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Sporadic fireball recorded from Sevilla (Spain) on 16th January 2021, at 04h20m52.3s UT (Credit J.M. Madiedo)

Contents

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Bright fireballs recorded during January 2021 in the framework of the Southwestern Europe Meteor Network

J.M. Madiedo[1], J.L. Ortiz[1], P. Santos-Sanz[1], J. Aceituno[2] and E. de Guindos[2]

[1] **Solar System Department, Institute of Astrophysics of Andalusia (IAA-CSIC), 18080 Granada, Spain**
madiedo@cica.es, ortiz@iaa.es, psantos@iaa.es

[2] **Observatorio Astronómico de Calar Alto (CAHA), E-04004, Almería, Spain**
aceitun@caha.es, guindos@caha.es

In this work we analyze some of the most relevant bright fireballs recorded in the framework of the Southwestern Europe Meteor Network (SWEMN) along January 2021. The absolute magnitude of these bolides, which were observed over the Iberian Peninsula and neighboring areas, ranged between –9 and –13. The emission spectra produced by some of these events are also presented and discussed.

1 Introduction

The Southwestern Europe Meteor Network (SWEMN) is a project conducted from Spain by the Institute of Astrophysics of Andalusia (IAA-CSIC). Its aim is to analyze the behavior and properties of meteoroids entering the Earth's atmosphere by means of photo, video and forward-scatter radio techniques. For this purpose, SWEMN develops the Spectroscopy of Meteoroids by means of Robotic Technologies (SMART) survey. SMART, which started operation in 2006, is currently being carried out at 10 meteor-observing stations in Spain (Madiedo, 2014; Madiedo, 2017). It employs an array of automated cameras and spectrographs to determine the atmospheric trajectory of meteors and the orbit of their parent meteoroids, but also to analyze the composition of these particles from the emission spectrum produced by these meteors (see, for instance, Madiedo et al., 2013; Madiedo et al., 2014). In addition, SMART also provides very valuable information for the Moon Impacts Detection and Analysis System (MIDAS) (Ortiz et al., 2015; Madiedo and Ortiz, 2018). This is because of the synergy that there exists between systems that analyze the behavior of meteoroids in the atmosphere and those that analyze their collisions on the Moon (Madiedo et al., 2019). Thus, to derive the velocity of meteoroids colliding with the lunar surface it is necessary to monitor by means of meteor-observing stations the value of the hourly rate (HR) and the zenithal hourly rate (ZHR) corresponding to the sporadic background and active meteor showers on Earth, respectively (Madiedo et al., 2015a; 2015b).

In this work we present a preliminary analysis of several bright fireballs spotted over Spain along January 2021. Their absolute magnitude ranged from –9 to –13. These meteor events were simultaneously recorded from several SWEMN stations, so that their atmospheric path and radiant could be obtained, and the orbit of the progenitor meteoroid before its encounter with our planet was calculated. The emission spectrum produced by some of these bolides is also discussed.

Figure 1 – Stacked image of the SWEMN20210102_040833 "Jerez de la Frontera" fireball as recorded from El Arenosillo.

2 Instrumentation and methods

To record the fireballs presented in this work and their emission spectra we have employed an array of low-lux analog CCD video cameras manufactured by Watec Co. (models 902H and 902H2 Ultimate). Some of these devices are configured as spectrographs by attaching holographic 1000 lines/mm diffraction gratings to their objective lens. These Watec cameras have a resolution of 720 × 576 pixels, and their field of view ranges, approximately, from 62 × 50 degrees to 14 × 11 degrees in order to get a good accuracy in the calculation of meteor positions and velocities. In addition to these black and white cameras, digital CMOS color cameras (models Sony A7S and A7SII) were also employed. They work in HD video mode (1920 × 1080 pixels), and their field of view is around 90 × 40 degrees. A detailed description of our hardware was given elsewhere (Madiedo, 2017).

At each meteor-observing station the cameras monitor the night sky and operate in a fully autonomous way by means of the MetControl software, developed by J.M. Madiedo

Figure 2 – Atmospheric path (left) and projection on the ground (right) of the trajectory of the SWEMN20210102_040833 "Jerez de la Frontera" fireball.

(Madiedo, 2014; Madiedo, 2017). The atmospheric trajectory and radiant of meteors, and also the orbit of their parent meteoroids, were obtained with the Amalthea software (Madiedo, 2014). This program employs the planes-intersection method to obtain the path of meteors in the atmosphere (Ceplecha, 1987). However, for Earth-grazing events atmospheric trajectories are obtained by Amalthea by means of a modification of this classical method (Madiedo et al., 2016). Emission spectra were analyzed with the CHIMET software (Madiedo, 2015a).

3 The 2021 January 2 fireball

On 2021 January 2 at $4^h08^m33.3 \pm 0.1^s$ UTC a mag. –12 ± 1 fireball (*Figure 1*) was spotted from the SWEMN meteor-observing stations at the astronomical observatories of La Sagra, La Hita, El Arenosillo, Sierra Nevada and Sevilla. According to its appearance date and time, this bolide was labeled in our meteor database with the code SWEMN20210102_040833. The emission spectrum of this event was also recorded by four spectrographs located at La Hita, El Arenosillo, Sierra Nevada, and La Sagra. A video showing some images of the fireball can be viewed on the YouTube channel of the SMART project[1].

Atmospheric path, radiant and orbit

The fireball was also recorded by our HD CMOS video cameras at Sevilla, which gave the opportunity to obtain results with a higher accuracy and reliability. The calculation of the atmospheric trajectory reveals that this fireball overflew the province of Cádiz (south of Spain). The meteoroid hit the atmosphere with an initial velocity $v_\infty = 65.7 \pm 0.5$ km/s and the bolide began at an altitude $H_b = 113.6 \pm 0.5$ km. The apparent radiant was located at the equatorial coordinates $\alpha = 205.4°$, $\delta = +22.4°$. The geocentric velocity yields $v_g = 64.5 \pm 0.5$ km/s. The bolide penetrated till a final height $H_e = 58.5 \pm 0.3$ km. At this final stage it was almost over the vertical of the city of Jerez de la Frontera. For this reason, the bolide was named after this city. The atmospheric path of this fireball and its projection on the ground are shown in *Figure 2*. The bolide exhibited a flare at a height of 68.7 ± 0.3 km, when the fireball had a velocity $v_g = 59.1 \pm 0.5$ km/s. This increase in luminosity took place due to the sudden disruption of the meteoroid, when the aerodynamic pressure S exceeded the tensile strength of the particle. This allows us to estimate the toughness of the meteoroid, as has been made in previous works (Madiedo et al., 2015b). Thus, at that height the value of the air density yields $\rho_{atm} = 9.73 \times 10^{-8}$ g/cm^3, according to the U.S. Standard Atmosphere Model. And so, the tensile strength of the meteoroid yields $S = \rho_{atm} \times v^2 = 31.2 \pm 0.1$ kPa. This relatively high strength explains why the meteoroid fragmented at a height significantly below (of the order of 10 km below) the typical break-up heights for cometary materials. And it would also explain why it reached a terminal height of around 58 km.

The orbital parameters of the parent meteoroid before its encounter with our planet are listed in *Table 1*. This heliocentric orbit is shown in *Figure 3*. According to the calculated value of the Tisserand parameter with respect to Jupiter ($T_J = -0.18$), the meteoroid followed a cometary orbit before entering our atmosphere. Radiant and orbital data reveal that the meteoroid belonged to the 40-Comae Berenicid stream (FOB#0576). This recently discovered annual shower peaks on January 2 (Gural et al., 2014), and

[1] https://youtu.be/nRdD_jEnRLQ

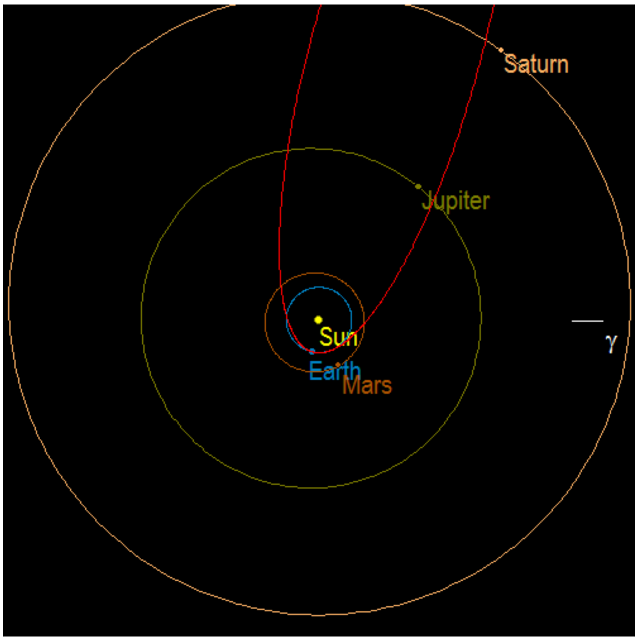

Figure 3 – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20210102_040833 fireball.

so, the Jerez de la Frontera fireball was recorded when the shower reached its maximum activity. Calculated values in *Table 1* are in very good agreement with orbital parameters listed in the IAU meteor database[2].

Table 1 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210102_040833 "Jerez de la Frontera" fireball.

a (AU)	9.5 ± 4.0	*ω* (°)	173.6 ± 0.3
e	0.897 ± 0.040	Ω (°)	281.69155 ± 10^{-5}
q (AU)	0.980 ± 0.004	*i* (°)	127.8 ± 0.3

It is worth mentioning that the large error bar in the calculated value of the semi major axis '*a*' is typical for orbits with high eccentricity. Thus, it is well-known that errors propagate in such a way that even small error bars in measured pre-atmospheric velocity result in large errors in parameter '*a*'. For this reason, the value of the semi major axis is usually omitted in these cases. And, in fact, it is omitted in the IAU meteor database for this shower.

Emission spectrum

The emission spectrum of the fireball was recorded by means of four video spectrographs. It was analyzed by following the same procedure employed in previous works (Madiedo, 2015b). Thus, the signal was calibrated in wavelength and corrected by taking into account the spectral sensitivity of the device. The calibrated spectrum is shown in *Figure 4*, where the most important contributions have been highlighted. As usual in meteor spectra, most lines identified in this signal correspond to neutral Fe (Borovička, 1993; Madiedo, 2014). Thus, as *Figure 4* shows, several multiplets of this element have been identified. The most important contribution comes from the emission from Fe I-4 at 393.3 nm, which appears blended

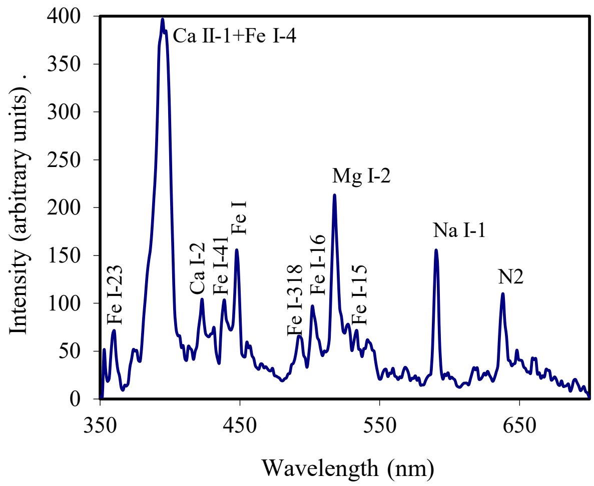

Figure 4 – Calibrated emission spectrum of the SWEMN20210102_040833 "Jerez de la Frontera" fireball.

with the H and K lines of Ca II-1. The emission lines of the Na I-1 doublet (588.9 nm) and the Mg I-2 triplet (516.7 nm) are also very prominent. The contributions from Ni I-18 at 352.4 nm and Ca I-2 at 422.6 nm were also observed. In addition, atmospheric N2 bands were identified in the red region of the spectrum.

Further analysis of this spectrum is currently being performed in order to obtain additional information about the chemical nature of the meteoroid from the relative intensity of most relevant emission lines.

4 The 2021 January 13 fireball

Several casual eyewitnesses, most of them located in the south of Spain, reported a bright and slow fireball on 2021 January 13. The event was recorded by SWEMN systems at $21^h10^m01.1 \pm 0.1^s$ UTC, and it reached a peak absolute magnitude of -9 ± 1 (*Figure 5*). The bolide was spotted from the meteor-observing stations at the astronomical observatories of La Sagra, Sierra Nevada, El Arenosillo, Calar Alto, and Sevilla. The fireball, which can be viewed on YouTube [3], was included in our meteor database with the code SWEMN20210113_211001.

Atmospheric path, radiant and orbit

According to our calculations, this fireball overflew the Mediterranean Sea and the north of Morocco. The meteoroid entered the atmosphere with an initial velocity $v_\infty = 18.5 \pm 0.2$ km/s. The bolide began at an altitude $H_b = 105.9 \pm 0.5$ km over the north of Morocco, over a point next to the vertical of the city of Alhucemas. For this reason, we named this event after this city. The terminal point of the fireball was reached at a height $H_e = 63.5 \pm 0.5$ km over the Mediterranean Sea. The apparent radiant was located at the equatorial coordinates $\alpha = 83.01°$, $\delta = -2.20°$. The atmospheric trajectory of this bolide and its projection on the ground are shown in *Figure 6*.

[2] http://www.astro.amu.edu.pl/~jopek/MDC2007/

[3] https://youtu.be/yGfCRR1n7Gk

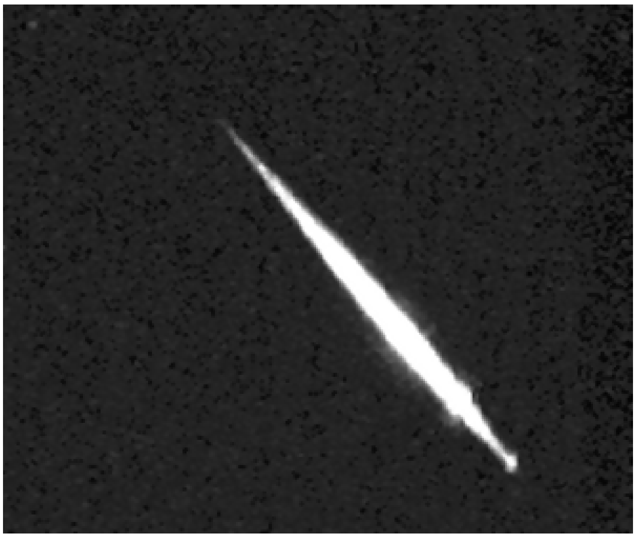

Figure 5 – Stacked image of the SWEMN20210113_211001 “Alhucemas” fireball as recorded from Sierra Nevada.

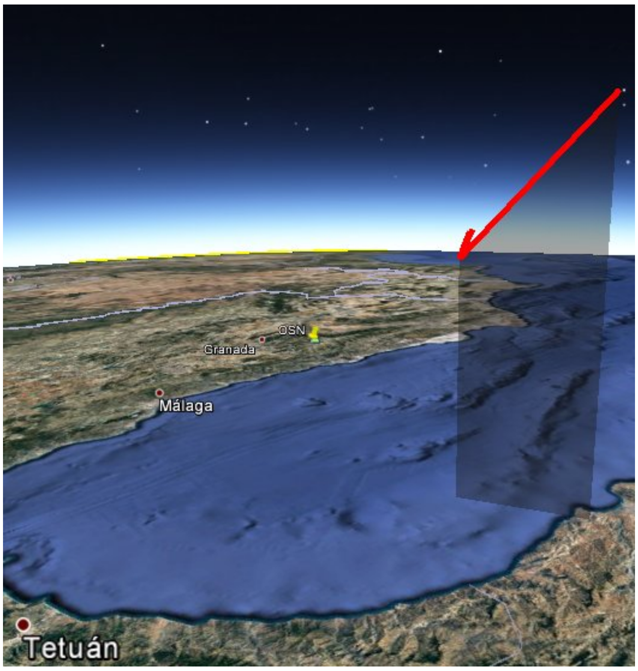

Figure 6 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210113_311001 “Alhucemas” fireball.

Table 2 shows the orbital parameters of the parent meteoroid. This orbit has been drawn in *Figure 7*. The calculated value of the Tisserand parameter with respect to Jupiter ($T_J = 2.56$) shows that the meteoroid followed a Jupiter family comet (JFC) orbit before its encounter with Earth. The geocentric velocity yields $v_g = 14.7 \pm 0.2$ km/s. Radiant and orbital data indicate that the meteoroid belonged to the sporadic background.

Table 2 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210113_211001 “Alhucemas” fireball.

a (AU)	3.5 ± 0.2	ω (°)	37.1 ± 0.1
e	0.74 ± 0.01	Ω (°)	113.61335 ± 10^{-5}
q (AU)	0.898 ± 0.001	i (°)	11.1 ± 0.1

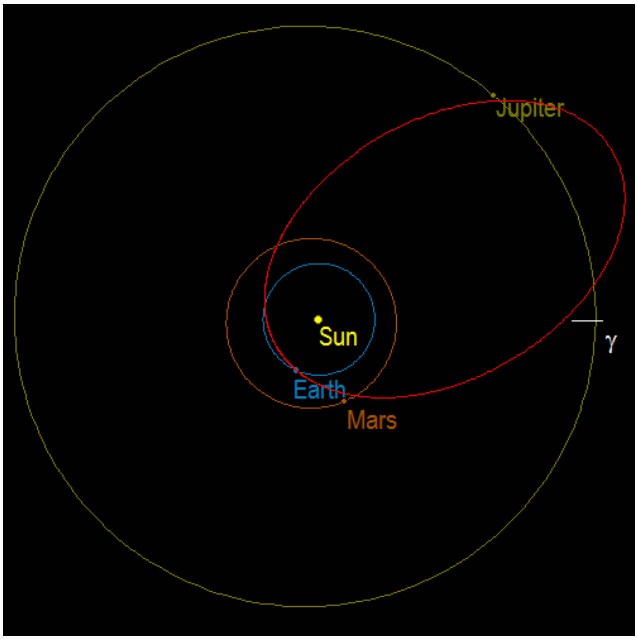

Figure 7 – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20210113_211001 fireball.

Emission spectrum

The spectrographs operating at Sierra Nevada and El Arenosillo meteor stations recorded the emission spectrum of the Alhucemas fireball. The calibration of the signal and the identification of emission lines was performed by means of the `ChiMet` software (Madiedo, 2015a). The calibrated spectrum is shown in *Figure 8*, where the most relevant lines have been indicated. The most important contribution is that of the Na-I doublet (588.9 nm). The emissions from Mg I-3 at 383.2 nm and Fe I-4 at 393.3 nm are also relevant. Both lines, however, appear blended in the spectrum. Other remarkable lines are the emissions from the Mg I-2 triplet (at 516.7 nm) and several Fe-I multiplets. It is worth mentioning that the FeO line at 565 nm was identified, and also atmospheric N2 bands in the red region of the spectrum. The analysis of the relative intensities of these lines will provide an insight into the chemical nature of the meteoroid.

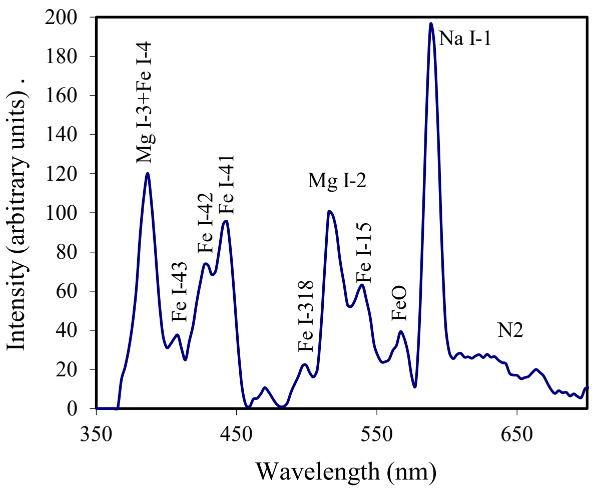

Figure 8 – Calibrated emission spectrum of the SWEMN20210113_211001 “Alhucemas” fireball.

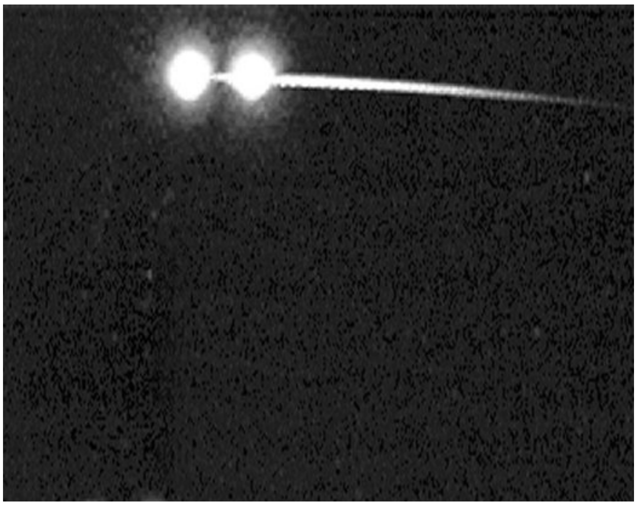

Figure 9 – Stacked image of the SWEMN20210115_012444 “Laazib” fireball as recorded from Sierra Nevada.

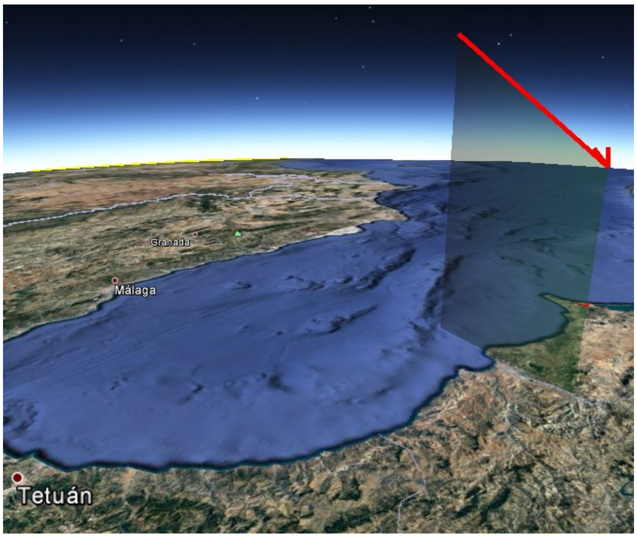

Figure 10 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210115_012444 “Laazib” fireball.

5 The 2021 January 15 fireball

On the night of 2021 January 15, at $1^h24^m44.1 \pm 0.1^s$ UTC, our systems spotted an absolute mag. –9 ± 1 fireball that exhibited several flares along its trajectory (*Figure 9*). The bolide was recorded from the meteor-observing stations at the astronomical observatories of La Hita, Sierra Nevada, El Arenosillo, Calar Alto, and Sevilla. A video showing this event was uploaded to YouTube [4]. The fireball was included in our meteor database with the code SWEMN20210115_012444.

Atmospheric path, radiant and orbit

From the analysis of the recordings, we obtained that the event overflew the Mediterranean Sea and the north of Morocco. The measured pre-atmospheric velocity was $v_\infty = 29.6 \pm 0.3$ km/s. The bolide began at an altitude $H_b = 104.5 \pm 0.5$ km over the Mediterranean Sea and ended at a height $H_e = 69.8 \pm 0.5$ km over Morocco. The meteor was named “Laazib”, since it overflew this town. The apparent radiant of the event was located at the equatorial coordinates $\alpha = 223.18°$, $\delta = +72.30°$. The atmospheric trajectory of the fireball and its projection on the ground are shown in *Figure 10*. The flares exhibited by the fireball along its atmospheric path provided an estimation for the toughness of the meteoroid. Thus, by calculating the aerodynamic pressure at which the particle broke up we obtained that the tensile strength was of about 20.3 ± 0.1 kPa.

Table 3 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210115_012444 “Laazib” fireball.

a (AU)	2.9 ± 0.1	ω (°)	203.2 ± 0.1
e	0.67 ± 0.01	Ω (°)	294.82750 ± 10^{-5}
q (AU)	0.9514 ± 0.0002	i (°)	43.7 ± 0.4

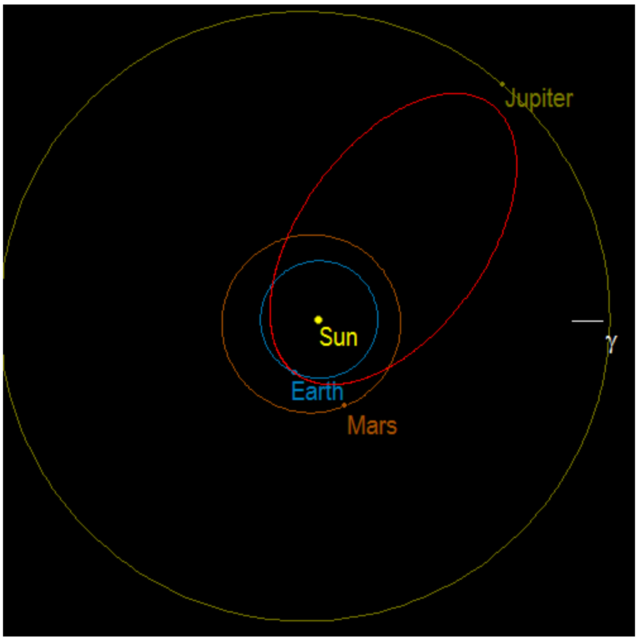

Figure 11 – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20210115_012444 “Laazib” fireball.

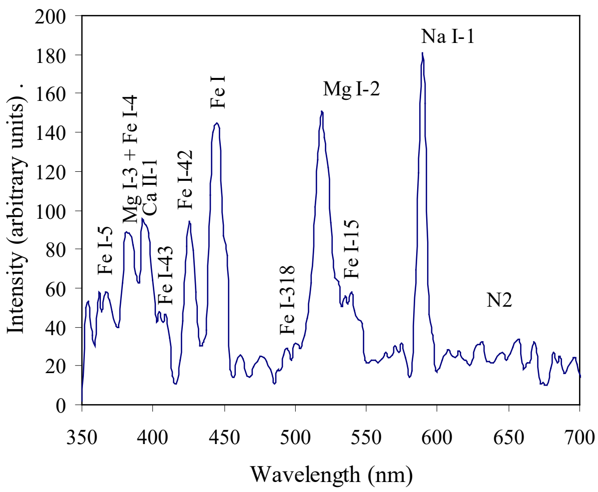

Figure 12 – Calibrated emission spectrum of the SWEMN20210115_012444 “Laazib” fireball.

The calculation of the orbital parameters of the meteoroid yields the results listed in *Table 3*. The geocentric velocity

[4] https://youtu.be/WAcC2eO2kcw

yields $v_g = 27.3 \pm 0.3$ km/s. The orbit is shown in *Figure 11*. The calculated value of the Tisserand parameter with respect to Jupiter ($T_J = 2.58$) shows that the meteoroid followed a Jupiter family comet (JFC) orbit before its encounter with Earth. Radiant and orbital data reveal that the meteoroid belonged to the γ-Ursae Minorid meteoroid stream (GUM#0404), which peaks around January 19. In fact, these data fit fairly well with radiant and orbital information obtained in previous works for this poorly-known stream, whose parent comet remains unknown (Madiedo et al., 2013).

Emission spectrum

The emission spectrum of the Laazib fireball was recorded from our meteor-observing stations located at Sierra Nevada, El Arenosillo and Calar Alto. The signal corrected by taking into account the sensitivity of the recording device and calibrated in wavelength by means of the ChiMet software (Madiedo, 2015a) is plotted in *Figure 12*. This spectrum is similar to the emission spectra obtained for the γ-Ursae Minorids (GUM#0404) in previous works (Madiedo et al., 2013). Thus, the most relevant contributions are due to the Na-I doublet (588.9 nm), the Mg I-2 triplet (516.7 nm), and several Fe-I multiplets. Among these we have identified the contribution from Fe I-4 at 393.3 nm, which appears blended with the emission from Mg I-3 at 383.2 nm. Other neutral Fe multiplets have been found, as for instance those of Fe I-5, Fe I-42, Fe I-43, Fe I-318, and Fe I-15. Molecular bands from atmospheric N2 are also present. The emission from Ni I-18 (at 352.4 nm) was also detected in the ultraviolet region of the spectrum.

6 The 2021 January 21 fireball

This bolide was observed at $2^h56^m33.1 \pm 0.1^s$ UTC on 2021 January 21. It experienced several bright flares along its atmospheric trajectory and reached a peak absolute magnitude of -13 ± 1 (*Figure 13*). The event was spotted from the meteor-observing stations deployed at the astronomical observatories of La Hita, La Sagra, Calar Alto, and Sevilla. A video showing this fireball and its trajectory can be viewed on the YouTube channel of the SMART project[5]. The bolide was included in our meteor database with the code SWEMN20210121_025633.

