meteor shower.

1 Introduction

A bright meteor captured by CAMS 315 (Johannink, Gronau) was identified as a December alpha Bootids (497), a minor shower detected only few years ago. The reference orbits listed in the IAU Meteor Shower list are based on a very small sample of related orbits that were identified with a very high threshold on the discrimination criteria. Except for its orbital elements, the shower remains poorly documented. The low numbers of orbits listed in the IAU Meteor shower list indicate that these meteors are rather rare and difficult to collect. The occurrence of one of these orbits in the CAMS BeNeLux data for 2017 triggered some curiosity if and how many orbits we had obtained previous years. At the same time this offers a good challenge to experiment with a stream search using the latest available orbit databases.

2 The December alpha Bootids (497) of 2017

In the early morning of December 16, just one minute before the CAMS session for that night closed, camera 312 in Gronau captured a very bright meteor through the clouds (*Figure 1*). Very soon, it became clear that six other stations in the BeNeLux captured this meteor too. Besides Gronau (*Carl Johannink*), Texel (*Robert Haas*; see *Figure 2*), Ooltgensplaat (*Piet Neels*), Wilderen (*Jean-Marie Biets*), Mechelen (*Paul Roggemans*) and Leiden (*Hans Betlem*). The first four stations could be used to calculate an orbit. We found a radiant near RA = 213.7° and Decl. = 21.2° with geocentric velocity v_g = 59.0 km/s, resulting in an orbit with orbital elements listed in *Table 1*. This corresponds very well with the radiant and orbital elements for # 497 DAB in the IAU database. Some all sky stations captured this meteor too (*Figure 3*; photo Ermelo, *Figure 4*; photo Bussloo). A search in all ~2500 orbits obtained by our network in December 2017, revealed no other DAB – meteors.

Figure 1 – December alpha Bootid 2017 December 16, $06^h38^m35.6^s$ UT on CAMS 312 (Gronau, Carl Johannink).

Figure 2 – December alpha Bootid 2017 December 16, $06^h38^m35.6^s$ UT on CAMS 812 (Texel, Robert Haas).

Table 1 – The orbit of the fireball of 2017 December 16, $06^h38^m35.6^s$ UT, with its D_D-criterion (Drummond, 1981) using the final orbit obtained in this study, based on 43 December alpha Bootids with D_D < 0.04 as parent orbit (see in Table 6).

$\lambda_\odot$ (°)	α_g (°)	δ_g (°)	v_g km/s	a AU	q AU	e	ω (°)	Ω (°)	i (°)	D_D	Source
264.3	213.7	+21.2	59.0	17.7 ±3.0	0.6576 ±.0002	0.9629 ±.0004	108.87 ±0.03	264.25	112.72 ±0.01	0.03	2017 Dec. 16, $06^h38^m35.6^s$ UT

Table 2 – The orbits of 5 DAB-candidates found in the CAMS BeNeLux data for 2014–2016, with the D_D-criterion (Drummond, 1981) using the final orbit obtained in this study, based on 43 December alpha Bootids with D_D < 0.04 as parent orbit (see in Table 6).

$\lambda_\odot$ (°)	α_g (°)	δ_g (°)	v_g km/s	a AU	q AU	e	ω (°)	Ω (°)	i (°)	D_D	Source
262.4	211.2	+21.4	60.6	-	0.6757 ±.0002	1.0239 ±0.066	112.35 ±3.06	262.36	115.50 ±1.16	0.03	2016 Dec. 14, $03^h49^m24.5^s$ UT
263.5	212.0	+21.6	60.6	-	0.688 ±0.005	1.0254 ±0.017	113.93 ±0.82	263.49	114.96 ±0.24	0.03	2016 Dec. 15, $06^h38^m31.0^s$ UT
268.5	218.6	+22.7	56.8	8.1 ±0.9	0.6822 ±0.007	0.9156 ±0.020	111.02 ±1.24	268.45	106.87 ±0.58	0.06	2016 Dec. 20, $03^h29^m51.2^s$ UT
268.6	216.0	+21.6	57.9	6.2 ±0.9	0.6910 ±0.003	0.8892 ±0.007	111.58 ±0.51	268.55	111.63 ±0.21	0.05	2016 Dec. 20, $05^h58^m33.2^s$ UT
269.5	212.4	+17.8	61.1	7.5 ±0.9	0.7005 ±0.013	0.9063 ±0.027	113.22 ±2.03	269.52	122.31 ±0.89	0.08	2016 Dec. 21, $04^h50^m00.0^s$ UT

Figure 3 – December alpha Bootid 2017 December 16, $06^h38^m35.6^s$ UT on All-sky (Ermelo, Koen Miskotte).

3 CAMS BeNeLux and DABs before 2017

What do we have from other years? We checked all our December data in the years since the start of our network in March 2012. No DAB-candidates in the years 2012 – 2013, but in the following years we captured several meteors that could belong to this stream, but only 5 orbits from 2016 fit the D criterion (*Table 2*). Another 4 preselected orbits from 2014 and 2015 were omitted as the D-criterion was above the cut-off value.

But how can we be sure whether a meteor really belongs to this stream?

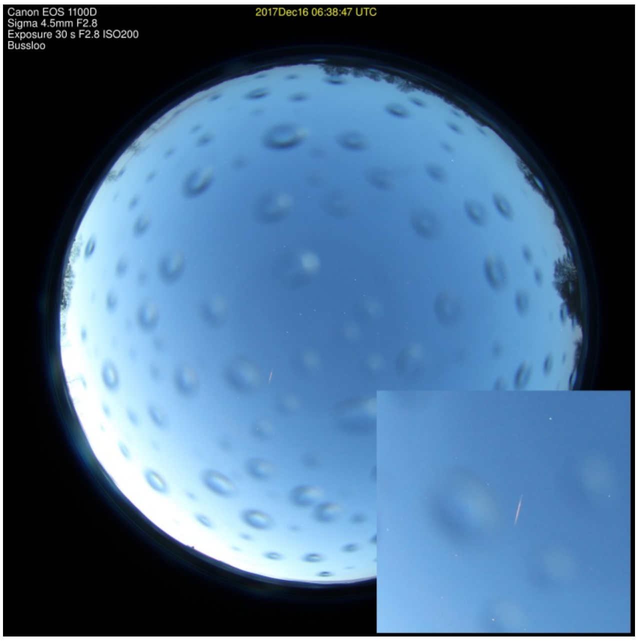

Figure 4 – December alpha Bootid 2017 December 16, $06^h38^m35.6^s$ UT on All-sky (Bussloo, Jaap Van 't Leven).

4 The challenge to identify meteor showers

Since the early start of meteor astronomy, meteor showers were recognized by visual observers whenever a significant number of shooting stars appeared to radiate from a small region at the sky, displaying a typical angular velocity. This simple approach permitted to list the principal major annual showers in a reliable way, but led to highly controversial minor shower identifications. Late 19^{th} and first half of the 20^{th} century dedicated meteor observers had no other techniques available. The believe that a relative small sample of backwards produced single station meteor trails allowed to define minor shower radiants resulted in vast number of minor showers, most of which were spurious.

Indeed any backwards produced meteor trail will intersect with its true radiant, but it is not so that a single station meteor which 'seems' to intersect with a radiant can be associated with any certainty with some shower radiant. In reality most backwards prolonged trails line up with one or more radiants by chance without having any physical relationship with the meteor shower(s) of the radiant(s). The only way to determine the radiant is by use of triangulation which requires multiple stations observing, with at least data from two different stations with a sufficient long baseline.

With our CAMS BeNeLux network we now manage to collect over 30000 multiple station meteors a year for which the radiant position, the atmospheric trajectory, the entrance velocity and the heliocentric orbit are known. Although that this information identifies an unambiguous radiant position as well as the orbit, the possible association with some meteor shower requires a careful analyses of the orbital similarity. The meteoroid distribution in the solar system consists of a large amount of sporadic meteoroids, particles that were released long ago from some parent source, which have been dispersed by perturbations to an extend that it becomes impossible to reconstruct their origin or to find any associations with any other particles. These lonely particles have radiants all over the sky and share radiant areas of real meteor showers as well as the 'empty' regions with no known meteor sources. Known meteor streams represent relative recently produced dust trails, released by parent bodies in the last few 1000^{ds} of years, which is very young in astronomical terms. Only few of these dust trails have favorable intersections with the Earth orbit to produce some major shower event. Some dust trails result from recent perihelion passages of parent comets and didn't yet distribute along the entire orbit of the stream parent, producing periodic events. Others intersect the Earth orbit at the outer edge of the dust trail and therefore display only few of their particles as meteors in our atmosphere. The main goal of most meteor camera networks is to sample orbits to map the distribution of the dust and to identify the dust trails and their parent objects.

5 Methodology

Being aware of the complexity, researchers developed some methods and tools to detect dust concentrations. One method is to compare each single orbit with all other orbits to find similar orbits. A popular tool to find possible associations is a discriminant to measure the degree of similarity between two orbits. There is no straight forward method to determine whether or not two orbits are physically related to some identical parent. Searching for orbit associations to define minor showers remains an approach to the best effort. The similarity criteria consider the distance between some of the orbital elements combined with the angle between the orbital planes. The first numeric discrimination criterion was proposed by Southworth and Hawkins (1963), referred to as D_{SH}. Later Drummond (1981) introduced a slightly different criterion, referred as D_D. Jopek (1993) proposed another version D_H, based on the former criteria. We can apply all three criteria combined:

First we determine Γ

$$\Gamma = \begin{cases} +1, & |\Omega_p - \Omega_m| \leq 180^{\circ} \\ -1, & |\Omega_p - \Omega_m| > 180^{\circ} \end{cases}$$

Then we calculate ψ, the angle between the two orbital planes from

$$\psi = \arccos\left[\cos i_p \cos i_m + \sin i_p \sin i_m \cos(\Omega_p - \Omega_m)\right]$$

Next we calculate Π, the angle between the perihelion points:

$$\Pi = \omega_p - \omega_m + 2\Gamma \arcsin\left(\cos\frac{i_p + i_m}{2} \sin\frac{\Omega_p - \Omega_m}{2} \sec\frac{\psi}{2}\right)$$

λ is the ecliptic longitude of the perihelion, with

$$\lambda = \Omega + \arctan(\cos i \tan \omega),$$

β is the ecliptic latitude of the perihelion, with

$$\beta = \arcsin(\sin i \sin \omega),$$

where λ has 180° added if $\cos \omega < 0$.

