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Stacked image of the SWEMN20211214_001628 fireball as recorded from Calar Alto. Read more page 120.

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Exploding meteor over Tiglit (Morocco) with fragments of an interesting meteorite collected

Ibhi Abderrahmane

University Museum of Meteorites, Ibn Zohr University, Agadir, Morocco
mum@uiz.ac.ma

A bright fireball entered the Earth's atmosphere in the south-east skies of Guelmim, Morocco, on Friday December, 10th, 2021 at 18^h45^m UT. Its interaction with the atmosphere led to brilliant light flashes accompanied with detonations. A large number of fragments survived the fireball phenomena. The Saharian living in the surrounding region then gather together searching for debris of this extraterrestrial rock. The first fragment has been discovered the next day. About a hundred people came to the region of Tiglit (Tata, Morocco) and thousands of fragments have been collected by the nomads, traders and hunters with some knowledge about extraterrestrial rocks. The members of the University Museum of Meteorites association found a block of 3 grams in the region, contacted Prof. Ibhi Abderrahmane, scientist and collector of meteorites at the Ibn Zohr University, in order to inform him about the findings of freshly fallen meteorites.

1 Introduction

Morocco is one of the most important countries in the world when it comes to meteorite falls, according to the "Meteorite Nomenclature Committee of the Meteoritical Society", 22 meteorite falls have been recorded. Southern Morocco is world famous for its meteorites. More than half of the scientific publications on extraterrestrial rocks worldwide are about Moroccan meteorites (Ibhi, 2013). The supervision on meteorite falls is essentially provided by nomads living and crossing the Moroccan desert all year round. These people form a real network of human cameras (Ibhi, 2014). Anyway, the Tiglit meteorite of the Guelmim region is added to the list of meteorite falls in Morocco.

On the evening of December 10th, 2021 around 19^h45^m Moroccan time (GMT+1,) a bright bolide was observed by thousands of eyewitnesses in an area about 140 km in distance from the South-East of the Guelmim town (South-East Morocco). A terminal fragmentation and sound phenomena were perceived near the end point of the trajectory. The bolide has traveled from North West to South East and has experienced several fragmentations along its atmospheric trajectory (*Figure 1*). This extraordinary and rare event is extremely valuable to the scientific community.

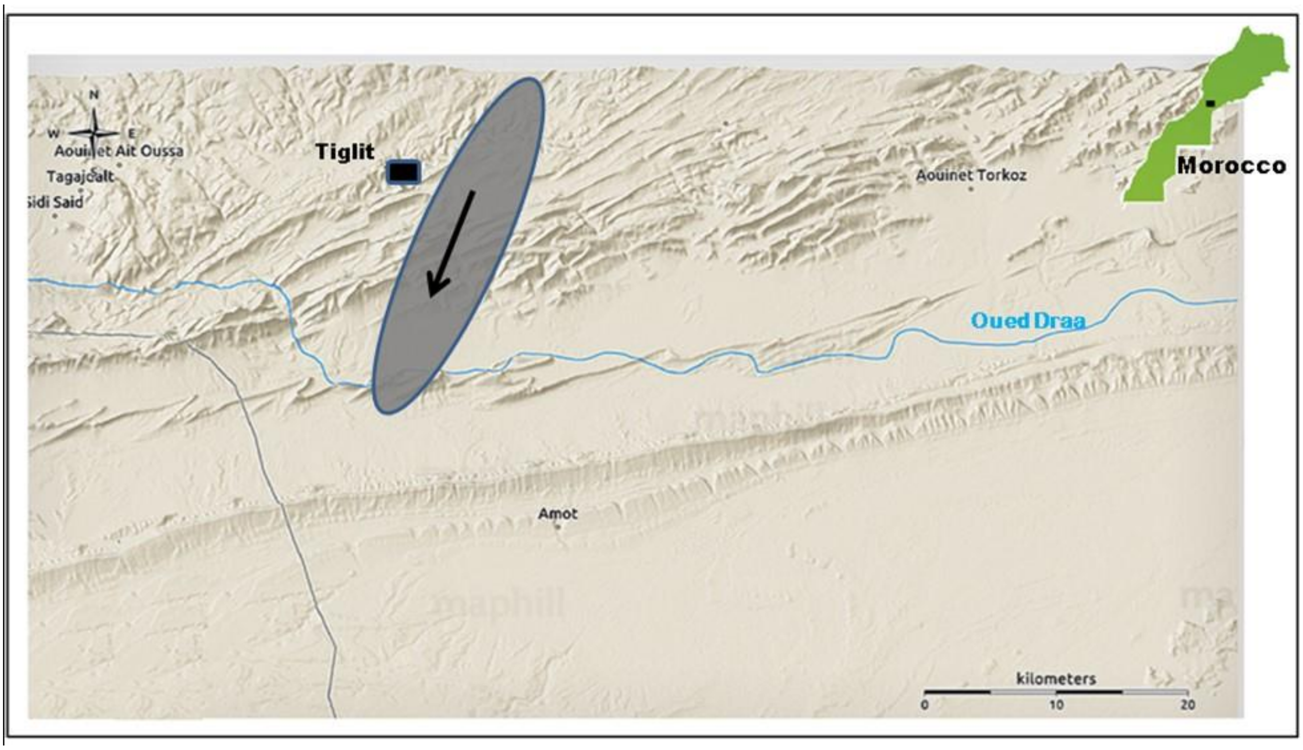

Figure 1 – Estimated flight path of the fireball that gave rise to the Tiglit meteorite.

Figure 2 – The location where the first fragments were found near the rural municipality of Tiglit.

2 Collecting informations

Eyewitnesses in several locations saw the bright fireball and heard audible of three detonations a few seconds later. Mr. Dair Ahmed a friend of the University Museum of meteorites and a resident of the Tiglit region, has testified that he and his friends saw a brilliant light across the sky. It seemed to be brighter than an electric welding light. Mr. Bachikh Mouloud, reported that the light was green before it splitted into three parts.

The following day, hundreds of people from surrounding Douars, villages and collectors of meteorite fragments from other cities (Guelmim, Laayoune, Es Smara, Aouinat Torkoz, etc.) moved to the site to search for the precious meteorites (*Figure 2*). The first fragments were found at 14 km from Tiglit village (28°23.533’ N, 10°22.632’ W). Most of the specimens found were quickly identified as meteorites because it exhibits a prominent fusion crust that covers a part of their surface. The majority of these fragments are relatively small pieces (*Figure 3*), with the largest officially reported weighing 1 kg at the time of this publication.

Figure 3 – Tiglit meteorite fall fragments.

3 Preliminary petrography

After receiving a sample (which was approximately 25 mm in diameter and about 10 mm thick with a weight of 3.5 grams) at the University Museum of Meteorite, preliminary analyzes were archived in the Scientific Research Center of Agadir (*Figure 4*) and showed that the Tiglit meteorite is a light-colored magmatic rock with a brownish fusion crust, mainly composed of large white crystals (Orthopyroxene) with some olivine crystals, iron-nickel alloy and a multitude of rare accessory minerals. The strongly brecciated texture reveals a violent history of its original body. Petrological and mineralogical features of the Tiglite meteorite were studied by electron microscopy (SEM) at the Scientific Research Center of the Faculty of Sciences of Agadir (Ibn Zohr University). Indeed, BSE imaging and petrographic examination were carried out using the JEOL JSM IT1000 scanning electron microscope which has just been assigned to the Faculty of Sciences of Agadir. The measurements were performed with a resolution of 4 nm at 20 kV. The engine is equipped with Energy-Dispersive Spectroscopy (EDS) detectors for qualitative/quantitative elemental analysis. Before analysis, the samples were submitted to a gold metallization process by JEOL JFC_1300 auto fine coater during 15 seconds, in order to eliminate the non-conductive sample charge accumulated during the analysis.

The Tiglit is a monomict breccia consisting of coarse-grained enstatite fragments, up to 5 mm, with a fine-grained matrix. Such structure is typical for common aubrites. The matrix consists of enstatite (Opx) with diopside (Cpx), olivine, glass and opaque minerals (*Figure 5*). Phases in the matrix are usually small in size (below 100 µm). Enstatite is almost homogeneous in composition (very rich in magnesium and poor in iron). Olivine is pure forsterite (very poor in iron) and clinopyrxene is a diopside. Minor metal, high in Ni and associated with troilite. Based on these data, it can be confirmed that this rock can be classified as an achondrite meteorite of the “Aubrite” type and not as a lunar feldspathic regolith breccia meteorite advanced by merchants.

Figure 4 – Observation and analysis of the Tiglit fragment performed at the University Museum of Meteorites.

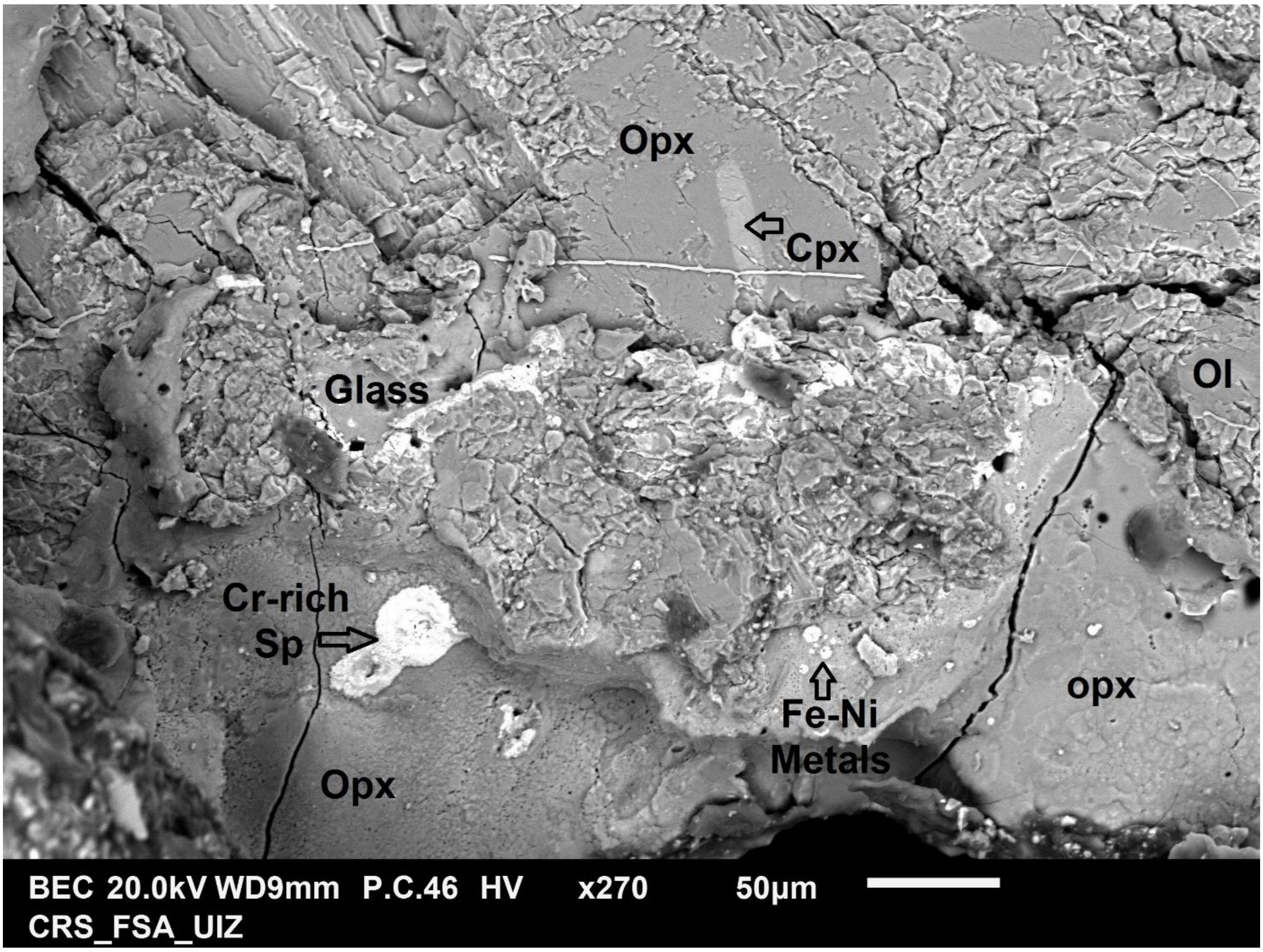

Figure 5 – Backscattered electron images, consisting of coarse-grained Enstatite (Opx), olivine (Ol) and pyroxene (Cpx) with interstitial materials Fe-Ni metals, Cr riche spinel and glass. (Photo mum).

4 Conclusion

Meteorite "falls", are meteorites collected after their fall from space while being observed by people or automated devices. More than twenty-two meteorite falls (all types combined) were observed and were picked up on Moroccan territory. Concerning the Aubrites, the Tiglit meteorite is the first observed fall which will bear the name of the village where it has landed. However, 6 finds were collected in Morocco (one in 2005, two in 2006, two in 2007 and one in 2019, and all of these rocks bear the name NWA). These falls and finds are golden sources of knowledge, these rocks from elsewhere contain precious information about the conditions of the formation of the solar system 4.5 billion years ago (Khiri and Ibhi, 2015), on the genesis of the planets and their internal composition.

The Tiglit meteorite fetched exorbitant prices, traded as a lunar meteorite. Analyzes carried out by the University Museum of Meteorites confirm that this is an Aubrite-type celestial rock of asteroidal origin.

Acknowledgments

We are very grateful to *Mr. Bachikh Mouloud*, *Mr. Dair Ahmed* (Tafraout) and *Mr. Lamghari Ali* for their help in collecting all information and *Mr. Lakhrouf* Omar for his help in getting a sample.