Atmospheric path, radiant and orbit

According to our analysis, the meteoroid entered the atmosphere with an initial velocity $v_\infty = 30.2 \pm 0.3$ km/s. Its apparent radiant was located at the equatorial coordinates $\alpha = 135.23°$, $\delta = +11.70°$. The bolide began at an altitude $H_b = 90.6 \pm 0.5$ km over the province of Madrid, and ended its luminous phase over the vertical of this city, at a height $H_e = 27.1 \pm 0.5$ km. Because of the location of this terminal point, we named this fireball "Madrid". *Figure 14* shows the atmospheric trajectory of this bolide and its projection on the ground. Despite the final height of the Madrid fireball was below 30 km, a detailed analysis of the terminal part of its luminous path reveals that the meteoroid was completely ablated in the atmosphere, and so the possibility of meteorite survival was discarded.

Figure 13 – Sum-pixel image of the SWEMN20210121_025633 "Madrid" fireball as recorded from La Hita meteor station.

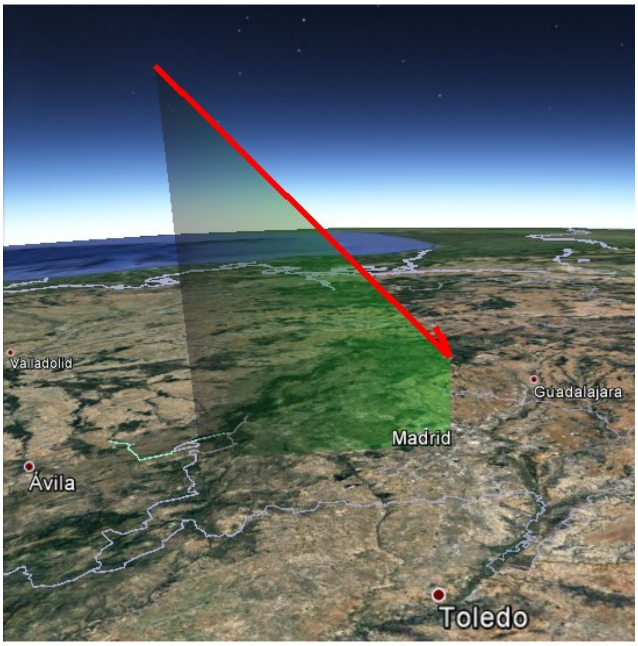

Figure 14 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210121_025633 "Madrid" fireball.

Table 4 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210121_025633 "Madrid" fireball.

a (AU)	2.01 ± 0.06	ω (°)	112.9 ± 0.1
e	0.816 ± 0.007	Ω (°)	120.98091 ± 10^{-5}
q (AU)	0.371 ± 0.004	i (°)	7.7 ± 0.1

Once the trajectory in the atmosphere was determined, the orbital elements of the meteoroid were computed (*Table 4*). The projection on the ecliptic plane of this orbit has been drawn in *Figure 15*. The geocentric velocity of the meteoroid yields $v_g = 28.2 \pm 0.3$ km/s. According to the information included in the IAU meteor database, these

[5] https://youtu.be/4GAyWJoMzT8

results point to an association of this fireball with the Southern δ-Cancrids (SCC#0097). The calculated value of the Tisserand parameter with respect to Jupiter (T_J = 3.29) shows that the meteoroid followed an asteroidal orbit before its encounter with Earth. In fact, asteroid 2001 YB5 has been proposed as the parent body of this meteoroid stream (Jenniskens et al., 2016).

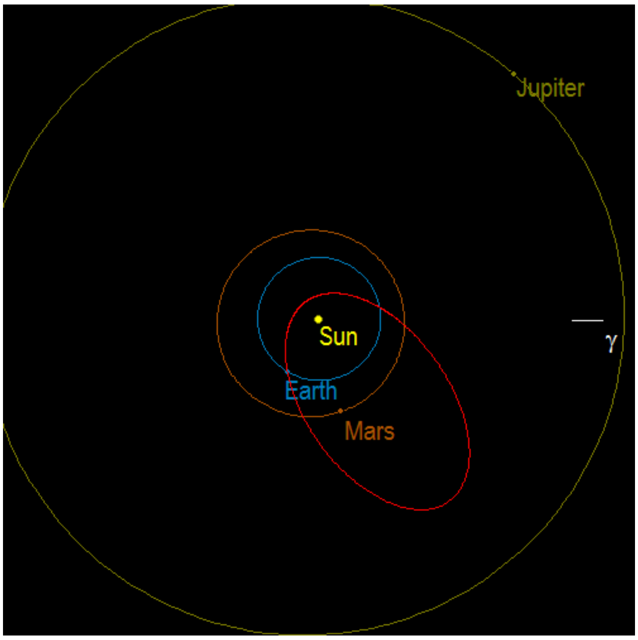

Figure 15 – Projection on the ecliptic plane of the orbit of the parent meteoroid of the SWEMN20210121_025633 "Madrid" fireball.

7 Conclusion

In this work we have analyzed four of the most remarkable fireballs observed over Spain during January 2021. The sample includes both shower and sporadic events. These bolides were recorded in the framework of the systematic monitoring campaign developed by the Southwestern Europe Meteor Network. Their absolute magnitude ranged from –9 to –13.

The event recorded on January 2 (named "Jerez de la Frontera") was associated with the 40 Comae Berenicids (FOB#0576), a recently discovered meteor shower. It overflew the south of Spain and reached a peak absolute magnitude of –12. The meteoroid followed a cometary orbit, and penetrated the atmosphere till a final height of about 58 km because of the relatively high strength of the particle.

The bolide "Alhucemas", spotted on January 13, was produced by a sporadic meteoroid following a JFC orbit. This slow-moving meteor (with a pre-atmospheric velocity of about 18 km/s) overflew the Mediterranean Sea and Morocco, and reached a peak absolute magnitude of –9.

A mag. –9 γ-Ursae Minorid (GUM#0404), named "Laazib", was recorded on January 15. This event also overflew Morocco and the Mediterranean Sea. The results derived from the analysis of this bolide are consistent with those obtained in previous works for other meteor events produced by this poorly-known meteoroid stream.

A deep-penetrating mag. –13 Southern δ-Cancrid (SCC#0097) fireball was observed on January 21 over Madrid. Its final height was low, at about 27 km. But a meteorite survival was discarded, since the analysis of the final part of its atmospheric path revealed that the terminal meteoroid mass was zero. Our results are consistent with an asteroidal origin for this meteoroid stream.

The emission spectra of three of these fireballs have been also presented, and the main lines appearing in these signals have been identified. Most of the features in the spectra correspond to neutral Fe, but other contributions have been found, such as those of Na I, Mg I, Ca I, Ca II, FeO and Ni I. Further analysis is currently in progress to obtain additional information about the chemical nature of the progenitor meteoroids.

Acknowledgment

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The September upsilon Taurid meteor shower and possible previous detections

Tim Cooper

Astronomical Society of Southern Africa, Coordinator CAMS South Africa

tpcoope@mweb.co.za

In September 2020, activity of a newly listed shower called the September upsilon Taurids (IAU #1045, code SUT) was detected by the CAMS and GMN video camera networks. This appears to have been an outburst, which means that this meteor shower has irregular activity. Reports of visual meteor activity emanating from Taurus during September were first mentioned in the early 1990s, while later reports talked about 'September Taurids'. This paper examines the visual observation history, reports on the new video observations in 2020, examines possible evidence of activity in previous year's CAMS data, and discusses the concomitant activity in the vicinity which may have influenced earlier visual observations.

1 Past reports of visual activity

Members of the Dutch Meteor Society (DMS) first reported the possibility of a radiant in Taurus during September as early as 1991 (Jenniskens, 1992). Koen Miskotte observed a number of fast meteors on the nights of September 11–12 and 13–14. Peter Jenniskens observed on September 15 for 1.5 hours, seeing several fast meteors from Taurus, as well as activity on the three subsequent nights. Plots of the observed meteors gave a radiant about RA = 76°, Decl. = +19°, shown as +[1] in *Figure 1*, which also shows the positions of other observed centers of activity determined by plotting, as well as radiant positions of known meteor showers listed in the IAU Meteor Data Centre (MDC) list of all showers (Jopek and Rudawska, 2020)[6].

The shower was also reported in later years. Robert Lunsford observed visual activity on the night of 1996 September 10–11 (O'Meara, 2004), and was confirmed the following night by George Gliba and Norman McLeod (Gliba, 2002). On 1996 September 11–12 McLeod observed weak activity from two possible radiants, determined as RA = 48°, Decl. = +18° and RA = 58.5°, Decl. = +16°, shown as +[2] and +[3] in *Figure 1*. McLeod also observed five fast-moving meteors between September 18, 06^h26^m and 09^h26^m UT from a radiant at RA = 63°, Decl. = +17.5° (*Figure 1*, +[4]).

Olech (2003), however, did not find the shower during an investigation of its existence using data from the Polish Visual Meteor Database (PVMD) during the period September 5–25, for the years 1996–2000. Based on observations by 25 observers totaling nearly 400 hours he concluded there was no trace of activity from the September Taurids and therefore no evidence to support the existence of the stream.

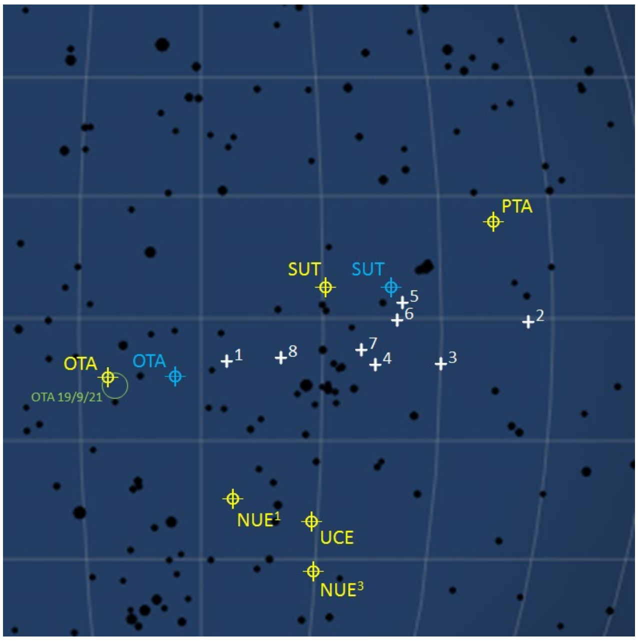

Figure 1 – Observed radiant positions determined by plotting (white + symbols) referred to in *Table 1*, and known radiant positions (coloured ⌖ symbols) of meteor showers listed in *Table 3*. Plotted positions are from: 1 = DMS 1991, 2 = McLeod 1996a, 3 = McLeod 1996b, 4 = McLeod 1996c, 5 = O'Meara 2001, 6 = Velkov 2002, 7 = Streicher 2004, 8 = Cooper 2004. Positions are as reported and have not been adjusted for zenith attraction. SUT radiant position with yellow ⌖ symbol is that derived from 2020 data for solar longitude 179.2° (2020 September 21.9). OTA#896, PTA#556, NUE#337 and UCE#194 with yellow ⌖ symbols are approximate positions of the radiant at $\lambda_{\odot} = 179°$ allowing for radiant drift from date of their listed maxima in *Table 3*. The radiants for NUE are as *Table 3*; NUE1 = Jenniskens et al. (2016) and NUE3 = SonotaCo (2009). That for NUE2 (Molau and Rendtel, 2009) is outside below the map. Cyan ⌖ symbols show the positions for SUT and OTA for $\lambda_{\odot} = 172°$ assuming a radiant drift of 1°/day eastwards parallel to the ecliptic. Green circle is the radiant location of 6 meteors logged by CAMS on 2019 September 17 as 130 Taurids (OTA#896), and was possibly an outburst of that shower.

[6] Jopek T. and Rudawska R. (2020). List of all meteor showers, IAU Meteor Data Centre, updated 2020 September 27, available at https://www.ta3.sk/IAUC22DB/MDC2007/

There were several reports of the stream reappearing in 2001. Stephen O'Meara (2002) observed from Hawaii on September 14, seeing six meteors between 13h35m–13h47m UT, and a further four during casual observations up to 14h14m UT. The meteors radiated from a point between the Hyades and Pleiades clusters. He followed up with a dedicated watch on September 15, seeing six members between 13h30m–14h30m UT, and a further seven between 14h30m–15h30m UT. He estimated the radiant as RA = 60°, Decl. = +22° (*Figure 1*, +[5]). All members were fast-moving. Lorna McCalman (O'Meara, 2004) observing from the Isle of Bute, saw twenty-five meteors in 3.5 hours on the night of September 15–16, confirming significant activity from the stream extended at about the same rate over a period of at least two nights. However, Alastair McBeath (2002) reporting on Society for Popular Astronomy (SPA) observations said "*Several of our visual watchers were active during this spell in 2001, although not on September 14–15 or 15–16, but plots made on other nights around these do not confirm a radiant between the Hyades and Pleiades*".

A number of further observations were made in 2002. Streicher observed six possible members on the morning of September 14 between 01h00m–02h30m UT, all reportedly fast-moving. Gliba observed six meteors between 04h00m–07h00m UT on September 14 (O'Meara, 2004). O'Meara observed between September 14, 12h22m–15h22m UT, seeing thirteen members from 12h22m–13h22m UT (all magnitude +4 or fainter), eleven from 13h22m–14h22m UT, and four members between 14h22m–15h22m. The majority of all observed September Taurids were magnitude +3 or fainter. Valentin Velkov (2003, 2021) reported observations by himself and Eva Bojurova from Bulgaria, where activity was seen on the night of 2002 September 14–15. From thirty-five plotted meteors, nine possible September Taurids were plotted from a radiant with diameter about 10° and centred at RA = 61°, Decl. = +21° (*Figure 1*, +[6]). All members were fast moving. Streicher also observed on September 15 between 02h00m–02h20m UT, but only observed two possible members under partly cloudy skies.

During 2004 Magda Streicher and Tim Cooper observed on the mornings of September 12–14, seeing weak activity on all three dates, and highest activity on the morning of September 12, with three September Taurids for both observing independently in 2.0 hours. The combined total for both observers was twelve September Taurids from seventy-one meteors in 8.5 hours observation. All meteors seen were plotted, and the derived radiant positions were 71.2°, +19.3° (Cooper, +[7]) and 63.7°, +19.3° (Streicher, +[8]).

A summary of all visual observations for the years 1996–2004 is given in *Table 1*. After 2004, the shower unfortunately appears to have been neglected, but with the advent of CAMS in 2011 (Jenniskens et al., 2011) a permanent record of activity now exists which can be examined for possible activity in more recent years.

Table 1 – Summary of possible September Taurid visual observations 1991–2004.

Date	Date, Time UT	Solar long. $\lambda_\odot$ (°)	N	T_{eff} (h)	Radiant (°)	Observer
1991	Sep 11–12	168.9				Miskotte
1991	Sep 13–14	170.8				Miskotte
1991	Sep 15	171.8		1.5	76, +19	Jenniskens
1996	Sep 10–11	168.3				Lunsford
1996	Sep 11–12	169.3				Gliba
1996	Sep 11–12	169.3	5		48, +18; 58.5, +16	McLeod
1996	Sep 18, 0626–0926	175.67–175.79	5	3.0	63, +17.5	McLeod
2001	Sep 14, 1335–1414	171.79–171.81	10	0.65		O'Meara
2001	Sep 15, 1330–1530	172.76–172.84	13	2.0	60, +22	O'Meara
2001	Sep 15–16	173.2	25	3.5		McCalman
2002	Sep 14, 0100–0230	171.03–171.09	6	1.5		Streicher
2002	Sep 14, 0400–0700	171.15–171.27	6	3.0		Gliba
2002	Sep 14, 1222–1522	171.49–171.61	28	3.0		O'Meara
2002	Sep 14–15	172.0	9		61, +21	Velkov
2002	Sep 15, 0200–0220	172.04–172.06	2	0.3		Streicher
2004	Sep 12, 0030–0235	169.53–169.62	3	2.0	63.7, +19.3	Streicher
2004	Sep 12, 0030–0235	169.53–169.62	4	2.0	71.2, +19.3	Cooper
2004	Sep 13, 0100–0300	170.52–170.61	2	2.0	63.7, +19.3	Streicher
2004	Sep 14, 0112–0212	171.51–171.55	2	1.0	71.2, +19.3	Cooper
2004	Sep 14	171.5	1		63.7, +19.3	Streicher
2020	Sep 21–22, 2220–0040	179.1–179.2	14		66.0, +24.1	CAMS
2020	Sep 21–22, 1950–0040	179.0–179.2	18			GMN

Notes: column N gives the number of meteors reported in time T_{eff} hours. CAMS and GMN video data used for confirmation are given as comparison.

Table 2 – Radiant position, peak activity and orbital details for September upsilon Taurids (SUT, #1045).

Radiant – RA (J2000) (°)	66.0 ± 1.2
Radiant – Decl. (°)	+24.1 ± 0.6
Peak activity – solar longitude λ_Θ (°)	179.15 ± 0.04
Duration – *FWHM* solar longitude (°)	0.14
Geocentric velocity – v_g km/s	67.8 ± 1.2
Perihelion distance – q AU	0.654 ± 0.007
Eccentricity – e	0.992 ± 0.015
Inclination – i (°)	174.9 ± 0.3
Argument of perihelion – ω (°)	252.7 ± 0.9
Longitude of ascending node – Ω (°, J2000.0)	179.15 ± 0.13

Table 3 – Showers with radiants in the vicinity of Taurus and active at the same time as the September upsilon Taurids.

Shower code	IAU #	Year	RA (°)	Decl. (°)	ΔRA (°)	ΔDec (°)	v_g km/s	λ_Θ (°) Max.
SUT	1045	2020	66.2	+24.1			67.8	179.2
OTA	896	2018	86.5	+17.9			72.4	179.3
PTA	556	2014	63.9	+29.1	1.15	0.20	60.2	193
NUE(1)	337	2008	61.5	+4.3	0.95	0.19	67.1	163.0
NUE(2)			74.7	+0.3	0.6	-1.9	67.0	165
NUE(3)			68.7	+1.1	0.14	-0.13	65.9	167.9
UCE	194	1999	38.6	-2.8			61.0	146.0

Notes: SUT = September upsilon Taurids, OTA = 130 Taurids, PTA = phi Taurids, NUE = nu Eridanids and UCE = upsilon Cetids. Year is that for which the shower is first referenced in the IAU MDC list. Data for NUE is from (1) = Jenniskens et al. (2016), 2 = Molau and Rendtel (2009), 3 = SonotaCo (2009). ΔRA and ΔDec are radiant drift from Jopek and Rudawska (2020).

Table 4 – List of confirmed and possible outbursts of September upsilon Taurids.

Year	Date, September	Solar longitude (°)	Type
1991	11–15	168–172	Visual
1996	11–13	169–171	Visual
2001	15–16	172–173	Visual
2002	14	171	Visual
2014	23	180	Video
2017	22	179	Video
2019	10, 22–23	167, 178–179	Video
2020	22	179.15	Video

2 The 2020 activity and confirmation of the shower

CAMS radiant plots for the period 2020 September 10–25 are shown in *Figures 2a and 2b*. The first possible detections by the CAMS network were on the night of September 22 (Cooper, 2020) when the author mailed Dr. Jenniskens "*could you check similarities of the bunch just north of Taurus in data for September 22 please? Location is approx. RA = 66 deg, Dec = +23.8 deg, v = approx. 68 km/s.*" That activity can be seen in *Figure 2b* lower left panel, as a tight bunching of points immediately north of the Hyades.

Closer examination of *Figure 2b* shows the shower may have been active one day either side of this date, but at reduced rates. In total fourteen shower members were detected (Jenniskens and Cooper, 2020), seven by CAMS Namibia, six by the United Arab Emirates Astronomical Camera Network, and one by CAMS Florida. Unfortunately, CAMS South Africa was clouded out. Nine meteors occurred between solar longitudes λ_Θ = 179.13–179.24°, corresponding to September 21.959 to 22.071 UT. In addition, eighteen members were detected by cameras operated by the Global Meteor Network (GMN), with peak between λ_Θ = 179.05 and 179.24°, corresponding to September 21.876 to 22.071 UT.

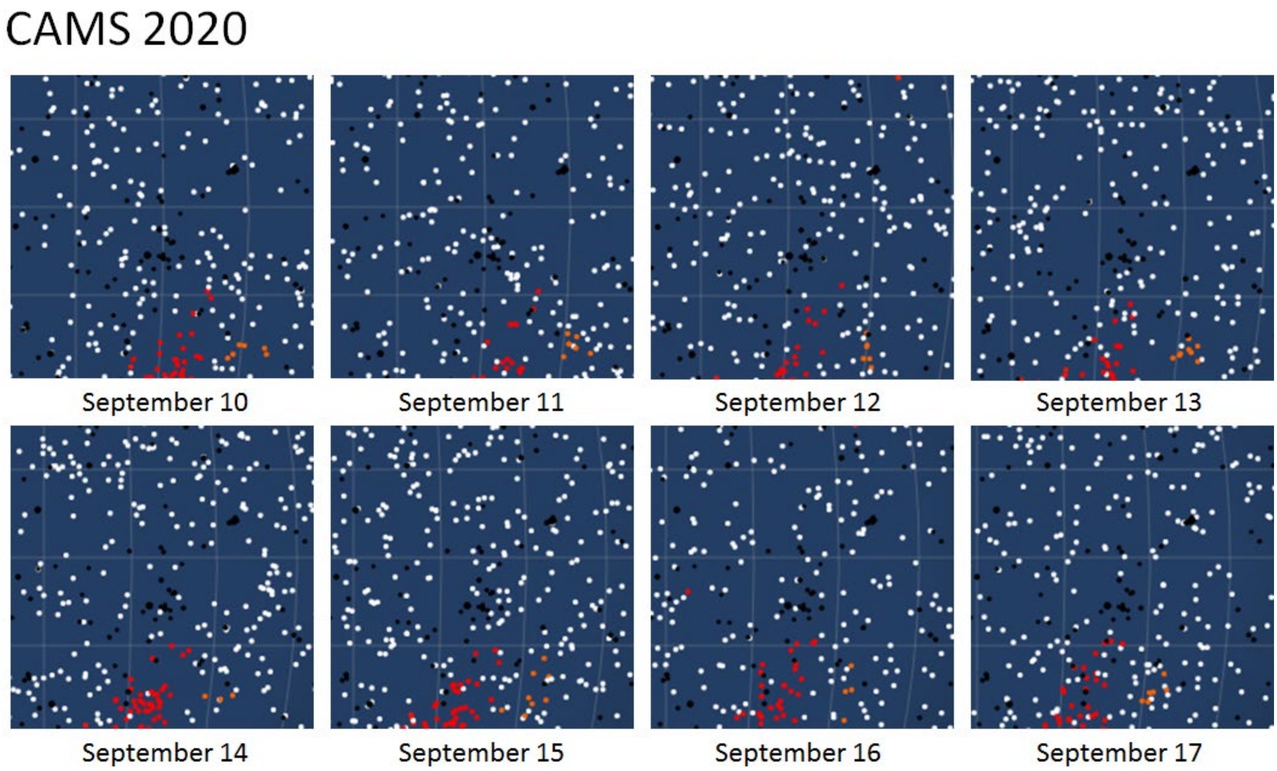

Figure 2a – Radiant plots from CAMS global data for 2020 September 10–17. Black dots are stars, white dots are either sporadic meteors or radiants not in the CAMS lookup table, red dots at the bottom of each frame are identified as nu Eridanids (NUE, #337), orange dots to their right (west) are upsilon Cetids (UCE, #194).

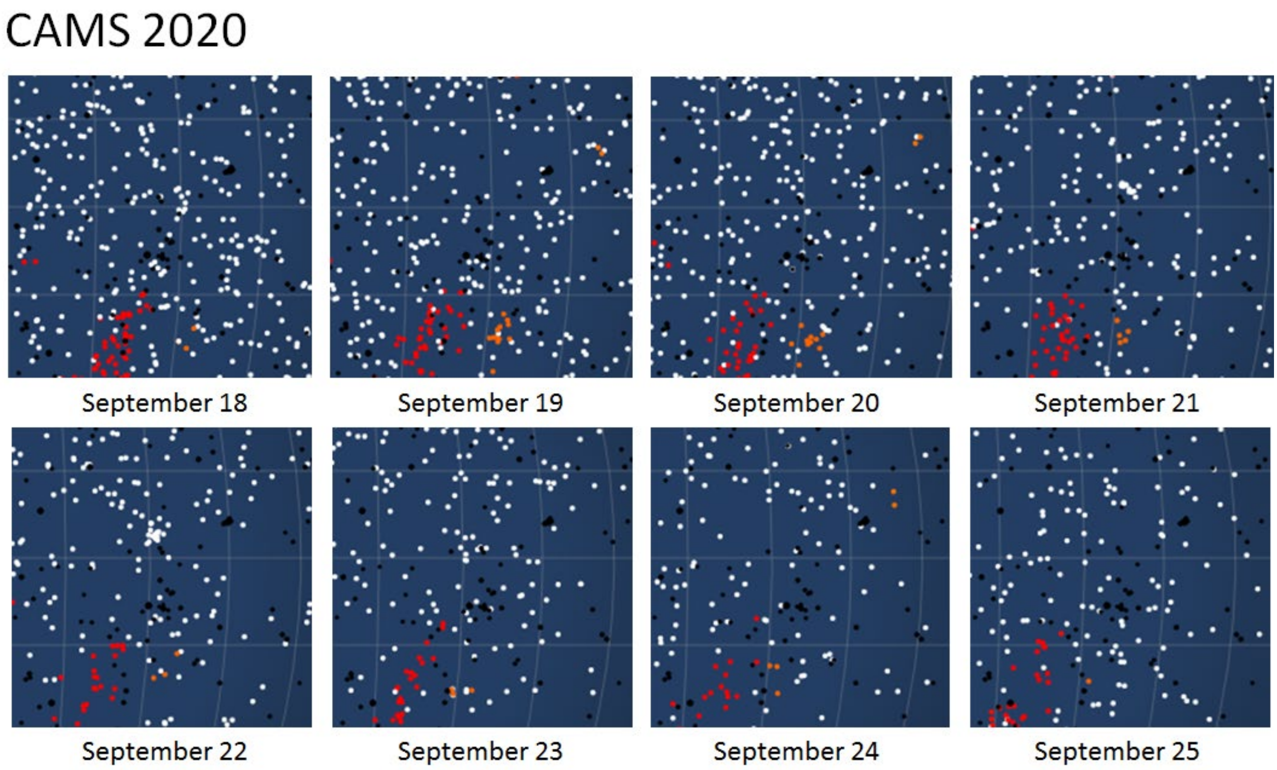

Figure 2b – Radiant plots from CAMS global data for 2020 September 18–25. Identities as *Figure 2a*, but in addition red dots on extreme left of frames are 130 Taurids (OTA, #896) and orange dots upper right are phi Taurids (PTA, #556). Concentrations of September upsilon Taurids for September 21 and 22 are clearly visible above the Hyades.

Based on these detections an outburst was announced (Jenniskens and Cooper, 2020), and the shower now becomes known in the IAU MDC Working List of Meteor Showers (Jopek and Rudawska, 2020) as the September upsilon Taurids (SUT, #1045). Derived properties of the meteor stream, including radiant position, peak activity and orbital details are shown in *Table 2*. The orbit is that of an as-yet unknown long period comet in a low inclination orbit. September upsilon Taurid meteors are fast moving, with geocentric velocity 67.8 km/sec.

3 Evidence of previous activity detected by CAMS and other video networks

Following the outburst in 2020, the author examined CAMS plots for similar concentrations during the period September 10–25 from 2015 onwards. Dates for which possible activity exist are shown in *Figure 3*. The summary of historical observations of meteors emanating from the vicinity of the Hyades and Pleiades clusters in Taurus is given in *Table 4*.

There is evidence of a close association of radiants at similar position to the 2020 activity on three nights in the past; 2014 September 23, 2017 September 22 and 2019 September 10. In all three cases activity was absent one day either side of these dates. There was also possible weak activity on the night of 2019 September 22, and this may have continued over into the following night also. Outside these dates, no instances were found of September upsilon Taurid rates exceeding the sporadic background during the years 2014–2019. The increasing number of points in the plots do not reflect increasing meteor activity, but rather an increase in the number of cameras operating as part of the CAMS network.