The angle θ between the two perihelion points on each orbit is given by the equation:

$$\theta = \arccos[\sin \beta_p \sin \beta_m + \cos \beta_p \cos \beta_m \cos(\lambda_p - \lambda_m)]$$

The three different discriminant criteria can now be calculated from the following equations, with D_{SH} for the Southworth Hawkins criterion, D_D for the Drummond criterion and D_H for the Jopek criterion:

$$D_{SH}^2 = (q_p - q_m)^2 + (e_p - e_m)^2 + \left(2\sin\frac{\psi}{2}\right)^2 + \left(\frac{e_p + e_m}{2} \cdot 2\sin\frac{\Pi}{2}\right)^2,$$

$$D_D^2 = \left(\frac{e_p - e_m}{e_p + e_m}\right)^2 + \left(\frac{q_p - q_m}{q_p + q_m}\right)^2 + \left(\frac{\psi}{180^{\circ}}\right)^2 + \left(\frac{e_p + e_m}{2}\right)^2 \cdot \left(\frac{\theta}{180^{\circ}}\right)^2,$$

$$D_H^2 = (e_p - e_m)^2 + \left(\frac{q_p - q_m}{q_p + q_m}\right)^2 + \left(2\,sin\frac{\psi}{2}\right)^2 + \left(\frac{e_p + e_m}{2}\right)^2 \cdot \left(2\,sin\frac{\Pi}{2}\right)^2.$$

The larger the values of ψ, Π or θ, the bigger the 'distances' between the orbits and the less the probability becomes for an association. Related orbits have values in the order of a few degrees. The final values for these similarity criteria are dimensionless numeric values, where 0 represents identical orbits. The smaller the D-values the higher the degree of similarity and the better the probability becomes for an association. The D criteria cannot be applied without caution as the results depend upon the type of orbit. High inclination orbits and retrograde streams prove rather challenging to determine orbit associations with a high probability for inclusion of sporadic meteors. The effect of the type of orbit on the applicability of the D-criteria has been described by Galligan (2001). This explains why the threshold on the D criteria had been put very high for the initial shower searches for DAB 497. As a result of this high threshold, many real DAB meteors were rejected leaving only some very similar orbits of the core of the shower. This way the actual activity duration of the shower remains underestimated.

6 Our approach

Having a well-known reference orbit for the DAB (497) meteor stream, the more likely method would be to take the known reference orbit as parent orbit and to match this with each individual orbit in our dataset to check if it fits within the D criteria cut-off.

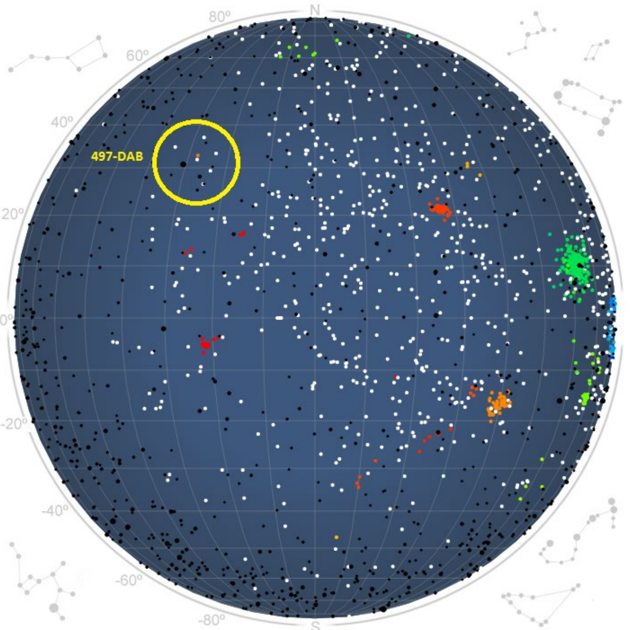

Figure 5 – A radiant map during the December alpha Bootids activity period shows the DAB-radiant location relative to other active shower radiants.

Another approach would be to skip through the dataset of orbits to match each orbit with all other orbits within for instance 15° in solar longitude before and after the instant of the orbit to check whether any clustering of similar orbits occurs. This method would perform an independent new stream search on the currently available datasets. This way would require a considerable amount of computing time and is rather beyond our abilities as amateurs.

Using a known reference orbit as parent orbit to link similar orbits introduces a strong bias to work towards the previously determined orbit. Therefore the authors decided to follow an alternative approach, applying the traditional method that visual observers can use at best to identify probable members of a certain meteor shower, e.g. meteors that appear from a specific area at the sky with comparable velocity within a limited period of time. The result of this preselection is a workable dataset with a limited number of orbits to be compared. If this sample includes a clustering of meteor orbits related to some meteor stream among the purely sporadic population, these orbits should be detected with the D criteria. *Figure 5* shows the location of the DAB radiant at a part of the sky with relative few sporadic radiants and away from any other active meteor shower radiant.

An iterative procedure was used, starting with the initial orbits that fulfilled the conditions used to make a preselection of orbits with similar radiant positions and velocity within a limited period of time. This preselection can be called the *radiant – velocity* method. Starting with a parent orbit based on the median values for the orbital parameters of all preselected orbits, computing the D criteria for each individual orbit relative to this parent orbit, most sporadic orbits in the sample will not fulfil the D criteria. Limiting the preselection to those orbits that fit the D-criteria, re-calculating again the median values for these orbits and substituting the resulting median values as new parent orbit, new D criteria are calculated. Repeating this procedure until all outliers get rejected, a number of very similar orbits will remain that fulfil the D criteria. The challenge is to choose correctly the margins to define the preselection as well as to define realistic cut-off values for the D criteria. Since no standard procedure exists, some try-and-error with common sense, is required to set the appropriate selection criteria.

7 What we already know about DAB - 497

The December alpha Bootids were mentioned a first time among other newly discovered minor showers which resulted from an analyses on the CAMS dataset with 40744 orbits available for the period 2010, October 21 to 2011, December 31 (Rudawska and Jenniskens, 2014). This shower appeared also in a list with detected showers based on the 4th edition of the EDMOND orbit database which included at that time 83369 orbits (Kornos et al., 2014). Finally another stream search with a high threshold of $D_{SH} < 0.05$ detected this shower again from 111233 orbits of the CAMS dataset until 2013, March 31 (Jenniskens and Nénon, 2016). The orbital elements of these references are shown in *Table 6* and compared with the results obtained by the authors.

It is not known if the DAB 497 shower was ever present in older stream searches of orbit catalogues such as radar orbits or photographic data. The photographic meteor orbit catalogue kept by the IAU which contains 4873 orbits does not include any single DAB orbit.

So far, the only information available on DAB has been derived from the CAMS and EDMOND orbit catalogues until 2012. Since then the datasets were tripled in size. We therefore conducted a search in the public available orbit lists, situation as end 2017, to locate more orbits of this shower in order to get a better idea about the activity period as well as the radiant drift. Instead of using a straight forward direct linking between the known DAB orbit and each possible candidate we have chosen to try to detect some clustering of related orbits from a preselected sample with the suspected radiant position and velocity range within a certain time span.

8 The practical work

We have the following data available for our search:

- EDMOND 05v03 with 252425 orbits (until 2015). EDMOND collects data from different European networks (Kornos et al., 2014).
- Sonotaco with 231024 orbits (2007–2016). Sonotaco is an amateur video network with over 100 cameras in Japan (SonotaCo, 2009).
- CMN with 39991 orbits (2007–2013). The Croatian Meteor Network is operated by amateurs with about 20 cameras (Šegon et al., 2012).
- CAMS with 111233 orbits (Oct. 2010 – March 2013), (Jenniskens et al., 2011). For clarity, the CAMS orbits from all CAMS networks between 2013 and 2017 are not included in this dataset.

A first approach

In a first approach we selected orbits within a short time period covering only 7 days with λ_O between 261° and 268°, from a radiant area with α_g between 210° and 216°, δ_g between 20° and 23° and a geocentric velocity v_g between 58 and 62 km/s. 51 orbits from EDMOND were found within this range but it was immediately clear that the period covered by this preselection was too short as more candidate DABs were spotted beyond these limits.

A second approach

In a second attempt the selection margins were set a bit wider, for λ_O between 248° and 279°, from a radiant area with α_g between 207° and 218°, δ_g between 16° and 26° and a geocentric velocity v_g of 59 ± 7 km/s. A total of 108 orbits from Sonotaco, 60 orbits from EDMOND and 18 orbits from CMN fitted the preselection conditions. The median values for this selection compared remarkable well with the earlier found orbit data for shower 497. Using these median values as the parent orbit, the D criteria rejected more than half of the 186 orbits as outliers with mainly higher inclination, lower eccentricity and larger perihelion distance q. The resulting orbit from the three networks separately as well as the combined data was in good agreement with the existing results from literature.

Table 3 – The median values for each sub-set of orbits, CMN, SonotaCo and EDMOND, the resulting orbit for all with D_D < 0.1 and the reference orbit from literature (Jenniskens and Nénon, 2016).

	CMN	SonotaCo	Edmond	All	Reference (2016)
α_g	212.0°	211.8°	212.1°	212.1°	213.0°
δ_g	+21.3°	+21.3°	+21.3°	+21.7°	+21.9°
v_g	60.3	59.7	59.2	59.6	59.8
q	0.704	0.690	0.691	0.693	0.683
e	0.931	0.951	0.898	0.951	0.989
ω	115.79°	113.50°	111.99°	113.11°	113.2°
Ω	267.46°	264.10°	264.21°	264.62°	264.3°
i	114.1°	114.3°	114.5°	114.8°	113.5°
N	18	108	60	186	8

A third approach

In an attempt to determine the activity duration, a third preselection was made covering a longer period of time for λ_O between 245° and 285°, from a radiant area with α_g between 205° and 220°, δ_g between 16° and 27° and a geocentric velocity v_g of 60 ± 5 km/s. A total of 199 orbits from Sonotaco, 95 orbits from EDMOND and 22 orbits from CMN fitted the preselection conditions. Applying the same preselection margins on the CAMS dataset, another 60 CAMS orbits were added to this selection. The resulting orbits from the four datasets as well as the combined 376 orbits resulted in a large spread on the orbital elements. Three quarter of all these orbits failed to fit the D criteria. Especially the first 5 days and the final 10 days of the 40 days selection was dominated by orbits with distinct higher inclination, smaller eccentricity and larger perihelion distance. The time span chosen included too many orbits that contaminated the sample to an extent that any clustering of related orbits became too difficult to detect.

A period of 40 days proved too long to approach the DAB orbits as the preselection sample got contaminated with too many sporadic orbits or perhaps some other dust sources in this region. However this third approach allowed us to detect the outer boundaries of the shower. A first DAB candidate was detected at λ_O = 257.4° and a last one at λ_O = 272.0°. With this information we could chose a realistic time span for another preselection.