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Visualizing meteor ground tracks on the meteor map

Tammo Jan Dijkema

ASTRON, Netherlands Institute for Radio Astronomy
t.j.dijkema@gmail.com

The meteor map is an online tool for visualizing meteor cameras and ground tracks of observed meteors. It has been online since January 2021. In this article, I introduce some of the lesser-known features.

1 Introduction

When I first built a meteor camera in December 2020, I was surprised that there was no easy way to visualize ground tracks of meteors, even though coordinates in the form of latitude/longitude pairs were readily available. So, I decided to build this visualization tool myself, using off-the-shelf software as much as possible[1].

The meteor map was quickly adopted and is now featured on the front page of the websites of both the Global Meteor Network[2] and CAMS[3]. The URL of the meteor map is: https://tammojan.github.io/meteormap.

2 Main features

The meteor map can visualize data from both the CAMS network (Jenniskens et al., 2011) and the Global Meteor Network (GMN, Vida et al., 2021).

User interface

After the meteor map has loaded (this can take quite some time, as the datasets of GMN can be around 20 MB), a map with meteors is presented. The user interface of the meteor map is shown in *Figure 1*.

Stations and fields of view

Since the data of the GMN is online, the meteor map can readily access it, either in monthly or in daily batches. As a user, you only need to select a day or a month, and the data is automatically loaded from the GMN to the map. The same thing is possible for certain days of CAMS, and for monthly logs from the 2010–2016 CAMS data release (Jenniskens et al., 2018). To view the CAMS map, visit the URL tammojan.github.io/meteormap?cams, i.e. append "?cams" to the URL.

Finally, it is also possible to drag and drop a compatible local file with orbits onto the map. The file should be in the format of the SummaryMeteorLog.txt files produced by the CAMS tool 'Coincidence'[4].

Station locations are shown in the map, where a random offset of about 2km is added to every station for privacy reasons. For the GMN, the stations are pulled from the central GMN sftp server, and the station names are pulled from IstraStream. For CAMS the station locations are obtained from the network coordinators (currently only in the CAMS BeNeLux). The same holds for field of view information.

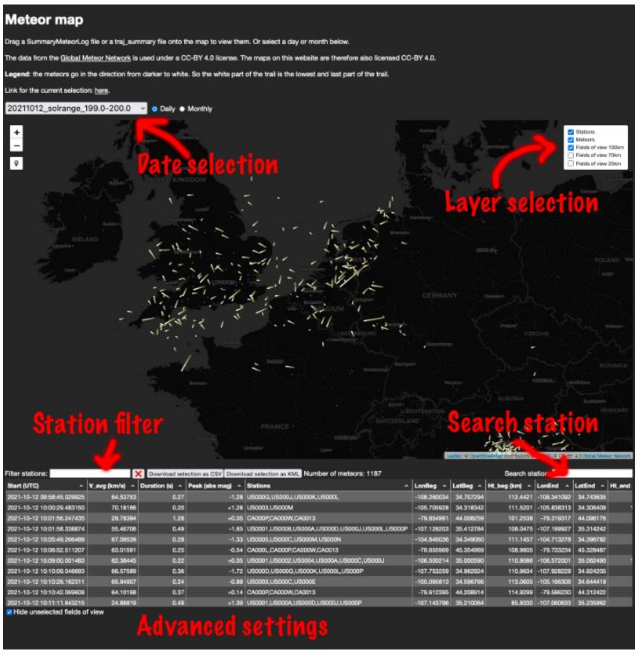

Figure 1 – Interface of the meteor map.

To locate a certain station ID, type that ID in the 'Search station' box in the bottom right below the map. The map will then center on that station.

Right clicking on an RMS station shows links to data of that station on IstraStream.

Inspecting and filtering meteors

A typical use case for the meteor map is to see which meteors are detected by a certain station. This can be done in the station filter. E.g., filtering with NL000D will only show meteors detected (also) by my station.

Partial matches are accepted, so filtering on "NL" will show detections from all Dutch stations. Combining multiple stations can be done with a comma, e.g. "NL,BE,DE" will

[1] The main libraries used are Leaflet for the map, Leaflet-omnivore for KML files, Papa Parse for parsing data, and Tabulator for presenting, sorting and filtering data.

[2] www.globalmeteornetwork.org

[3] cams.seti.org/

[4] www.meteornews.net/cams/7-10-coincidence/

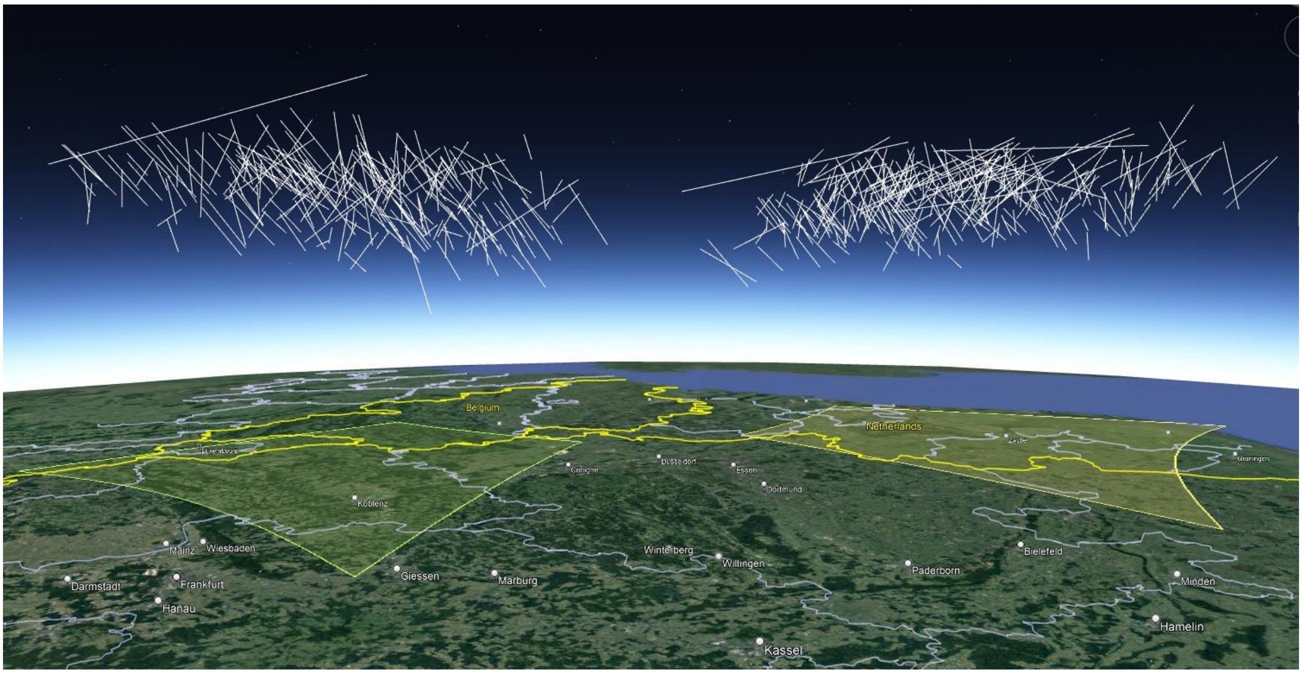

Figure 2 – Export from the meteor map shown in Google Earth. In this image all trajectories are shown, obtained by BE0002 (right) and BE0004 (left) during October 2021. The camerafields were added in Google Earth projected on the ground to locate the position.

show detections with Dutch, Belgian or German stations. If instead of a comma a semicolon is used, only detections are selected in which all of the stations are involved. E.g. “NL;DE” will select meteors with at least one Dutch and at least one German station involved.

If a nice view is selected in the meteor map, the permanent link shown at the top of the page can be used to save that view or share it with others.

To look for interesting meteors, the table below the map can be sorted on for example the duration, peak magnitude or height of the meteor (to keep the table clear, only a subset of the available columns is shown). Sorting on the ‘stations’ column will sort on the number of stations involved in the detection.

When a meteor is selected in the table, it is highlighted on the map.

The (possibly filtered) table with meteor data can be downloaded as a comma-separated file for inspection in, for example, Excel. It can also be downloaded as a KML file, which can be opened in Google Earth Pro. When viewing meteors in Google Earth, also the height dimension can be inspected visually, see *Figure 2*. To show this 3D map in Google Earth, hold “Ctrl” (or Command on a Mac) and drag the mouse down.

Planning camera placement

The meteor map can be used to spot areas in the sky that are not well covered by existing cameras. With this knowledge, new cameras can be placed strategically. The meteor map for GMN now contains fields of view at 100km, 50km and 25km above the ground. Obviously, the coverage decreases at lower altitudes.

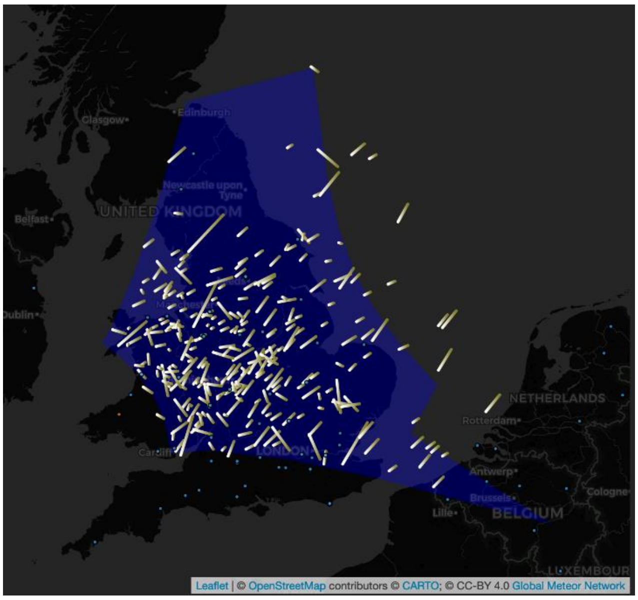

Figure 3 – Field of view of UK0029 with August 2021 meteors.

When clicking on the meteor map (not on a meteor), the cameras whose field of view contains that point are selected. This can help to predict with which stations simultaneous detections can be expected.

It is also informative to view the field of view of a station, along with a lot of detections of this station. The example in *Figure 3* shows that for station UK0029, almost the entire field of view at 100km is also covered by other cameras. These kinds of maps are best made with Perseids or Geminids data.

For making this map, I enabled the new option (in the advanced options, below the table) to hide the fields of view of stations that are not selected.

Figure 4 – All meteors that my station NL000D detected in 2021 as part of the Global Meteor Network.

Creating a year overview

With the publicly available data from the GMN, it’s quite easy to make an overview of all meteors recorded from a certain station. To this extent, it is necessary to download all 2021 data files from the GMN data site[5] to your local machine, and concatenating them into one file with the header and only the relevant orbits.

This can be done with a plain text editor like Notepad. On a Mac or Linux machine, it can be done by running the following few shell commands in the directory where the data files reside:

```
# Create header
head -n 4 traj_summary*_202101.txt > NL000D_2021.txt
# Add all lines containing my station NL000D
for traj in traj_summary_monthly_*.txt; do
    grep NL000D ${traj} >> NL000D_2021.txt
done
```

Dragging the resulting file NL000D_2021.txt onto the meteor map created *Figure 4*.

3 Help welcome!

The source code of the meteor map is available[6] at Github. The full code of the map itself is in one html file, but the repository also hosts the camera location files.

The meteor map started as (and still is) a side project, for which I do not have a lot of time available. But if you spot a bug or missing feature, please do report it at the issue tracker at Github. Or better even, implement the fix or feature, and create a pull request.

Features that are high on my wish list are an update to the style sheet, so that the table and map can be inspected more easily on mobile devices. Also, in the future it would be good to store the trajectories in a database with a spatial index, so that only the visible trajectories need to be loaded. This would make browsing meteors a lot faster.

4 Conclusion

The meteor map is a nice tool to visualize the Earth-facing view of the pipeline results of the Global Meteor Network and CAMS.

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[5] globalmeteornetwork.org/data/traj_summary_data/monthly/

[6] github.com/tammojan/meteormap

Global Meteor Network report 2021

Paul Roggemans[1], Denis Vida[2] and Damir Šegon[3]

[1] **Pijnboomstraat 25, 2800 Mechelen, Belgium**
paul.roggemans@gmail.com

[2] **Department of Earth Sciences, University of Western Ontario, London, Ontario, N6A 5B7, Canada**
denis.vida@gmail.com

[3] **Astronomical Society Istra Pula, Park Monte Zaro 2, 52100 Pula, Croatia**

A status update is presented for the Global Meteor Network. Since the start of the network, 388545 orbits have been collected, 411 different meteor showers have been identified among these orbits. At the end of 2021, 390 operational cameras were involved, installed in 22 countries. Major progress has been made in the UK where about 100 RMS cameras got installed. An important progress has been made in global coverage with the installation of many new cameras in Australia, Brazil and New Zealand. An overview is presented of the camera coverage at the end of 2021.

1 Introduction

Meteor astronomy has been popular among amateur astronomers since the 19th century. In the early years the only way to study meteor showers was to use the naked eye until photographic techniques became available. Meteor photography offered more precise measurements but proved to be expensive and not very efficient. Both visual and photographic meteor work were much affected by weather circumstances and only fractions of ongoing meteor events could be well observed. Radio and radar observations looked very promising in the 1940s, but forward scatter radio echo counts do not allow to identify any meteor shower association. Meteor radars weren't affordable for amateurs while the radiants and orbits obtained by radar techniques were much less reliable than photographic results.