There is no evidence for September upsilon Taurid activity in CAMS plots prior to 2014, although it should be noted that far fewer data points exist due to the aforementioned fewer operating cameras, with only 60 cameras in 2011, growing to around 530 cameras in 2020. The shower was not identified by Molau and Rendtel (2009) based on analysis of more than 10 years observations by the IMO Video Network. The shower was also not detected by SonotaCo (2009) in its catalog based on video observations of around 240000 meteors during 2007–2008.

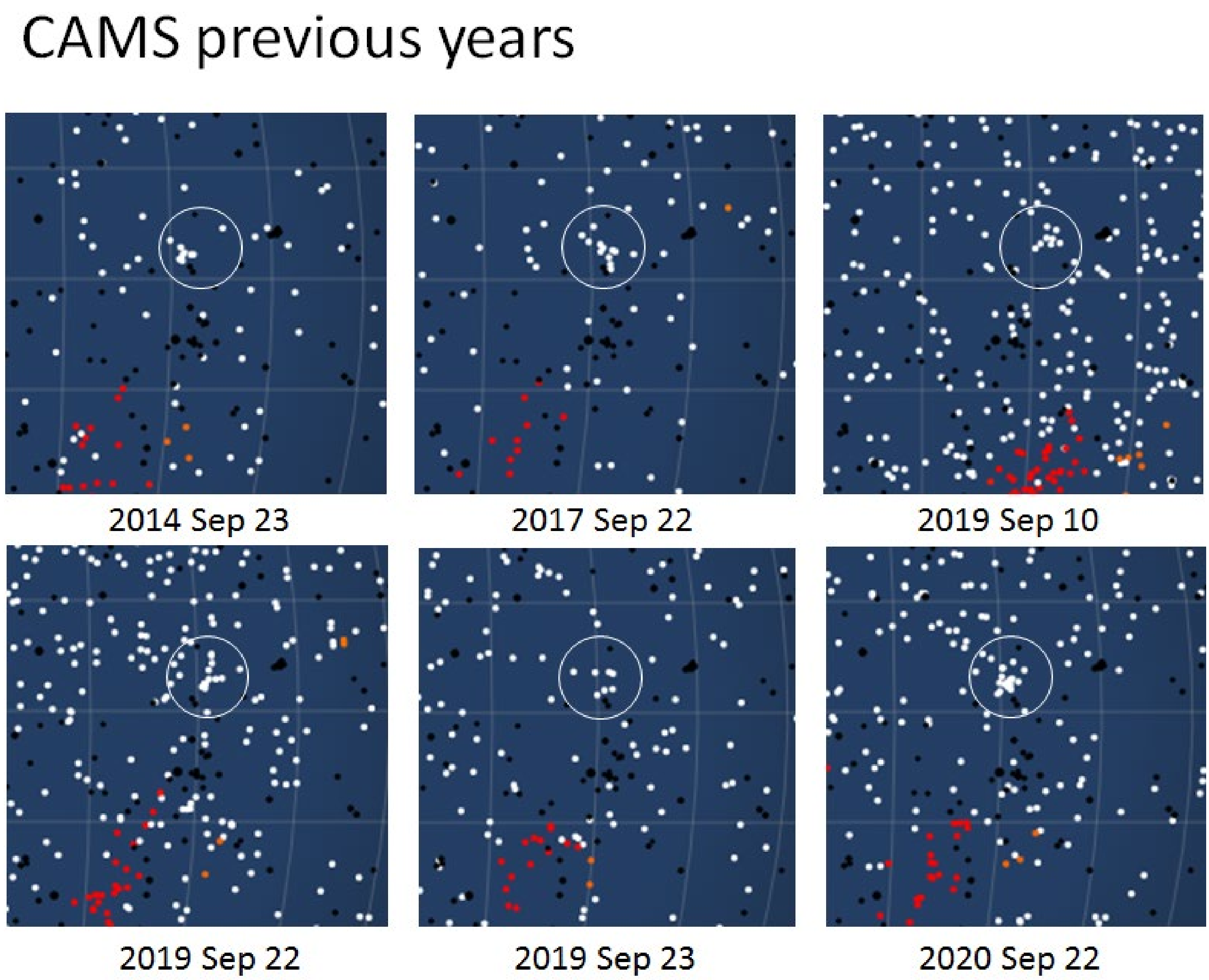

Figure 3 – Possible previous detections of September upsilon Taurids by CAMS. Upper row shows captures for 2014 September 23, 2017 September 22 and 2019 September 10. Lower row shows plots for the nights of 2019 September 22 and 23, with 2020 September 22 on the right as reference. The white circles are roughly centred on the same position as the 2020 activity.

4 Concomitant activity

There are several other meteor showers active at the same time as the September upsilon Taurids, with radiants in the vicinity of the Hyades and Pleiades clusters, most of which were not known at the time of the first mentioned visual observations cited here. Details are shown in *Table 3*, which includes the year in which such activity first became known, and radiant positions are identified in *Figure 1*.

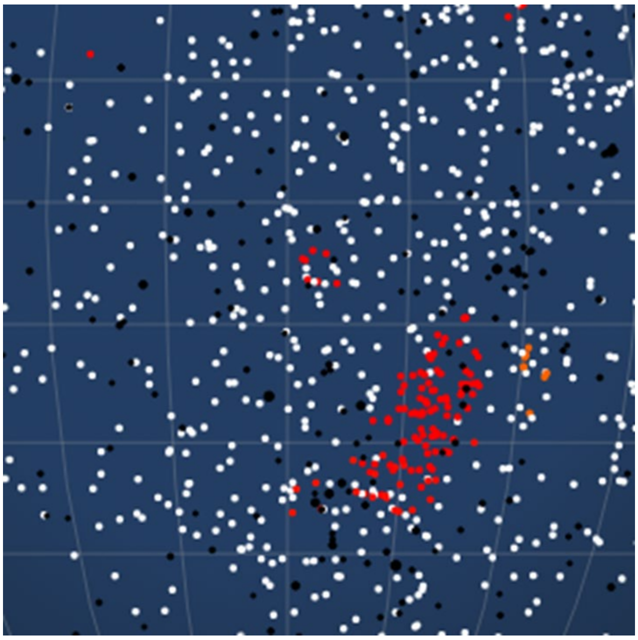

Figure 4 – Possible outburst of 130 Taurids (OTA#896) on 2019 September 21, red dots left of centre. The Hyades cluster is to the centre right, and the Pleiades can be seen just inside top right. The broad swathe of red dots at bottom are nu Eridanids, and to their right the orange dots are upsilon Cetids.

In particular the 130 Taurids (OTA, #896) and phi Taurids (PTA, #556) have their radiants nearby, but slightly east and west of the September upsilon Taurids respectively. Both showers are weak, but often present, and active over a period of several days. The 2019 plots are notable for a probable outburst of 130 Taurids, with the appearance of at least six members on the night of September 21 (*Figure 4*), and appearing just one night earlier than the weak September upsilon Taurid activity that year (*Figure 3* bottom left panel). There was also discernible activity of 130 Taurids on 2017 September 15, preceding the possible September upsilon Taurid activity that year by seven days. *Figure 1* also shows the close proximity of the 130 Taurid (OTA) radiant position at solar longitude 172° to the radiant derived by Dutch Meteor Society members at solar longitude 171.8° in 1991, which might have been a further outburst of that shower.

The nu Eridanids (NUE, #337) have their radiant center some 20° south of the September upsilon Taurids, though the actual positions differ according to SonotaCo (2009), Molau and Rendtel (2009) and Jenniskens et al. (2016). The radiant positions are shown in *Figure 1*. Irrespective, by careful plotting their identity can easily be resolved, although the radiant is rather extended so that some outliers may contaminate plots of September upsilon Taurids. They are active throughout September nights on all years in CAMS data, sometimes at significant rates. Similarly, to their west are to be found the upsilon Cetids (UCE, #194), which show lower rates from a more compact radiant close by the nu Eridanids. While they can easily be differentiated from the September upsilon Taurids, they presumably cannot be separated from the nu Eridanids by visual means.

Taken together, these radiants would make for a complex pattern of visual activity emanating from the vicinity of Taurus during September each year. Like the September upsilon Taurids (v_g = 68 km/s), the 130 Taurids (v_g = 72 km/s) and nu Eridanids (v_g = 67 km/s) have similar apparent speeds. The phi Taurids and upsilon Cetids are only slightly slower. All this requires careful plotting on behalf of the visual observer to make sense of the yearly changes taking place in activity from this region of sky. CAMS does not suffer from this problem, and the membership of a particular shower is established by comparing the orbital details of captured meteors to the current lookup table used by the CAMS software.

5 Conclusions

The existence of the September upsilon Taurids was established in 2020 in data from the CAMS and GMN video networks. These results showed a brief outburst with peak activity on 2020 September 21.92 – 22.02 ($\lambda_\odot$ = 179.15°± 0.04°). Past visual records show possible September upsilon Taurid activity during 1991 September 11–15, 1996 September 11–13, 2001 September 15–16, and 2002 September 14. Examination of historical CAMS video data shows probable activity on 2014 September 23, 2017 September 22, 2019 September 10, with a second burst on 2019 September 22, and still perceptible activity on September 23. In most cases the activity is of short duration and confined to one or two nights.

Reports of visual activity are generally one week earlier than the video data, possibly due to bias in the visual observers focusing around the first recorded dates in the 1990s. Outside the mentioned dates activity does not exceed the sporadic background.

There are several concomitant showers with radiants in the near vicinity, and which may have affected visual observations in the past from the area nearby the Hyades and Pleiades clusters. In particular the 130 Taurids have shown activity during most years, most notably during 2019 when rates appear to have been higher than normal. The proximity of the 130 Taurid radiant at $\lambda_\odot$ = 172° to the DMS radiant of 1991 at $\lambda_\odot$ = 171.8° is noted, and the possibility that the 1991 activity was due to 130 Taurids rather than September upsilon Taurids cannot be discounted. The efficiency of CAMS and other video networks in elucidating complex meteor activity is demonstrated.

Acknowledgments

Thanks to Dr. Peter Jenniskens (NASA Ames Research Centre and SETI Institute, and CAMS Principal Investigator) for information used in this paper. Also, to the camera operators of the global CAMS network, whose data were used for the radiant plots used in this paper. Radiant plots are from the CAMS site[7]. Comments made by Valentin Velkov used in the preparation of this article are greatly appreciated. Data from the Global Meteor Network is released under the CC BY 4.0 license, and is available online[8]. Solar longitudes were calculated using the application SollongCalc[9] by Kristina Veljkovic, University of Belgrade, Serbia.

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Velkov V. (2021). Private communication in email dated 2021 January 5.

[7] http://cams.seti.org/FDL/
[8] https://globalmeteornetwork.org/data/
[9] https://kikimoreau.shinyapps.io/SollongCalc/

The 2020 return of the Volantids (VOL#758)

P. Jenniskens[1] and T. Cooper[2]

[1]**SETI Institute, 189 Bernardo Ave, Mountain View, CA 94043, USA**
pjenniskens@seti.org

[2]**Astronomical Society of Southern Africa, Coordinator CAMS South Africa**
tpcoope@mweb.co.za

The Volantid meteor shower was again detected by southern hemisphere CAMS networks on 2020 December 27–28 after not having been seen since their discovery by the CAMS New Zealand network in 2015. Following this initial announcement, the shower gradually increased in intensity and peaked on New Year's Eve at 12^h UT. The shower was detected until 2021 January 3 and behaved much like in 2015. Median orbital elements for the 2020–2021 return are presented. Visual observations under Moon-lit conditions confirmed the activity.

1 Introduction

The Volantid meteor shower was discovered by the CAMS video network in New Zealand during the night of 2015 December 31 (Jenniskens et al., 2016) and was confirmed by VHF radar observations that recorded the shower for several additional days when the New Zealand CAMS stations were clouded out (Younger et al., 2016). The meteors radiated from the constellation Volans, the flying fish.

The meteor shower was not detected in the following years, but it re-emerged on 2020 December 27 and 28, when the southern hemisphere CAMS networks[10] spotted the first Volantids of this return. A CBET telegram was published and observers were alerted in order to facilitate targeted observations to cover this event. The activity was expected to intensify and to last for a number of nights if the shower would behave in the same way as in 2015 (Jenniskens, 2020; 2021a).

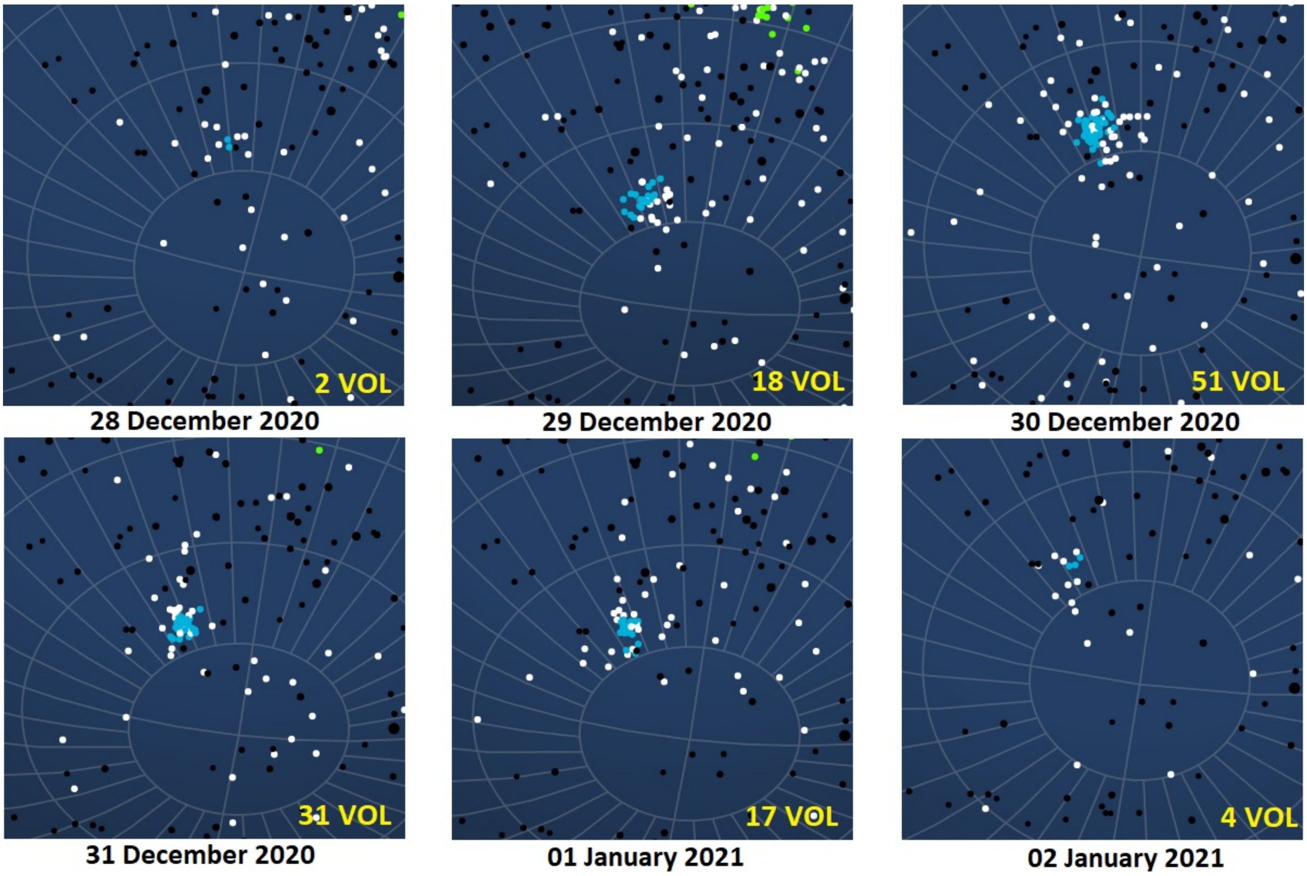

Figure 1 – The Volantid radiants (marked in blue) detected among the meteoroid orbits collected by the CAMS networks between 2020 Dec. 28.0 ± 0.5 and 2021 Jan. 02 ± 0.5 UT. The nearby white points are likely also Volantids, but with orbits measured slightly different from those of the 2015-detected shower members.

[10] http://cams.seti.org/FDL/ look for the dates of 2020 Dec. 28 until 2021 Jan. 02.

Here, we report on subsequent observations of the shower, which confirm that the shower returned much like in 2015. The shower peaked on New Year's Eve.

2 Results 2020–2021

The 2020 – 2021 Volantids were detected by the CAMS networks in New Zealand (J. Baggaley), Australia (M. Towner), South Africa (T. Cooper), Namibia (T. Hanke), and Chile (S.Heathcote and E. Jehin). The activity period covered 2020 December 27 until 2021 January 3 (*Figure 1*).

The meteor shower peaked at $\lambda_{\odot} = 280.0 \pm 0.1°$ or 2020 December 31 at 12^h UT (equinox J2000.0). The full-width-at-half-maximum of the shower was 1.6 ± 0.2°, which corresponds to 38 ± 5 hours (*Figure 2*). In total 247 triangulated meteors resulted in valid orbits of the Volantid meteor shower, detected over the solar-longitude range 271.95° – 283.91°. Most were faint, with a magnitude distribution index of 3.8 (+0.6/-0.1) (Jenniskens 2021b).

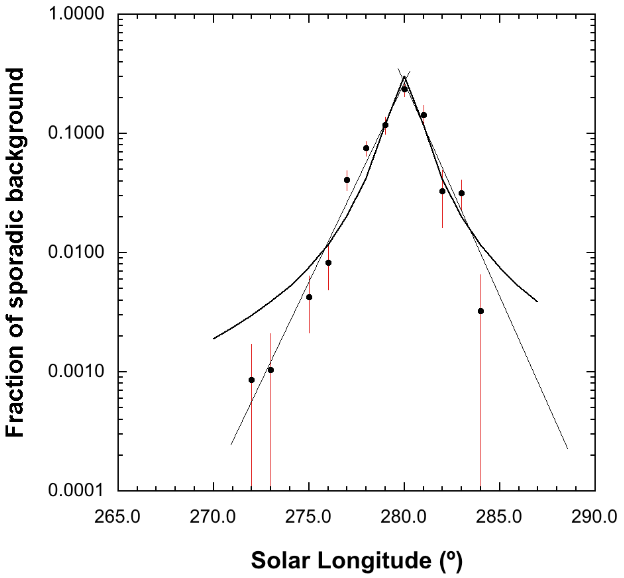

Figure 2 – Volantid shower rates as a fraction of the rate of observed sporadic meteors during each night. Lines are the best-fit exponential and Lorentzian curves.

Table 1 presents the median radiant and orbit parameters obtained during this season. Results are compared to those obtained during the discovery of the Volantids in 2015–2016. Errors give the apparent 1-sigma dispersion in the measurements based on 21 meteors observed during a short time interval in 2015 and the 247 meteors detected this year. There is good agreement, confirming that this is a return of the Volantids. There is no known parent body.

Visual observations were conducted by Tim Cooper, Astronomical Society of Southern Africa, from Bredell, South Africa, for a 3.6-hour period 2020 Dec. 29^{d}21^{h}00^m–30^{d}00^{h}12^m ($\lambda_{\odot}$ 278.330° –278.466°), with a limiting magnitude of 5.2 and Full Moon, with some scattered clouds, and the radiant rising from altitude 35.8° to 45.5°. Under these circumstances a total of three Volantids and six other meteors were seen, which corresponds to an average Zenith Hourly Rate (ZHR) of 7.9 ± 4.5 Volantids per hour.

The night of December. 30–31 was overcast all night. The night of December 31–January 1 ($\lambda_{\odot}$ 280.284° – 280.461°) yielded again three visual Volantids and five other meteors during 2.75 hour of observations under similar observing conditions, resulting in a ZHR = 11.2 ± 6.5 meteors/hour.

Table 1 – The radiant and orbits for the Volantid meteor shower for the discovery and the first return of the shower.

	2015–2016	2020–2021
$\lambda_{\odot}$	279.27°	280.0 ± 0.1°
α_g	122.9 ± 4.7°	123.3 ± 4.9°
δ_g	–71.9°± 1.9°	–71.9 ± 2.3°
v_g	27.4 ± 1.5 km/s	30.4 ± 2.2 km/s
a	2.23 AU	2.84 AU
q	0.975 ± 0.004 AU	0.974 ± 0.005 AU
e	0.562 ± 0.093	0.657 ± 0.125
i	47.8 ± 2.0°	50.6 ± 2.9°
ω	347.7 ± 3.4°	347.7 ± 3.6°
Ω	99.256 ± 0.066°	98.8 ± 1.7°
Π	87.0 ± 3.4°	86.5 ± 3.6°
Q	3.5 ± 0.9 AU	4.7 AU
P	3.3 Y	4.8 Y
T_J	3.06	2.54

We conclude that the Volantids returned in 2020 much like they were seen in 2015. The new shower was the most prominent meteor shower in CAMS data (on both hemispheres) from 2020 December 30 to 2020 January 1 (see those dates at the CAMS website[10]). On New Year's Eve, many firework displays were curtailed due to the COVID pandemic, but observers on the southern hemisphere could enjoy an unusual natural meteor shower.

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Outburst of gamma Crucids in 2021 (GCR#1047)

P. Jenniskens

SETI Institute, 189 Bernardo Ave, Mountain View, CA 94043, USA
pjenniskens@seti.org

A meteor outburst from what may be a previously unknown shower now called the gamma Crucids (code GCR and IAU shower number 1047) was recorded by Southern hemisphere CAMS networks on 2021 February 13 – 15. The meteors radiated from R.A. = 192.6, Decl. = –56.0 degrees. It is possible that this is a return of the alpha Centaurids (IAU#102), a strong shower observed by visual observers in 1980 on February 8. Those meteors radiated from a radiant at R.A. = 210.9, Decl. = –58.2.

1 Introduction

In mid-February, an unexpected meteor shower was detected in observations of the Southern hemisphere low-light video camera networks CAMS Australia (M. Towner), CAMS Chile (S. Heathcote and E. Jehin), and CAMS New Zealand (J. Baggaley). See the meteor shower radiant maps posted at the CAMS website[11] and select the dates in the calendar for 2021 February 13 – 15 (Jenniskens, 2021). The meteors radiated from a point near the constellation the Southern Cross and appeared to be a previously unknown shower, which now has been given the name gamma Crucids (GCR, IAU#1047).

2 Results

The meteors radiated from a geocentric radiant at R.A. = 192.6 ± 3.3, Decl. = –56.0 ± 1.6 deg, with a velocity of v_g = 55.8 ± 1.7 km/s. The first shower meteors were triangulated on 2021 February 11 at 1^h UTC (322.7 degrees solar longitude, Equinox J2000). Activity peaked on February 14. The most recently analyzed meteor occurred on 2021 February 15 at 9^h UTC (326.6 deg). 40 meteors give the median orbital elements and 1-sigma dispersions of:

- a ~ 17 AU,
- q = 0.930 ± 0.023 AU;
- e = 0.946 ± 0.174;
- i = 100.8 ± 2.7 deg;
- ω = 28.5 ± 6.1 deg;
- Ω = 144.21 ± 0.99 deg

The meteoroid stream belongs to an unknown Halley-type comet in a steeply inclined orbit to the ecliptic plane. It is possible that this is a return of the alpha Centaurids (IAU#102), a strong shower observed by visual observers in 1980. At that time, the radiant position was reported to be at higher right ascension R.A. = 210.9, Decl. –58.2 and an annual shower around this position was recently given that shower number, but perhaps incorrectly so.

The question whether or not the 2021 outburst is a return of the 1980 outburst can perhaps be answered from the original plots of the visual observers or dynamical modeling. This question remains under investigation.

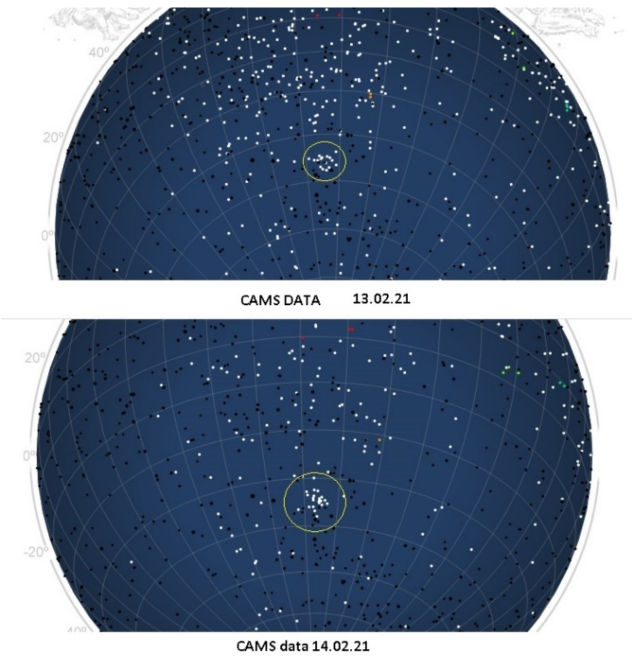

Figure 1 – The circle marks the concentration of radiants of the gamma Crucid outburst in the recent CAMS radiant maps. Image courtesy of Ivan Sergei (Belarus).

Reference

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[11] http://cams.seti.org/FDL

No Meteors from 2020 BZ_{12} According to Global Meteor Network Orbit Data

John Greaves

cpmjg@tutanota.com

Examination of Global Meteor Network orbit data for January and February 2021 reveals that evidence for the existence of any meteor shower associated with 2020 BZ_{12} is lacking.

1 Introduction

In Greaves (2020) it was noted that the minor planet 2020 BZ_{12} had a comet-like orbit and according to D criteria had a borderline chance of presenting meteors in January 2021, which was post-perihelion. Caveats included the threshold level of the actual D value suggesting a marginal Earth crossing orbit and that the nature of the orbit could lead to any putative meteors not being due until they returned to the pre-perihelion part of the orbital arc. Equally it was also noted that candidate meteors existing in the currently extant meteor orbit datasets were too few to sufficiently show then current evidence for such a shower. Accordingly, the full January 2021 and up to late February 2021 orbital data were obtained from the Global Meteor Network (Vida et al., 2019a; 2019b) and tested against the 2020 BZ_{12} orbit in the same manner as in the original paper.

2 Results

The analysis revealed that according to Global Meteor Network data the number of potentially associated orbits was exactly zero. Minor caveats include an increasingly problematic waxing moon during the potential shower period until late in the month which was only a few days past Full Moon at month end when the Moon was actually in Virgo, the constellation of the most likely site of the radiant. On the other hand, the dataset had good nightly coverage throughout the month.

3 Conclusion

Any potential shower associated with 2020 BZ_{12} is not confirmed in any way by Global Meteor Network data.

Acknowledgement

The Global Meteor Network and its dedicated observers are thanked for making their data not only publicly but promptly accessible as without this data this analysis would not be possible at this time. The data of the Global Meteor Network[12] was used which is released under the CC BY 4.0 license[13].

References

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[12] https://globalmeteornetwork.org/data/

[13] https://creativecommons.org/licenses/by/4.0/

November 2020 report CAMS BeNeLux

Paul Roggemans

Pijnboomstraat 25, 2800 Mechelen, Belgium
paul.roggemans@gmail.com

A summary of the activity of the CAMS BeNeLux network during the month of November 2020 is presented. 17241 multiple station meteors were recorded. In total 5441 orbits were collected during this month, a second-best November month for CAMS BeNeLux.

1 Introduction

November is a typical autumn month with rather unstable weather over the BeNeLux. Completely clear nights are rare during this time of the year. However, during the long nights with 13 to 14 hours dark sky, it is also rare that clouds remain all night present. Very often clear gaps appear during which meteors can be registered. To be successful in a month like November is a matter of having the cameras operational. With most stations running Auto CAMS seven days on seven, still a lot of double station meteors can be registered during periods with unexpected clear sky.

2 November 2020 statistics

CAMS BeNeLux collected 17241 multi-station meteors (9339 in 2019), good for 5441 orbits (3237 in 2019, 6916 in 2018). This is a much better result than in 2019. November 2018 was an exceptional favorable month of November and November 2020 is the second best. AutoCams functioned at 18 camera stations, at 5 stations the cameras were only started when there was a chance for clear skies. Not all the camera stations could participate during the entire month.

This month counted 18 nights with more than 100 orbits (10 in 2019 and16 in 2018). Two nights produced more than 500 orbits in a single night (1 in 2019 and 6 in 2018). The best November night in 2020 was 12–13 with as many as 2240 multi-station meteors, good for 611 orbits in this single night. Only two nights remained without any orbits. The statistics of November 2020 are compared in *Figure 1* and *Table 1* with the same month in previous years since the start of CAMS BeNeLux in 2012. In 9 years, 207 November nights allowed to obtain orbits with a grand total of 25236 orbits collected during November during all these years together.