At this point we should be aware that all these 376 meteors radiated from the same area at the sky displaying similar angular velocities. Any single station video system would identify all of these meteors as belonging to one and the same meteor shower, based on all observable characteristics. In reality less than 1 on 4 of all these look-alike meteors are real candidate members for the DAB meteor shower, based on accurate orbital data. The low hourly rates of these minor streams make it statistically irrelevant to attempt any single station shower identification. It is the law of (too) small numbers that makes single station observing of this kind of low rate showers of no use. Visual observations will suffer the same contamination in any attempt to derive radiant positions and activity levels from single station statistics. Using single station meteor positions, either by video or visual observing, will always produce some results, but may be spurious. This explains the need for multiple station work in order to obtain unambiguous radiant and orbit identifications.

A fourth and final approach

The previous preselection allowed us to select more appropriate margins for a fourth approach. In this final approach we cover 20 days with λ_O between 255° and 275°, from a radiant area with α_g between 205° and 220°, δ_g between +16° and +26° and a geocentric velocity v_g = 60 ± 4 km/s. This preselection resulted in 13 orbits from CMN, 90 orbits from Sonotaco, 38 orbits from EDMOND and 30 orbits from CAMS.

To check if the preselection is suitable to detect any clustering of orbits, if this would be present at all, the median values were calculated for the 4 different datasets separately. In case these preselected samples were contaminated by too many randomly distributed sporadic orbits, a significant spread should appear on the different median values. However all 4 sub-sets had perfectly comparable median values. The presence of possible DAB candidates was checked by applying the three D criteria starting with a rather low threshold set as D_{SH} < 0.25, D_D < 0.12 and D_H < 0.25. When all three conditions were fulfilled, the orbit was considered to be a candidate orbit. The reason to start with a very low threshold is to eliminate outliers step by step without excluding any relevant candidate DAB's orbits. The type of orbit, high inclination and retrograde, means that the D criteria are not ideal to identify related orbits as explained by Galligan (2001), mentioned in section 5. Common sense and visual evaluation of the numeric data remain essential to obtain a realistic result.

10 out of the 13 CMN orbits, 59 out of the 90 Sonotaco orbits, 28 out of the 38 EDMOND and 19 out of the 30 CAMS orbits survived the first filtering round, altogether 116 orbits of the initial 171 preselected orbits. The average orbits for each sub-set of orbits that fulfil the D-criteria were in perfect agreement with each other as well as with these of the previously published orbits for DABs. A visual check on the parameters used in the D criteria shows that this filtering has removed mainly those orbits with a combination of unfavorable elements such as a too large angle between the orbital planes and a too low eccentricity or a too large angle between the points of perihelion and a deviant inclination.

In order to eliminate the remaining orbits with a significant difference in one of the elements compared to the median value, the cut-off value of the D-criteria was restricted to D_{SH} < 0.2, D_D < 0.1 and D_H < 0.2 for the whole 171 preselected orbits, sorted on solar longitude. 90 orbits fulfil these criteria and most rejected outliers occur in the first 5° and last 5° in solar longitude. Most DAB candidates appear in the λ_O interval 261°– 270°.

Setting the D criteria cut-off to D_{SH} < 0.2, D_D < 0.08 and D_H < 0.2 further reduces the number of remaining DAB candidates to 78 orbits. Then an iterative procedure is applied that recalculates the D-criteria, substituting the averaged values of the previous result as parent orbit. The clustering of similar orbits becomes very well visible in a plot of inclination *i* versus the length of perihelion *Π* (*Figure 6*).

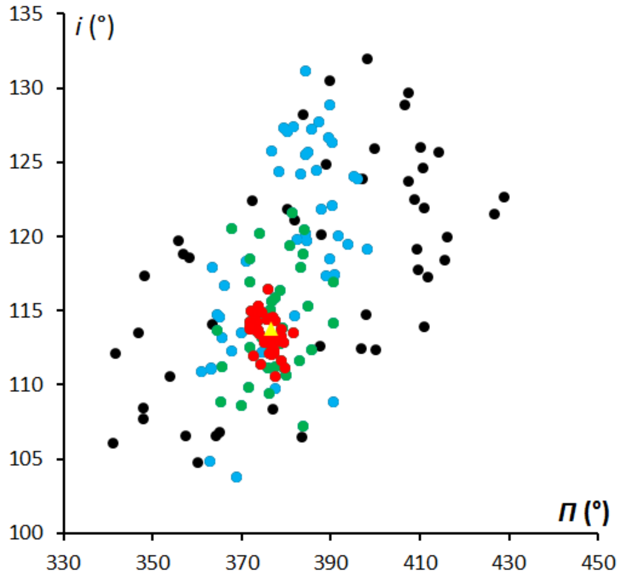

Figure 6 – Plot of inclination *i* versus length of perihelion *Π*. The black dots are all 171 preselected orbits, the blue dots are the orbits which fit D_{SH} < 0.25, D_D < 0.12 and D_H < 0.25. The green dots are orbits that fit D_{SH} < 0.2, D_D < 0.08 and D_H < 0.2 and the red dots orbits that fit D_{SH} < 0.1, D_D < 0.04 and D_H < 0.1. The yellow triangle is the position for the final reference orbit.

9 The results

7 out of the 13 CMN orbits, 41 out of the 90 Sonotaco orbits, 18 out of the 38 EDMOND and 12 out of the 30 CAMS orbits survived the final eliminations, altogether 78 orbits of the initial 171 preselected orbits. Sonotaco and CMN did not list any shower association for any of these meteors. EDMOND listed shower associations and had 41 DAB orbits listed 18 of which fit the criteria set in this analyses which includes 1 sporadic orbit listed in EDMOND. CAMS mentioned 8 DAB orbits of which 7 passed our criteria, one orbit failing mainly due to a deviant eccentricity, but 5 sporadic CAMS orbit survived our elimination routine.

From the distribution of the number of orbits against solar longitude we can define the activity period covering 257° to 273° in solar longitude, which is about 9th until 25th December (see *Table 4*). Maximum activity seems to occur at λ_O ~263.9°, shortly after the Geminid maximum. Jenniskens and Nénon (2016) list a period from 261° to 268° with a maximum at 264°.

There is no indication for any periodic nature in the activity from year to year (*Table 5*). The number of orbits is still too small to conclude anything about an activity profile. The variations in number of orbits per year can be explained as due to the weather circumstances for each of the contributing networks, combined with years covered by each network. Sonotaco contributed for 2007–2016, EDMOND for 2006–2015, CMN for 2007–2013 and CAMS for 2010–2012.

Table 4 – The number of orbits counted for each interval of 1° in solar longitude.

$\lambda_{\odot}$	Orbits	$\lambda_{\odot}$	Orbits
256–257	0	265–266	5
257–258	3	266–267	6
258–259	1	267–268	1
259–260	2	268–269	5
260–261	0	269–270	0
261–262	13	270–271	3
262–263	13	271–272	1
263–264	17	272–273	1
264–265	7	273–274	0

Table 5 – The number of DAB orbits per year.

Year	Orbits	Year	Orbits
2006	1	2012	20
2007	4	2013	10
2008	4	2014	3
2009	7	2015	4
2010	11	2016	5
2011	9	2017	–

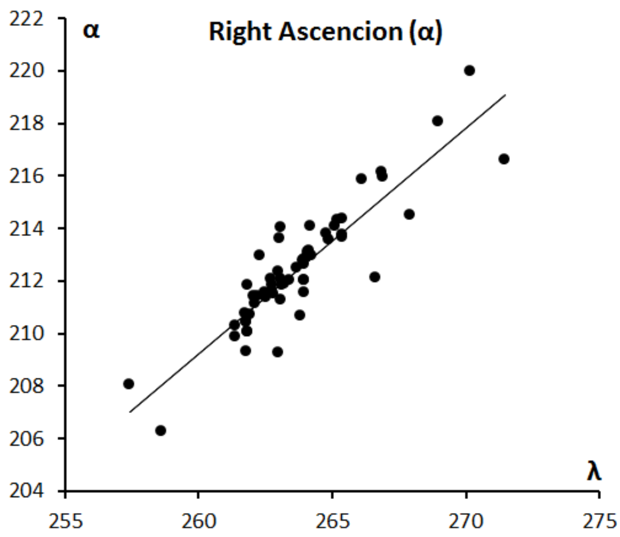

Figure 7 – Linear fit for the right ascention α in function of the solar longitude $\lambda_{\odot}$.

To determine the radiant drift we limit the selection of radiant points to those orbits with a more strict threshold with $D_D < 0.06$, having still 60 data points included. The radiant drift displays a nice trend line with a rather small spread, resulting in a radiant drift of $\Delta\alpha$ = 0.86° and $\Delta\delta$ = –0.21° (*Figures 7 and 8*). The drift corrected radiant shows a relative compact radiant with a size of ~7° in Right Ascension and ~5° in declination (*Figure 9*).

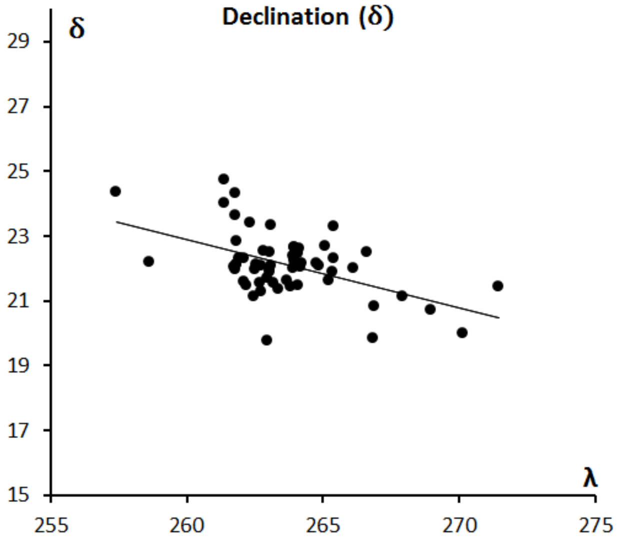

Figure 8 – Linear fit for the declination δ in function of the solar longitude $\lambda_{\odot}$.

With a geocentric velocity v_g of 59.6 km/s the December alpha Bootids (DAB-497) compare very well with the Perseids in August. These meteors start well above the average meteor population in height, with an average beginning height of 109.2±4.7 km and an ending height at 93.8±6.4 km. The Perseids for instance start at 110.9±4.0 km and end at 98.0±4.8 km (Roggemans, 2017).