Since many years experiments have been done with TV and video cameras which resulted in affordable meteor video cameras for amateurs. The availability of powerful personal computers enabled the creation of video meteor networks dedicated to collect large numbers of reliable orbits necessary to study meteor showers.

One of the pioneers in this field was the Croatian Meteor Network (Gural and Šegon, 2009). The SonotaCo Network started in 2007 in Japan with their UFO Capture software (SonotaCo, 2009). Soon several national and regional video camera networks got started by amateurs across Europe which merged into EDMOND (Kornoš et al., 2014). In the United States a major professional video network, CAMS, became operational in October 2010 (Jenniskens et al., 2011). Other camera networks were dedicated to fireballs in order to locate possible meteorite dropping events, such as the French FRIPON network (Colas et al., 2020), the Southwestern Europe Meteor Network (Madiedo et al., 2021), the Spanish Meteor Network (Peña Asensio et al., 2021) and several others. SonotaCo, EDMOND and CAMS were dedicated to cover the fainter range of meteors in order to study meteor showers. Meanwhile hundreds of previously unknown meteor showers have been discovered and many predicted and unpredicted shower outbursts could be monitored.

Based on the significantly improved Raspberry Pi solution introduced by Zubović et al. (2015) and Vida et al. (2016), at the end of 2018 the Global Meteor Network emerged starting with 6 cameras located in New Mexico, using IP cameras controlled by a Raspberry with its own dedicated software and reduction pipeline (Vida et al., 2021). GMN became the fastest growing meteor video network with 76 operational cameras at the end of 2019 and 173 at the end of 2020. The former EDMOND network was discontinued and GMN became a logic successor with most European amateur networks now building and installing RMS cameras. The growth of GMN is exceeding the most optimistic expectations.

2 Global Meteor Network status 2021

The aim of the GMN is to cover all latitudes and longitudes to assure a global coverage of meteor activity in order to let no unexpected meteor event pass unnoticed. A lot of progress has been made to achieve this coverage but still a lot more cameras are required in different parts of the world. In this report we describe the progress that was made during 2021 in different regions of the world. The status of the camera coverage is illustrated with maps showing the fields of view intersected at an elevation of 100 km in the atmosphere, projected and clamped to the ground. This way the actual overlap between the camera fields is shown without any effects of 3D perspectives. Where possible the camera ID has been mentioned on the plots.

The network has been rapidly expanding during 2021 to 390 operational cameras that contributed successfully in triangulations. In total 228 new cameras started to deliver data for successful triangulations in 2021. 11 camera IDs from 2020 did no longer appear in the 2021 results. The real number of new cameras added in 2021 is even higher as more RMS cameras were built and most of them installed, however, the numbers in this report represent only those cameras that effectively contributed in orbit data.

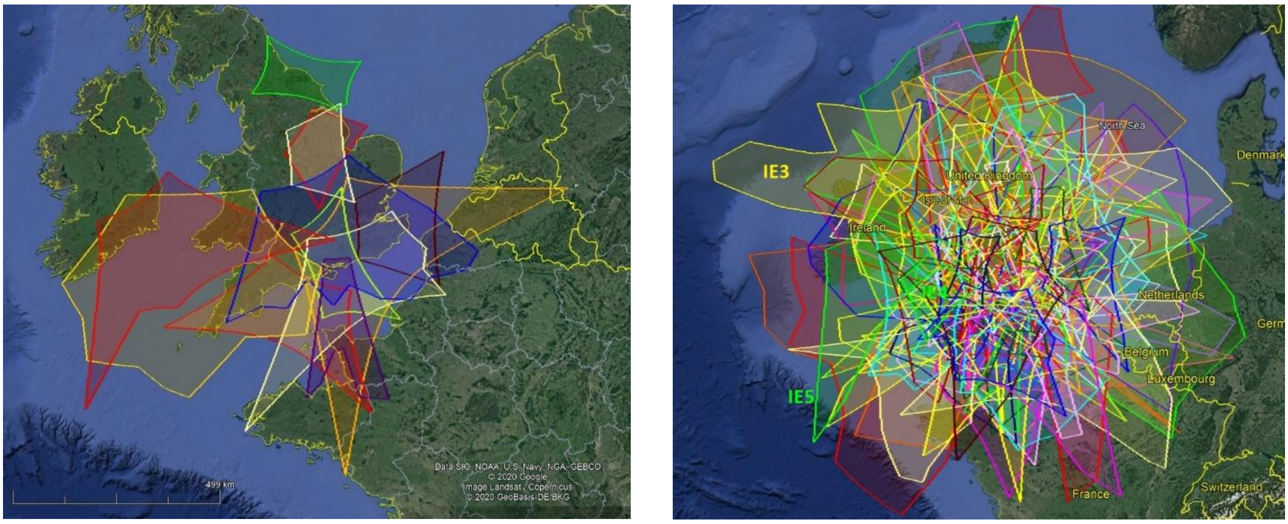

Figure 1 – GMN cameras installed in Ireland and the UK, left the coverage in October 2020, at right the coverage at the end of 2021.

Many RMS cameras with 4 mm optics have the horizon at the bottom of their field of view what results in a huge camera field at 100 km elevation. Rather few meteors will be bright enough to get registered near the horizon. The large distance between the camera station and the meteor also reduces the chances to obtain a useable triangulation. The number of paired meteors at the outskirts of these large camera fields is very small. However, cameras pointing so low towards the horizon turn out to be very useful regarding obtaining coverage at lower heights where meteorite dropping fireballs end their visible path. When looking for camera overlap, it is strongly recommended to look for an optimized overlap between cameras. A most interesting study on this topic for the New Mexico Meteor Array has been published by Mroz (2021).

The number of multi-station events mentioned per country corresponds to the number of orbits, unless an orbit was based on camera data from different countries, then it was counted once for each country. That meteors have no borders is obvious as there are 44598 cross border multi-station events in the GMN orbit dataset. International cooperation is a must for video meteor networks.

The UK and Ireland

The most impressive progress has been made in the UK. The UK got its first 13 RMS cameras by the end of 2020. *Figure 1* shows the status as it was in October 2020 compared to the coverage achieved at the end of 2021 when 97 operational RMS cameras were contributing orbit data. The coverage can still be improved above Scotland and Ireland, but anywhere else the overlap between the cameras will produce many multi-station events if the weather is clear. With the UK network now at full strength, it became one of the major contributors to GMN. In 2021, UK cameras were involved in 27436 multi-station events against 1889 events in 2020. The UK network also covers a vast surface of the sea and the western part of the continent.

The three operational RMS cameras in Ireland were involved in 424 multi-station events in 2021. Unfortunately, only one IE-camera remained active during the last few months of 2021. Most of the paired meteors were obtained thanks to the overlap provided by UK cameras. The three IE cameras have been marked on the map in *Figure 1* (right), all others being UK camera fields without camera ID because of the large number of cameras. To find out where each UK camera is pointing, you may use the tool provided by UKMON[7], you can select a camera, then select an altitude. Click on “Show” to reveal the coverage of the selected camera at the chosen altitude.

Belgium and the Netherlands

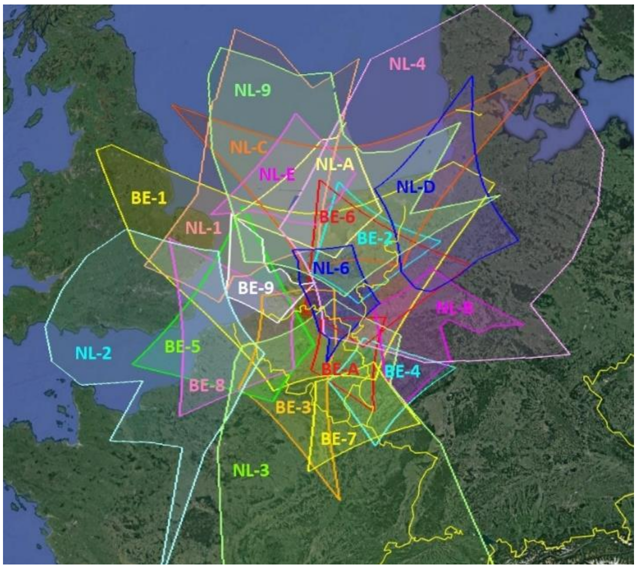

Figure 2 – GMN camera fields intersected at 100 km elevation, for 21 cameras installed in Belgium and the Netherlands. The letter code refers to the camera ID, e.g., NL-3 = NL0003.

Figure 2 shows the GMN coverage end 2021 for both countries. The number of RMS cameras remained at 11 in the Netherlands but increased from 4 to 10 in Belgium.

[7] https://archive.ukmeteornetwork.co.uk/latest/coverage-maps.html

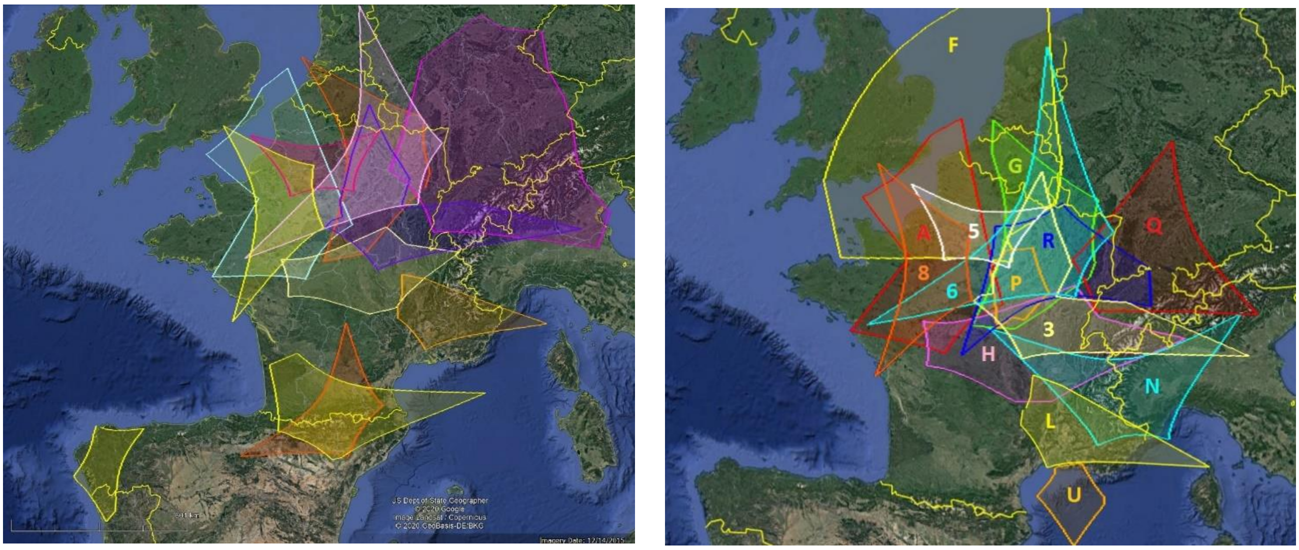

Figure 3 – GMN camera fields intersected at 100 km elevation, 2020 situation in France and Spain at left, in France in 2021 at right. The letter code refers to the camera ID, e.g., F = FR000F. The situation in Spain at the end of 2021 is shown in *Figure 4*.

The map can be compared with the situation end October 2020 in the previous GMN status report (Roggemans, 2021). These 21 cameras were involved in 16486 multi-station events against 10141 events in 2020 with 15 cameras.

Most of the RMS cameras are being installed for the re-enforcement of the CAMS-BeNeLux network. For this purpose, the 6 mm and 8 mm lenses are preferred which have significant less distortion than the 3.6 mm. All cameras are pointed in function of an optimal geographic overlap. 2021 brought rather unfavorable weather for CAMS-BeNeLux, in addition to several CAMS camera stations being unavailable for various technical issues. In spite of these problems, 2021 had the second-best number of orbits in 10 years for CAMS-BeNeLux and this was thanks to the extra coverage created by the RMS cameras. More RMS cameras will be installed in 2022 to replace the Watec H2 Ultimate after several years of service.

France and Spain

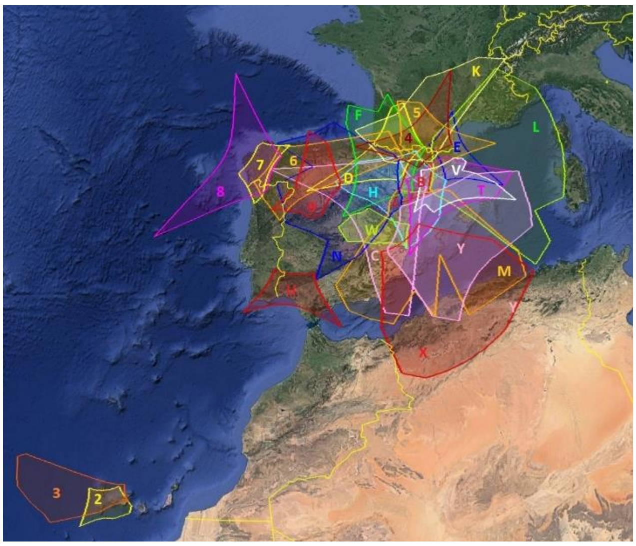

Figure 4 – GMN camera fields intersected at 100 km elevation, for 23 cameras installed in Spain. The letter code refers to the camera ID, e.g., M = ES000M.

The number of French RMS cameras increased from 10 to 14 and 1 camera quit providing data in 2021. The 14 French cameras were involved in 5652 multi-station events against 3195 events in 2020 with 10 cameras. The Southern and Western part of France remain still poorly covered (*Figure 3*).