While November 2019 had 77 cameras at best and 71.1 on average, November 2020 had 88 cameras at best and 72.6 on average. Since the last major expansion of CAMS BeNeLux in 2017, the number of operational cameras remained stable with a number of new cameras compensating the number of cameras that ceased participation in the CAMS network.

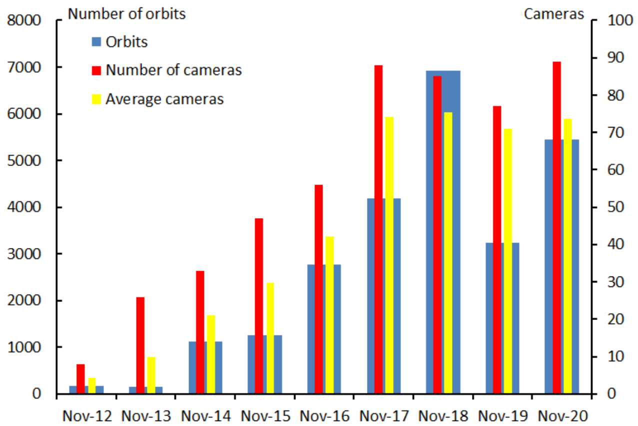

Figure 1 – Comparing November 2020 to previous months of November in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bar the average number of cameras running per night.

Table 1 – November 2020 compared to previous months of November.

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	14	165	6	8	-	4.4
2013	13	142	10	26	-	9.8
2014	24	1123	14	33	-	21.1
2015	23	1261	15	47	10	29.8
2016	24	2769	19	56	19	42.2
2017	26	4182	22	88	57	74.2
2018	28	6916	21	85	59	75.3
2019	27	3237	20	77	60	71.1
2020	28	5441	23	88	57	72.6
Total	207	25236				

3 Conclusion

November 2020 brought exceptionally favorable autumn weather for the BeNeLux what resulted in a second-best November month during 9 years of CAMS BeNeLux.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. This report is based on the data from the CAMS-website[14] with thanks to *Martin Breukers* for providing the information for the camera stations.

The CAMS BeNeLux team was operated by the following volunteers during the month of November 2020: *Hans Betlem* (Leiden, Netherlands, CAMS 371, 372 and 373), Felix Bettonvil (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 328 and 329), *Guiseppe Canonaco* (Genk, RMS 3815), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805), *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 003814), *Uwe Glässner* (Langenfeld, Germany, RMS 3800), *Luc Gobin* (Mechelen, Belgium, CAMS 3890, 3891, 3892 and 3893), *Tioga Gulon* (Nancy, France, CAMS 3900 and 3901), *Robert Haas* (Alphen aan de Rijn, Netherlands, CAMS 3160, 3161, 3162, 3163, 3164, 3165, 3166 and 3167), *Robert Haas* (Texel, Netherlands, CAMS 810, 811, 812 and 813), *Robert Haas / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822), *Kees Habraken* (Kattendijke, Netherlands, RMS 000378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain Belgium, CAMS 816), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Koen Miskotte* (Ermelo, Netherlands, CAMS 351, 352, 353 and 354), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *Paul and Adriana Roggemans* (Mechelen, Belgium, CAMS 383, 384, 388, 389, 399 and 809, RMS 003830 and 003831), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).

[14] http://cams.seti.org/FDL/index-BeNeLux.html

Quadrantids 2021

Mike Otte

Pearl City, IL, USA
mike.otte96@gmail.com

A report is presented on the radio observations of the Quadrantids meteor shower. Peak activity occurred at January 3, 11^h UT or solar longitude 283.00° and a possible second peak on January 3, 19^h UT. Activity was so great as to provide almost a continuous reflection for several hours.

1 Introduction

Radio meteor data interpretation is an inexact science. The direction of the antenna, the power of the transmitter, nature of the signal (analog or digital carrier), direction of the radiant, where you are relative to the rotation of the Earth and many other things influence your echo counts and meteor rates. Yet if we understand some of these spoilers of data, we can get some useful information out of the numbers.

I have been collecting Radio Meteor data for a couple decades. The collection setup has changed through the years from FM car radio to a ham transceiver to a rtl/sdr usb stick presently. I use DL4YHF's Spectrum Lab to detect and count the meteors. Currently I use a Canadian analog TV station on TV channel 3 at a frequency of 61.259.500 Mhz.

My antenna is a 5 element Yagi pointing south and at a 45° elevation mounted on a wooden post with the reflector element inches from the ground. Aiming the antenna is not like ham radio's "higher the better". Keep it low. This minimizes any direct signal. I demonstrate at star parties with a wire dipole on 3 "electric fence" fiberglass supports about 30 inch off of the ground. I rotate the beam for minimum interference and no continuous carriers. J.S. Hey using radar after WWII said to aim the antenna perpendicular to the meteor's path. So, the transmitted signal bounced back to his receiver and was detected. My case is more a compromise orientation because I am using someone else's transmitter. So, the angles will be more shallow and usually will not be directly aimed toward the transmitter.

2 Method

My receiver is a Nooelec NESDR smart with a TV preamplifier. The sdr was not as sensitive as the ham radio transceiver before it. The program is SDR#.

Spectrum Lab is an audio spectrum analyzer that has the ability to run scripts that tell the program where to look (frequency or range of frequencies), what amplitude to trigger events, it can time the events, log the events, record the audio, and take snapshots of the screen. It does this 24/7/365 except when Gremlins hit. Power outages and SDR# quitting plague me.

Every hour, Colorgramme RMOB by Pierre Terrier reads the data file recorded by SpecLab and makes it into little colored squares representing the counts per hour. Then it sends them into RMOB.org for display to the world wide web.

The data I record hourly is: meteor counts, meteor counts lasting > 2 sec, accumulated refection time during the hour, meteor counts below the carrier, meteor counts lasting >2 sec below carrier, accumulated reflection time. This second set of data below the carrier is usually not very active but during showers it must have additional stations that it detects.

3 Results

Here we can see a nice representation of the Quadrantid meteor shower. It actually started a couple days before and lasted a couple days beyond which is "sharp" for meteor showers.

I am assuming you know about "diurnal variation" which is the rotation of the Earth that hides you from the meteors during the evening, accelerates you into the stream during the early morning, and holds you in the stream during the day till evening again. This "diurnal variation" is a good indication of valid data. Because of my position on the Earth, I should have a good view of the peak of this shower.

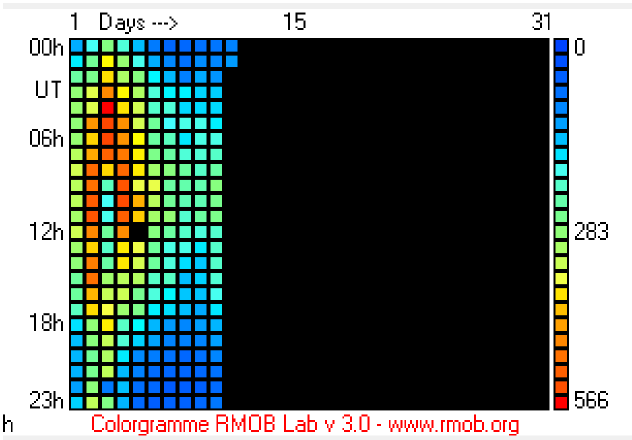

Figure 1 – January 2021 RMOB Colorgramme chart for Mike Otte's data.

So, the glaring bad data is on day 3, between 8^h and 14^h. Time is in UT (Universal time). I live a few miles before the 90° west meridian, so day break is about 12h00m UT or 6am local. Why is the peak of the shower showing low counts indicated by the light blue squares? So, I am counting in a band of frequencies about 200hz near the carrier. There are so many counts that they over lap and give a continuous reflection like if these are one.

In *Figure 2* you can see how crazy the meteors were. The numbers on the screenshot with a comma in are the meteor counts and the duration (rough time in sec, loops in the program). I take a screenshot at the end of the hour so I can recreate the data in case it forgets to reset counts sometimes. Along the right side, you see the effective reflection time for that hour (here again it is approximate).

Another problem on the Colorgramme chart is the blue square on day 3 hour 22. This was a software shutdown of the SDR# program for no apparent reason.

The third problem on the Colorgramme chart is in the 5th day 12th hour when we had a power outage because they were deicing the power lines.

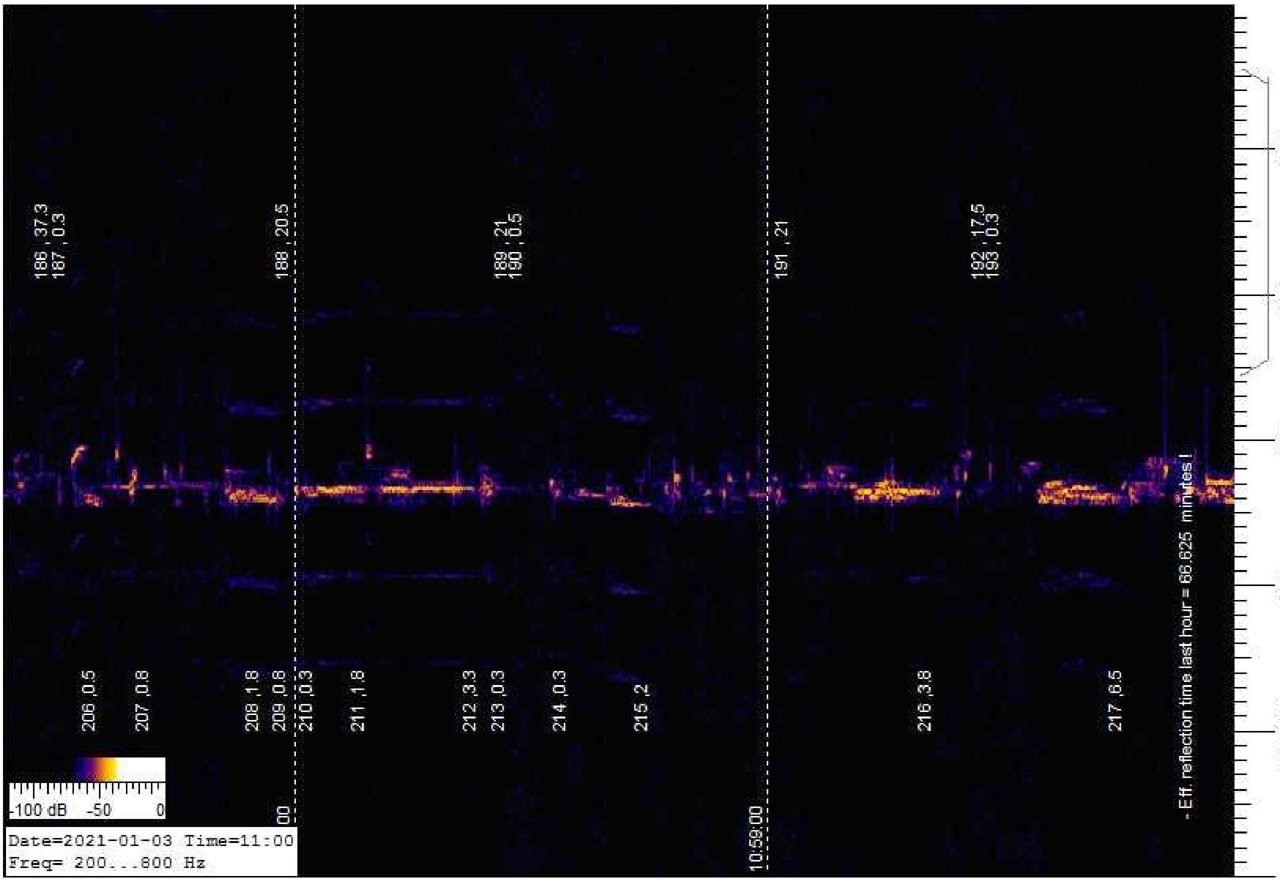

Figure 2 – This is a screen shot of Spectrum Lab at 11h00m UT showing almost continuous reflection.

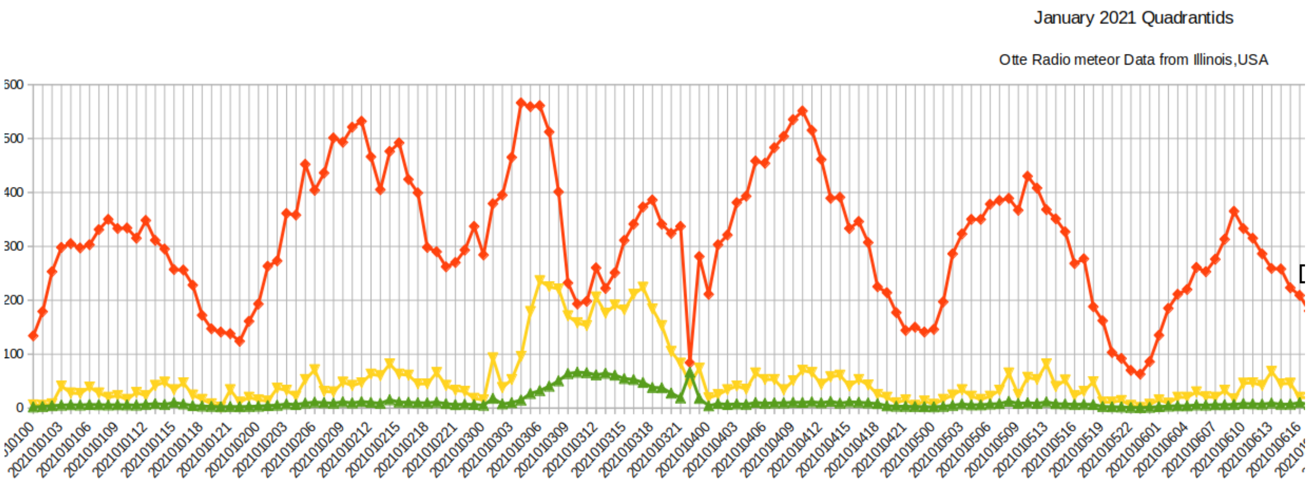

Figure 3 – January 2021 Quadrantids Radio Meteor Data.

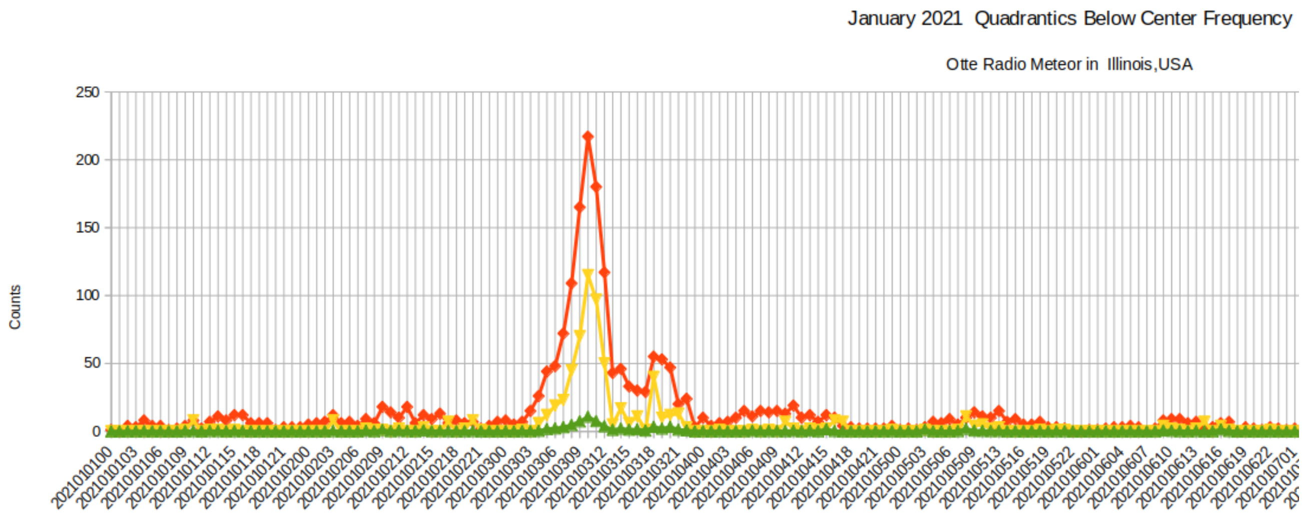

Figure 4 – January 2021 Quadrantid Radio Meteor Data looking at the 200 hz band below.

So now let's look at the data on line charts and see if we can locate the peak better. Looking at *Figure 3,* the green line (refection time in minutes/hour) shows the peak but again it is flat topped with maybe two peaks that are more apparent in the numeric data. Disregard the "teepee" on the mountain. That was the SDR# quitting. The red line represents the counts and the yellow shows the counts over 2 sec long. Neither looks useful here at this time. They dipped when they should be peaking.

In *Figure 4* is the data that I normally do not submit. These are the counts in a 200 hz band below the carrier frequency where there may be other transmitters.

I hardly ever look at this data because usually there aren't many counts. Here though, it looks like I have a clear peak at 11^h00^m UT ($\lambda_{\odot}$ = 283.00°) and a smaller second peak at 19^h00^m UT ($\lambda_{\odot}$ = 283.34°). There are two inflections on the main peak which may indicate "strands" and the second peak has a small increase after it too. This indicates the meteoroid stream is not homogeneous. So, the narrow peak is about 7 hours wide and the Earth travels this distance: 7 hours × 108000 km/h = 756000 kilometers.

Looking back on *Figure 3*, you could think that during the peak when the counts should be going up they actually go down. In this inverted world the deepest valley should be the highest peak and this valley lines up with the results from *Figure 4*.

4 Conclusion

Radio Meteor Astronomy is a nice pastime that allows one to "see" meteors during the day and when it is cloudy in addition to night time. Living in the Midwest US, 60% of the days are cloudy. I submit data hoping some scientists can make use of it.

The Quadrantids is one shower that I think I have not seen any meteors from visually. Winter is cold and cloudy here. It is a stream of debris that Earth bumps into every year. As we get closer to space travel again, knowing where the debris lies will help us avoid it.

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Quadrantids 2021 with Worldwide Radio Meteor Observations

Hiroshi Ogawa[1] and Hirofumi Sugimoto[2]

[1] h-ogawa@amro-net.jp

[2] **The Nippon Meteor Society**
hiro-sugimoto@kbf.biglobe.ne.jp

Worldwide Radio Meteor Observations recorded strong Quadrantid activity in 2021. The strong peak was observed at $\lambda_\odot$ = 283.11°. This peak was twice as strong as in previous years. The other sub-peak occurred at $\lambda_\odot$ = 282.77°. It is possible that the estimated ZHR_r reached a value of over 200 during the time bin $\lambda_\odot$ = 282.0°–283.1°.

1 Introduction

Worldwide radio meteor observation data were provided by the Radio Meteor Observation Bulletin (RMOB)[15] (Steyaert, 1993) and by the radio meteor observation network in Japan (Ogawa et al., 2001). Radio meteor observations are possible even with bad weather and during daytime.

2 Method

For analyzing the worldwide radio meteor observation data, the meteor activity is calculated by the "Activity Level" index (Ogawa et al., 2001). The activity profile was estimated by the Lorentz activity profile (Jenniskens et al., 2000). Besides of this analysis, also the Zenithal Hourly Rates were estimated (Sugimoto, 2017).

3 Results

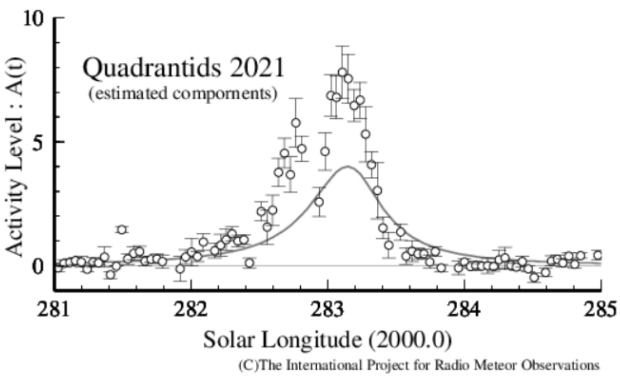

Figure 1 – The Activity Level Index by radio meteor observations from all over the world (the line is the average obtained for the period of 2001–2020).

Figure 1 shows the result for the Quadrantids 2021 based on the calculations with the Activity Level Index. The line represents the average for the period of 2001–2020. The higher activity was very distinct compared with past returns. The maximum activity level was estimated 7.8 ± 1.1 at $\lambda_\odot$ = 283.11° (January 3, 13^h UT). The other peak was detected at $\lambda_\odot$ = 282.77° (January 3, 5^h UT) with an Activity Level = 5.8 ± 1.0. *Table 1* shows the results around the peak value.

Figure 2 shows the detailed Quadrantid 2021 activity structure with the two components separated using the Lorentz activity profile (Jenniskens, 2000). One component (Comp. 1) has a peak activity level of 7.5 at $\lambda_\odot$ = 283.11° (January 3, 13^h UT) with full width half maximum (FWHM) –3.5 / +4.5 hours. The other component (Comp. 2) reached an activity level of 4.0 at $\lambda_\odot$ = 282.77° (January 3, 5^h UT) with full width half maximum (FWHM) –4.0 / +1.5 hours (see *Table 2*).

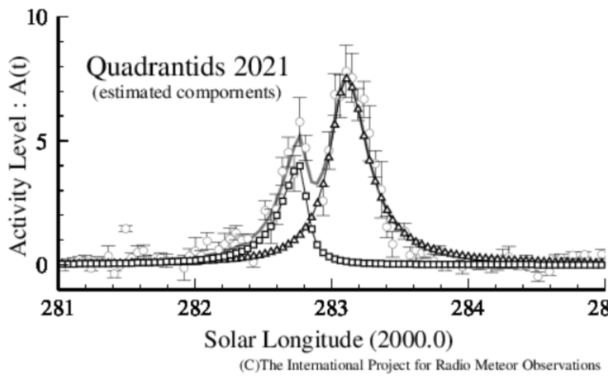

Figure 2 – Estimated components using the Lorentz profile. The curve with triangles represents Comp. 1, the curve with the squares is Comp. 2. The black line represents Comp. 1 and Comp. 2 combined. The circles with error margins are the Quadrantids observed in 2021.

4 Discussion

4.1. Estimated *ZHR$_r$*

The Zential Hourly Rate (ZHR_r), on the other hand, was estimated by using the Radio Meteor Observations (*Figure 3*). Peak times occurred at January 3, 11^h ($\lambda_\odot$ = 283.02°), and 5^h ($\lambda_\odot$ = 282.77°). The estimated ZHR_r reached 278 ± 21 and 125 ± 9. Since the peak ZHR_r was too

[15] http://www.rmob.org/

strong, it needs to be compared with visual and video observations in the future.

4.2 Strong activities

Quadrantids sometimes showed a strong activity. During the analyzed period (2001–2021), such strong activities were recorded in 2002, 2004, 2014, 2016, 2019 and 2021 (Ogawa and Steyaert, 2017). *Figure 4* shows the result of the four recent strong activities with the peak activity level. Although there were not enough data in 2002 and 2004, strong activities occurred at $\lambda_O = 283.31°$ and $\lambda_O = 283.13°$. The sub-peak observed at $\lambda_O = 282.77°$ in 2021 was also present in 2008 ($\lambda_O = 282.72°$), 2011 ($\lambda_O = 282.88°$), 2019 ($\lambda_O = 282.91°$) and 2020 ($\lambda_O = 282.52°$). It needs to be discussed what caused these two characteristics.

Table 1 – The Activity Level Index around the peak time, $Av_{01–20}$ means the average for the period of 2001–2020.

Date (UT)	λ_O	ActivityLevel	$Av_{01–20}$	Date (UT)	λ_O	ActivityLevel	$Av_{01–20}$
Jan.2, 12^h	282.046°	0.4±0.2	0.4	Jan.3, 12^h	283.065°	6.8±0.9	3.8
Jan.2, 13^h	282.089°	1.0±0.3	0.4	Jan.3, 13^h	283.108°	7.8±1.1	3.9
Jan.2,15^h	282.173°	0.6±0.3	0.5	Jan.3, 14^h	283.150°	7.5±1.0	4.0
Jan.2,16^h	282.216°	0.8±0.4	0.5	Jan.3, 15^h	283.193°	6.5±0.6	3.9
Jan.2,17^h	282.258°	1.1±0.4	0.5	Jan.3, 16^h	283.235°	6.7±0.7	3.7
Jan.2,18^h	282.301°	1.3±0.3	0.6	Jan.3, 17^h	283.277°	5.3±1.1	3.4
Jan.2,19^h	282.343°	1.0±0.2	0.6	Jan.3, 18^h	283.320°	4.1±0.5	3.0
Jan.2,20^h	282.386°	1.1±0.2	0.7	Jan.3, 19^h	283.362°	3.0±1.1	2.7
Jan.2,21^h	282.428°	0.1±0.2	0.8	Jan.3, 20^h	283.405°	1.5±0.4	2.3
Jan.2,23^h	282.513°	2.2±0.4	0.9	Jan.3, 21^h	283.447°	0.8±0.5	2.0
Jan.3,00^h	282.556°	1.6±0.7	1.0	Jan.3, 23^h	283.532°	1.4±0.3	1.5
Jan.3,01^h	282.598°	2.2±0.6	1.1	Jan.4, 00^h	283.575°	0.4±0.3	1.3
Jan.3,02^h	282.641°	3.8±0.6	1.3	Jan.4, 01^h	283.617°	0.6±0.4	1.2
Jan.3,03^h	282.683°	4.5±0.6	1.4	Jan.4, 02^h	283.660°	0.5±0.2	1.0
Jan.3,04^h	282.725°	3.7±0.7	1.6	Jan.4, 03^h	283.702°	0.5±0.2	0.9
Jan.3,05^h	282.768°	5.8±1.0	1.8	Jan.4, 04^h	283.745°	0.2±0.3	0.8
Jan.3,06^h	282.810°	4.7±0.5	2.1	Jan.4, 05^h	283.787°	0.6±0.2	0.7
Jan.3,09^h	282.938°	2.6±0.6	2.9	Jan.4, 06^h	283.829°	–0.1±0.1	0.7
Jan.3,10^h	282.980°	4.6±0.8	3.2	Jan.4, 09^h	283.957°	–0.1±0.3	0.5
Jan.3,11^h	283.023°	6.9±0.8	3.5	Jan.4, 10^h	283.999°	0.2±0.2	0.4

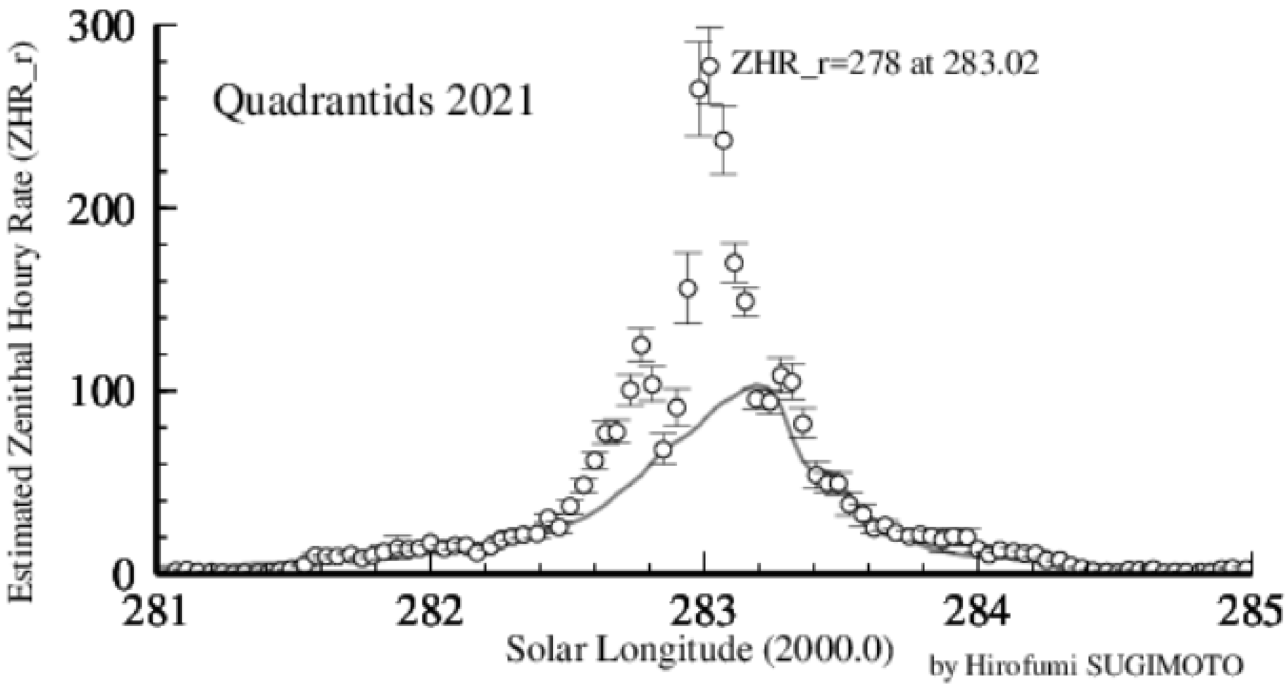

Figure 3 – The estimated ZHR_r (the solid line represents the average for the period of 2004–2020).