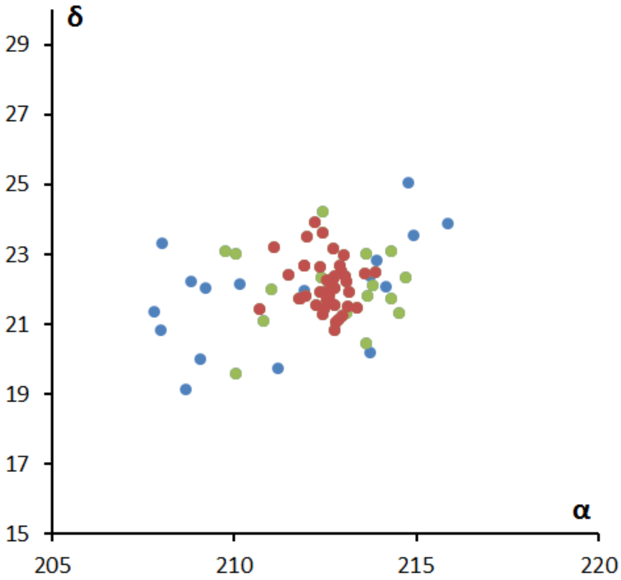

Figure 9 – Radiant drift corrected radiants for 78 orbits that fullfil $D_D < 0.08$ (blue), 60 orbits that fit a higher threshold of $D_D < 0.06$ (green) and 43 orbits with the highest threshold $D_D < 0.04$ (red).

A striking characteristic is that 42 of the 78 identified DAB meteors had negative magnitudes, with a remarkable absence of faint meteors in the selection, the faintest DAB orbit was obtained for a +2.0 magnitude meteor. Without

Table – 6 The orbital data for the December alpha Bootids (DAB-497) all J2000, the standard deviation σ is listed as ± where available. The four orbits published in other papers compare well with the orbits derived from our analyses. For comparison the individual orbit for the 2017 fireball registered by CAMS BeNeLux has been added too.

$\lambda_{\odot}$ (°)	α_g (°)	δ_g (°)	$\Delta\alpha$ (°)	$\Delta\delta$ (°)	v_g km/s	a AU	q AU	e	ω (°)	Ω (°)	i (°)	N	Source
263.9	213.5	+22.3	–	–	59.5	–	0.686	1.002	113.3	263.9	112.3	7	Rudawska, 2014
261.8 ±0.7	210.6 ±1.1	+22.9 ±1.2	–	–	59.5 ±0.3	–	0.690 ±0.025	0.967 ±0.021	113.1 ±3.3	261.8 ±0.7	113.6 ±0.5	5	Kornos et al., 2014
264.0	213.0	+21.9	0.83	-0.33	59.8	62.1	0.683	0.989	113.2	264.3	113.5	8	Jenniskens, 2016
263.0	212.0	+22.1	–	–	60.2	999	0.686	1.017	113.4	263.0	114.0	22	Jenniskens, 2017
263.9 ±3.0	212.3 ±2.8	+22.0 ±1.2	0.86	-0.21	59.6 ±1.0	-	0.687 ±0.023	0.972 ±0.056	112.8 ±3.3	263.9 ±2.8	113.8 ±2.5	78	This analysis (D_D<0.08)
263.5 ±1.3	212.2 ±1.5	+22.2 ±0.7	–	–	59.4 ±0.6		0.685 ±0.014	0.970 ±0.032	112.4 ±1.9	263.5 ±1.3	113.4 ±1.2	43	This analysis (D_D<0.04)
264.3	213.7	+21.2			59.0	17.7 ±3.0	0.6576 ±.0002	0.9629 ±.0004	108.87 ±0.03	264.25	112.72 ±0.01	-	2017 Dec. 16, $06^h38^m35.6^s$ UT

drawing any conclusions, the large portion of bright meteors and this type of orbit may be an indication that this stream is a remnant of some old cometary debris.

10 Conclusion

Rather few orbits have been listed for the December alpha Bootids based on data available until 2012. A search on the orbital data from the major video camera networks worldwide, listing ~635000 orbits available end 2017, resulted in 78 candidate orbits. An analysis of each dataset per network as well as for the combined data reveals the clustering of orbits that are perfectly comparable to the previously published orbits for this shower. Members of this shower have been detected in each year since 2006 in a time span between 257° and 273° in $\lambda_{\odot}$ with a maximum at about $\lambda_{\odot}$ = 263.9°. There is no indication for any periodicity in the stream activity. The DAB meteors ablate at heights comparable to the Perseids (similar velocity) and the shower is rich in bright meteors and deficient in faint meteors.

From this analysis it appears appropriate to consider the December alpha Bootids (DAB-497) as an established meteor stream.

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Their efforts are most important for the achievements of our network.

[1] http://www.daa.fmph.uniba.sk/edmond
[2] http://meteornews.org/edmond/
[3] http://sonotaco.jp/doc/SNM/

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August gamma Cepheids (523-AGC)

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Favorable weather conditions between 19 August and 5 September 2017 enabled the CAMS BeNeLux network to collect 3189 orbits. A radiant concentration was spotted which was identified as the August gamma Cepheids (523-AGC). An independent search on a selection from all available meteor orbit lists coming from the suspect radiant area and velocity range was made. This resulted in 283 similar orbits, radiating from R.A. 358.4° and Decl. +76.2° with a geocentric velocity of 43.7 km/s in a time lapse between 146° and 165° in solar longitude with best activity at ~155.7°. The orbital elements match perfectly with previously published results. There is no indication for any periodicity in the shower displays from year to year. The AGC-meteors are remarkably rich in bright meteors and rather deficient in faint meteors. Being detected independently from orbital data collected by different video networks, confirmed by 283 orbits with a medium threshold D criterion $D_D < 0.08$ and 125 orbits with a high threshold of $D_D < 0.04$, this minor shower could be considered to be listed as an established meteor shower.

1 Introduction

The month of August is one of the richest meteor months of the year, not only due to the annual Perseid display but mainly because of the combined activity of many different meteor showers. All these different sources add activity onto the sporadic background, with different activity profiles and variable maxima. The complex mixture of shower and non-shower origin of the total hourly rates makes it impossible to determine the actual diurnal sporadic background activity. Except for the major contribution from the Perseid, the Aquariid and Capricornid radiants, the many different sources that contribute to this rich but complex activity are poorly known. For most of the minor shower radiants single station meteor observations will fail to identify the shower membership in a statistical relevant way. Triangulation and accurate velocity determination are required to determine the individual meteor orbits. These orbits can help to detect similarity between orbits and resolve the complex mixture of many different sources, their activity period, activity profile and other characteristics.

One of these minor showers, the 'August gamma Cepheids (523 AGC)', caught the attention of the BeNeLux CAMS network operator (Johannink, 2017). This relative recently discovered minor stream is an interesting case study to check what we can find in the datasets of the main video camera networks.

2 CAMS BeNeLux and the AGC-523

The BeNeLux CAMS network collected 3189 orbits between 19 August and 5 September 2017. Only two nights suffered poor weather circumstances and had less orbits. A stream search for the AGC-523 was applied, using the previously determined orbit of CAMS as parent orbit with the D_D criterion of Drummond (1981). This resulted in 66 orbits that fulfilled $D_D < 0.105$. Using a stronger criterion with $D_D < 0.06$ still resulted in 25 candidate orbits for this shower. These orbits are listed in *Table 2*. No sign of any radiant drift could be noticed.

3 AGC (523) history

An effort to locate any earlier records of this meteor shower remained negative. The photographic meteor orbit catalogue with 4873 accurate photographic orbits contains only one possible AGC orbit ($D_D < 0.02$) recorded in 1979. The Harvard radar orbit catalogues 1961–1965 and 1968–1969 contain only two orbits with $D_D < 0.08$, one in 1962 and one in 1963. One photographic and two radar orbits do not make yet a meteor shower; hence we do not have any positive confirmation from past observations.

This minor shower was first noticed in a stream search on CMN (Croatian Meteor Network) and SonotaCo (Japan) orbit data 2007–2012 (Andreić et al., 2013). 44 similar orbits were associated with this stream between 21 August and 4 September with a maximum at 28 August. The radiant appeared to be very diffuse; the data is listed in *Table 2*.

Dr. Peter Jenniskens confirmed the ACG meteor shower with 15 orbits recorded in 2011–2012 (Jenniskens et al., 2016).

4 Available data end 2017

Since the current knowledge of this minor shower is based upon the available orbit data until 2012, 5 years ago, the author decided to run a search on the combined data for the major video camera networks. We have the following data, status as of end 2017, available for our search:

- EDMOND 05v03 with 252425 orbits (until 2015). EDMOND collects data from different European networks (Kornos et al., 2014).
- SonotaCo with 231024 orbits (2007–2016). SonotaCo is an amateur video network with over 100 cameras in Japan (SonotaCo, 2009).
- CMN with 39991 orbits (2007–2013). The Croatian Meteor Network is operated by amateurs with about 20 cameras (Šegon et al., 2012).
- CAMS with 111233 orbits (October 2010 – March 2013), (Jenniskens et al., 2011). For clarity, the CAMS BeNeLux orbits 2013–2017 are not included in this dataset.

5 Preliminary orbit selection

A preselection is made in order to limit the number of orbits to be analyzed. The selection criteria should be chosen carefully to cover the possible activity period as well as the dispersion that characterizes diffuse minor meteor showers. Taking the known parameters from Andreić et al. (2013) and Jenniskens et al. (2016), a dataset is extracted from the available orbit catalogues. If a cluster of similar orbits occurs in the selection, this should be detected by the D-criteria. The approach has been explained in a previous case study (Roggemans and Johannink, 2018). The author uses three slightly different criteria and consider an orbit similar when all three criteria are fulfilled. The three criteria used are D_{SH}, or Southworth and Hawkins (1963), D_D, Drummond (1981) and D_H, Jopek (1993). To avoid any bias the preselection is defined with sufficient margins relative to the known parameters. The existing orbital parameters are currently used to identify shower members for CAMS (see *Figure 1*).