A lot of progress was made in Spain where the number of RMS cameras increased from 8 to 23 in 2021. All 8 cameras from 2020 remained active. A separate map has been plotted with the camera overlap for Spain (*Figure 4*). The 23 Spanish cameras were involved in 15113 multi-station events against 1207 events in 2020 with 8 cameras.

Central Europe

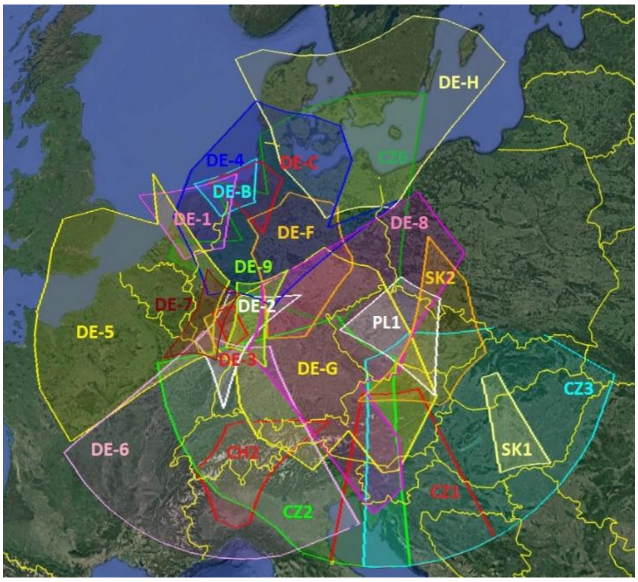

Figure 5 – GMN camera fields intersected at 100 km elevation, for cameras installed in Czechia, Germany, Poland, Slovakia and Switzerland. The letter code refers to the camera ID, e.g., CZ3 = CZ0003.

In Germany two new cameras got their first orbits. The 12 German cameras were involved in 7136 multi-station events against 4152 events in 2020 with 10 cameras. Some cameras in the North-Western part of Germany were installed as part of the CAMS-BeNeLux network. The 4 Czech cameras were involved in 468 multi-station events against 170 events in 2020 with 3 cameras. The single Polish camera was involved in 67 multi-station events against 35 events in 2020. Slovakia got its first camera in 2021 with 37 paired meteors and Switzerland got one camera with 3 paired meteors in 2021.

Central Europe definitely needs more cameras and we hope that more amateurs get involved from the former networks that were participating in EDMOND. *Figure 5* shows the current situation at the end of 2021.

South-Eastern Europe

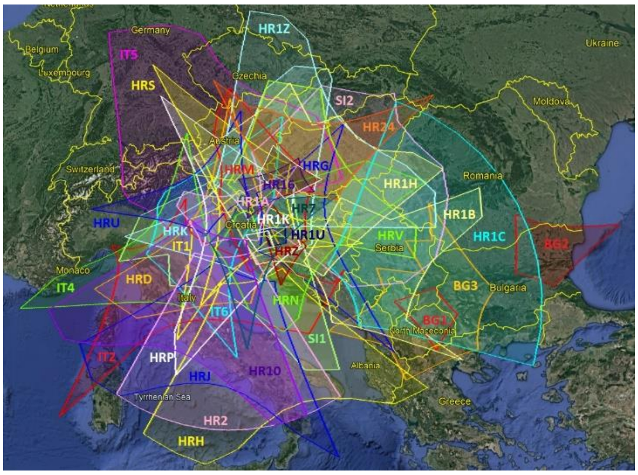

Figure 6 – GMN camera fields intersected at 100 km elevation, for cameras installed in Bulgaria, Croatia, Italy and Slovenia. The letter code refers to the camera ID, e.g., HRH = HR000H.

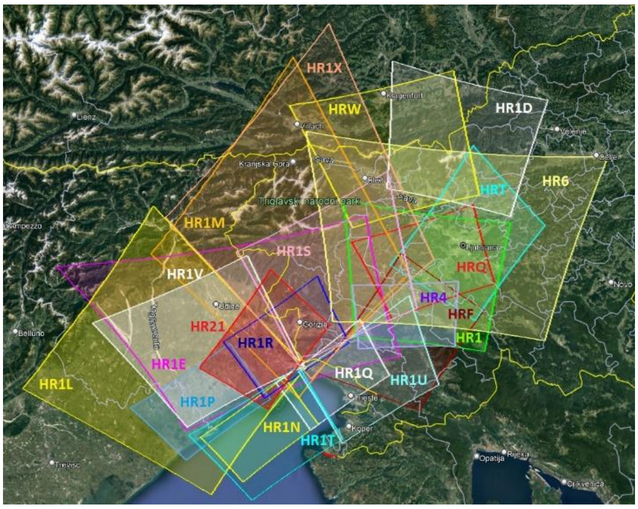

Figure 7 – Close-up for small GMN camera fields intersected at 100 km elevation, for cameras installed in Croatia.

Croatia was the first European country in May 2019 to harvest orbits with three RMS cameras. By the end of 2019 Croatia had already 23 cameras successfully contributing in triangulations, good for 12221 multi-station events. The Croatian branch of GMN had 48 cameras in 2021 that were involved in 38650 multi-station events against 35275 events in 2020 with 32 cameras. Croatia plays a major role in the coordination of GMN, maintaining the IStream website[8], offering RMS cameras plug & play for sale and providing technical assistance to participants in the GMN project worldwide. The density of the camera field coverage barely permits to mention all the camera IDs (*Figure 6*). A number of Croatian cameras have a very small FoV to register fainter meteors with higher positional accuracy. For clarity, these camera fields are shown in close-up in *Figure 7*.

Slovenia had its first RMS contributing in August 2019 and got its second RMS in August 2021. The two cameras were involved in 6191 multi-station events against 4081 events in 2020 with a single camera. The number of RMS cameras in Italy increased from 1 to 5 and these cameras were involved in 5559 multi-station events against 5505 events in 2020 with a single camera. Bulgaria got its first 3 RMS cameras installed in 2021 of which two had 420 multi-station events.

Russia

The number of RMS cameras having paired meteors remained stable at 21 in Russia. With 6208 orbits in 2021 against 13438 in 2020. Dmitrii Rychkov explains that there were problems with the maintenance of some meteor stations, which reduced the number of paired observations. This should be solved in 2022. Some single RMS devices (*Figure 8*) got installed elsewhere in Russia, waiting for coverage from other RMS cameras at a suitable distance.

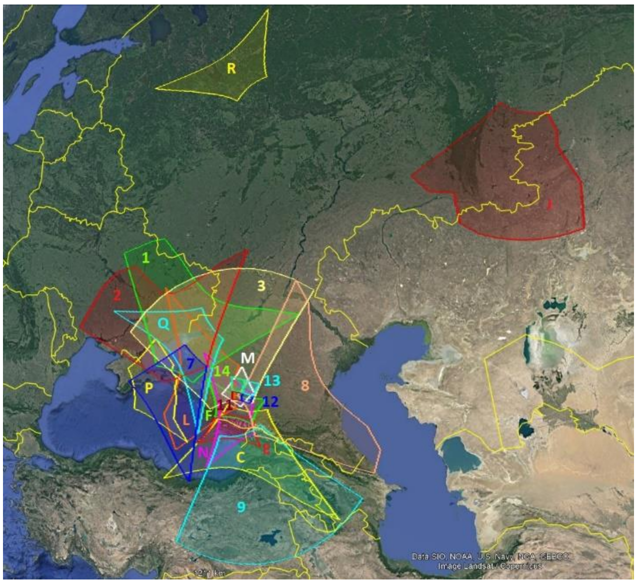

Figure 8 – GMN camera fields intersected at 100 km elevation, for cameras installed in Russia. The letter code refers to the camera ID, e.g., R = RU000R.

Overview picture of Europe

Plotting all the camera fields of Europe in a single map shows the concentrations of the network around the UK and around Croatia (*Figure 9*). Everything in between still needs more cameras to guard the atmosphere above Europe. Northern Europe is still completely missing as well as Eastern Europe.

[8] http://istrastream.com/

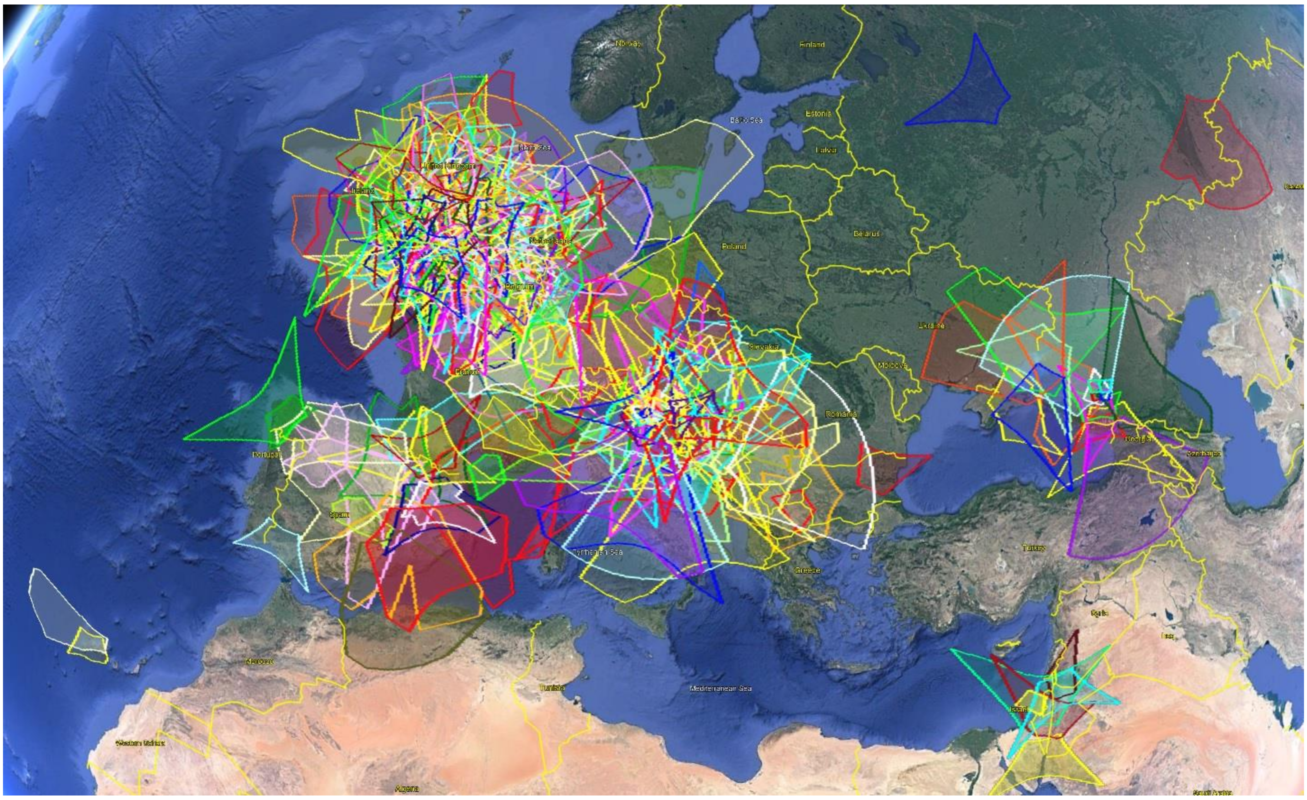

Figure 9 – GMN camera fields intersected at 100 km elevation, for 266 cameras installed in Europe and 6 in Israel.

Israel

GMN got some extra cameras in Israel where 2009 orbits were recorded by 6 cameras in 2021 against 553 orbits with 3 cameras in 2020 when the first cameras got operational in November. Some cameras are waiting for some extra overlap (*Figure 10*).

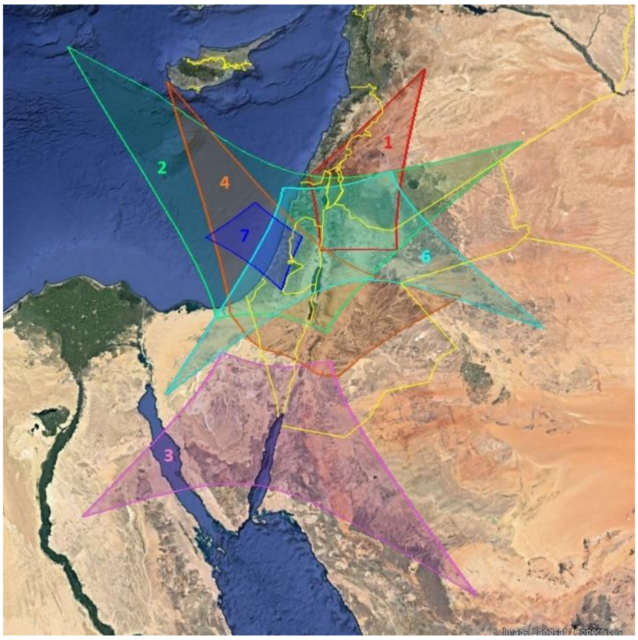

Figure 10 – GMN camera fields intersected at 100 km elevation, for cameras installed in Israel. The letter code refers to the camera ID, e.g., 3 = IL0003.

Brazil

The BRAMON network had its first two RMS cameras getting paired meteors in October 2020. The network expanded to 13 operational cameras, with 1645 orbits in 2021 against 40 orbits with two cameras in the last quarter of 2020. The cameras cover a huge amount of atmosphere and when more RMS get installed the number of multi-station hits will increase a lot at these strategic important southern latitudes.