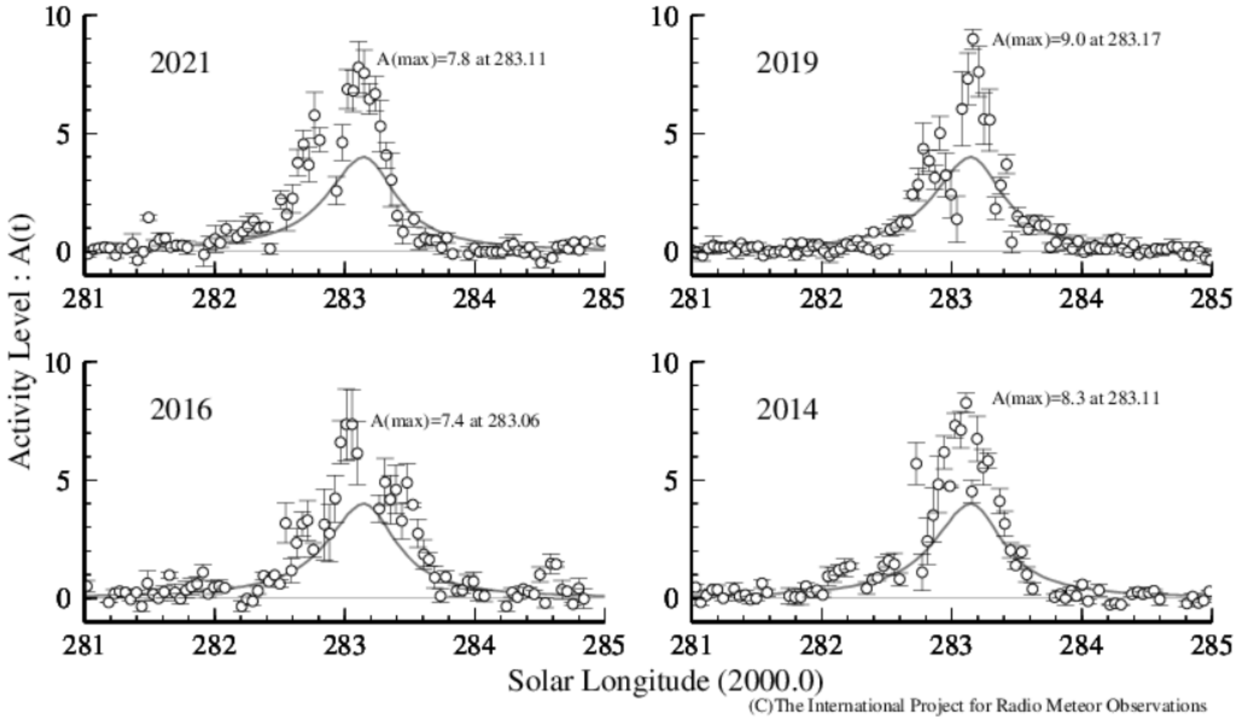

Figure 4 – Strong Quadrantid actitivities in 2014, 2016, 2019 and 2021 (the solid line represents the average for the period of 2001–2020).

Table 2 – The estimated components of the Quadrantids 2021 (annual represents the average for the period of 2001–2020).

Comp.	Maximum (UT)	$\lambda_{\odot}$	Activity Level	FWHM (hours)
Comp. 1	Jan.3, 13^h	283.11°	7.5	–3.5 / +4.5
Comp. 2	Jan.3, 05^h	282.77°	4.0	–4.0 / +1.0
Annual	Jan.3, 14^h	283.15°	4.0	–8.0 / +7.0

Acknowledgment

The Quadrantids 2021 data were provided by the following observers: *Chris Steyaert* (Belgium), *Felix Verbelen* (Belgium), *Johan Coussens* (Belgium), *ALFAPCE-R0* (Czech Republic), *DDMTREBIC-R3* (Czech Republic), *FLZ-R0* (Czech Republic), *HFN-R1* (Czech Republic), *OBSJAROMER-R5* (Czech Republic), *OBSUPICE-R6* (Czech Republic), *ZEBRAK-R5* (Czech Republic), *ZVPP-R7* (Czech Republic), *Cousin Marie-Helene* (France), *Daniel D SAT01_DD* (France), Jean Marie F5CMQ (France), *WHS Essen* (Germany), *Per DL0SHF* (Germany), *Balogh Laszlo* (Hungary), *Istvan Tepliczky* (Hungary), *Fabio Moschini IN3GOO* (Italy), *GAML Osservatorio Astronomico Gorga* (Italy), *Mario Bombardini* (Italy), *Hirofumi Sugimoto* (Japan), *Hironobu Shida* (Japan), *Hirotaka Otsuka* (Japan), *Kenji Fujito* (Japan), *Masaki Kano* (Japan), *Masaki Tsuboi* (Japan), *Nobuo Katsura* (Japan), *Tomohiro Nakamura* (Japan), *Salvador Aguirre* (Mexico), *Juan Zapata* (Mexico), *Rainer Ehlert* (Mexico), *Kees Meteor* (Netherlands), *Rafael Martinez* (Puerto Rico), *Karlovsky Hlohovec Observatory* (Slovakia), *Jose Carballada* (Spain), *Jochen Richert* (Switzerland), *Bill Ward* (UK), *Ian Evans* (UK), *Philip Norton* (UK), *Simon Holbeche* (UK), *Mike Otte* (USA), *Stan Nelson* (USA).

The worldwide data were provided by the Radio Meteor Observation Bulletin (RMOB).

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Radio observations in December 2020

Ivan Sergei

Mira Str.40-2, 222307, Molodechno Belarus
seriv76@tut.by

This article presents the results of radio observations in December 2020, as well as a study of the activity of the Geminids by the Canadian orbital radar CMOR.

1 Introduction

The observations were carried out at a private astronomical observatory near the town of Molodechno (Belarus) at the place of Polyani. A 5 element-antenna directed to the west was used, a car FM-receiver was connected to a laptop with as processor an Intel Atom CPU N2600 (1.6 GHz). The software to detect signals is Metan (author – Carol from Poland). Observations are made on the operating frequency 88.6 MHz (the FM radio station near Paris broadcasts on this frequency). The "France Culture" radio broadcast transmitter (100 kW) I use is at about 1550 km from my observatory; It has been renewed in 1997.

The purpose of the radio observations was to monitor the activity of the main meteoroid streams, to patrol the outburst activity of the Ursid meteor shower and to check the activity of the sporadic background meteors. Listening to the radio signals 1 to 3 times a day for one hour was done in order to control the level of the hourly activity, as well as to distinguish between periods of tropospheric passage and other natural radio interference.

2 Geminids (GEM#0004)

The Geminid peak activity occurred between 21^h and 22^h UT on December 13, 2020, with hourly numbers of up to 240 echoes. Also, high flux activity was recorded in the interval 6^h–7^h UT on December 13. My results agree well with the IMO Meteor Calendar (Rendtel, 2020) which indicated that the peak flux activity was expected between December 13, 08^h UT and December 14, 08^h UT. The maximum number of meteor echoes heard at maximum was up to 330 echoes per hour. Since the radio method captures fainter meteors than the visual method, the peak is a day earlier than the traditional visual maximum (fainter particles encounter the Earth earlier than larger particles). *Figure 1* Shows the maximum of minor meteor showers in black, medium activity showers in blue, variable activity showers in green and the major meteor shower in red.

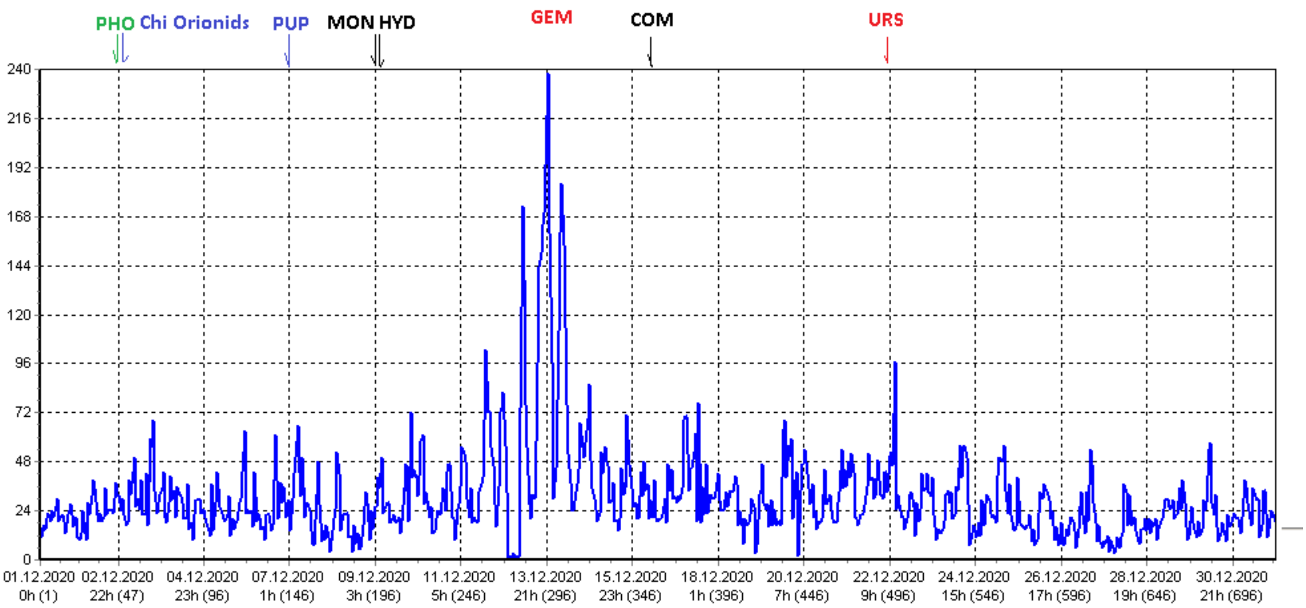

Figure 1 – Radio meteors echo counts at 88.6 MHz for December 2020.

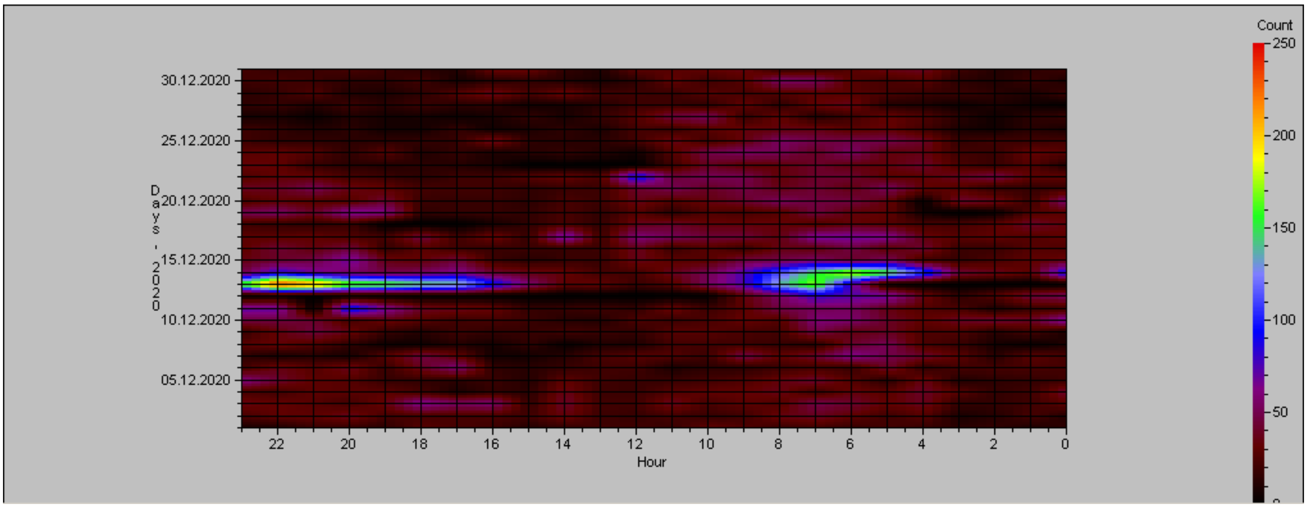

Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for December 2020.

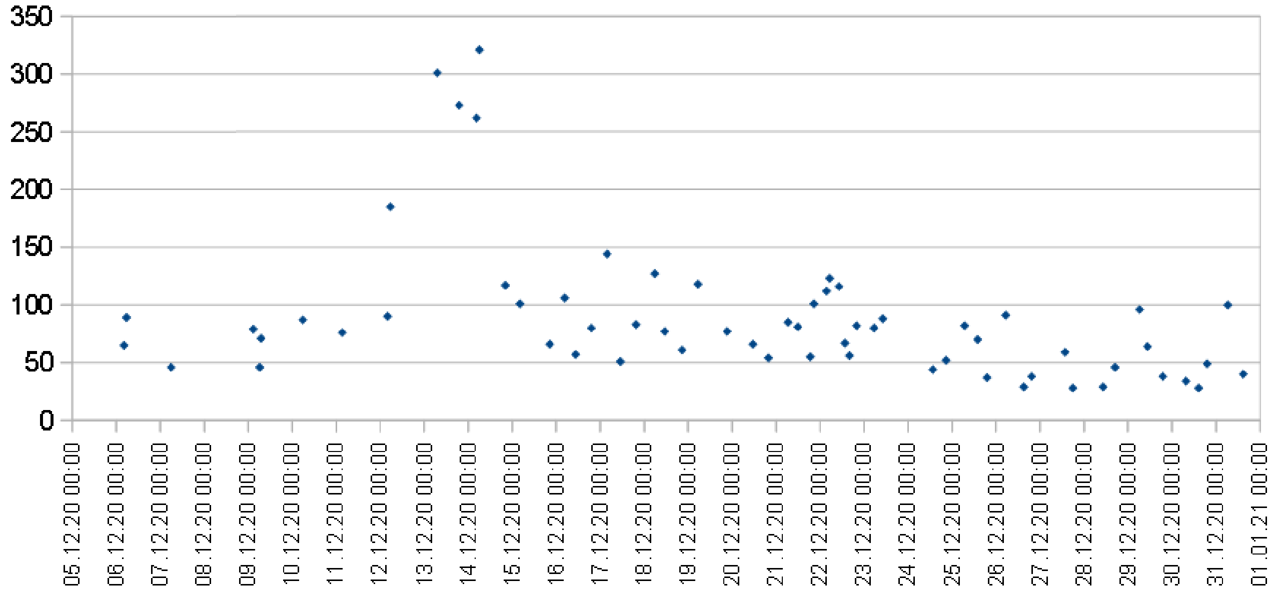

Figure 3 – The result with the calculated hourly numbers of echoes of meteors by listening to the radio signals for December 2020.

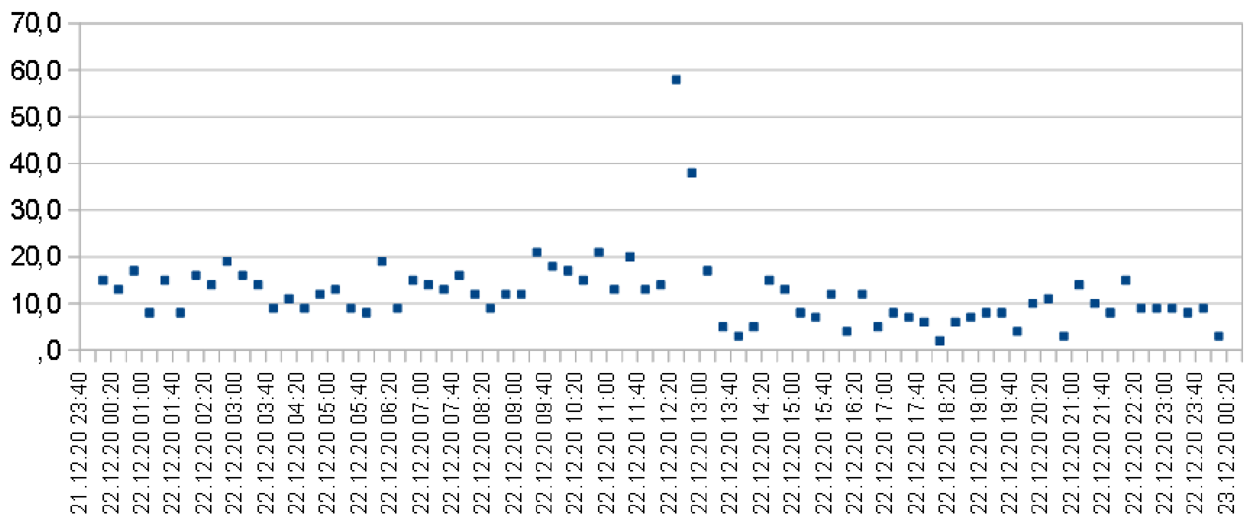

Figure 4 – Number of meteor echoes at 20-minute intervals on December 22, 2020 from automatic radio observations.

3 Ursids (URS#0015)

The Ursid meteoroid stream is one of the major showers at the end of the year in the month of December. For 2020, there were some dust trail encounters predicted based on the calculations by J. Vaubaillon, P. Jenniskens, E. Lyytinen and M. Sato for the period of December 22 03^h – 22^h (UT). (Rendtel, 2019).

The Ursid (#0015) maximum was recorded at 11^h30^m–12^h30^m UT ($\lambda_O = 270.80°$ to $270.84°$) on December 22, which agrees well with the predicted data. The hourly number of radio echoes heard was up to 150 per hour, while the one recorded by the Metan program was about 100 signals. This can be explained by the fact that the method by listening allowed to hear more very weak echoes, which cannot be registered by the program because of the settings for the threshold of triggering. If you reduce the threshold for the detection of music and speech signals, the program starts to record false detections, thus distorting the real picture of what is happening in the radio atmosphere. The threshold in the Metan program is set optimally as a result of many years of experimental observations. The total amount of time listening for meteor echoes in December was 62 hours.

4 Fireballs

For the fireball activity statistics, I have selected signals from the log-files with a peak power of less than 10000 as being fireballs. Signals with a peak power of less than 10000 are an overlap of the echoes of one or two neighboring FM station, which results in random triggers in the Metan program.

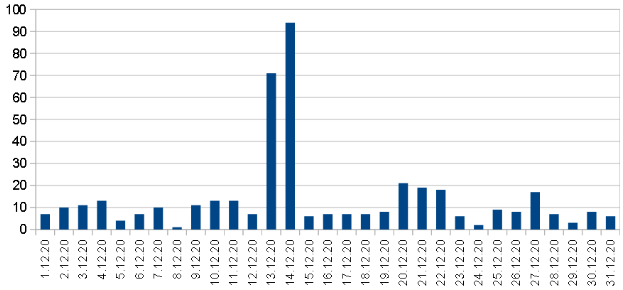

Figure 5 – Daily activity of radio fireballs in December 2020.

Table 1 shows a list of the most powerful radio fireballs signals with Max > 30000, which were registered at night.

Table 1 – List of the most powerful radio fireball signals with Max > 30000 in December 2020. Bck: Background signal level, Thr: Radio signal triggering (detection) threshold, L: signal duration (sec.), A: amplitude signal power, Max: peak signal level, Noise: noise level.

Date and Time		Bck	Thr	L	A	Max	Noise
10.12.2020	$23^h01^m19^s$	8083	3000	119.38	271004	35232	1270
11.12.2020	$05^h58^m26^s$	6477	3000	15.08	80773.6	34389	1225
13.12.2020	$23^h22^m52^s$	9030	3000	22.18	118067	31258	1817
14.12.2020	$02^h31^m07^s$	8224	3000	9.78	49966.7	38715	2381
14.12.2020	$16^h19^m26^s$	8988	3000	22.98	156795	34868	4370
14.12.2020	$19^h42^m53^s$	8387	3000	13.98	44261	31884	3447
16.12.2020	$01^h00^m22^s$	10072	3000	35.66	169522	33088	2221
16.12.2020	$04^h31^m11^s$	9992	3000	16.54	194551	30689	870
21.12.2020	$05^h39^m23^s$	8444	3000	12.28	74019.8	31289	1915
22.12.2020	$04^h09^m56^s$	6925	3000	15.48	54248.3	32469	813
23.12.2020	$02^h31^m42^s$	8298	3000	14.88	65045.1	35442	853
26.12.2020	$04^h05^m32^s$	9382	3000	13.02	118174	30849	1142
28.12.2020	$19^h04^m54^s$	7171	3000	18.28	102208	36636	3256
30.12.2020	$00^h35^m44^s$	8369	3000	12.26	86668.6	30255	2258
30.12.2020	$01^h30^m45^s$	8431	3000	10.68	70792.4	33978	3275

5 Geminids from CMOR data

The images were analyzed by CMOR radar (Brown, 2005) data, the images were stored several times during the day. The *SNR* value determined by the MaximDL photometry software with correction modifications (R, Y, G) was used to determine the activity level. A manual search was performed to detect the most optimal *SNR* value. *SNR* values were obtained by moving the cursor over the radiant image on the radar maps. General formula for calculating the shower activity level: $SNR_{act} = SNR_1 + R + Y + G$, where SNR_1 is the total *SNR* level of the white and pink radiant area, *R* is the size in pixels of the radiation area on the radar maps, marked in red, *Y* is the size in pixels of the radiation area, marked in yellow on the radar maps, *G* is the size in pixels of the radiation area, marked in green on the radar maps.

The maximum flux activity is recorded between 11^h on December 13 and 9^h on December 14, which is slightly earlier than the calculated time of the peak activity. This can be explained by the fact that radar observations are more sensitive and the Earth first crosses a region of smaller particles. A dual radiant flux structure appeared in late November, merging into a single radiant on December 5.

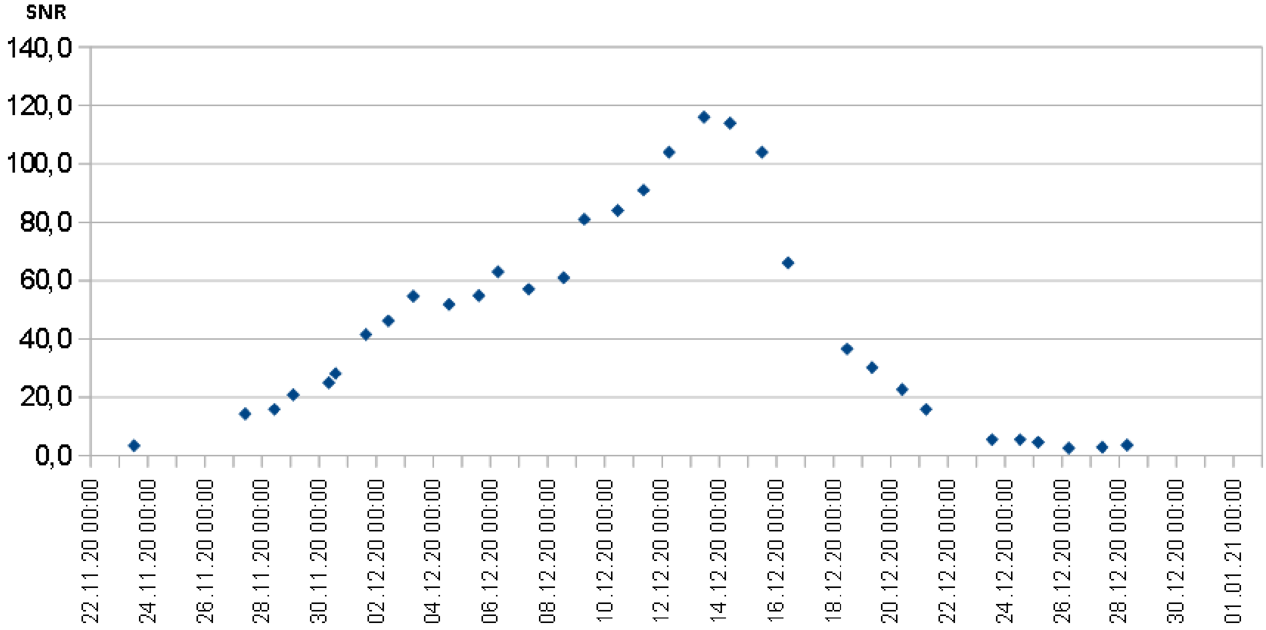

Figure 6 – The Geminid activity according to CMOR. (Signal-to-Noise Ratio – *SNR* is defined as the ratio of signal power to the background noise power).

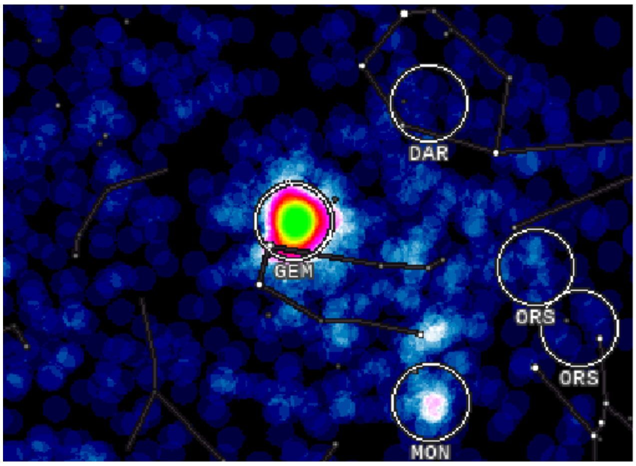

Figure 7 – The Geminid radiant position 14 December 2020 09h15^m UT according to CMOR.

Acknowledgment

I would like to thank Sergey Dubrovsky for the software they developed for data analysis and processing of radio observations, the team of the CMOR radar for making their observations public available. I thank Karol from Poland for the Metan software. I thank Jean-Louis Rault for the information about the FM transmitter in France. Thanks to Paul Roggemans for his help in the lay-out and the correction of this article.

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Radio observations in January 2021

Ivan Sergei

Mira Str.40-2, 222307, Molodechno Belarus
seriv76@tut.by

This article presents the results of radio observations made in January 2021. The results of the radio observations are compared with the CAMS video network summaries.

1 Introduction

The observations were carried out at a private astronomical observatory near the town of Molodechno (Belarus) at the place of Polyani. A 5 element-antenna directed to the west was used, a car FM-receiver was connected to a laptop with as processor an Intel Atom CPU N2600 (1.6 GHz). The software to detect signals is Metan (author – Carol from Poland). Observations are made on the operating frequency 88.6 MHz (the FM radio station near Paris broadcasts on this frequency). "The "France Culture" radio broadcast transmitter (100 kW) I use is at about 1550 km from my observatory which has been renewed in 1997.

The purpose of the radio observations was to monitor the activity of the main meteor streams to patrol the activity of the Quadrantid meteor shower, and to check the activity of the sporadic background meteors. Listening to the radio signals 1 to 3 times a day for one hour was done in order to control the level of the hourly activity, as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 83 hours. In order to quickly search for signals of the radio fireballs, the program SpectrumLab was running in parallel to the Metan program.

2 Quadrantids (QUA#0010)

Peak Quadrantid activity was recorded at the 11^h–14^h UT interval with hourly signal numbers of 250, which corresponds well to the 2021 Meteor Shower Calendar data (Rendtel, 2020). My result agrees well with the IMO data. According to IMO data[16], a high peak activity was observed from about 12^h to 16^h UT on January 3. Unfortunately, the IMO has no data on flux activity within that time interval.

The hourly numbers while listening to the radio echoes were as high as 600 signals. This can be explained by the fact that the human ear is a more sensitive organ in terms of detecting weak signals at the limit of recognition, which the software cannot detect. My numerous experiments with reducing the trigger threshold for the Metan software in order to better detect weak and very weak signals were not successful – the software detects false alarms. In this regard, a certain trigger for musical-speech signals of meteors was found and set experimentally. *Figure 1* Shows the maximum of minor meteor showers in black, medium activity showers in blue, variable activity showers in green and the major meteor shower in red.