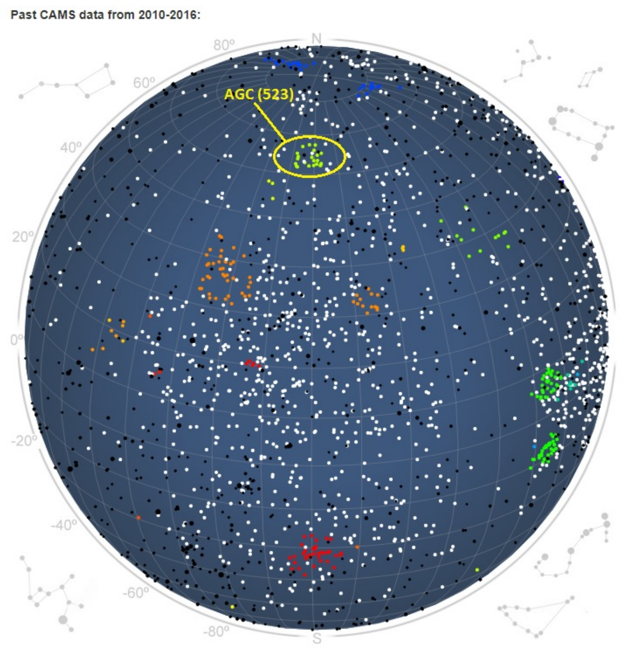

Figure 1 – Radiant map for August 28 based on 2010–2016 data of CAMS. The AGC (523) radiants are the green dots marked on the map.

The activity period was known to start on 21 August ($\lambda_\odot = 148°$) and to end about 4 September ($\lambda_\odot = 161°$). In order to include possible earlier or later orbits, a first selection covered a timespan $140° < \lambda_\odot < 172°$. The radiant was reported to be diffuse without any trace of radiant drift, the high declination results in a large spread in Right Ascension. The radiant area was chosen as $340° < \alpha < 15°$ and $+72° < \delta < +82°$ with a geocentric velocity interval of 41 to 47 km/s. A total of 343 orbits fulfilled these conditions.

A first parent orbit was approached as the median values of the orbital elements of these 343 orbits obtained in this time span from the suspected radiant area and geocentric velocity interval. The resulting parent orbit proved remarkably similar to the known orbit for the August γ Cepheids (AGC-523). Applying the D-criteria with $D_{SH} < 0.2$, $D_D < 0.08$ and $D_H < 0.2$ resulted in 237 orbits, with median values that compare perfectly with the previously published values. 122 orbits fulfilled the D-criteria set with a high threshold $D_{SH} < 0.1$, $D_D < 0.04$ and $D_H < 0.12$. The first 6 and the last 6 days of the selected time span produced not any single possible AGC orbit, while the radiant area seemed to be taken too small.

Based on this first approach, a second selection was made, limiting the time span to $146° < \lambda_\odot < 166°$ in order to reduce the contamination of the sample with sporadic orbits beyond the activity period. On the other hand a larger radiant area was set as $330° < \alpha < 25°$ and $+68° < \delta < +86°$ with 41 km/s $< v_g <$ 47 km/s. A total of 485 orbits matched these conditions as suspect sample.

The median values of these 485 orbits were used as parent orbit for a first test with the D-criteria set as $D_{SH} < 0.2$, $D_D < 0.08$ and $D_H < 0.2$ and resulted in 290 orbits within these similarity limits. 125 orbits fitted within $D_{SH} < 0.1$, $D_D < 0.04$ and $D_H < 0.1$. Taking the median values of the orbits that fit the high threshold condition as new parent orbit, 283 orbits prove to respect the D-criteria with $D_{SH} < 0.2$, $D_D < 0.08$ and $D_H < 0.2$. The presence of a cluster of similar orbits is very obvious in the selected dataset as the median values for the orbital elements at each step differ only by very small amounts in the decimals.

The author reminds that the D-criteria allow finding similarity between different orbits. Similar orbits have a high probability to represent meteoroids of a same meteor stream, but it does not prove a common origin. In theory similar orbits can occur without any physical relationship. On the other hand some orbits that fail to respect the D-criteria may be real shower members. Meteoroids in meteor streams get perturbed during their lifetime, spreading on dispersed orbits until no similarity can be detected. Although triangulation is the most accurate method to determine the actual radiant position, velocity and orbit, measuring errors or unfavorable geometric configurations result in significant error margins on the final results, especially the velocity determination is very sensitive to errors in the registration technique.

6 Case study AGC-523: results

The final sample of 283 probable AGC-523 orbits includes 20 CAMS orbits (from 31), 19 CMN orbits (from 33), 175 EDMOND orbits (from 308) and 69 SonotaCo orbits (from 113).

The 485 preselected orbits fulfill all criteria which a single station visual or video observer has to identify shower membership. Only 58% of these orbits qualified as probable AGC-523 members with semi-strict D-criteria and only 26% fit the high threshold D-criteria. The high contamination of the sample with sporadic meteors raises questions as to which extend single station video work can be used in a statistical reliable way.

Plotting the inclination *i* against the length of perihelion *Π* shows the outliers marked with black dots, these orbits differ too much from the parent orbit to fit any similarity criteria. The orbits that fulfill the D-criteria appear as a nice cluster (green dots) with a core of orbits that fit the high threshold criteria (red dots) (*Figure 2*).

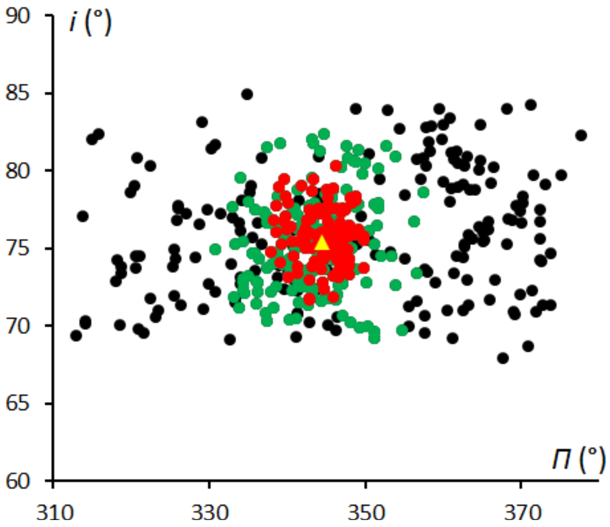

Figure 2 – A plot of the inclination *i* against the length of perihelion *Π* for the 485 preselected orbits which have a radiant position and velocity in the suspected AGC-range. The black dots failed to fit the similarity criteria. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots $D_D < 0.04$. The yellow triangle marks the position of the final reference orbit.

The activity period and profile

The first AGC-523 orbit was registered at $\lambda_\odot = 146.1°$, the last at $\lambda_\odot = 164.4°$. This corresponds to an activity period from roughly 19 August until 8 September. The main activity takes place in the time interval $151° < \lambda_\odot < 160°$, or 24 August until 3 September, with the highest AGC activity on 29 August at $\lambda_\odot = 155.7°$ (*Figure 3*). There is no indication for any annual variation in AGC activity. The variation in number of orbits collected year by year reflects the total amount of orbits contributed by all the camera networks (see *Table 1*). Since no hourly rates can be determined for this kind of minor showers, the number of orbits collected for each degree in solar longitude provides an idea about the activity profile, showing the activity period as well as the solar longitude at which the largest number of orbits has been collected. The activity period to check for AGC-523 orbits can be defined as $\lambda_\odot > 145°$ and $\lambda_\odot < 165°$, with $\lambda_{\odot max} = 155.7°$. This profile is given in *Figure 3*.

Table 1 – The number of AGC-523 orbits per year.

Year	Orbits	Year	Orbits
2006	0	2012	53
2007	5	2013	35
2008	7	2014	46
2009	15	2015	34
2010	32	2016	10
2011	46	2017	–

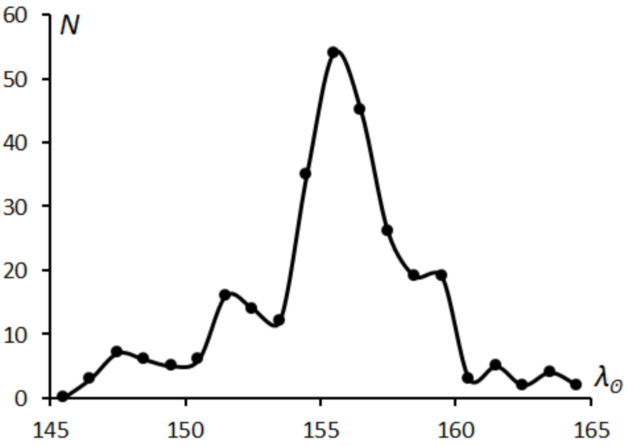

Figure 3 – The number of AGC-523 orbits collected per degree of solar longitude $\lambda_\odot$ during the period 2007–2016.

The radiant position, drift and diameter

The radiant was previously reported to be diffuse without any sign of radiant drift (Andreić et al., 2013). Jenniskens et al. (2016) derived a radiant drift based on 15 AGC-523 orbits. The radiant being at a high declination, the spread is rather large in Right Ascension just because of the coordinate system (*Figure 4*).

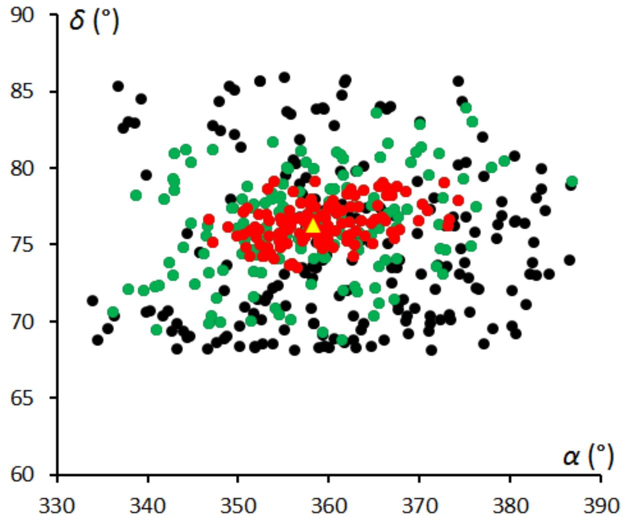

Figure 4 – The radiant positions for all 485 preselected orbits. The black dots failed to fit the similarity criteria. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots $D_D < 0.04$. The yellow triangle marks the position of the radiant position of the final reference orbit.

To check for radiant drift we look at the ecliptic coordinates as the radiant is far enough away from the ecliptic pole (*Figure 5*). Using the ecliptic coordinates for our 283 AGC orbits we find a nice radiant drift of 1.39° in ecliptic longitude λ per degree in solar longitude $\lambda_{\odot}$ and no change in ecliptic latitude β. With other words the radiant moves at ~1.4° per day at $\beta = 63.6°$ parallel to the ecliptic.