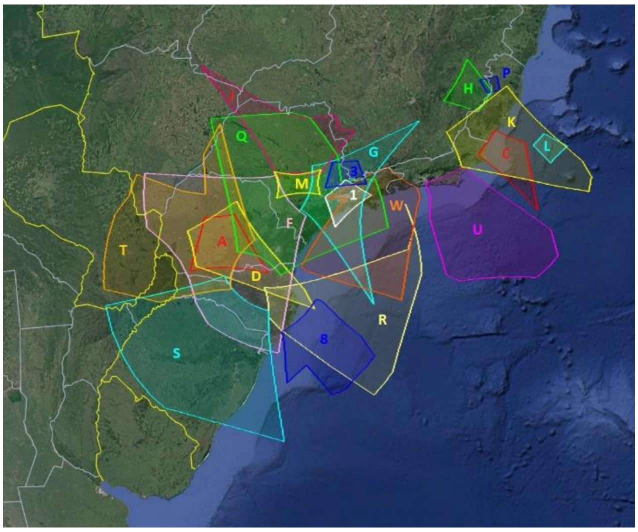

Figure 11 – GMN camera fields intersected at 100 km elevation, for cameras installed in Brazil. The letter code refers to the camera ID, e.g., S = BR000S.

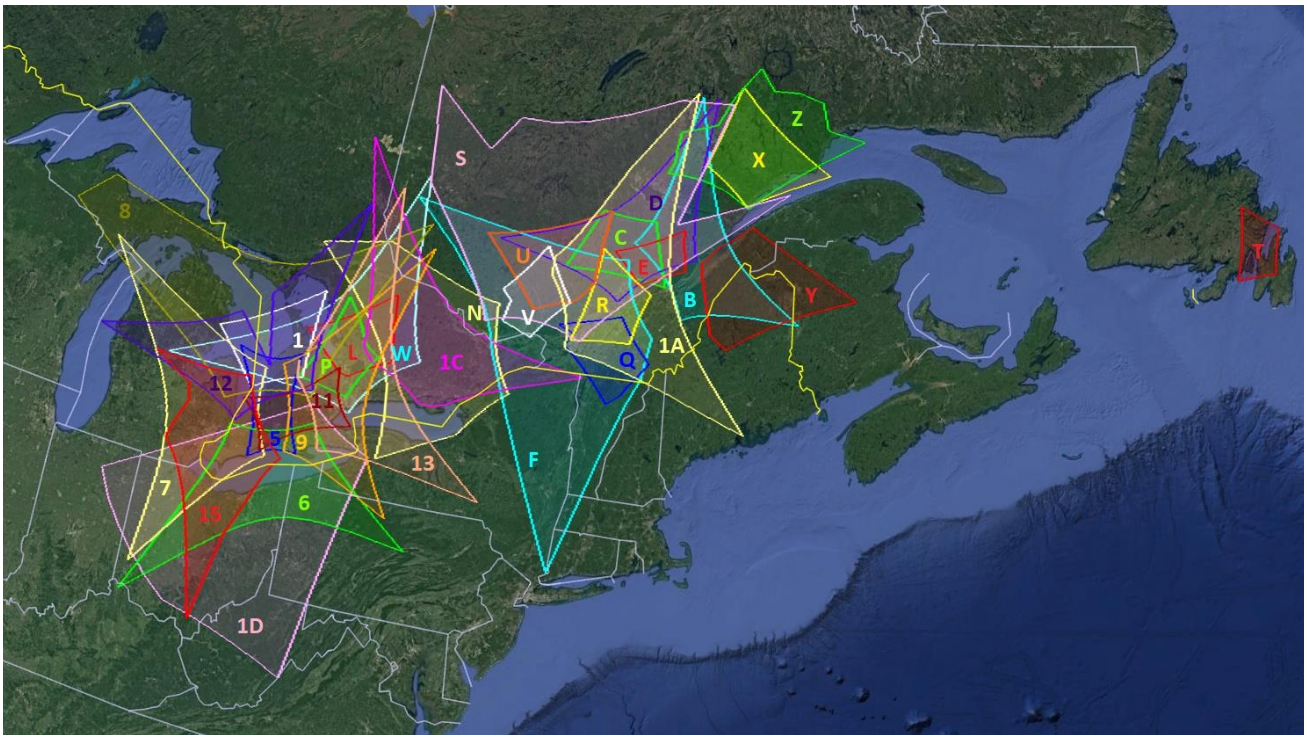

Figure 12 – GMN camera fields intersected at 100 km elevation, for cameras installed in Canada. The letter code refers to the camera ID, e.g., 1D = CA001D.

Canada

The Canadian GMN network got its first 5 operational RMS cameras providing orbits in June 2019 and expanded to 11 cameras by the end of 2019 and 18 cameras at the end of 2020. During 2021, 15 new camera IDs appeared in the list with orbits while 4 former IDs disappeared. 8809 orbits were recorded with 29 cameras in 2021 against 10815 orbits in 2020 with 18 cameras. The reason for the decrease in multi-station hits may be due to the weather and technical issues.

New Zealand

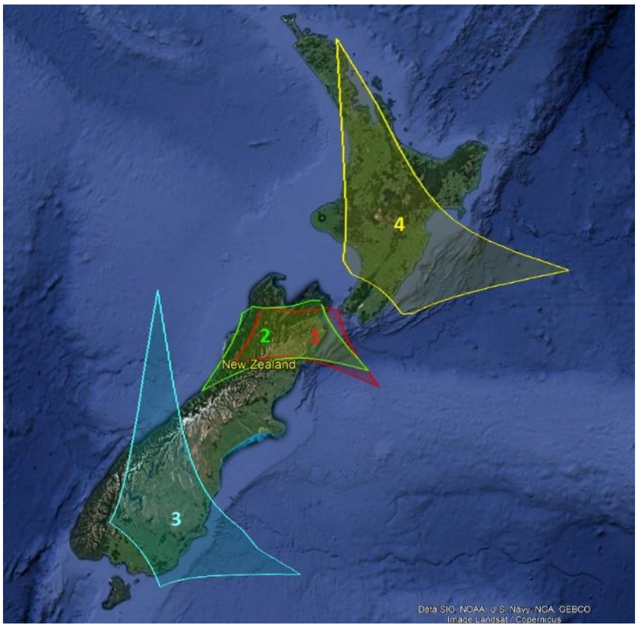

Figure 13 – GMN camera fields intersected at 100 km elevation, for cameras installed in New Zealand. The letter code refers to the camera ID, e.g., 3 = NZ0003.

The first 88 orbits for the RMS cameras in New Zealand were recorded in July 2021. Two camera fields are waiting to get coverage from other RMS cameras (*Figure 13*). In total 1146 orbits were collected in 2021. The strategic position of New Zealand is most important to collect orbits from the Southern hemisphere at these poorly covered longitudes.

Malaysia

A first RMS has been installed in Malaysia waiting for coverage from cameras installed at a suitable distance to get good triangulations (*Figure 14*). A meteor camera network in this part of the world would be the first as far as known. Close to the equator at this longitude such camera network would help to monitor meteor activity at these poorly covered longitudes.

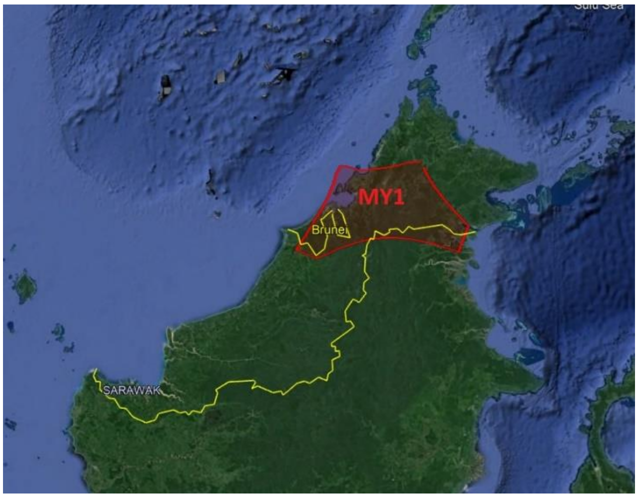

Figure 14 – GMN camera field intersected at 100 km elevation, for the first camera installed in Malaysia. The letter code refers to the camera ID, e.g., 1 = MY0001.

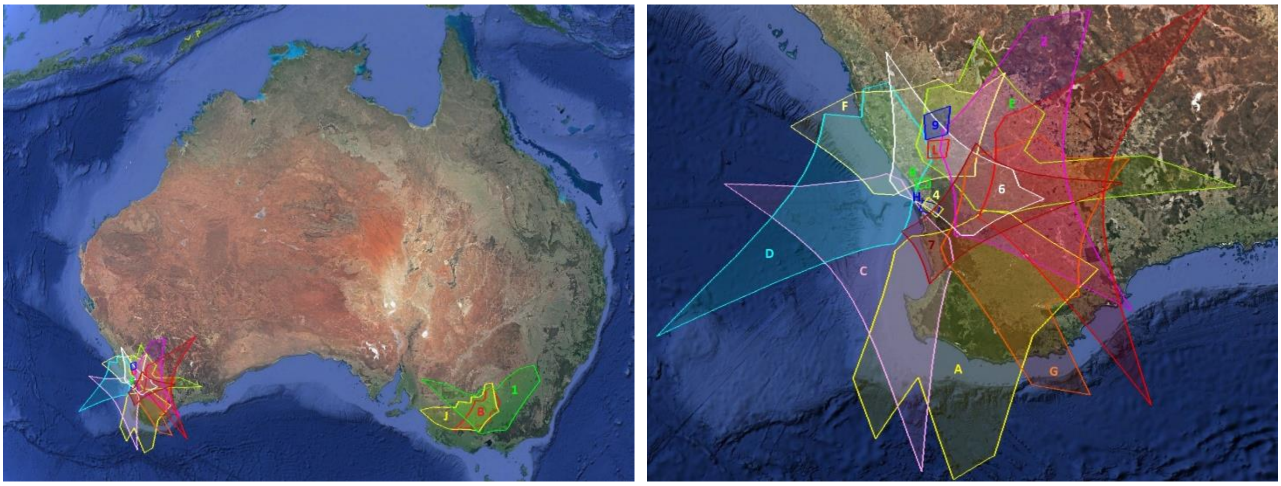

Figure 15 – GMN camera fields intersected at 100 km elevation, for cameras installed in Australia, global view at left and a close up for West Australia at right. The letter code refers to the camera ID, e.g., 1 = AU0001.

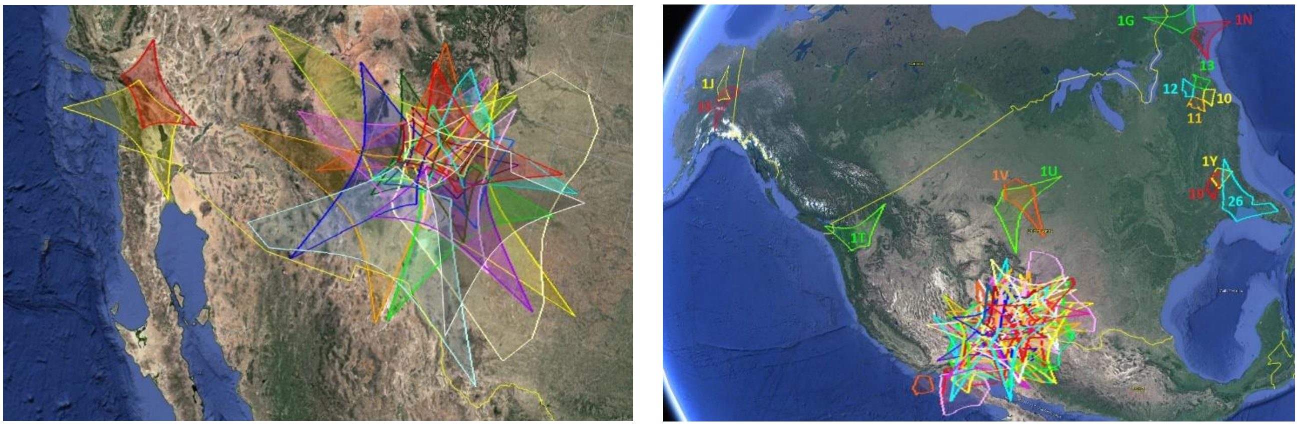

Figure 16 – GMN camera fields intersected at 100 km elevation, for cameras installed in the USA. At left the situation like it was by end October 2020, at right all US camera fields at the end of 2021. The letter code refers to the camera ID, e.g., 1U = US001U.

Australia

The first 31 meteor orbits by Australian RMS cameras were registered in September 2021 when the first 5 cameras got ready to harvest meteors. By the end of 2021 already 12 cameras managed to obtain orbits (*Figure 15*). In December 2021 Australian cameras collected 937 orbits, resulting in 1871 orbits in the final 4 months of 2021.

Past visual observations in Australia often enjoyed most favorable weather conditions, a situation which has been confirmed by the Australian CAMS network in West Australia. No doubt that Australia will become a major supplier of orbit data to GMN.

USA

The American New Mexico Meteor Array was the pioneering network of the GMN as it started to harvest meteors in December 2018 with 6 cameras, good for 497 orbits. It remained the only data provider for GMN until May 2019 when the first 3 Croatian cameras started to deliver orbits. At the end of 2019, the number of US cameras had increased to 20 collecting 27643 orbits in 2019.

Figure 16 at left shows the GMN status like it was end of October 2020 with 24 RMS cameras in the US. The expansion of the network shown at right is impressive. The 36 RMS cameras of the Lowell Observatory and those in New Mexico and California have significant overlap if we compare the camera fields of the Lowell Observatory in *Figure 18* with the other US camera fields in the same region shown in *Figure 17*.