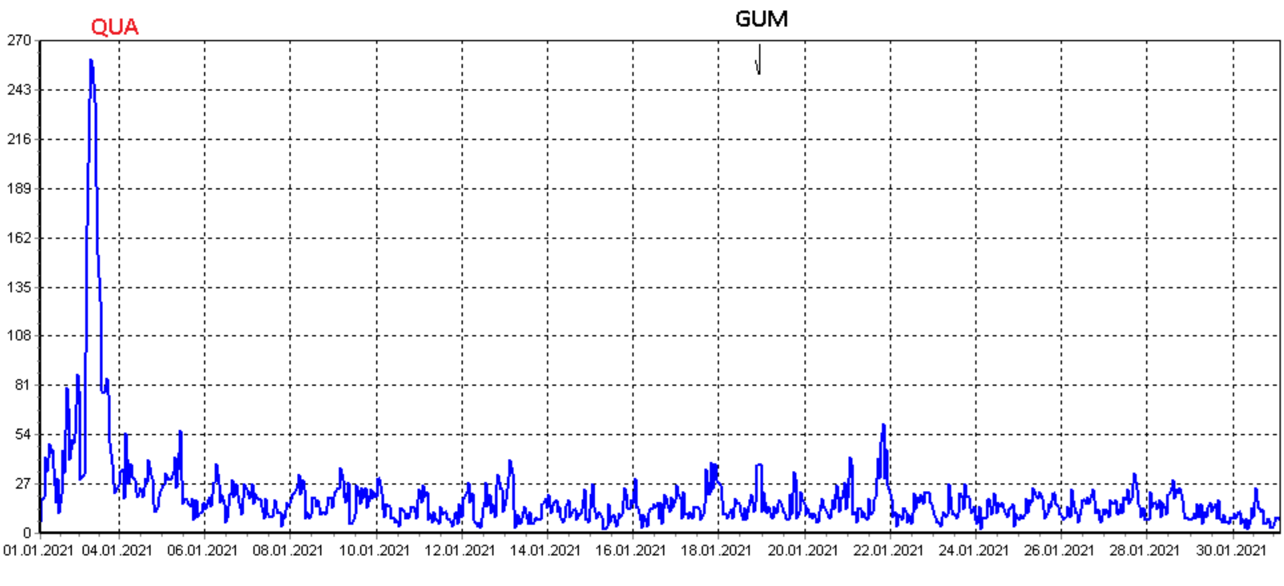

Figure 1 – Radio meteor echo counts at 88.6 MHz for January 2021.

[16] https://www.imo.net/members/imo_live_shower/summary?show=QUA&year=2021

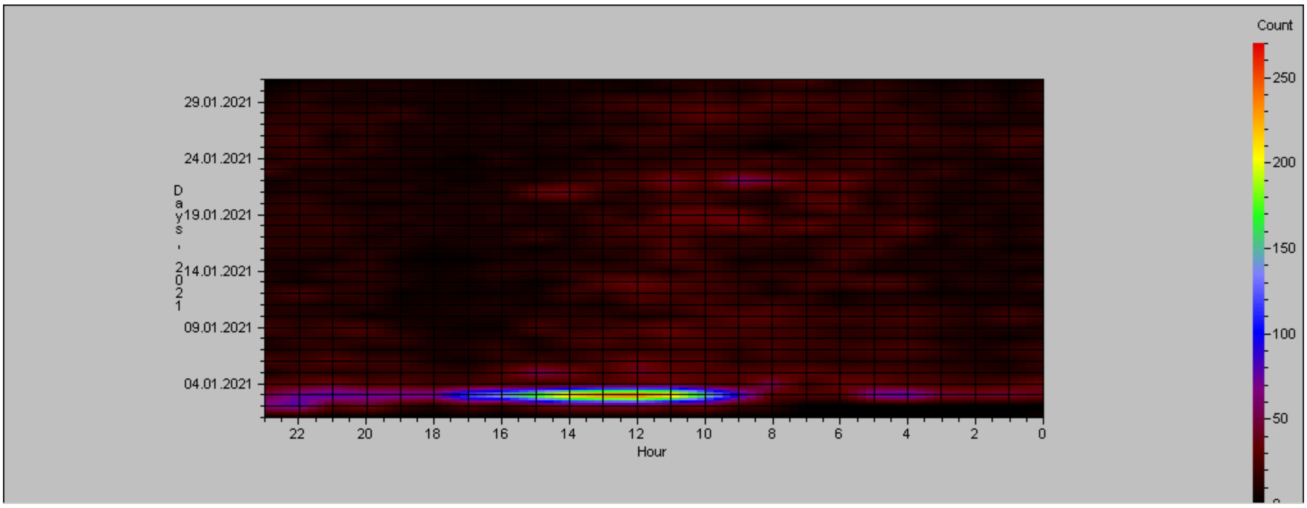

Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for January 2021.

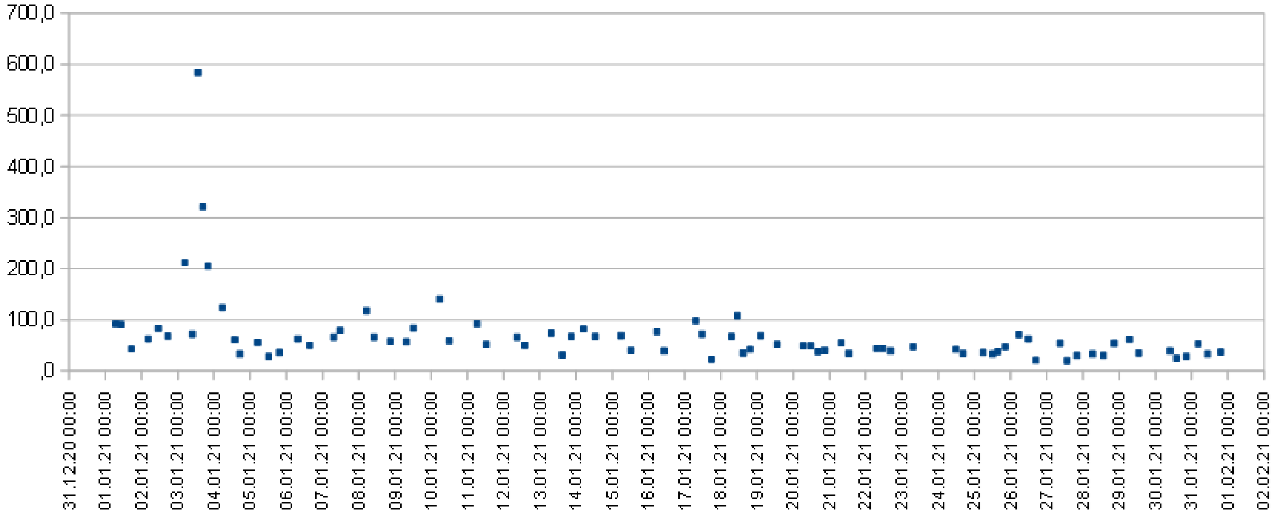

Figure 3 – The result with the calculated hourly numbers of meteor echoes by listening to the radio signals for January 2021.

It was not possible to isolate the peak of the low gamma Ursae Minorids (GUM#0404) activity in a reliable way. Some increase in signal activity has been observed around January 18 while listening to the meteor echoes and on January 22 when echoes were automatically being detected. On January 10, I counted an increased level of hourly echo activity (140), while the background level of activity was between 30–45 signals. My observations are confirmed by the CAMS video network, which shows an increase in shower meteor and sporadic meteor activity not only on January 10, but also on January 11 (*Figure 4*).

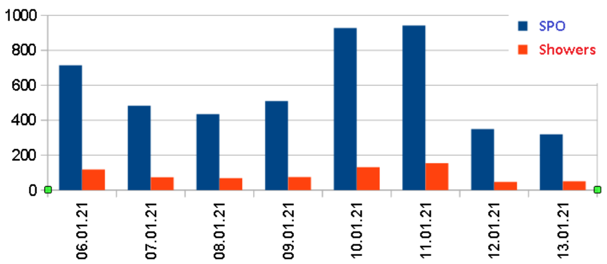

Figure 4 – Daily meteor activity according to CAMS video networks in January 2021.

The graph of the radio echo activity shows that the activity of radio signals decreased after January 19. My observations are confirmed by data from the CAMS video networks, showing a decrease in the meteor shower activity and sporadic background after January 19.

3 Fireballs

For fireball activity statistics, I have selected signals from the log files with a peak power greater than 10000 as fireballs and with a signal duration greater than 10 seconds. Some correlation between the radio fireballs and CAMS video meteor activity is noticeable. From the graph we can conclude that the large meteoroid particles that produce radio bolides are distributed very irregularly in space.

Acknowledgment

I would like to thank Sergey Dubrovsky for the software they developed for data analysis and the processing of radio observations (software Rameda). I thank Carol from Poland for the Metan software. Thanks to Paul Roggemans for his help in the lay-out and the correction of this article.

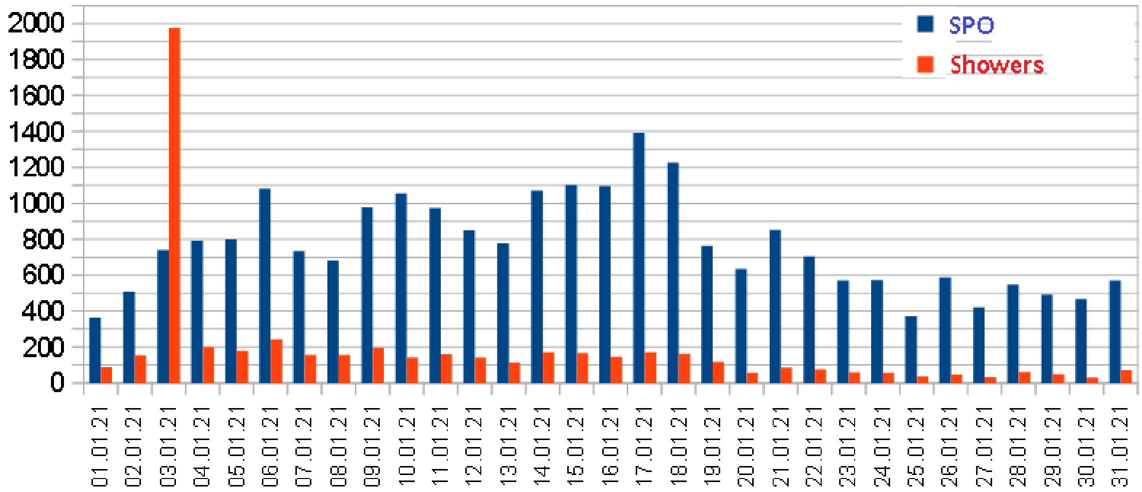

Figure 5 – Daily video meteor activity in January 2021 according to CAMS video networks.

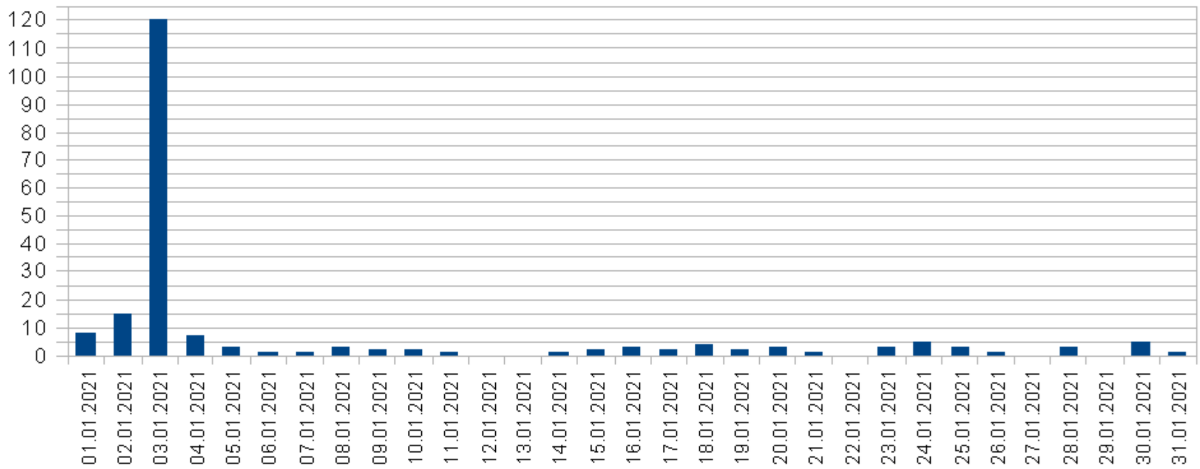

Figure 6 – Daily activity of radio fireballs in January 2021.

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Radio meteors December 2020

Felix Verbelen

Vereniging voor Sterrenkunde & Volkssterrenwacht MIRA, Grimbergen, Belgium
felix.verbelen@skynet.be

An overview of the radio observations during December 2020 is given.

1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of "all" reflections counted automatically, and of manually counted "overdense" reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of December 2020.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference and unidentified noise remained low for most of the month, and no lightning activity was detected, but there was an interruption of the beacon signal for about two hours on December 28th; the missing data were taken into account as accurately as possible on the basis of the observations on 49.97 MHz (BRAMS beacon at Dourbes/BE).

The eye-catchers this month were of course the Geminids in the period December 11th-15th and the Ursids on December 20th-22nd. In both cases the intensity increased rather gradually and quickly disappeared after the maximum.

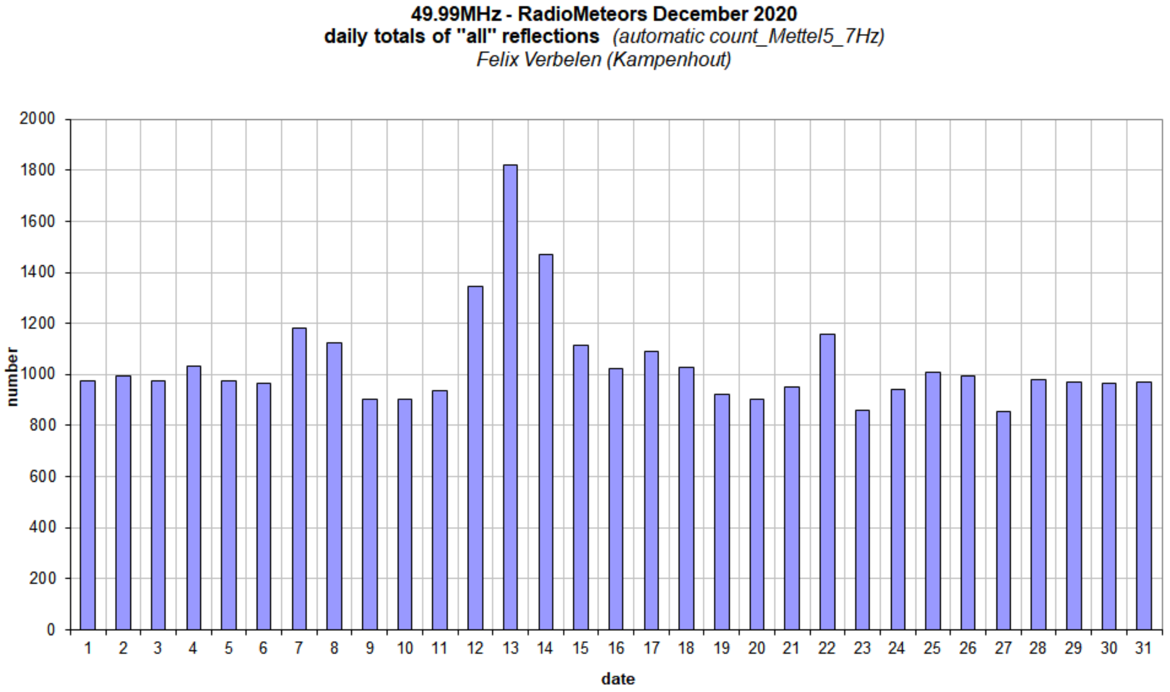
A few screenshots at the time of the Geminids' maximum are included (*Figures 5, 6 and 7*).

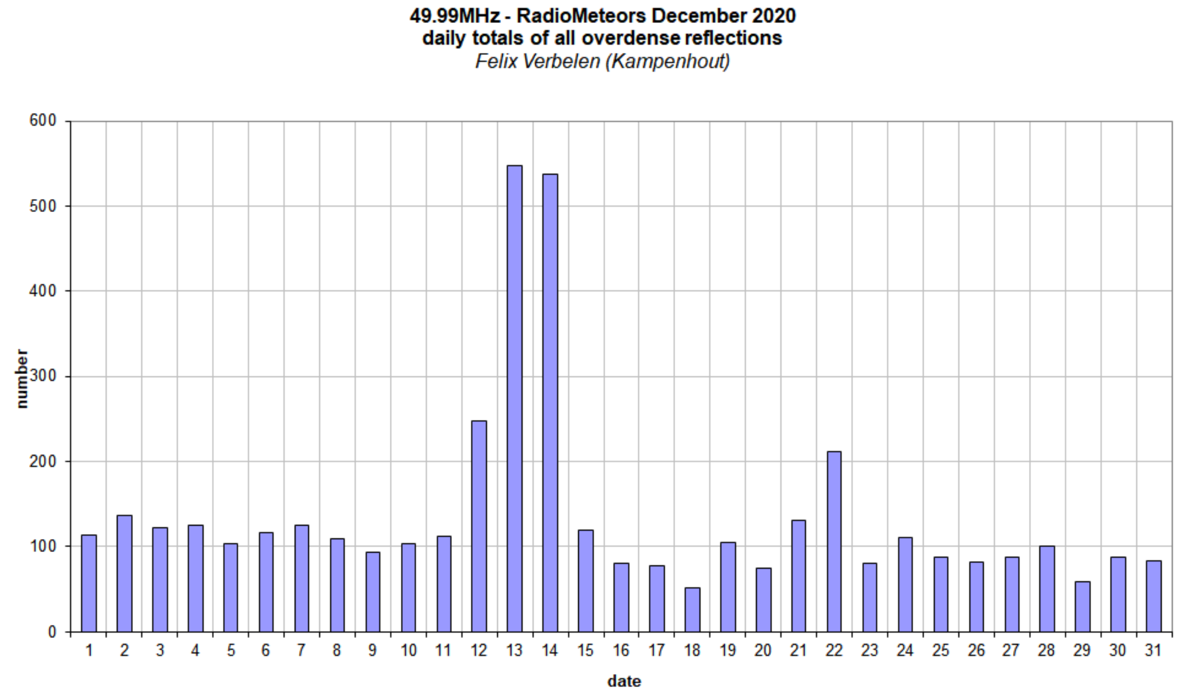
Especially during the first days of the month, but also at other times the activity of smaller meteor showers was clearly noticeable, but reference is made to the raw counts for this.

This month, only 7 reflections of more than 1 minute were observed here.

A selection of these, along with some other interesting reflections, is included (*Figures 8, 9, 10, 11 and 12*).

If you are interested in the actual figures, or in plots showing the observations as related to the solar longitude (J2000) rather than to the calendar date. I can send you the underlying Excel files and/or plots, please send me an e-mail.





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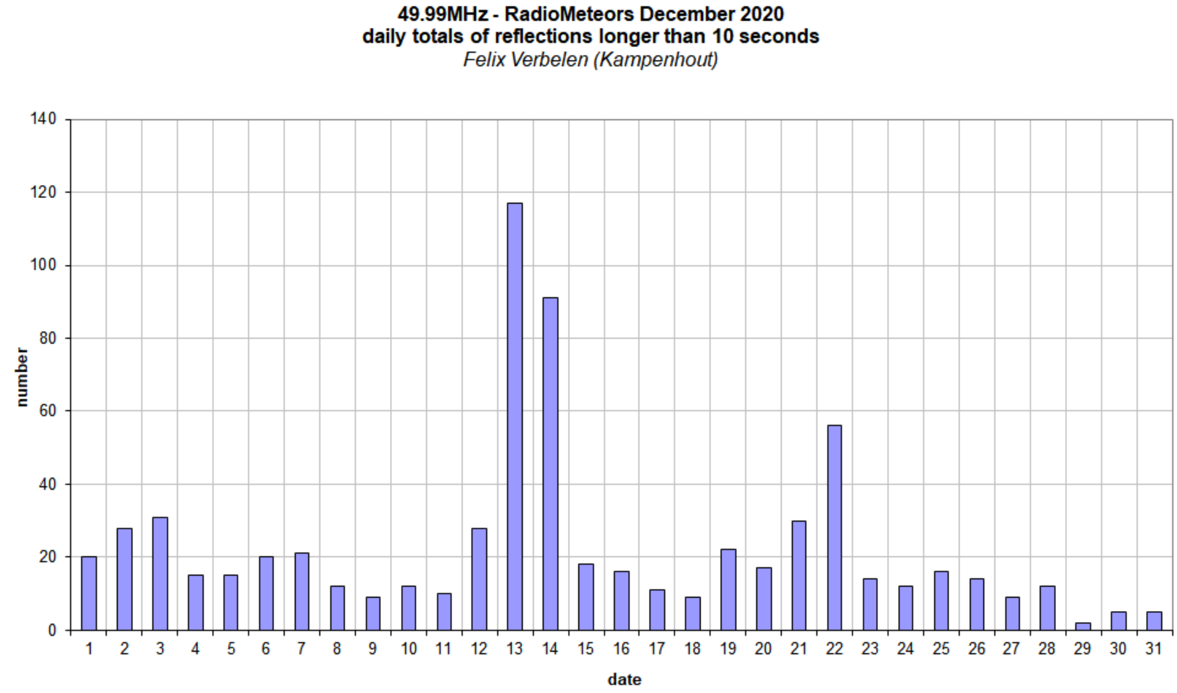


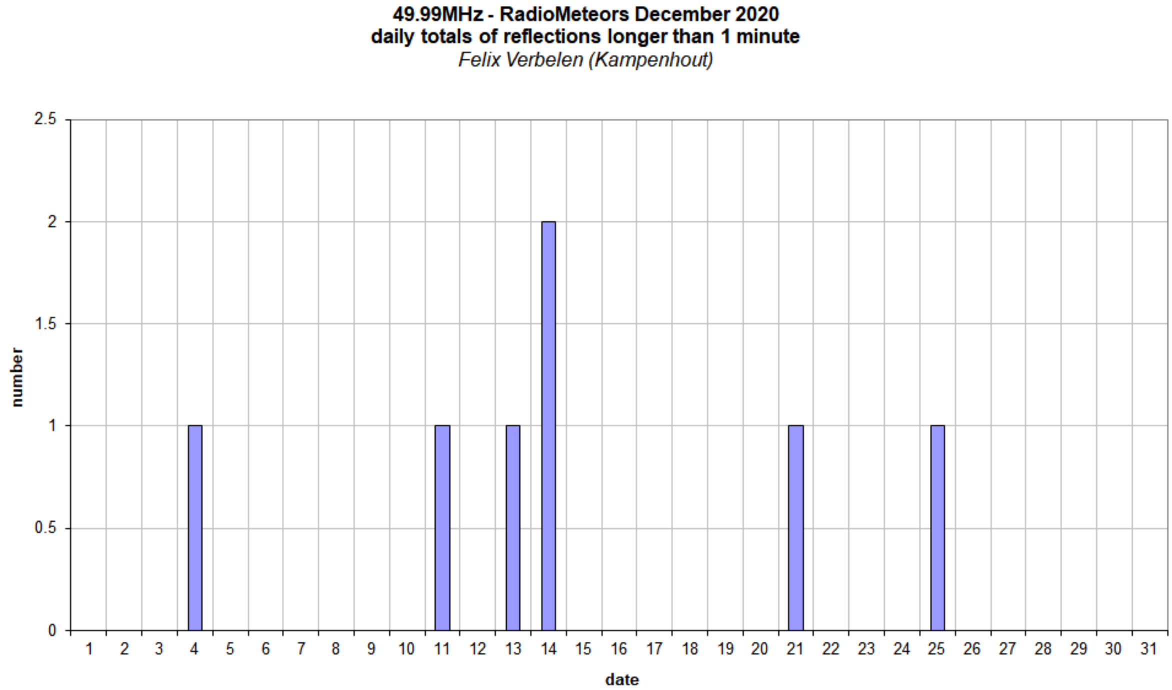
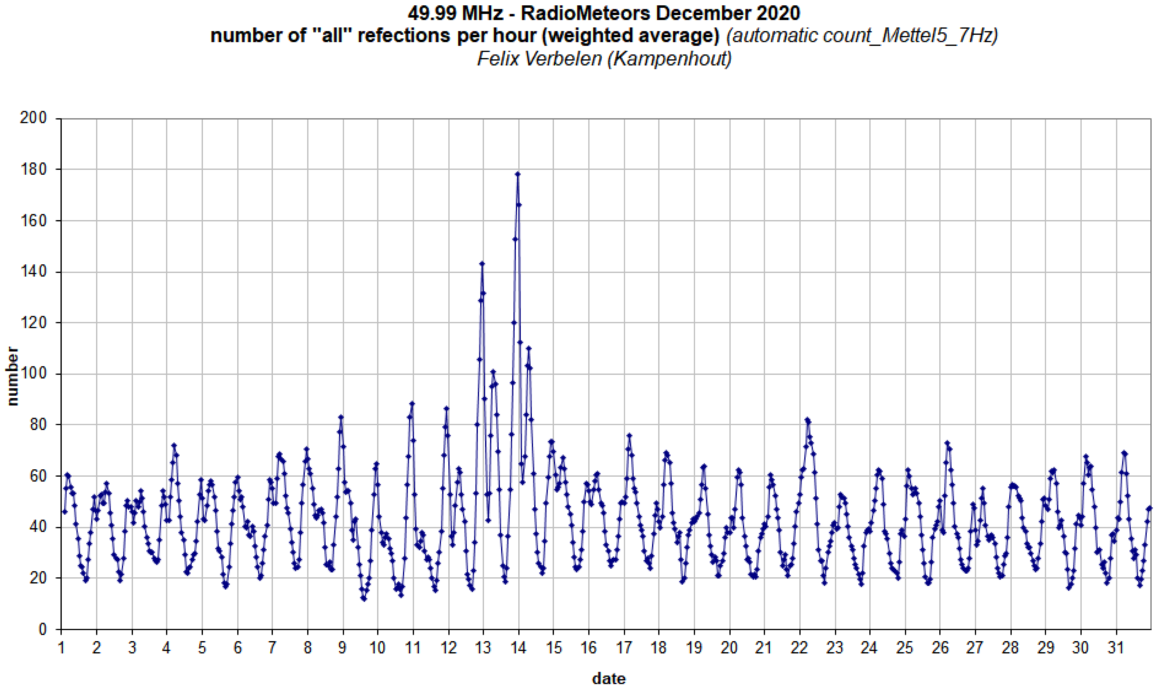


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2020.