The scatter in Right Ascension is indeed important, but in ecliptic coordinates the radiant drift is very obvious. *Figure 6* shows the radiant drift in α (R.A.) against $\lambda_{\odot}$. The green dots are orbits that fulfill the D-criteria with $D_D < 0.08$ and cover the entire activity period in $\lambda_{\odot}$ between 146° and 165°. The red dots fulfill the high threshold criteria with $D_D < 0.04$ and cover only the inner part of the shower between $\lambda_{\odot}$ 150° to 160°. *Figure 7* shows the radiant drift in δ (declination) against $\lambda_{\odot}$. The scatter in declination is less than in Right Ascension. We consider the inner part with the better similarity scores to derive the radiant drift which results in a radiant drift as:

$$\Delta\alpha = 1.23° / \lambda_{\odot} \quad \text{and} \quad \Delta\delta = 0.47° / \lambda_{\odot}.$$

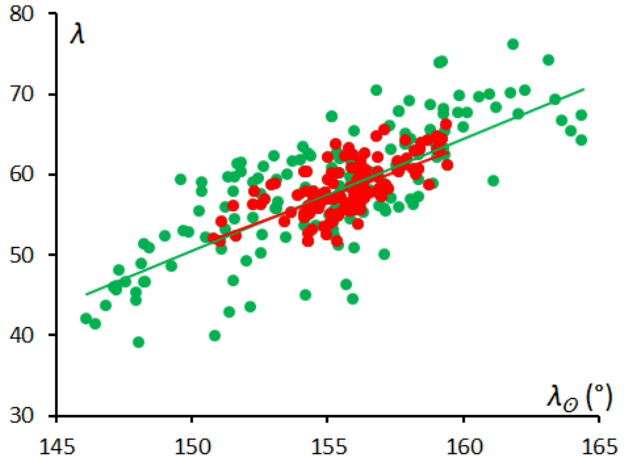

Figure 5 – Radiant drift in ecliptic longitude λ against solar longitude $\lambda_{\odot}$. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots with $D_D < 0.04$.

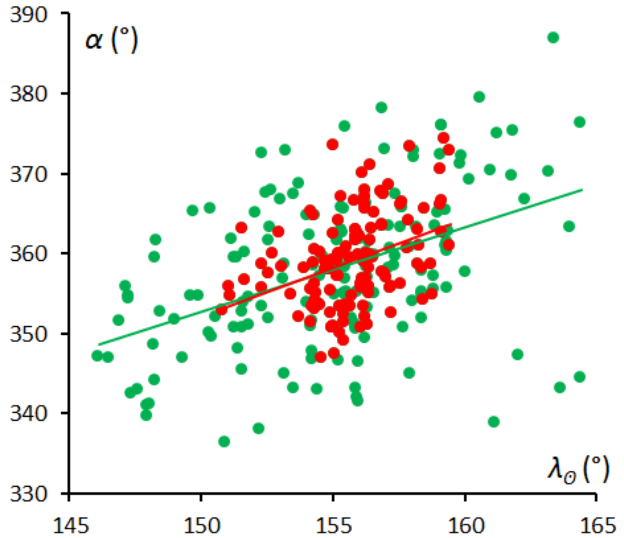

Figure 6 – Radiant drift in Right Ascension α against solar longitude $\lambda_{\odot}$. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots with $D_D < 0.04$.

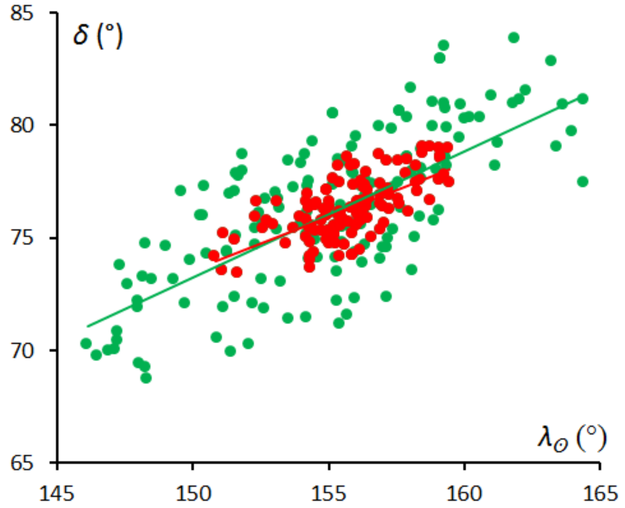

Figure 7 – Radiant drift in declination δ against solar longitude $\lambda_{\odot}$. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots with $D_D < 0.04$.

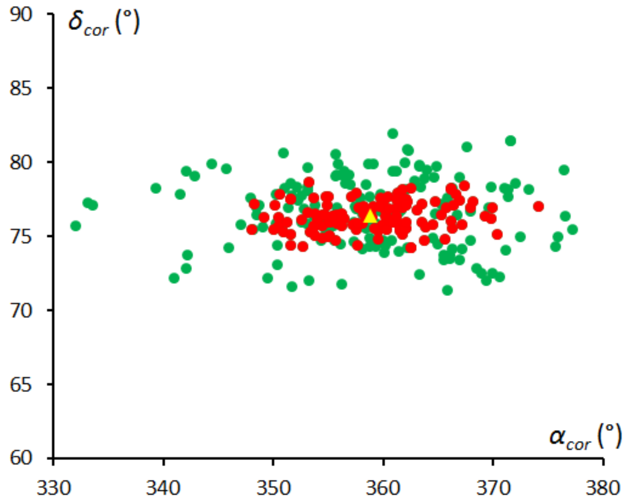

Figure 8 – The radiant drift corrected positions of all 283 radiants in equatorial coordinates. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots with $D_D < 0.04$. The yellow triangle marks the position of the radiant position of the final reference orbit.

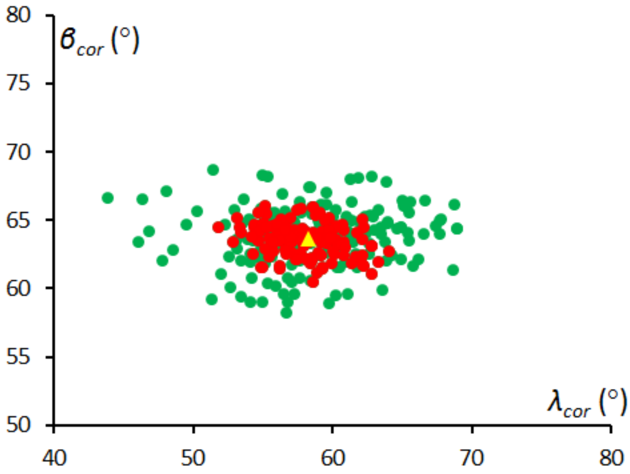

Figure 9 – The radiant drift corrected positions of all 283 radiants in ecliptical coordinates. The green dots are orbits that fit the D-criteria with $D_D < 0.08$ and the red dots with $D_D < 0.04$. The yellow triangle marks the position of the radiant position of the final reference orbit.

To get an idea about the shape and diameter of the radiant we plot the radiants corrected for the daily motion which results in an elongated radiant area with a large spread of over 40° in Right Ascension and about 10° in declination around α = 358.8° and δ = +76.4° (*Figure 8*). The high declination explains to a large extend the spread in Right Ascension. In ecliptic coordinates the drift corrected radiant positions look more compact with the radiant dispersed parallel to the ecliptic over about three times the dispersion in ecliptic latitude (*Figure 9*).

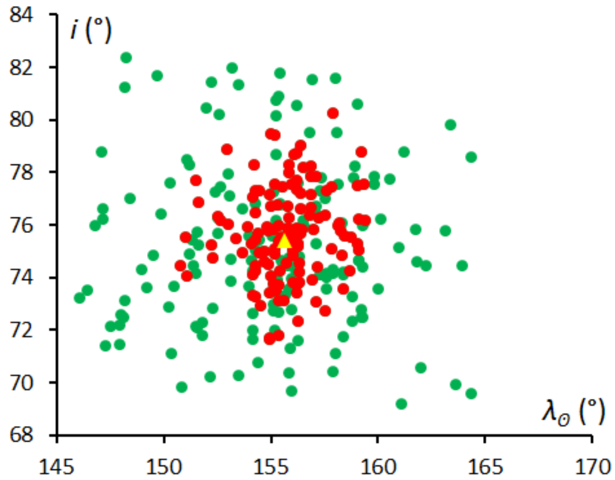

Figure 10 – The distribution of the inclination i in function of the solar longitude. The green dots are orbits that fit the D-criteria with D_D < 0.08 and the red dots with D_D < 0.04. The yellow triangle marks the position of the final reference orbit.

The dispersed nature of this minor meteor shower is also very well illustrated in the plot of the inclination versus solar longitude (*Figure 10*). The particles have been smeared out relative to the parent orbit in all directions. The number of bright August gamma Cepheids and the lack of faint meteors is typical for an old meteor stream where most small particles disappeared during the aging process, leaving the larger particles on dispersed orbits. From the available information we can assume that this minor shower is the remnant of an old prograde Halley-type meteor shower.

Other shower characteristics

With a geocentric velocity v_g of 43.7 km/s, the AGC-523 are slightly faster than the Southern delta Aquariids with 41.3 km/s (SDA-5) and slightly slower than the April Lyrids with 46.7 km/s (LYR-6). The atmospheric trajectories of the AGC-523 meteors start at 103.4 ± 3.9 km and end at 89.6 ± 5.6 km, heights right in between those for the Southern delta Aquariids and Lyrids (Roggemans, 2017).

7 Conclusion

A search on the orbital data from the major video camera networks worldwide, listing ~635000 orbits available end 2017, resulted in 283 candidate AGC-orbits. 125 orbits fulfill the high threshold D-criteria of D_D < 0.04. An analysis of the available orbits proved the presence of a distinct cluster of similar orbits independently from previous stream searches. The resulting reference orbit compares very well with the previously published orbits.

Members of this shower have been detected in each year since 2006 in a time span between 146° and 165° in solar longitude with a maximum at about λ_O = 155.7°. There is no indication for any periodicity in the stream activity. The dispersed nature of this meteor stream together with the abundant proportion of bright meteors and deficiency in faint meteors indicate that this is an old dust stream. Although the radiant is rather diffuse the radiant drift could be calculated.

From this analysis it appears appropriate to consider the August gamma Cepheids (AGC-523) as an established meteor stream.

Table – 2 The orbital data for the August gamma Cepheids (AGC-523) all J2000, the standard deviation σ is listed as ± where available.