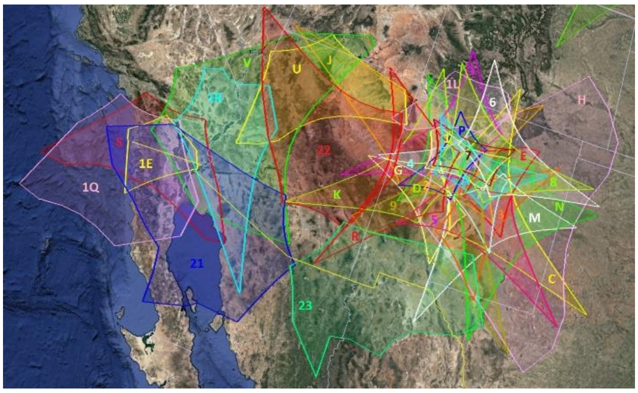

Figure 17 – GMN camera fields intersected at 100 km elevation, for cameras installed in the US, close up for the NMMA. The letter code refers to the camera ID, e.g., M = US000M.

In December 2020 the Lowell CAMS team at Lowell Observatory, Arizona, added 9 RMS cameras to their CAMS network and another 14 RMS cameras got installed elsewhere in the US. The 33 operational cameras in the US collected as many as 50607 orbits in 2020. The Lowell team added another 27 RMS cameras to their CAMS network in 2021 and 12 cameras got installed in California and elsewhere in the US. With 72 RMS cameras registering paired meteors in the US, a total of 91901 orbits got obtained, 51425 of them had RMS cameras of the Lowell Observatory involved. Without the important contribution by the Lowell RMS cameras, the total number of orbits for the US in 2021 would have been less. The implementation of RMS cameras in the Arizona CAMS network has been a win-win for both projects, CAMS and GMN. RMS cameras proved to be a perfect alternative for the more expensive Watecs since RMS cameras were successfully integrated in the CAMS-BeNeLux network in 2019.

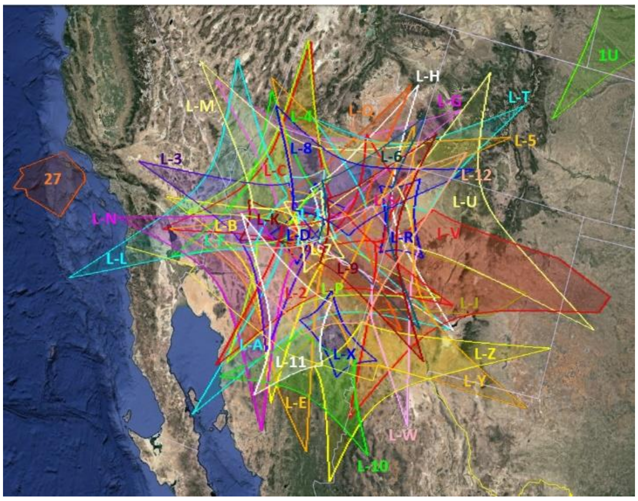

Figure 18 – GMN camera fields intersected at 100 km elevation, for cameras installed in the US, close up for the Lowell network in Arizona. The letter code refers to the camera ID, e.g., L-T = USL00T.

It is worthwhile mentioning that all RMS camera IDs that got installed and contributing in orbits in the US remained in service. Having many cameras is nice, to keep them all functioning is a challenge and requires care and maintenance.

Some lonely, newly installed RMS cameras wait for partners at a suitable distance for triangulations. Cameras installed in the North-East of the US can easily connect to the Canadian branch of the GMN. The GMN output delivers UFO-Capture output and simply adding a CAMS ID in the config file is sufficient to obtain CAMS compatible output. This makes the GMN concept of particular interest for existing networks.

3 GMN statistics 2021

When a first GMN status report got published, including all data until end October 2020, 140 operational cameras were involved and 144950 orbits had been collected (Roggemans, 2021). Meanwhile, 14 months later, we can compare 3 years of GMN work.

Figure 19 shows the accumulated number of orbits obtained and the number of contributing cameras during each calendar month. The rapid growth of the network can be seen from the increment in numbers of orbits with time. The number of cameras involved in GMN increased rapidly during 2021 while the number of orbits did not increase at the same pace. In spite of many more cameras and a lot more atmosphere covered, the gain in number of orbits is not proportional to the increased capacity of the network. It looks like the weather has been less favorable than previous years worldwide. The details per month for the number of orbits is given in *Table 1*. The number of cameras is given in *Table 2*. With many more cameras installed but not yet contributing, it is a matter of getting enough clear sky. Whenever some unexpected meteor activity occurs, the Global Meteor Network has good chances to cover it.

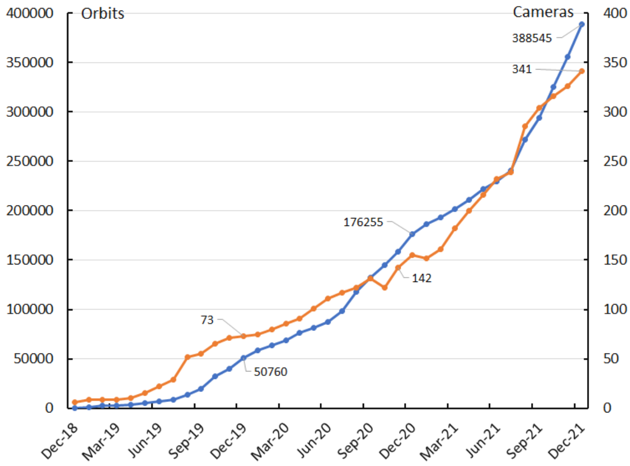

Figure 19 – The accumulated number of orbits (blue) and the actual number of operational cameras involved in triangulations (orange). The numbers at the end of each year are indicated.

Table 1 – Total number of orbits obtained by the Global Meteor Network cameras per calendar month.

Month	2018	2019	2020	2021	Total
01	–	564	7539	9919	18022
02	–	1284	5330	6567	13181
03	–	537	5101	8829	14467
04	–	876	7248	9655	17779
05	–	1242	5698	10268	17208
06	–	1523	5738	8020	15281
07	–	1961	10973	11325	24259
08	–	5387	19422	31296	56105
09	–	6058	14258	21435	41751
10	–	11978	13097	31503	56578
11	–	7710	13228	30414	51352
12	497	11143	17863	33059	62562
Totals	497	50263	125495	212290	388545

At the end of 2021 the Global Meteor Network had cameras providing orbits in 22 different countries. *Table 3* lists the number of multi-station events per country. For countries without cross-border triangulations this number is the same as the number of orbits recorded by these cameras, which is the case for Australia, Brazil, Israel, New Zealand and Russia. All other countries had meteors paired with cameras in neighboring countries. Therefore, we speak about multi-station events instead of orbits. For instance, an orbit obtained by cameras in Belgium, Germany, France, the Netherlands and the United Kingdom will be counted as 5 multi-station events, one for each country, regardless the number of cameras that contributed to it in each country. 27436 multi-station events recorded from the UK means that cameras in the UK contributed in the triangulation of 27436 orbits.

Table 2 – Total number of operational cameras within the Global Meteor Network per calendar month.

Month	2018	2019	2020	2021	Total
01	–	9	75	152	165
02	–	9	80	161	174
03	–	9	86	182	196
04	–	10	91	200	220
05	–	15	101	216	234
06	–	22	111	232	256
07	–	29	117	239	264
08	–	52	122	285	303
09	–	55	131	304	327
10	–	65	122	316	341
11	–	71	142	326	356
12	6	73	155	341	375

Table 3 – Total number of multi-station events recorded in each country for each year.

	2018	2019	2020	2021	Total
AU	–	–	–	1871	1871
BE	–	921	5705	8751	15377
BG	–	–	–	420	420
BR	–	–	40	1645	1685
CA	–	3599	10815	8809	23223
CH	–	–	–	3	3
CZ	–	–	170	468	638
DE	–	200	4152	7136	11488
ES	–	–	1207	15113	16320
FR	–	–	3195	5652	8847
HR	–	12221	35275	38650	86146
IE	–	–	120	424	544
IL	–	–	553	2009	2562
IT	–	862	5505	5559	11926
NL	–	278	4436	7735	12449
NZ	–	–	–	1146	1146
PL	–	–	35	67	102
RU	–	5715	13438	6208	25361
SI	–	2753	4081	6191	13025
SK	–	–	–	37	37
UK	–	–	1889	27436	29325
US	497	27643	50607	91901	170648

Table 4 – Total number of cameras in each country for each year.

RMS	2018	2019	2020	2021	Total
AU	–	–	–	12	12
BE	–	4	4	10	10
BG	–	–	–	2	2
BR	–	–	2	13	13
CA	–	11	18	29	33
CH	–	–	–	1	1
CZ	–	–	3	4	4
DE	–	4	10	12	13
ES	–	–	8	23	23
FR	–	–	10	14	15
HR	–	23	32	48	51
IE	–	–	2	3	3
IL	–	–	3	6	6
IT	–	1	1	5	5
NL	–	2	11	11	12
NZ	–	–	–	2	2
PL	–	–	1	1	1
RU	–	10	21	21	22
SI	–	1	1	2	2
SK	–	–	–	1	1
UK	–	–	13	97	97
US	6	20	33	72	72
Total	6	76	173	389	400

4 Meteor showers covered by GMN

Using the Working List of Meteor Showers[9] (Jenniskens et al., 2020; Jopek and Kaňuchová, 2017; Jopek and Jenniskens, 2011; Neslušan et al., 2020) as a reference, 411 of the showers listed could be associated with orbits collected by the Global Meteor Network. The number of orbits recorded for each of these showers is listed in *Table 5* for each year since 2018.

The GMN meteor shower association has been based on the table of Sun-centered ecliptic shower radiant positions given in Jenniskens et al. (2018). 654 entrees of the Working List of Meteor Showers have no matching orbits in the GMN database yet. Some of the showers are periodic and display only some activity once every few years, some showers have been detected only by radar in a fainter range of magnitudes than what GMN cameras cover and others are known as daylight meteor showers. While GMN is getting better coverage at the southern hemisphere, more of the low declination meteor showers will get covered. For a number of listed meteor showers their absence in the GMN orbit database may be explained because the evidence for the existence of the shower could be missing. One of the goals of the GMN project is to help to identify ghost meteor showers that should be removed from the Working List.

[9] https://iaumeteordatacenter.org/

Table 5 serves as an inventory of what the GMN orbit database has available until end 2021. Of course, the number of shower members detected depends on the criteria used to associate a meteor with a known meteor shower radiant. The GMN shower association criterion assumes that meteors within 1° in solar longitude, within 3° in radiant, and within 10% in geocentric velocity of a shower reference location are members of that shower. Further details about the shower association are explained in Moorhead et al. (2020). This is a rather strict criterion since meteor showers often have a larger dispersion in radiant position and velocity. Therefore, using the orbit similarity criteria (Drummond, 1981; Southworth and Hawkins, 1963; Jopek, 1993) will certainly detect more shower candidates but at the risk of including sporadic orbits that fulfil similarity criteria by pure chance.

Table 5 – Total number of orbits according to the meteor shower association (IAU number + code) for each year.

No	Code	2018	2019	2020	2021	Total
–	SPO	188	27834	71462	116282	215766
1	CAP	0	139	793	641	1573
2	STA	0	1388	1650	3421	6459
3	SIA	0	25	53	61	139
4	GEM	200	2664	7310	12163	22337
5	SDA	0	350	1560	1570	3480
6	LYR	0	46	733	1044	1823
7	PER	0	1809	8615	14719	25143
8	ORI	0	2771	3423	6905	13099
9	DRA	0	4	3	10	17
10	QUA	3	139	919	1710	2771
11	EVI	0	5	102	424	531
12	KCG	0	51	237	2559	2847
13	LEO	0	426	912	1598	2936
15	URS	5	134	336	259	734
16	HYD	7	557	779	2116	3459
17	NTA	1	963	1336	2477	4777
18	AND	0	61	126	1034	1221
19	MON	12	184	330	791	1317
20	COM	17	367	767	925	2076
21	AVB	0	15	156	194	365
22	LMI	0	109	134	269	512
23	EGE	0	168	198	598	964
25	NOA	0	145	170	234	549
26	NDA	0	203	687	905	1795
27	KSE	0	3	17	45	65
28	SOA	0	180	324	663	1167
31	ETA	0	218	654	1608	2480
33	NIA	0	108	188	299	595
40	ZCY	0	32	362	607	1001
47	DLI	0	7	99	73	179
61	TAH	0	0	0	1	1
65	GDE	0	1	6	22	29
69	SSG	0	31	87	113	231
81	SLY	0	15	99	149	263
88	ODR	0	4	20	21	45
89	PVI	0	1	41	114	156
96	NCC	1	45	154	197	397
97	SCC	1	81	223	227	532
101	PIH	0	152	272	533	957
110	AAN	0	3	26	19	48
145	ELY	0	10	64	202	276
149	NOP	0	7	25	23	55
150	SOP	0	3	22	45	70
151	EAU	0	15	71	75	161
152	NOC	0	2	4	7	13
161	SSC	0	9	5	27	41
164	NZC	0	143	605	617	1365
165	SZC	0	32	108	131	271
170	JBO	0	0	5	3	8
171	ARI	0	6	19	34	59
175	JPE	0	43	254	351	648
176	PHE	0	2	1	24	27
182	OCY	0	1	19	19	39
183	PAU	0	9	55	73	137
184	GDR	0	10	140	84	234
186	EUM	0	1	12	5	18
187	PCA	0	11	45	63	119
188	XRI	0	0	1	0	1
190	BPE	0	11	52	60	123
191	ERI	0	88	232	321	641
194	UCE	0	51	109	169	329
195	BIN	0	0	1	6	7
197	AUD	0	176	464	586	1226
206	AUR	0	58	152	263	473
208	SPE	0	196	426	814	1436
210	BAU	0	84	275	304	663
212	KLE	0	2	4	10	16
215	NPI	0	71	121	138	330
216	SPI	0	20	49	38	107
220	NDR	0	39	124	127	290
221	DSX	0	7	4	27	38
225	SOR	0	71	114	228	413
242	XDR	0	33	60	166	259
243	ZCN	0	2	2	13	17
245	NHD	0	13	39	127	179
246	AMO	0	25	30	41	96
250	NOO	1	396	489	1340	2226
252	ALY	0	2	5	9	16
253	CMI	1	65	96	166	328
256	ORN	8	172	186	380	746
257	ORS	3	279	385	759	1426
281	OCT	0	27	11	57	95
286	FTA	0	51	39	89	179