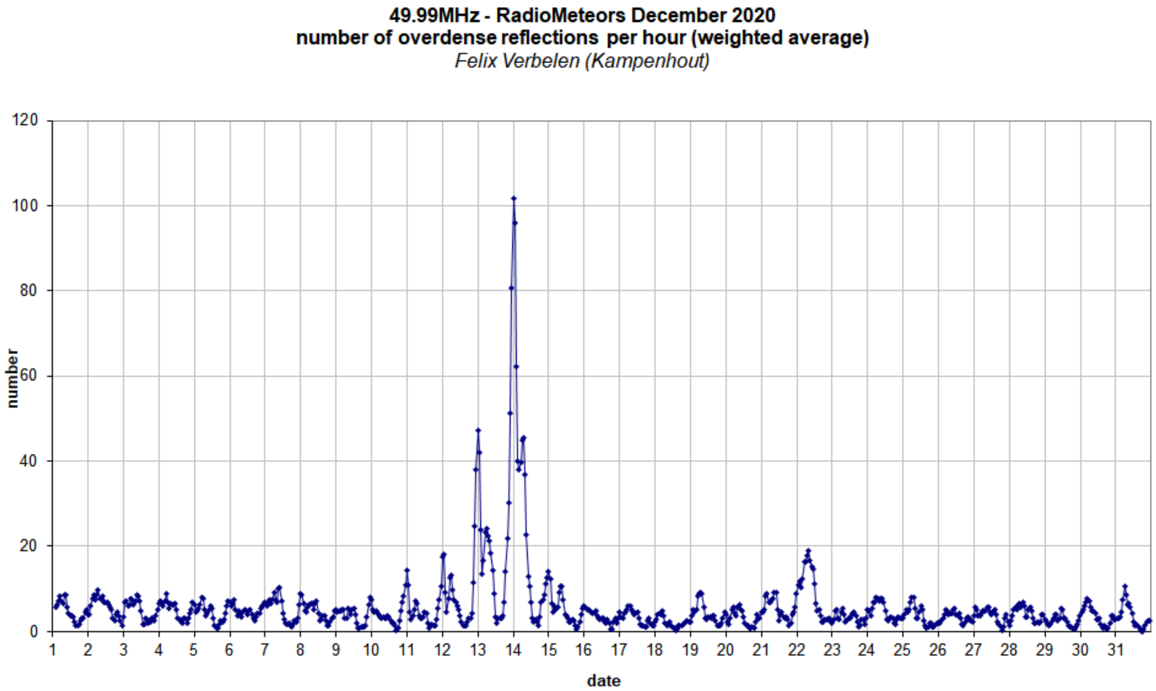
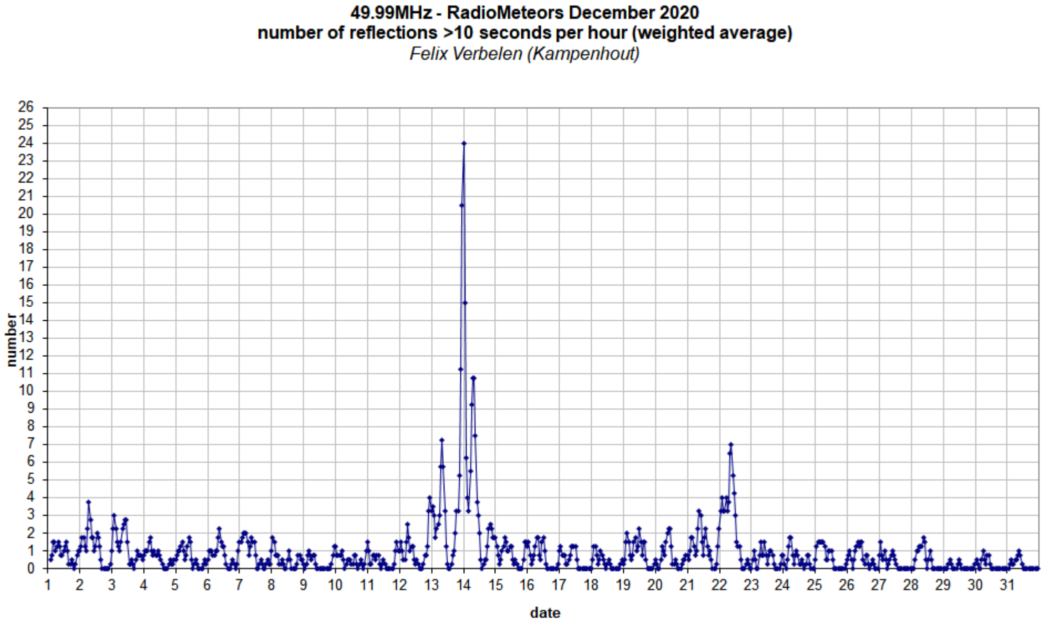
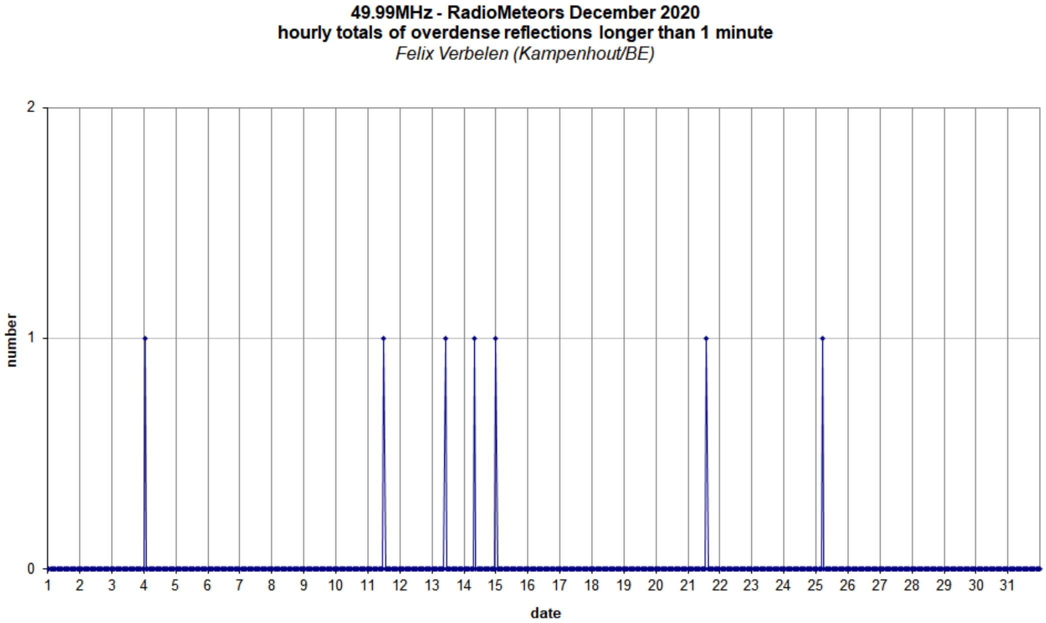


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2020.





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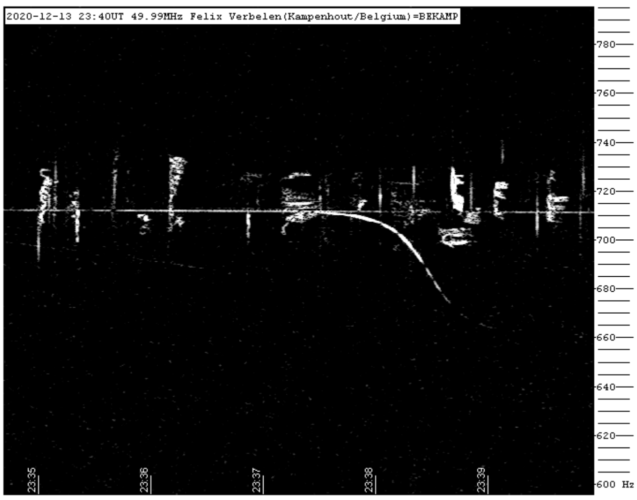


Figure 5 – Meteor reflection 13 December 2020, 23^h40^m UT.

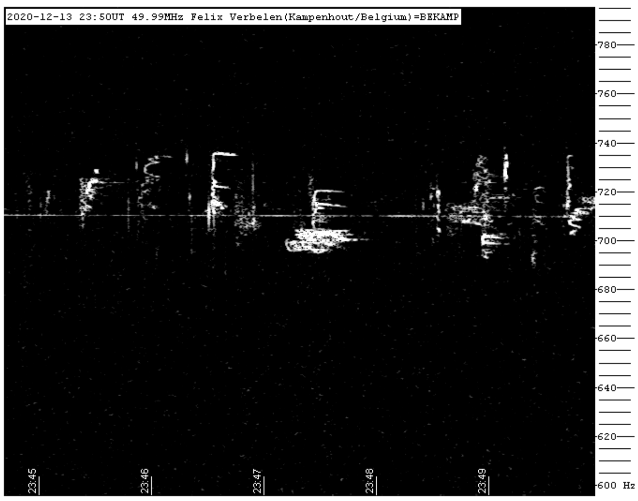


Figure 6 – Meteor reflection 13 December 2020, 23^h50^m UT.

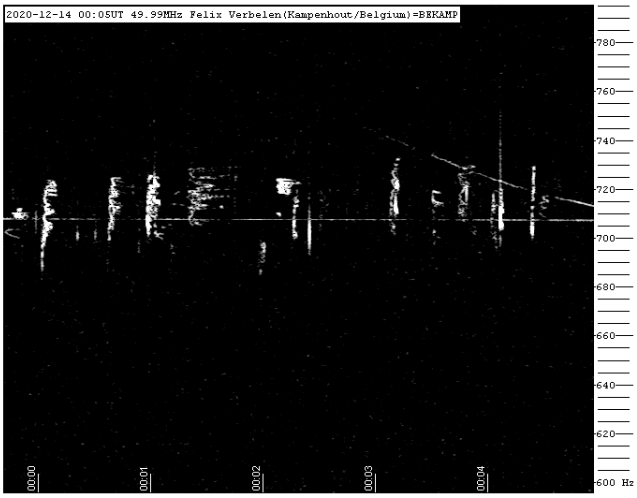


Figure 7 – Meteor reflection 14 December 2020, 00^h05^m UT.

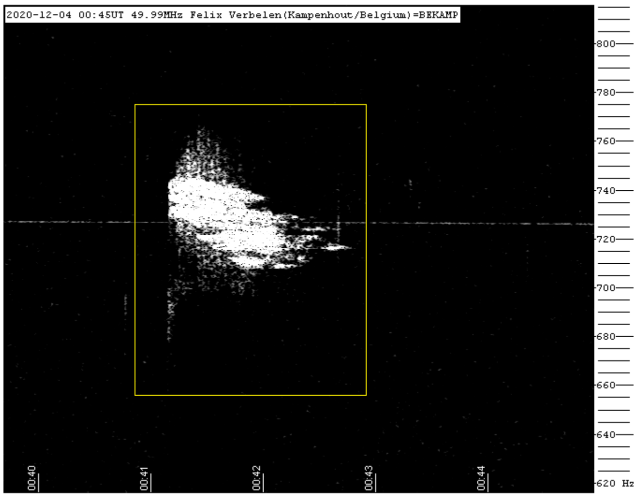


Figure 8 – Meteor reflection 4 December 2020, 00^h45^m UT.

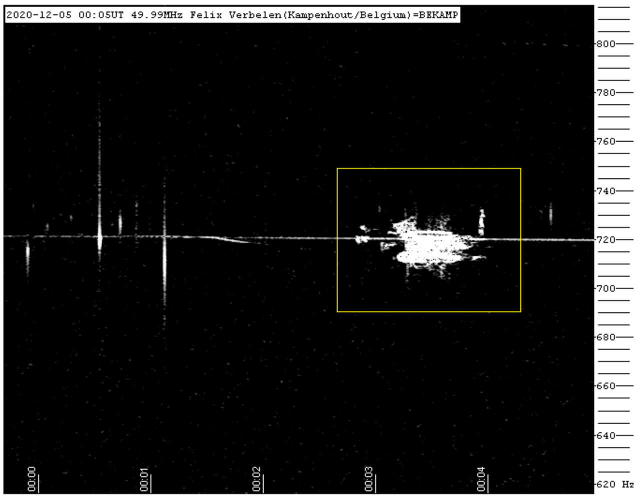


Figure 9 – Meteor reflection 5 December 2020, 00^h05^m UT.

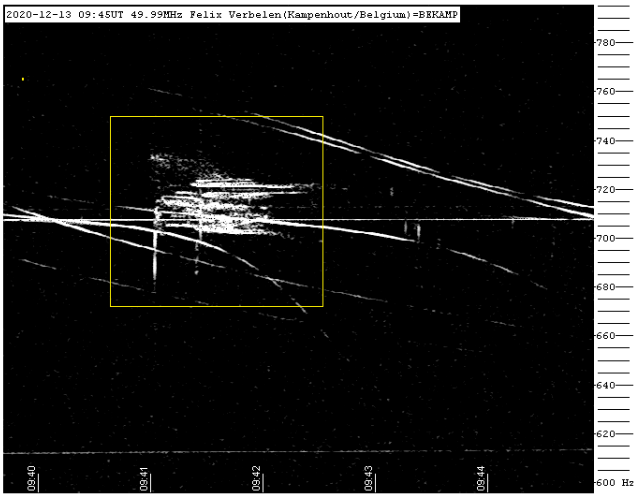


Figure 10 – Meteor reflection 13 December 2020, 09^h45^m UT.

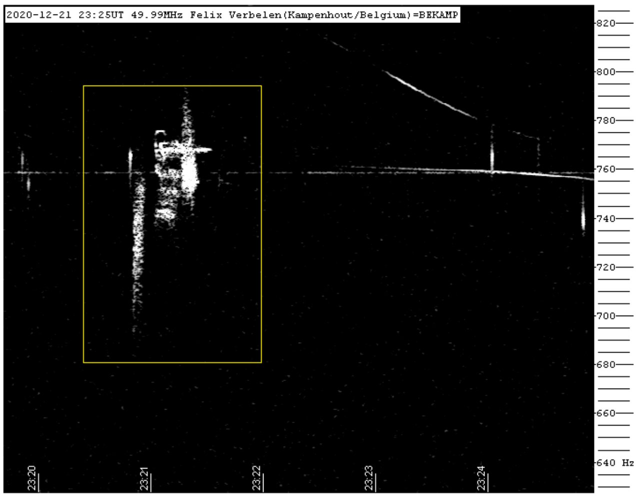


Figure 11 – Meteor reflection 21 December 2020, 23^h25^m UT.

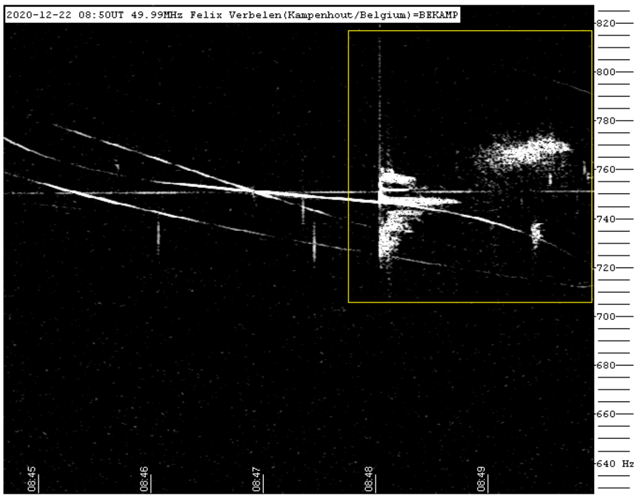


Figure 12 – Meteor reflection 22 December 2020, 08^h50^m UT.

Radio meteors January 2021

Felix Verbelen

Vereniging voor Sterrenkunde & Volkssterrenwacht MIRA, Grimbergen, Belgium
felix.verbelen@skynet.be

An overview of the radio observations during January 2021 is given.

1 Introduction

The graphs show both the daily totals (*Figure 1 and 2*) and the hourly numbers (*Figure 3 and 4*) of "all" reflections counted automatically, and of manually counted "overdense" reflections, overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during the month of January 2021.

The hourly numbers, for echoes shorter than 1 minute, are weighted averages derived from:

$$N(h) = \frac{n(h-1)}{4} + \frac{n(h)}{2} + \frac{n(h+1)}{4}$$

Local interference and unidentified noise remained low for most of the month and no lightning activity was detected.

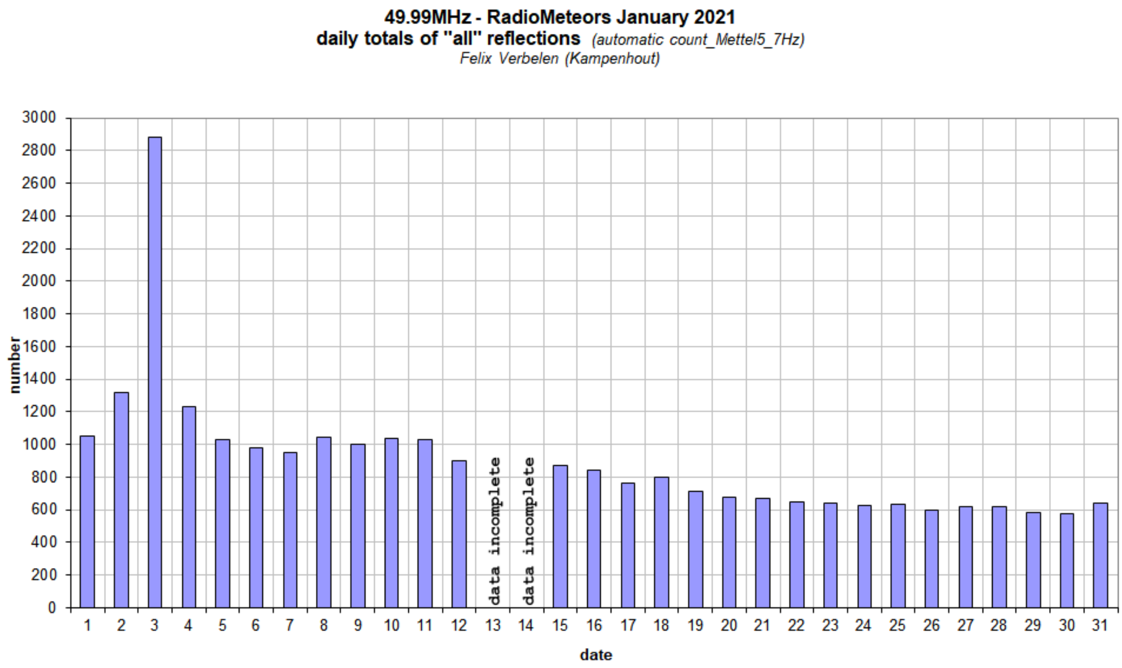
Due to a technical malfunction in the receiving installation, the data for the period 2021 January 13, 14^h00^m till 2021 January 14, 10^h00^m UT were lost.

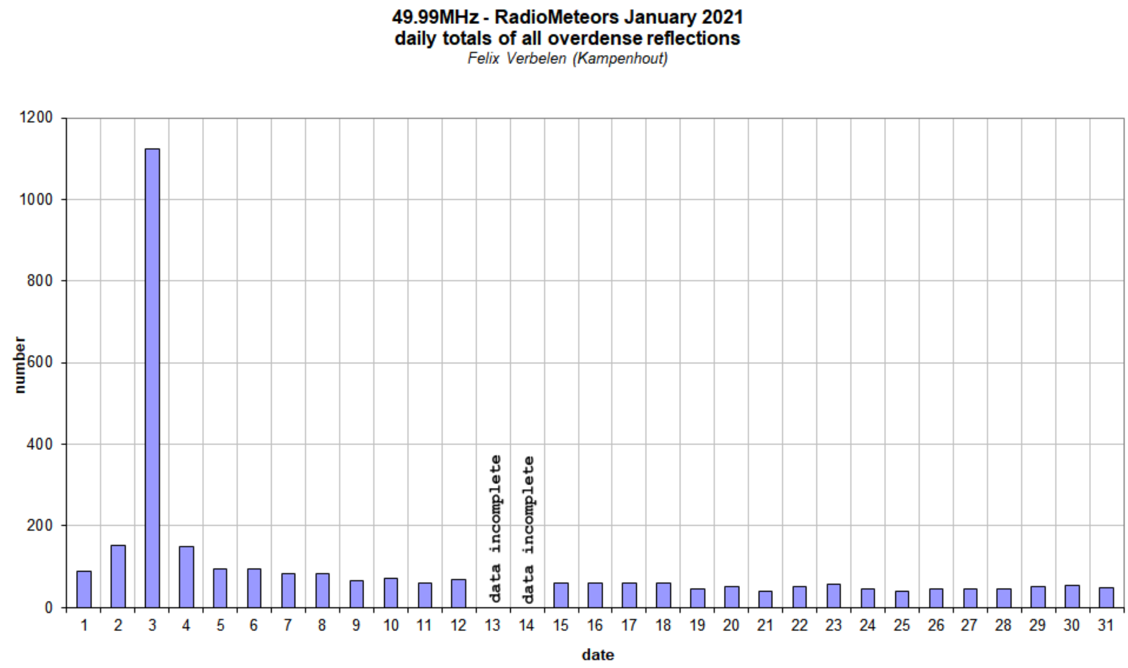
The eye-catchers this month were of course the Quadrantids, which reached their maximum here on January 3rd. Also this year the shower was very active, with sometimes more than 5 reflections per minute, many of which were overdense. Attached are some 5-minute screen dumps showing the shower's intensity. (*Figures 5, 6, 7, 8 and 9*).

The rest of the month was relatively calm, but at various times the activity of smaller showers was obvious; for this, reference is made to the raw counts.

This month only 5 reflections lasting longer than 1 minute were observed here. (*Figures 10, 11, 12, 13 and 14*).

If you are interested in the actual figures, or in plots showing the observations as related to the solar longitude (J2000) rather than to the calendar date. I can send you the underlying Excel files and/or plots, please send me an e-mail.





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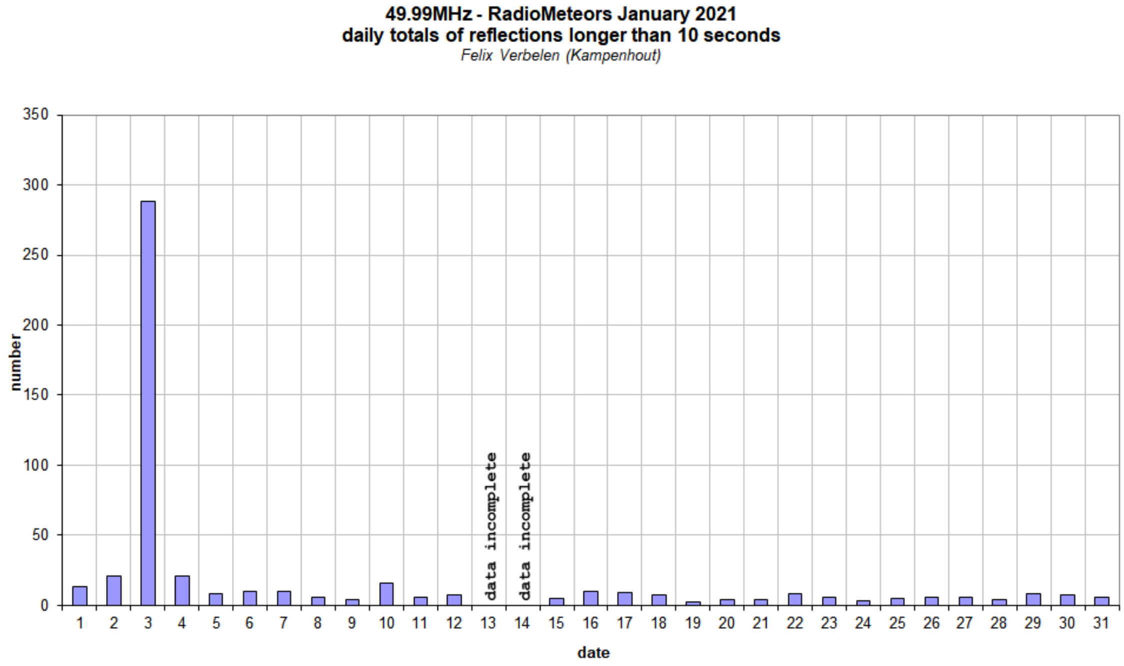


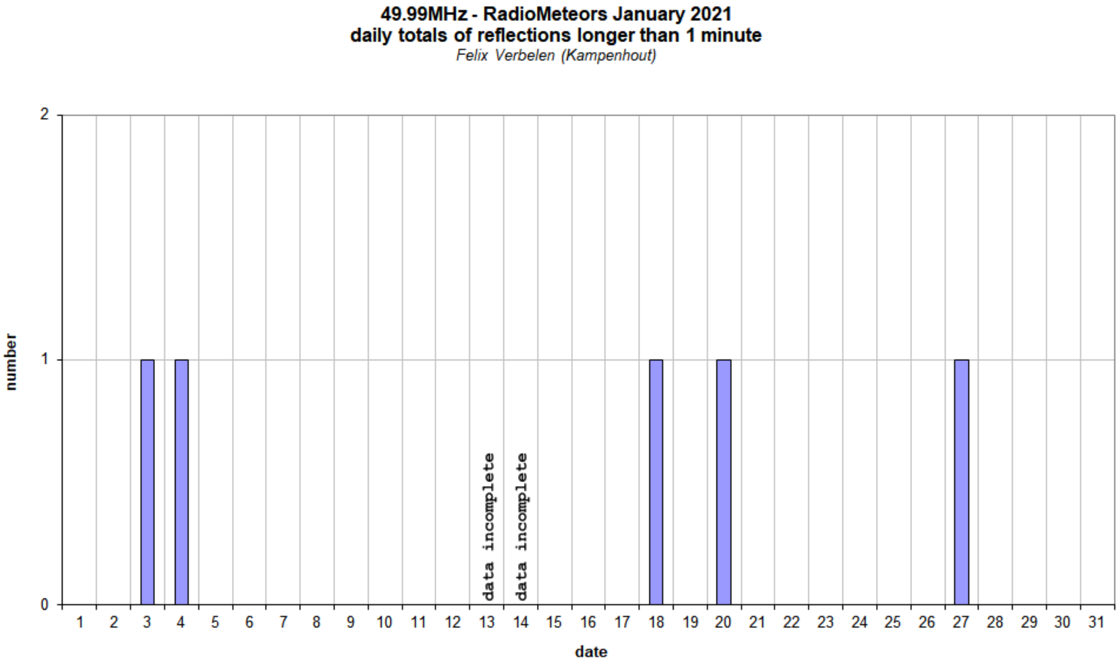
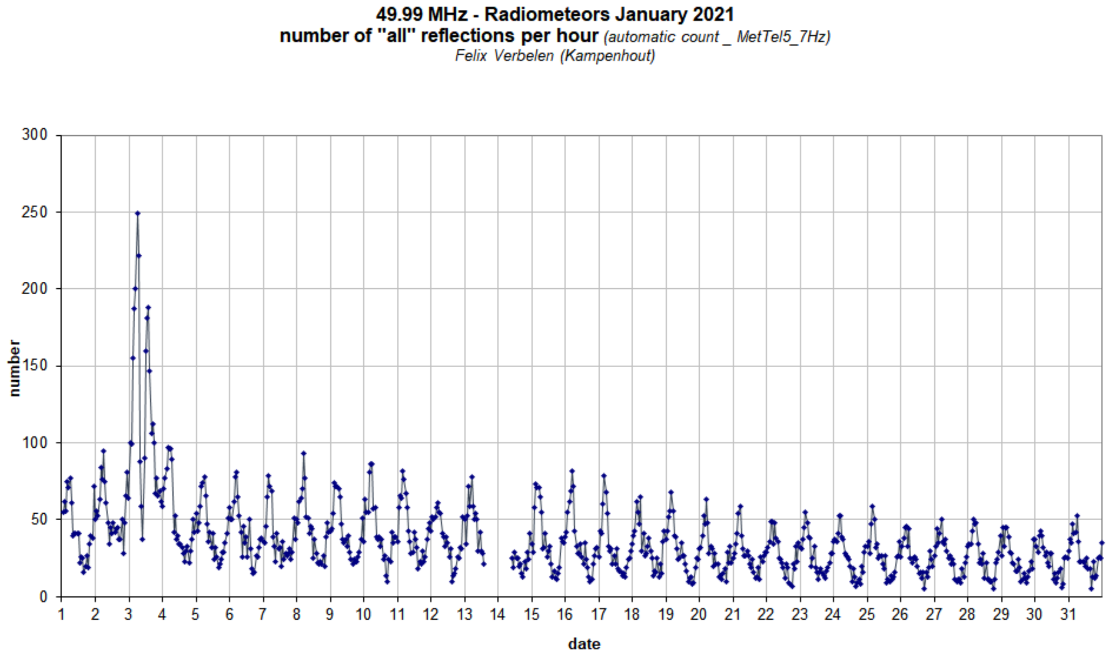


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2021.



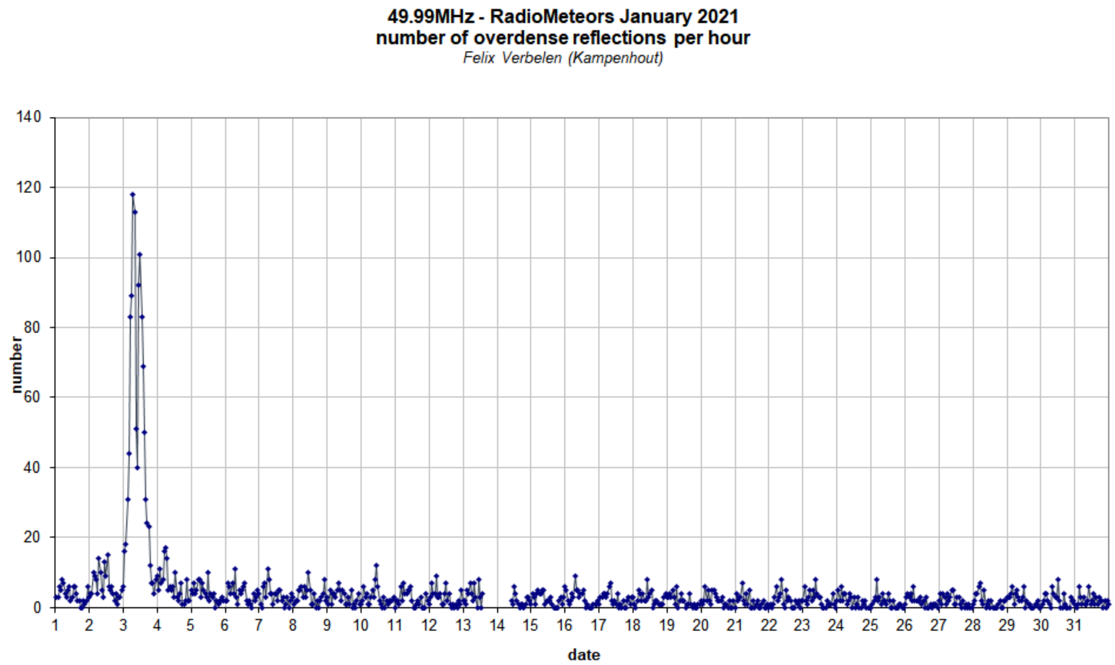


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2021.