λ_O (°)	α_g (°)	δ_g (°)	$\Delta\alpha$ (°)	$\Delta\delta$ (°)	v_g km/s	a AU	q AU	e	ω (°)	Ω (°)	i (°)	N	Source
155.1	358	76.4	–	–	44.0	9	1.005	0.892	188	155	76	44	Andreić et al. (2013)
156.0	354.2	76.6	0.76	0.40	43.9	11.4	1.005	0.913	188.1	156.1	75.6	15	Jenniskens et al. (2016)
154.9	356.4	76.7	–	–	43.6	8.8	1.005	0.885	187.4	154.9	75.0	109	Jenniskens et al. (2017)
							1.002	0.901	187.5	155.4	74.8	66	Johannink (2017) D_D < 0.105
							1.005	0.914	187.1	156.3	76.5	25	Johannink (2017) D_D < 0.06
155.7	358.4 ±8.2	76.2 ±2.7	1.05	0.56	43.7 ±1.3	–	1.004 ±0.005	0.881 ±0.055	188.8 ±4.4	155.7	75.4 ±2.6	283	This analysis D_D < 0.08
155.7	358.7 ±5.8	76.3 ±1.3	1.23	0.47	43.9 ±0.9	8.5 3.0	1.004 ±0.003	0.882 ±0.032	189.1 ±2.5	155.9	75.7 ±1.7	125	This analysis D_D < 0.04

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The author is very grateful to the network coordinators and their camera operators of the following networks: *Croatian Meteor Network* (CMN), *EDMOND*[4][5], *SonotaCo Network Simultaneously Observed Meteor Data Sets SNM2007-SNM2016*[6], and *CAMS*. Thanks to Masahiro Koseki for providing the Harvard radar meteor orbit lists. Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts.

The CAMS BeNeLux team is operated by the following volunteers:

Hans Betlem (Leiden, CAMS 371, 372 and 373), *Felix Bettonvil* (Utrecht, CAMS 376 and 377) , *Jean-Marie Biets* (Wilderen, CAMS 380, 381 and 382), *Martin Breukers* (Hengelo, CAMS 320, 321, 322, 323, 324, 325, 326 and 327), *Bart Dessoy* (Zoersel, CAMS 397, 398, 804, 805 and 806), *Franky Dubois* (Langemark, CAMS 386), *Luc Gobin* (Mechelen, CAMS 390, 391, 807 and 808), *Robert Haas* (Alphen aan de Rijn, CAMS 360, 361, 362, 363, 364, 365, 367 and 368), *Robert Haas / Edwin van Dijk* (Burlage, CAMS 801, 802, 821 and 822), *Klaas Jobse* (Oostkapelle, CAMS 330, 331, 332, 333, 334, 337, 338 and 339) , *Carl Johannink* (Gronau, CAMS 311, 312, 313, 314, 315, 316, 317 and 318), *Hervé Lamy* (Dourbes / Ukkel, CAMS 394 and 395/ 393), *Koen Miskotte* (Ermelo, CAMS 351, 352, 353 and 354), *Piet Neels* (Ooltgensplaat, CAMS 340, 341, 342, 343, 344 and 345, 349, 840), *Tim Polfliet* (Gent, CAMS 396), *Steve Rau* (Zillebeke, CAMS 385 and 387), *Paul Roggemans* (Mechelen, CAMS 383, 384, 388, 389, 399 and 809), *Hans Schremmer* (Niederkruechten, CAMS 803) and *Erwin van Ballegoij* (CAMS 347 and 348).

Their efforts are most important for the achievements of our network.

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[4] http://meteornews.org/edmond/
[5] http://www.daa.fmph.uniba.sk/edmond
[6] http://sonotaco.jp/doc/SNM/

Fireball events

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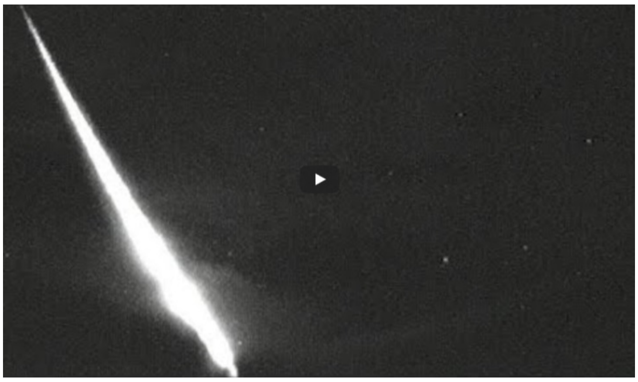
An overview is presented of exceptional fireball events by the meteor observing stations operated by the SMART Project (University of Huelva) from Sevilla and Huelva during the period January – February 2018.

1 Summary of the 2018 Quadrantids from Sierra Nevada

This video shows an accelerated view of the meteor activity recorded during the peak of the Quadrantids. The "meteorlapse" was prepared from the images obtained by one of the cameras operating in the framework of the SMART Project (University of Huelva) from the astronomical observatory of Sierra Nevada (Granada, Spain).

2 Fireball on 29 January 2018 over Spain

This amazing fireball[7], brighter than the Moon, was recorded over the South of Spain on 29 Jan. 2018, at 6:47 local time (5:47 UT). The event began at an altitude of 101 km over the province of Jaen, and ended at a height of about 41 km over the province of Albacete. According to the preliminary analysis performed by Prof. Jose M. Madiedo, the event was produced by a rock from an asteroid.



3 Bright meteor 17 February 2018

This bright meteor[8] was spotted over Spain on Feb. 17, at 2:10 local time (1:10 universal time). It was produced by a fragment from an asteroid that hit the atmosphere at about 100000 km/h. The meteor overflew the south of Spain. It began over the province of Murcia at a height of around 90 km, and ended at an altitude of about 35 km. It was recorded in the framework of the SMART Project (University of Huelva) from the astronomical observatories of Calar Alto (Almería), Sierra Nevada (Granada), Sevilla and Huelva.

4 Fireball on 18 February 2018

This stunning meteor[9] was spotted over Spain on Feb. 18, at 5:42 local time (4:42 universal time). It was produced by a fragment from an asteroid that hit the atmosphere at about 100000 km/h. The meteor overflew the provinces of Albacete, Murcia and Alicante. It began over the province of Albacete at a height of around 101 km, and ended over Alicante at an altitude of about 32 km. The event was recorded in the framework of the SMART Project (University of Huelva) from the astronomical observatories of Calar Alto (Almería), La Sagra (Granada), La Hita (Toledo) and Sevilla.

[7] https://www.youtube.com/watch?v=jU9o17CuFMc&t=347s

[8] https://www.youtube.com/watch?v=524hnIVFi2I&t=130s

[9] https://www.youtube.com/watch?v=F1picpmu5uE&t=342s

Fireball February 21, 20h09m UT over North Eastern France

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On 2018 February 21 at 20h09m05s UT a brilliant fireball appeared over the North Eastern part of France. Casual witnesses described the event as colorful, showing a green to yellow flash, ending into a lot of fragmentation with orange colors.

1 Introduction

The event appeared right into the camera operated by Tioga Gulon at Fléville (France) and is shown in *Figure 1*. An animated gif from the BOAM Twitter page is included too[10]. Another station from the French camera network BOAM captured this fireball also (*Figure 2*, the image by Marc Herrault at Chaligny, France). The FRIPON network got the fireball at 9 of its stations, in this post only the image from Chatillon (France) is included (*Figure 3*).

Figure 1 – Fireball 2018 February 21, 20h09m38s UT by Tioga Gulon.

Figure 2 – Fireball 2018 February 21, 20h09m38s UT by Marc Herrault at Chaligny (France, Latitude: 48.6239°, Longitude: 6.0852°), FOV: 170 °, Camera: KPC350BH and Objectif: 1.6 mm.

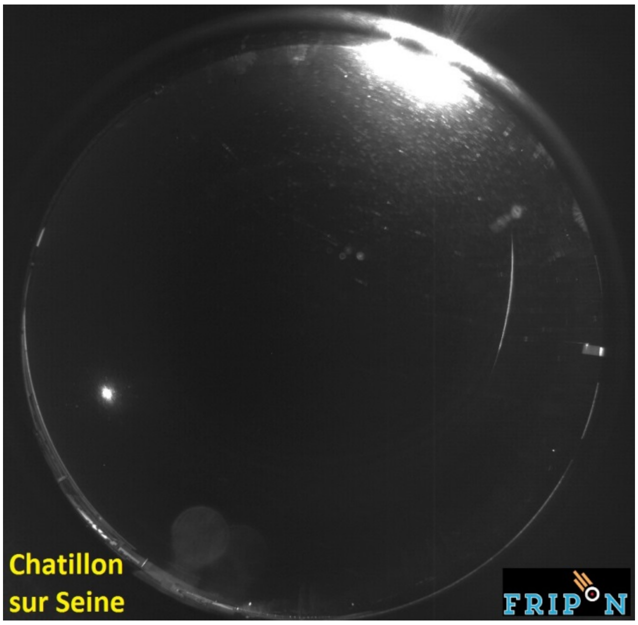

Figure 3 – Fireball 2018 February 21, 20h09m38s UT by FRIPON at Chatillon.

[10] https://twitter.com/BOAM_meteore/status/966447506866540545

Fireball over Belgium 2018 February 24, 0h11m UT

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A -10 magnitude fireball was recorded by several all-sky stations and CAMS stations in the BeNeLux. The fireball started at an elevation of 105 km and ended at 33.5 ± 0.7 km. The radiant position at R.A. 133° and Decl. -17° with a geocentric velocity of 17.6 km/s indicates a sporadic event.

1 Introduction

About an hour and half after its appearance the French astronomer *François Collas* announced that a very bright fireball had been registered at $0^h11^m33^s$ UT by 10 FRIPON cameras most of them in France: Arras, Wimereux, Lille, Noordwijk (Netherlands), Bruxelles (Belgium), Charleville, Cappellelagrande, Hochfelden, Maubeuge and Oostkapelle (Netherlands).

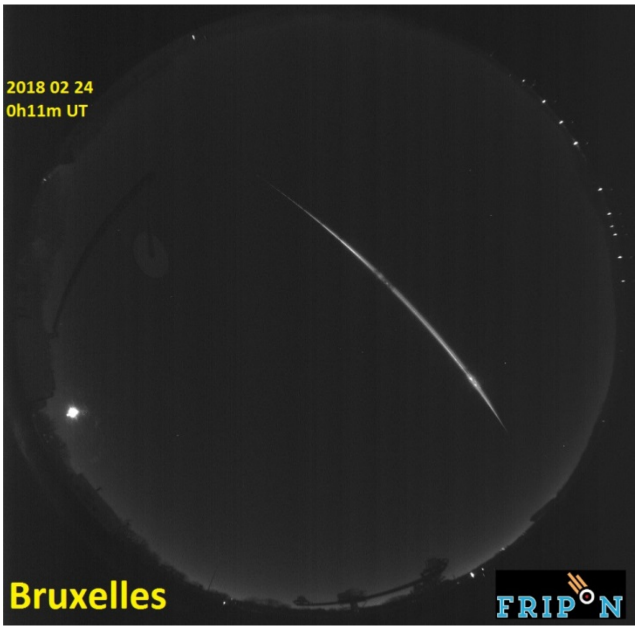

Figure 1 – Fireball recorded by the FRIPON camera at Brussels, Belgium.