No	Code	2018	2019	2020	2021	Total
288	DSA	3	46	70	74	193
289	DNA	0	20	23	144	187
307	TPU	0	1	0	6	7
308	PIP	1	28	32	62	123
318	MVE	0	15	27	52	94
319	JLE	0	0	9	7	16
320	OSE	0	1	1	2	4
322	LBO	0	0	6	16	22
323	XCB	0	0	26	48	74
324	EPR	0	1	13	3	17
326	EPG	0	12	63	94	169
330	SSE	0	2	3	0	5
331	AHY	1	30	100	130	261
333	OCU	0	51	72	182	305
334	DAD	5	271	419	1068	1763
335	XVI	1	68	95	145	309
336	DKD	1	129	54	385	569
337	NUE	0	403	797	1554	2754
338	OER	0	243	272	614	1129
339	PSU	0	45	37	178	260
340	TPY	2	41	74	114	231
341	XUM	0	0	28	40	68
343	HVI	0	18	191	28	237
345	FHE	0	2	31	69	102
346	XHE	0	6	50	100	156
347	BPG	0	0	1	8	9
348	ARC	0	12	95	112	219
349	LLY	0	0	4	7	11
362	JMC	0	9	38	93	140
372	PPS	0	111	572	664	1347
376	ALN	0	4	11	23	38
384	OLP	0	24	21	64	109
386	OBC	0	37	49	93	179
388	CTA	0	145	141	439	725
390	THA	3	50	107	193	353
391	NDD	0	2	2	13	17
392	NID	0	37	76	167	280
394	ACA	1	35	26	75	137
395	GCM	2	34	65	61	162
404	GUM	0	0	35	29	64
410	DPI	0	3	12	17	32
411	CAN	0	31	222	317	570
416	SIC	0	5	46	76	127
424	SOL	0	29	103	127	259
427	FED	0	1	7	5	13
428	DSV	5	87	195	337	624
429	ACB	0	6	28	21	55
431	JIP	0	3	17	11	31
444	ZCS	0	34	193	330	557
445	KUM	0	30	81	192	303

No	Code	2018	2019	2020	2021	Total
446	DPC	0	24	17	102	143
448	AAL	0	2	11	14	27
450	AED	0	3	26	42	71
451	CAM	0	4	1	2	7
456	MPS	0	57	159	262	478
458	JEC	0	5	46	74	125
459	JEO	0	41	16	3	60
460	LOP	0	0	0	3	3
465	AXC	0	7	31	74	112
466	AOC	0	0	15	30	45
473	LAQ	0	16	34	36	86
476	ICE	0	9	40	27	76
480	TCA	0	131	149	395	675
486	NZP	0	11	30	26	67
488	NSU	0	13	21	25	59
494	DEL	0	39	59	207	305
497	DAB	0	4	15	23	42
501	FPL	0	1	31	51	83
502	DRV	2	58	81	186	327
505	AIC	0	69	186	264	519
506	FEV	0	14	127	196	337
507	UAN	0	25	121	170	316
510	JRC	0	1	19	58	78
512	RPU	0	17	53	71	141
514	OMC	0	0	18	24	42
515	OLE	0	31	73	138	242
516	FMV	0	6	81	92	179
517	ALO	0	1	5	29	35
518	AHE	0	1	13	4	18
519	BAQ	0	8	13	41	62
520	MBC	0	5	23	45	73
523	AGC	0	31	94	135	260
524	LUM	0	19	14	91	124
526	SLD	0	18	26	104	148
529	EHY	4	88	145	315	552
530	ECV	0	6	45	83	134
531	GAQ	0	11	43	107	161
533	JXA	0	15	61	90	166
535	THC	0	0	4	9	13
536	FSO	0	1	1	2	4
543	TTB	0	4	7	7	18
544	JNH	0	3	25	17	45
545	XCA	0	2	6	9	17
546	FTC	0	17	86	95	198
547	KAP	0	92	368	564	1024
549	FAN	0	5	75	79	159
552	PSO	0	61	184	394	639
555	OCP	0	23	32	83	138
556	PTA	0	16	13	65	94
557	SFD	0	100	125	309	534

No	Code	2018	2019	2020	2021	Total
559	MCB	0	10	18	28	56
561	SSX	1	10	33	40	84
563	DOU	3	38	59	46	146
564	SUM	0	14	23	17	54
569	OHY	0	16	48	65	129
570	FBH	0	6	19	16	41
571	TSB	0	1	11	16	28
575	SAU	0	7	19	23	49
580	CHA	0	16	53	37	106
581	NHE	0	11	104	166	281
582	JBC	0	3	23	49	75
584	GCE	0	22	56	86	164
585	THY	1	9	24	38	72
587	FNC	0	6	18	33	57
589	FCA	0	13	38	66	117
590	VCT	0	1	5	2	8
591	ZBO	0	3	30	41	74
592	PON	0	3	9	16	28
593	TOL	0	17	26	80	123
594	RSE	0	0	3	2	5
599	POS	0	8	96	190	294
601	ICT	1	4	5	7	17
602	KCR	0	0	5	27	32
608	FAR	0	4	14	35	53
613	TLY	0	5	19	90	114
618	THD	0	1	5	7	13
623	XCS	0	33	123	134	290
624	XAR	0	214	330	288	832
625	LTA	0	43	123	98	264
626	LCT	0	171	53	340	564
627	NPS	0	79	37	239	355
628	STS	0	175	134	415	724
629	ATS	0	126	170	220	516
630	TAR	0	183	164	615	962
631	DAT	0	192	63	449	704
632	NET	0	54	138	344	536
633	PTS	2	75	52	172	301
634	TAT	0	150	256	267	673
635	ATU	0	67	388	665	1120
636	MTA	0	59	25	177	261
637	FTR	0	69	95	237	401
638	DZT	2	10	11	37	60
640	AOA	0	123	413	480	1016
641	DRG	0	1	10	4	15
644	JLL	1	39	60	83	183
647	BCO	0	10	61	114	185
648	TAL	0	18	188	265	471
651	OAV	0	27	65	144	236
652	OSP	0	4	18	35	57
653	RLY	0	6	64	67	137

No	Code	2018	2019	2020	2021	Total
655	APC	0	1	2	3	6
657	GSG	0	1	6	16	23
658	EDR	0	2	28	35	65
660	EPS	0	3	21	50	74
661	OTH	0	1	17	35	53
664	MXA	0	0	0	1	1
665	MUC	0	3	30	42	75
668	JMP	0	2	20	23	45
671	MCY	0	0	5	11	16
672	HNJ	0	2	5	22	29
677	FCL	0	0	0	5	5
679	MUA	0	10	19	41	70
680	JEA	0	7	10	13	30
681	OAQ	0	4	19	21	44
683	JTS	0	0	8	6	14
685	JPS	0	3	11	5	19
686	JRD	0	1	3	8	12
687	KDP	0	1	7	4	12
689	TAC	0	17	64	46	127
691	ZCE	0	1	2	20	23
692	EQA	0	32	165	331	528
693	ANP	0	23	55	94	172
694	OMG	0	59	132	221	412
695	APA	0	9	13	12	34
696	OAU	0	8	30	41	79
698	AET	0	4	40	47	91
701	BCE	0	2	10	8	20
702	ASP	0	1	9	7	17
704	OAN	0	53	192	285	530
706	ZPI	0	28	59	110	197
707	BPX	0	0	1	3	4
708	RLM	0	0	2	18	20
712	FDC	0	3	16	14	33
713	CCR	0	2	12	10	24
714	RPI	0	56	121	167	344
715	ACL	0	145	373	641	1159
716	OCH	0	43	56	145	244
720	NGB	0	8	3	19	30
721	DAS	0	12	10	42	64
722	FLE	0	16	16	73	105
726	DEG	3	15	35	6	59
727	ISR	1	4	6	1	12
728	PGE	0	8	8	5	21
729	DCO	0	2	10	3	15
730	ATV	0	1	11	3	15
732	FGV	0	4	17	25	46
734	MOC	0	1	14	16	31
736	XIP	0	2	6	14	22
737	FNP	0	2	7	11	20
738	RER	0	1	11	28	40

No	Code	2018	2019	2020	2021	Total
739	LAR	0	3	12	31	46
745	OSD	0	22	42	81	145
746	EVE	0	19	24	202	245
747	JKL	0	13	44	87	144
748	JTL	0	6	32	44	82
749	NMV	0	13	84	113	210
750	SMV	0	20	122	178	320
751	KCE	0	38	88	91	217
755	MID	0	0	5	8	13
757	CCY	0	19	515	48	582
758	VOL	0	0	0	2	2
771	SCO	0	1	0	4	5
783	ILU	0	0	1	0	1
784	KVE	0	0	5	43	48
785	TCD	0	0	0	10	10
786	SXP	0	2	5	1	8
792	MBE	0	0	0	2	2
793	KCA	0	0	8	6	14
796	SED	0	19	9	62	90
797	EGR	0	0	0	4	4
802	ADS	0	2	14	15	31
803	LSA	0	5	11	43	59
807	FLO	0	11	100	130	241
810	XCD	0	29	18	57	104
812	NAA	0	6	19	22	47
814	CVD	0	1	11	9	21
815	UMS	0	1	10	9	20
816	CVT	0	2	15	19	36
818	OAG	0	9	11	13	33
822	NUT	0	0	4	9	13
823	FCE	0	14	34	39	87
824	DEX	0	2	16	12	30
825	XIE	0	10	11	22	43
826	ILI	0	9	52	60	121
827	NPE	0	1	17	25	43
828	TPG	0	0	1	1	2
829	JSP	0	6	19	28	53
830	SCY	0	3	40	24	67
831	GPG	0	4	9	21	34
832	LEP	0	4	5	9	18
833	KOR	0	10	8	20	38
834	ACU	0	1	1	6	8
835	JDP	0	0	0	1	1
836	ABH	0	0	2	7	9
837	CAE	0	2	0	2	4
838	ODS	0	2	0	5	7
839	PSR	0	1	9	19	29
840	TER	0	0	5	9	14
841	DHE	0	1	7	26	34
842	CRN	0	0	0	6	6

No	Code	2018	2019	2020	2021	Total
843	DMD	1	9	9	9	28
844	DTP	0	17	8	60	85
845	OEV	0	0	1	1	2
847	BEL	0	4	1	15	20
848	OPE	0	2	5	4	11
849	SZE	0	1	15	19	35
850	MBA	0	0	2	8	10
854	PCY	0	3	28	50	81
855	ATD	0	0	3	11	14
856	EMO	0	6	12	14	32
858	FPB	0	8	34	36	78
859	MTB	0	2	8	23	33
860	PAN	0	0	4	14	18
861	JXS	0	3	7	3	13
862	SSR	0	1	12	28	41
863	TLR	0	0	5	12	17
864	JSG	0	0	1	9	10
865	JES	0	4	5	6	15
866	ECB	0	2	7	12	21
867	FPE	0	3	8	3	14
868	PSQ	0	1	4	2	7
869	UCA	0	0	16	8	24
870	JPG	0	0	12	9	21
871	DCD	0	0	6	5	11
872	ETR	0	1	10	15	26
873	OMI	0	3	7	12	22
874	PXS	0	8	37	38	83
875	TEI	0	12	11	25	48
876	ROR	0	9	11	15	35
877	OHD	0	6	9	26	41
878	OEA	0	3	4	4	11
879	ATI	0	6	8	26	40
880	YDR	0	16	22	45	83
881	TLE	0	3	1	15	19
882	PLE	0	3	8	9	20
883	NMD	0	1	6	3	10
884	NBP	0	0	3	2	5
885	DEV	0	4	12	8	24
886	ACV	2	2	7	18	29
887	DZB	0	7	12	10	29
888	SCV	0	0	2	7	9
889	YOP	0	0	1	2	3
890	ESU	0	1	3	6	10
891	FSL	0	6	30	29	65
892	MCN	0	0	0	3	3
893	EOP	0	0	21	37	58
894	JMD	0	3	19	26	48
895	OAB	0	0	0	1	1
896	OTA	0	8	22	12	42
897	OUR	0	9	2	22	33

No	Code	2018	2019	2020	2021	Total
898	SGP	0	5	12	24	41
899	EMC	0	1	0	5	6
900	BBO	0	2	28	61	91
901	TLC	0	1	5	5	11
902	DCT	0	11	18	30	59
903	OAT	0	8	13	9	30
904	OCO	0	2	4	13	19
905	MXD	0	0	4	9	13
906	ETD	0	4	26	22	52
907	MCE	0	0	8	19	27
909	SEC	0	0	1	6	7
910	BTC	0	3	33	24	60
911	TVU	0	3	18	39	60
912	BCY	0	0	30	58	88
914	AGE	0	0	3	0	3
915	DNO	0	0	0	2	2
917	OVI	0	1	1	2	4
918	TAG	0	4	7	14	25
919	ICN	0	0	1	1	2
920	XSC	0	5	10	28	43
921	JLC	0	3	21	8	32
922	PPE	0	1	2	2	5
923	FBO	0	0	1	1	2
924	SAN	0	1	3	21	25
925	EAN	0	3	4	3	10
926	OMH	0	0	0	1	1
1130	ARD	0	0	0	6	6
1131	OZP	0	0	0	14	14
	Total	497	50263	125495	212290	388545

5 Joining the Global Meteor Network

More information about this project can be found in Vida et al. (2021) and on the GMN website[10]. A nice video presentation about the Global Meteor Network project can be watched online[11]. Many sites and participants are still waiting to find partners to improve the coverage on their cameras. New participants are welcome to expand the network.