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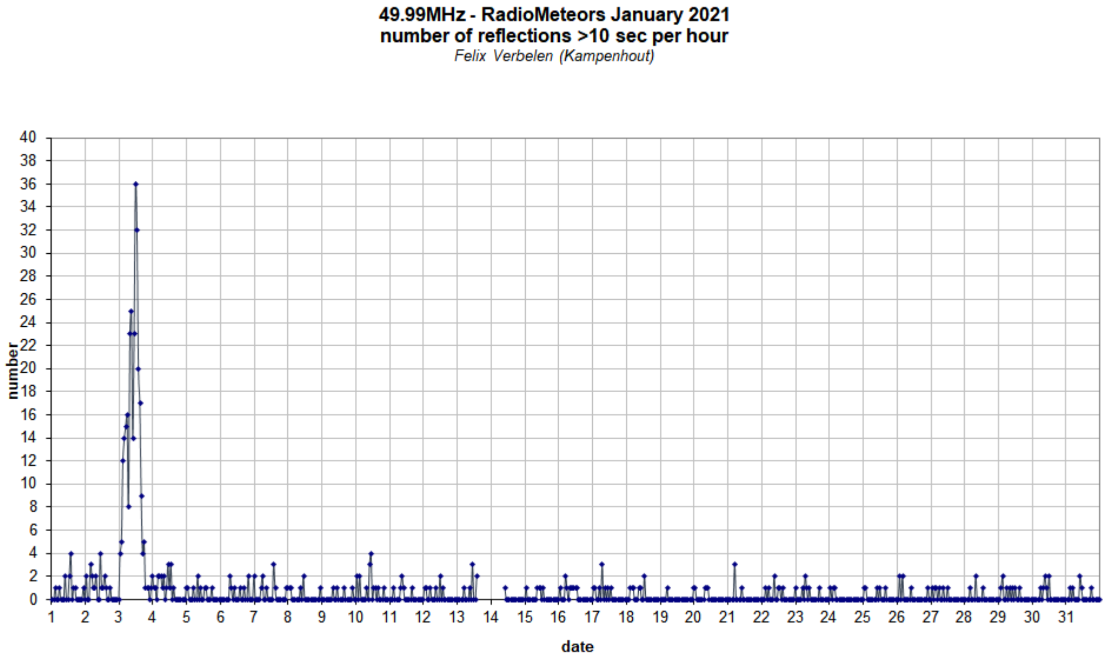

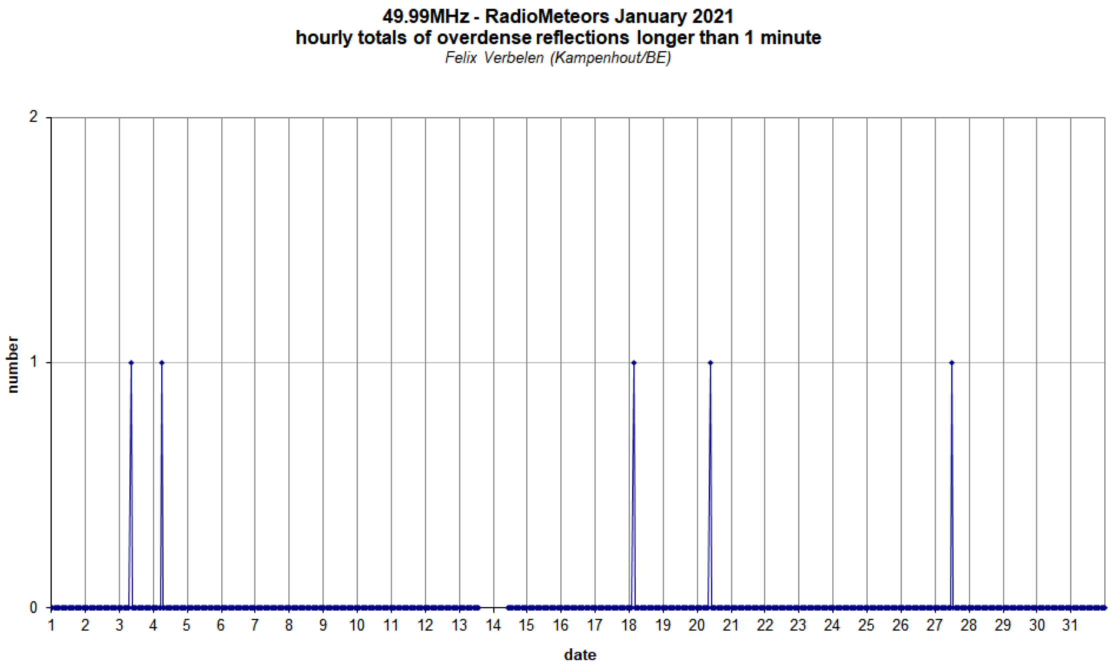

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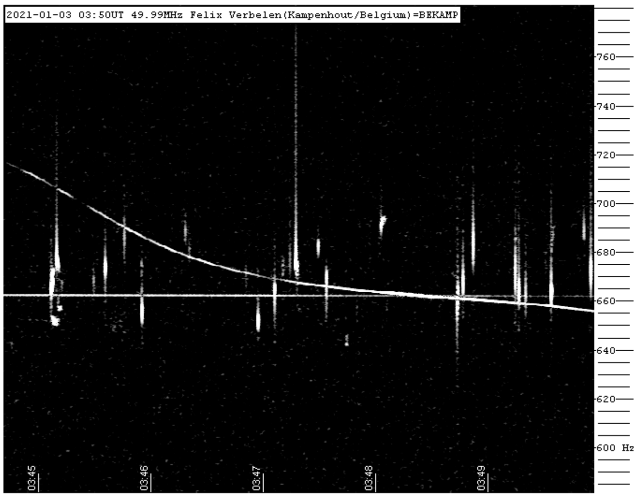

Figure 5 – Meteor reflection 03 January 2021, 03ʰ50ᵐ UT.

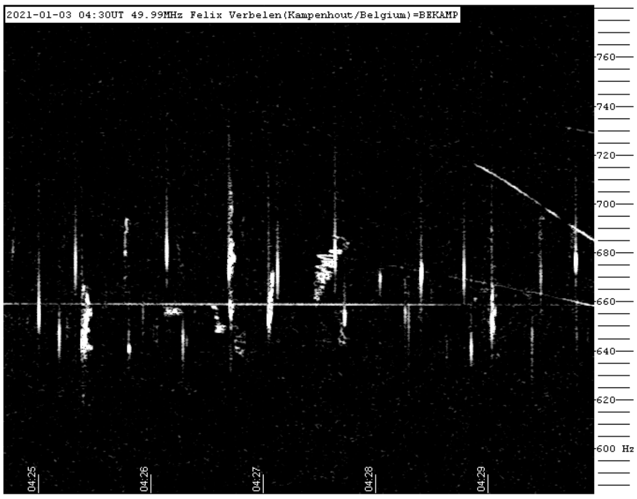

Figure 6 – Meteor reflection 03 January 2021, 04ʰ30ᵐ UT.

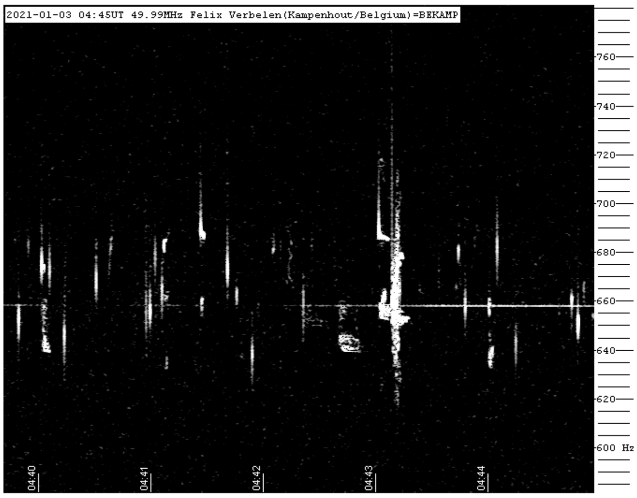

Figure 7 – Meteor reflection 03 January 2021, 04ʰ45ᵐ UT.

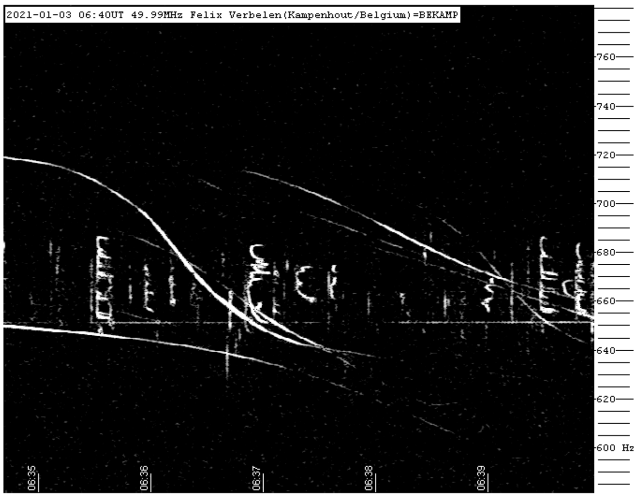

Figure 8 – Meteor reflection 03 January 2021, 06ʰ40ᵐ UT.

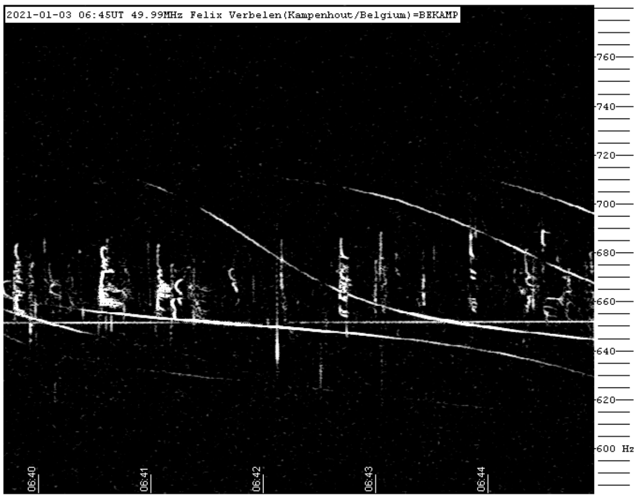

Figure 9 – Meteor reflection 03 January 2021, 06ʰ45ᵐ UT.

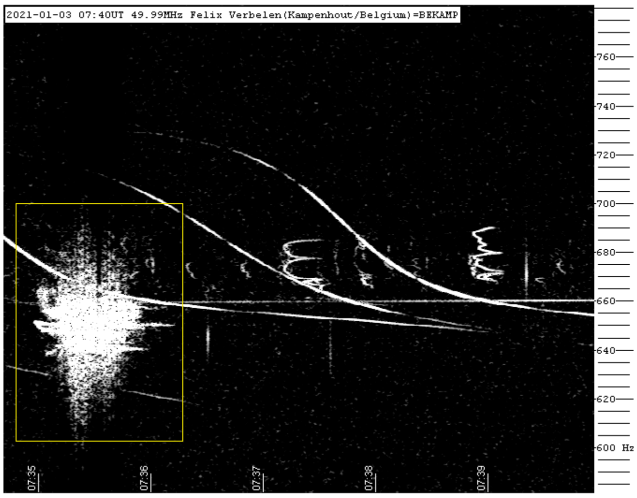

Figure 10 – Meteor reflection 03 January 2021, 07ʰ40ᵐ UT.

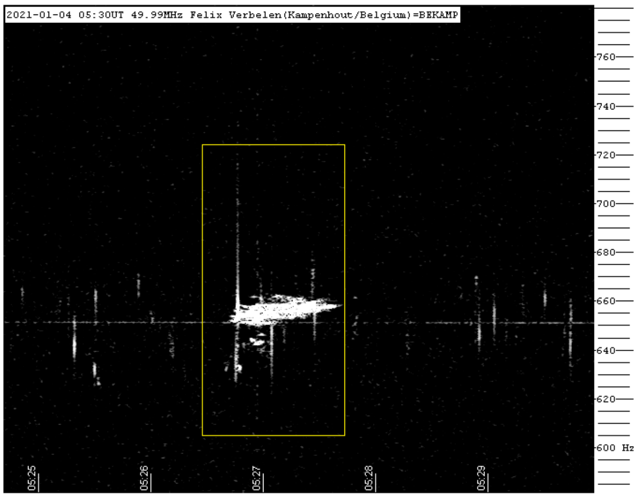

Figure 11 – Meteor reflection 04 January 2021, 05^h30^m UT.

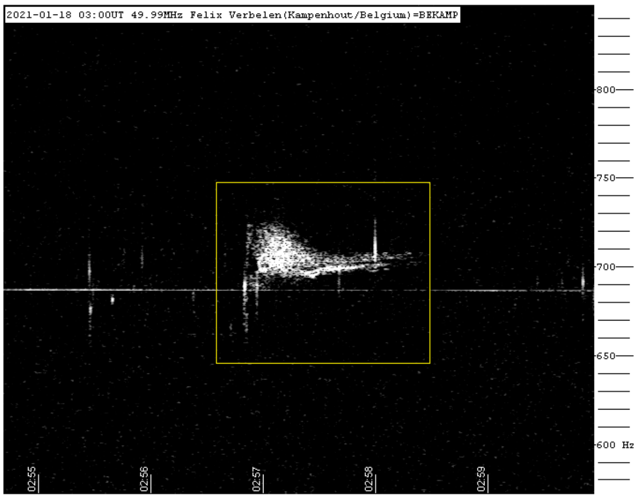

Figure 12 – Meteor reflection 18 January 2021, 03^h00^m UT.

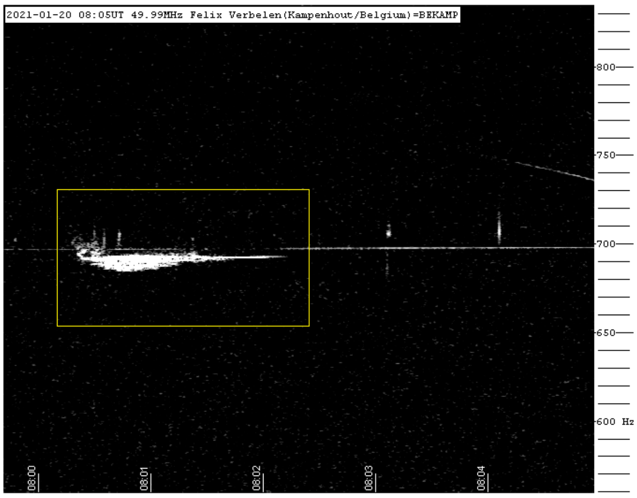

Figure 13 – Meteor reflection 12 January 2021, 08^h05^m UT.

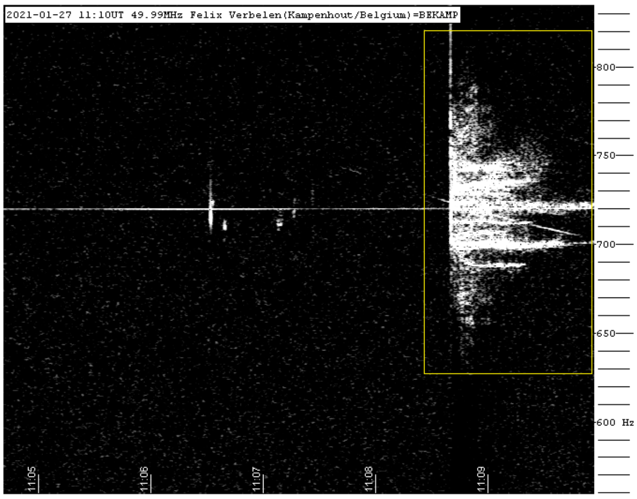

Figure 14 – Meteor reflection 27 January 2021, 11^h10^m UT.

Fireball of 2021 January 22 above Belgium

François Colas

IMCCE, Observatoire de Paris, 77 av. Denfert-Rochereau, 75014 Paris, France
colas@imcce.fr

Three stations of the FRIPON network registered a fireball on 22 January 2021, $06^h51^m50^s$ UT above Belgium. The trajectory and orbit could be computed. The slow fireball penetrated deep into the atmosphere until an ending height of 27 km at a final velocity of 6 km/s. There is a possibility that a remnant has reached the surface.

1 Introduction

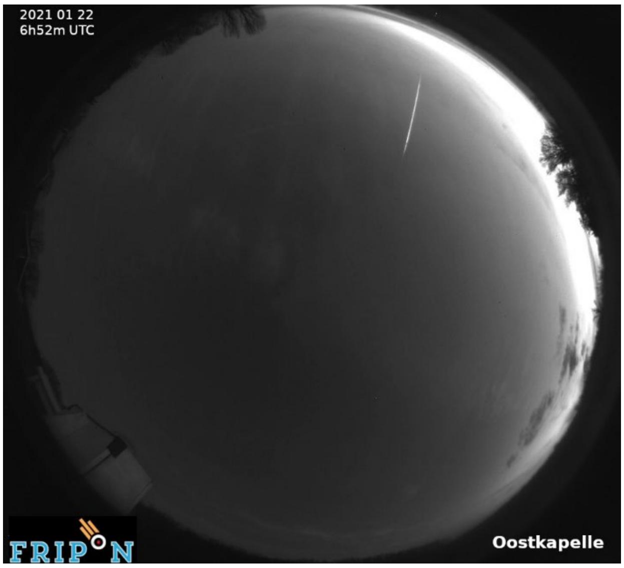

Figure 1 – The 2021 January 22 fireball at $6^h51^m50^s$ UT as recorded by the FRIPON camera at Oostkapelle, the Netherlands (credit FRIPON).

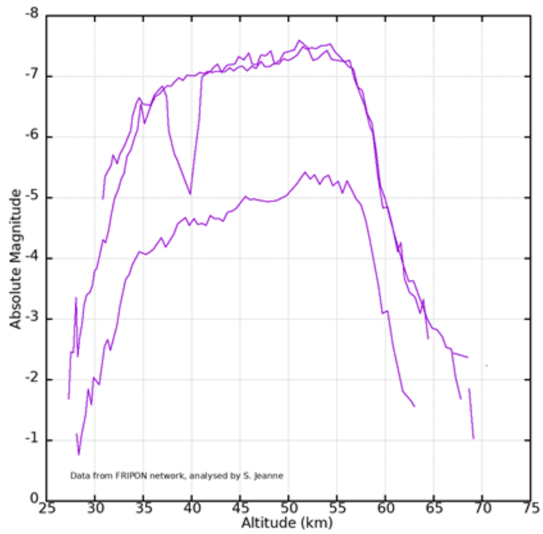

Figure 2 – The 2021 January 22 fireball at $6^h51^m50^s$ UT luminosity profile (credit FRIPON).

In the early morning of 2021 January 22, a slow-moving fireball appeared above Belgium at $6^h51^m50^s$ UT, shortly after that most meteor cameras in the BeNeLux had stopped capturing once the Sun passed above 8° under the horizon. Most camera stations suffered bad weather circumstances with a complete overcast sky.

Figure 3 – The FRIPON camera on the roof of the BISA institute in Uccle, Belgium (credit Hervé Lamy).

The fireball was seen by many casual eyewitnesses as the time of appearance was when many people were on their way to go to work. The event was immediately discussed on social media with some video recordings and descriptions. Luckily, some cameras of the FRIPON network caught the fireball at Noordwijk, the Netherlands (NLWN01), Oostkapelle, the Netherlands (NLWN02) (*Figure 1*) and Brussels, Belgium (BEBR01, *Figure 3*). The fireball reached an absolute magnitude of almost –8 (*Figure 2*).

2 The fireball trajectory

The meteor entered the atmosphere above the Belgian-Dutch border, between the cities of Antwerp and Gent, ending above Dendermonde with a rather steep entrance angle with a total duration of about 3.5 seconds (*Figure 4*). Detected at a height of 70 km, the fireball penetrated deep into the atmosphere with an ending height at 27 km, suggesting that any possible left over may have dropped as a meteorite on the surface (*Figure 5*). With an initial velocity of 16 km/s this was a very slow event, the deceleration during the decent through the atmosphere resulted in a final velocity of 6 km/s, which is also favorable for the chances of a small remnant to have reached the ground (*Figure 6*). More computation work by the FRIPON team determined that any possible fragments that survived the transit through the atmosphere may have landed south of Dendermonde and Berlare, north of the city Aalst (*Figure 7*). Any reports from owners who may discover some suspect meteorite like objects on their property may help if some remnant did reach the surface.

Figure 4 – The 2021 January 22 fireball at $6^h51^m50^s$ UT the fireball trajectory above Belgium (credit FRIPON).

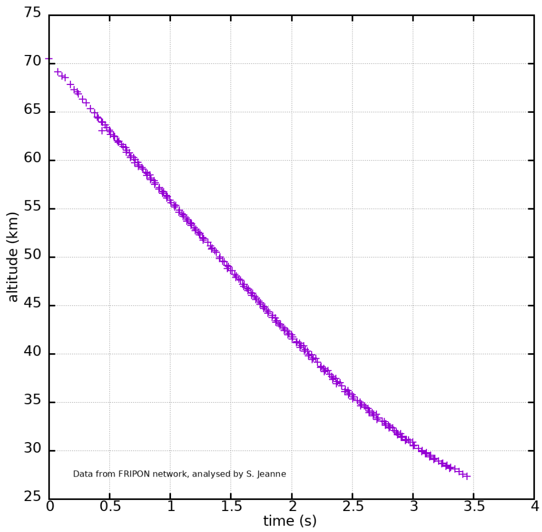

Figure 5 – The 2021 January 22 fireball at $6^h51^m50^s$ UT the altitude versus time profile (credit FRIPON).

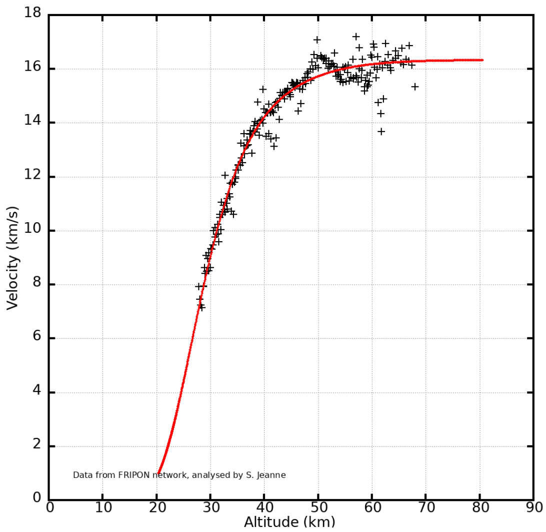

Figure 6 – The 2021 January 22 fireball at $6^h51^m50^s$ UT the velocity and deceleration in function of the altitude (credit FRIPON).

Figure 7 – The 2021 January 22 fireball at $6^h51^m50^s$ UT the strewn field (credit FRIPON).

3 The orbit

The orbit could be calculated and suggests an asteroidal origin (*Figure 8*). A check-up with the IAU meteor shower list revealed no association to any known meteor shower, hence we can conclude this was a sporadic fireball.

- $q = 0.9575 \pm 0.0002$ AU
- $a = 1.28 \pm 0.007$ AU
- $e = 0.2519 \pm 0.0038$
- $i = 20.08 \pm 0.09°$
- $\omega = 210.10 \pm 0.24°$
- $\Omega = 302.20 \pm 0.0004°$
- $T_j = 4.97$

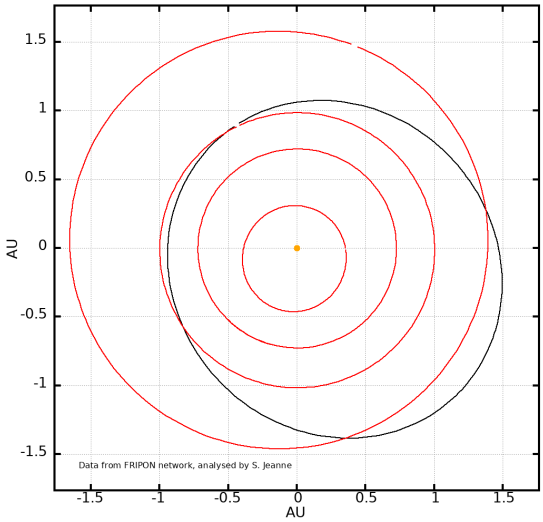

Figure 8 – The 2021 January 22 fireball at $6^h51^m50^s$ UT the orbit of the fireball (dark line) (credit FRIPON).

First Global Meteor Network meeting

Paul Roggemans

Pijnboomstraat 25, 2800 Mechelen, Belgium
paul.roggemans@gmail.com

A short report is presented about the first meeting of the Global Meteor Network with more than 50 participants from many countries around the globe.

1 Introduction

On 20 February 2021 Global Meteor Network had its first meeting. More than 50 participants attended the meeting online. The meeting took about 6 hours including some breaks. Apart from a workshop and Q&A session, there were several presentations. You can watch the video of this meeting online[17]. You can skip through the program using the timing on the sliding bar in YouTube. As far as available the presentations can be consulted online too.

If you are interested in an up-to-date presentation of the origin and evolution of our solar system, and what our meteor observations can actually learn about this, the main talk by Denis Vida (*A brief history of the Solar System and the case for the Global Meteor Network*) is much recommended.

Interested to join this fascinating project? On the Global Meteor Network website[18] you will find all the information you need, about the project, how to purchase RMS cameras plug-and-play or how to build your own camera. Global Meteor Network is the fastest growing camera network but still needs more volunteers to obtain worldwide coverage on both northern and southern hemisphere. GMN has a very active community[19] discussing problems and solutions. If you need some help, you will easily get tips and tricks from other participants.

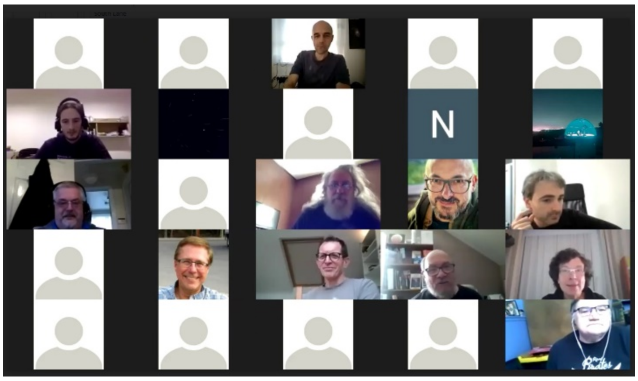

Figure 1 – Screenshot with some of the participants at the Zoom meeting of Global Meteor Network.

2 Meeting schedule

The following topics were presented and discussed.

UT	Topic
16:00	Meeting begins – Introductions
16:10	*Denis Vida* – A brief history of the Solar System and the case for the Global Meteor Network.
17:10	Break
17:15	Workshop
18:00	Dinner/lunch/brunch break
18:15	*Nick Moskovitz* – Development of the Lowell Observatory GMN/CAMS Network
18:27	*Pete Eschman* – The New Mexico Meteor Array
18:39	*Dmitrii Rychkov* – Experience of deployment of a meteor network in the south of Russia
18:51	*Tammo Jan Dijkema* – A tour of the meteor map
19:03	*Damir Šegon* – The 16mm Lens Equipped RMS – Why?
19:15	Break
19:25	*Pete Eschman* – The New Mexico Meteor Array: Lessons Learned
19:37	*Eugene Mroz* – No Meteor Unobserved: Camera Network Optimization
19:49	*Pete Gural* – Applying Deep Learning to RMS Meteor Classification – First Look
20:01	*Paul Roggemans* – Orbit similarity criteria and meteor shower identification
20:13	*Lovro Pavletić* – First GMN analysis of the the new Epsilon Ursae minorid meteor shower observed in 2019
20:25	*Damir Šegon* – Some experiences in calibrating casual recordings of meteorite-dropping fireballs
20:37	*Hector Socas-Navarro* – Current status and future plans of RMS camera(s) on Tenerife
20:49	Break
21:00	Q&A

[17] https://youtu.be/QXBTLPnPDWs
[18] https://globalmeteornetwork.org/
[19] https://groups.io/g/globalmeteornetwork

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Webmaster & account administrator:

Richard Kacerek (United Kingdom): rickzkm@gmail.com

Contributing to this issue:

- ***J. Aceituno***
- ***F. Colas***
- ***T. Cooper***
- ***E. de Guindos***
- ***J. Greaves***
- ***P. Jenniskens***
- ***R. Kacerek***
- ***J.M. Madiedo***
- ***H. Ogawa***
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Valašské Meziříčí Observatory, Vsetínská 78, 75701 Valašské Meziříčí, Czech Republic

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