2 Image gallery

Soon next morning the first CAMS BeNeLux stations started to confirm the detections of past night. Several stations had this fireball in their data. CAMS 815 (operated by *Jean-Paul Dumoulin* and *Christian Wanlin*) had the start of the fireball (*Figure 2*) on two successive frames. *Paul Roggemans* found the end of the fireball on his CAMS 384, while it passed the edge of CAMS 383 which was totally overexposed. All 6 cameras turned white overexposed at the moment of the brightest flare (*Figure 3*). *Bart Dessoy* had the fireball on CAMS 804 (*Figure 4*), and for once the otherwise annoying reflection on the window of the camera housing offers a nice thumbnail image of the fireball. The video version of CAMS 804 may confuse many readers. Whenever an overexposed detection happens, CAMS reduces the brightness which results in a weird cloud of snow running though the picture. At some instant you see the black silhouette of the fireball as negative image[11]. *Luc Gobin* got the fireball on CAMS 807 and 808 at Mechelen (*Figure 5*). *Jean-Marie Biets* at Wilderen had the event on CAMS 380 (*Figure 6*) and on his all-sky camera.

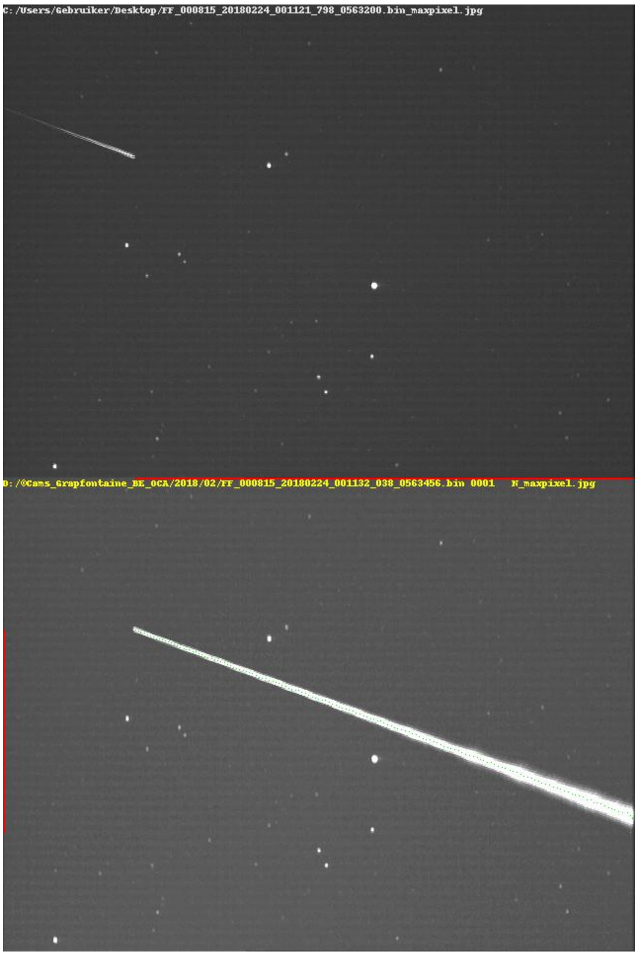

Figure 2 – The two frames with the begin of the fireball in the constellation Auriga, from CAMS 815 at Grapfontaine (OCA, Observatoire Centre des Ardennes) confirmed by Jean-Paul Dumoulin.

[11] https://www.facebook.com/Bartje2428/videos/10216304370748504/

Figure 3 – On top the end of the fireball on CAMS 384 in Mechelen.

Figure 4 – At top the flare of the fireball on CAMS in Zoersel, at bottom the image of the end of the fireball on CAMS 804 in Zoersel (Bart Dessoy). Due to the overexposure, the reflection of the fireball on the glass of the camera housing produces a nice thumbnail image of the fireball.

The messages started to appear in the meteor news groups as well as on Facebook. We give an overview of the first images we collected for this fireball from CAMS and from the EN All-sky cameras. Koen Miskotte at Ermelo (Figure 7), Klaas Jobse at Oostkapelle (Figure 9) and Jos Nijland at Benningbroek (Figure 10) registered this fireball with their all-sky cameras.

Figure 5 – The start of the fireball on CAMS 807 registered by Luc Gobin in Mechelen.

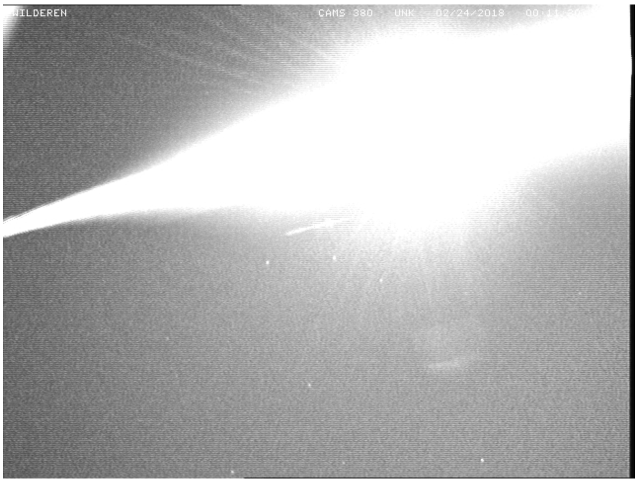

Figure 6 – Fireball on CAMS 380 registered by Jean-Marie Biets in Wilderen.

Figure 7 – The 2018 Feb. 24, 00^h11^m UT fireball from the All-sky camera of Koen Miskotte at Ermelo (Netherlands).

Figure 9 – The fireball of 2018 Feb. 24 00^h11^m UT by the All Sky camera of Astronomy projects at Oostkapelle, by Klaas Jobse.

Figure 10 – The fireball of 2018 Feb. 24 00^h11^m UT by the All Sky camera at Wilderen, by Jean-Marie Biets.

Washington coast meteorite

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Public reports about a bright flash of light, sonic booms and some shaking of the ground could be associated with a giant dust cloud registered on a Doppler radar image, indicating an explosion of a bolide about 20 miles off the coast followed by an impact in the ocean.

1 Introduction

On Wednesday 7 March 2018 at around 7:10 PM a large number of witnesses along the Washington coast (USA) reported flashes of light, loud boom and some even shaking of the ground. Grays Harbor Emergency Management received public phone calls and "tons of reports" according to the agency manager Charles Wallace.

2 Meteorite impact?

While we can speculate what caused these events, it is believed that a large meteor caused the flash with subsequent impact into the ocean is the most likely scenario. A Doppler radar image from Marc Fries with NASA and NOAA, shows the giant dust cloud as the bolide meteor exploded 20 miles off the coast.

National Weather Service meteorologist Johnny Burg said. "There was no thunderstorm or lightning detected in that area."

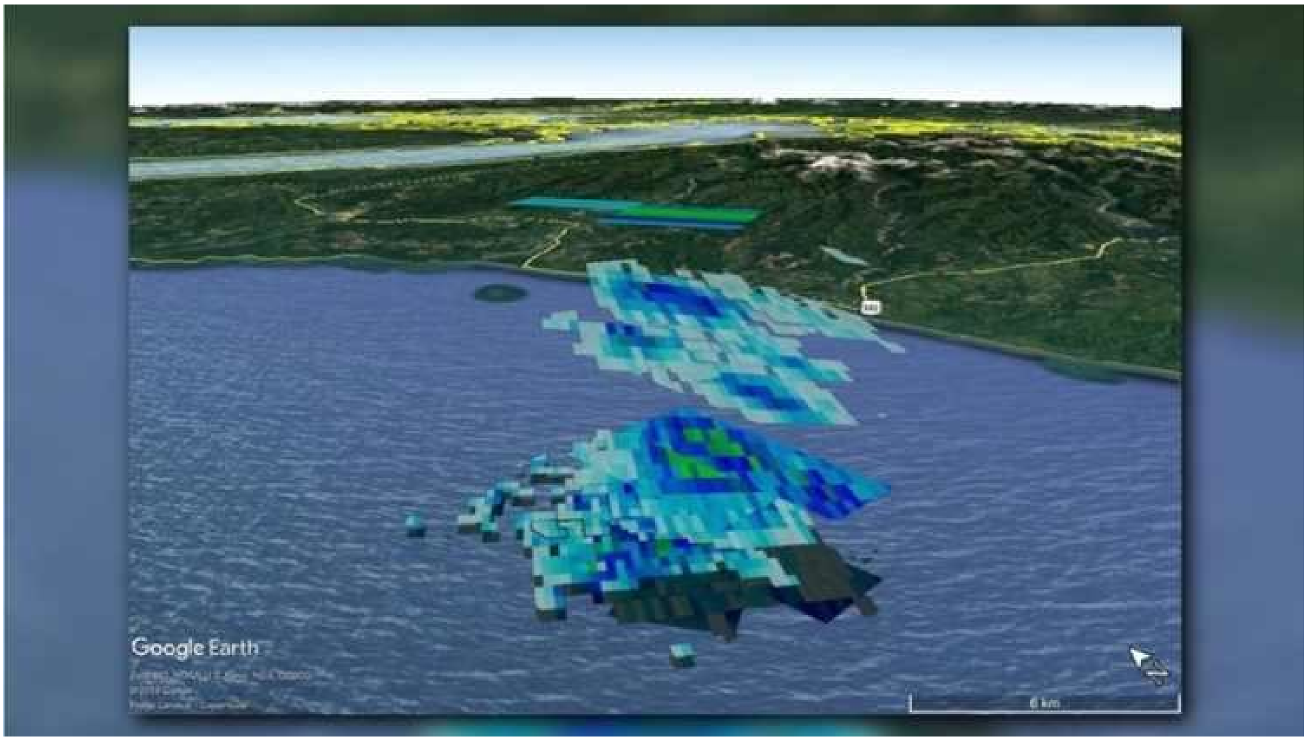

Figure 1 – Doppler radar image (NASA and NOAA) showing the giant dust cloud as the bolide meteor exploded 20 miles off the coast.

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