To obtain a camera for participation you can either buy it plug&play from Istream[12], or you buy the components and build your own camera for about 200 euro. The RMS cameras are easy to build and operate. If you are interested in building your own camera you can find detailed instructions online[13].

The daily status of most (not all) meteor stations can be followed on a webpage[14]. The GMN results and data are publicly available and daily updated online[15]. The British UKMON maintains a nice archive[16] and daily update[17] which may inspire others. Their Wiki-page[18] may be helpful to people outside the UK as well as their the github repos[19,20].

The meteor map[21] is an online tool for visualizing meteor cameras and ground tracks of observed meteors. Each participant can check the results obtained with each camera, check the location of the meteor trajectories and combinations with other camera stations. The tool has been described in a recently published article (Dijkema, 2022).

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[10] https://globalmeteornetwork.org/
[11] https://www.youtube.com/watch?v=MAGq-XqD5Po
[12] https://globalmeteornetwork.org/?page_id=136
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December 2021 report CAMS BeNeLux

Carl Johannink[1] and Paul Roggemans[2]

[1] **Am Ollenkamp 4, 48599 Gronau, Germany**
c.johannink@t-online.de

[2] **Pijnboomstraat 25, 2800 Mechelen, Belgium**
paul.roggemans@gmail.com

A summary of the activity of the CAMS BeNeLux network during the month of December 2021 is presented. 19579 meteor detections were recorded of which 9080 multiple station meteors. The weather was very unfavorable; all rich Geminid nights were completely missed. 25 nights allowed to collect some orbits with 8 nights with more than 100 orbits. In total 3072 orbits were added to the CAMS BeNeLux database.

1 Introduction

December is one of the top months for meteor astronomy. The nights are long, meteor activity is high, not only because of the rich sporadic activity, but also thanks to very active meteor showers. The Geminids being the most impressive meteor shower of the year, but also some minor showers deserve attention during this month. What would this year bring, could we be lucky with the weather in 2021?

2 December 2021 statistics

CAMS BeNeLux collected 19579 meteor detections of which 9080 paired meteors in December 2021 (against 8150 in 2020 and 12329 in December 2019). Indeed, this number suggests the weather circumstances were not favorable at all this year. All the rich Geminid nights 12–13, 13–14 and 14–15 December remained totally cloudy. The final number of orbits reached a total of 3072 orbits (against 2693 in 2020), still an impressive number when taking the poor weather circumstances into account. But this result is far less than the 4908 orbits of December 2018 when CAMS BeNeLux had its best December month ever.

This month counted only 8 nights with more than 100 orbits (8 in 2020 and 13 in 2019) and 6 nights remained without any orbits (7 in 2020 and 3 in 2019). Best night of December 2021 was 21–22 with 559 orbits, during the Ursid maximum. Until 2020 this night remained one the nights with the lowest number of orbits since 2012, with only 24 orbits collected during all previous years before 2021. It is mostly thanks to the result of the night 21–22 as well as 8–9 and 20-21 December that the month got at more than 3000 orbits. These three nights were good for about half of the monthly total. Especially the Netherlands got to deal with partial or completely cloudy nights. During many nights only a part of the operational cameras could register meteors.

The statistics of December 2021 are compared in *Figure 1* and *Table 1* with the same month in previous years since the start of CAMS BeNeLux in 2012. In 10 years, 231 December nights allowed to obtain orbits with a grand total of 25392 orbits collected during December during all these years together.

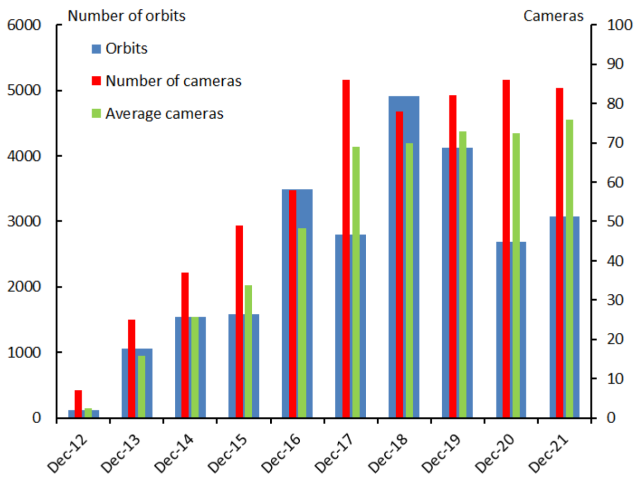

Figure 1 – Comparing December 2021 to previous months of December in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the green bars the average number of cameras running per night.

Table 1 – December 2021 compared to previous months of December.

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Avg. Cams
2012	12	117	6	7	-	2.4
2013	23	1053	10	25	-	15.7
2014	19	1540	14	37	-	25.8
2015	27	1589	15	49	8	33.8
2016	25	3492	21	58	25	48.3
2017	25	2804	22	86	49	68.9
2018	23	4908	21	78	52	69.8
2019	28	4124	21	82	64	72.8
2020	24	2693	24	86	56	72.4
2021	25	3072	25	84	67	76.0
Total	231	25392				

Table 2 – Data for the observed alpha Hydrids in December 2021 with the geocentric radiant position (source: data CAMS BeNeLux).

Date	Time UT	Sites	R.A.	Decl.
Dec. 22	$01^h18^m46^s$	Ermelo-Gronau	117.7°	–4.4°
Dec. 22	$03^h03^m05^s$	Oostkapelle-Alphen a/d Rijn-Mechelen-Gent-Grapfontaine	120.3°	–5.4°
Dec. 22	$03^h21^m26^s$	Ermelo-Gronau	119.1°	–8.4°
Dec. 25	$01^h59^m08^s$	Flatzby- Holdorf	120.0°	–5.7°
Dec. 26	$02^h18^m31^s$	Ermelo-Woold	122.2°	–7.5°

December 2021 had 84 cameras at best and 76.0 on average capturing meteors. The network was expanded with one new camera, on December 16 *Tim Polfliet* got RMS 3820 operational in Gent.

3 Some peculiar data

A significant dataset has been obtained for the Ursids which will be covered in another article. Of course, several other showers were recognized as well. During the last decade of the year five alpha Hydrids (AHY, #00331) were recorded. The radiant of this minor shower is located about 10 degrees south of the radiant of the sigma Hydrids (HYD, #0016), which could be observed visually at the middle of the month. The alpha Hydrids with v_g = 43 km/s, are slower than the sigma Hydrids with v_g = 59 km/s and the orbits of both meteoroid streams differ mainly in inclination *i*. *Table 2* lists some details of the observed alpha Hydrids.

On December 9, at $02^h48^m18^s$ UT, *Jean-Marie Biets, Luc Gobin* and *Paul Roggemans* recorded an alpha Canis Majorid (ACA, #00394). It is remarkable we could record a member of this southern hemisphere meteor shower from our northern latitudes (50° to 53° north). The geocentric radiant of this meteor was at R.A. = 106.0° and decl. = –12.4°.

As early as December 17 at $00^h37^m54^s$ UT, *Paul Roggemans* and *Klaas Jobse* recorded the first Quadrantid of the season. Data for this major shower will be discussed in the January report.

4 Conclusion

December 2021 brought barely better weather than previous year. With more cameras operational 7 on 7 than previous years, mainly newly installed RMS cameras, the best could be derived from partial clear nights. December 2021 wasn't as bad as December 2020, but will remain one of the poorest months of December in the CAMS BeNeLux history.

Acknowledgment

This report is based on the online data taken from the CAMS website[23] and the CAMS BeNeLux own data. Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The CAMS BeNeLux team was operated by the following volunteers during the month of December 2021:

Hans Betlem (Woold, CAMS 3071, 3072 and 3073), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Ludger Boergerding* (Holdorf, Germany, RMS 3801), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 319, 328 and 329), *Giuseppe Canonaco* (Genk, RMS 3818, RMS 3819), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805 and 806), *Tammo Jan Dijkema* (Dwingeloo, Netherlands, RMS 3199), *Isabelle Ansseau*, *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 3814, RMS 3817), *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 811, 812 and 813), *Kees Habraken* (Kattendijke, Netherlands, RMS 378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 3100, 3101 and 3102), *Reinhard Kühn* (Flatzby, Germany, RMS 3802), *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 3051, 3052, 3053 and 3054), *Tim Polfliet* (Gent, Belgium, CAMS 396, RMS 3820), *Steve Rau* (Zillebeke, Belgium, CAMS 3850, 3852, RMS 3851, RMS 3853), *Paul and Adriana Roggemans* (Mechelen, Belgium, RMS 3830 and 3831, CAMS 3832, 3833, 3834, 3835, 3836 and 3837), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803).

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

January 2022 report CAMS BeNeLux

Carl Johannink

Am Ollenkamp 4, 48599 Gronau, Germany
c.johannink@t-online.de

A summary of the activity of the CAMS BeNeLux network during the month of January 2022 is presented. This month gave many cloudy nights due to a persistent moisty type of weather. Especially the northern parts suffered from this weather, with sometimes 5 consecutive totally clouded nights. A total of 12018 meteors were registered of which 4741 multi-station meteors, good for 1744 orbits.

1 Introduction

Although there is approximately 15 hours of darkness in January in the BeNeLux, this month isn't a month with high scores for our network.

Meteor activity is still at a fairly good level, but weather isn't cooperating most of the time. 2022 unfortunately wasn't an exception.

2 January 2022 statistics

January 2022 was very mild, with a mean temperature above 5 degrees Celsius. This is not a good sign for astronomical observations. Observations of our network were hampered by clouds during many nights. Complete clear nights were very rare this month for most parts of the BeNeLux. Especially the northern parts of the BeNeLux saw many nights that were completely clouded out, sometimes 5 nights in a row as from January 11 – 16 and again from January 21 – 26.

Table 1 – Number of meteors per camera and number of meteors per camera per day for stations Hengelo (HL) and Mechelen (ML). RMS-data HL from CAMS 319 and 328.

	Hengelo (HL)		Mechelen (ML)	
	8 Watecs	2 RMS	6 Watecs	2 RMS
Tot. meteors	563	366	978	400
Per Watec	70.4	183.0	163.0	200.0
Per night	2.3	5.9	5.3	6.5

More southern parts were a bit luckier, but there too, many nights remained clouded or only partly clear nights. This has an effect on the efficiency of cameras on different sites in the BeNeLux. *Table 1* gives data for two stations in our network. Hengelo (HL) in the northeastern parts of the Netherlands and Mechelen (ML) in the central part of Belgium. Both sites have Watecs and RMS-cameras that are working 7 nights on 7. But from *Table 1* the disadvantage of Hengelo in collecting data this month, is clearly visible. As can be seen from this table, RMS cameras are more productive than Watecs, but in regions with much light pollution the difference seems not to be very large.

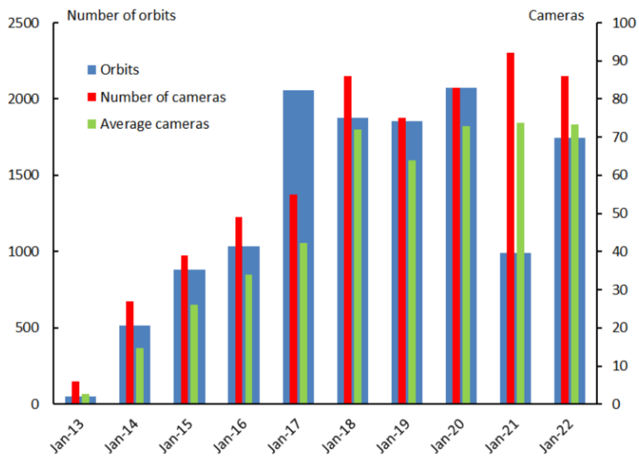

Figure 1 – Comparing January 2022 to previous months of January in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the green bars the average number of cameras running per night.

Table 2 – January 2022 compared to previous months of January.

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Avg. Cams
2013	7	49	6	6	–	2.6
2014	21	514	11	27	–	14.8
2015	22	880	14	39	–	26.1
2016	25	1037	15	49	10	34.0
2017	23	2058	18	55	18	42.3
2018	25	1878	22	86	53	72.1
2019	22	1857	20	75	54	64
2020	23	2075	21	83	64	72.9
2021	22	991	26	92	64	73.7
2022	28	1744	26	86	65	73.2
Total	218	13083				

CAMS BeNeLux collected 12018 meteors of which 4741 or 39% multi-station meteors this month, resulting in a total of 1744 orbits, mainly from more southern locations in some clear spells. On the other hand, we had only three nights with no orbit at all this month.

As a consequence of the variable circumstances, nearly 60% of our orbits were derived from only two stations which is a fairly high number.

The lack of totally clear nights is the explanation for these numbers. For instance, the station of Hengelo, the Netherlands, had 13 fully clouded nights despite 7 on 7 coverage. At Mechelen, Belgium, only 4 nights were fully clouded this month.

3 Conclusion

The results for January 2022 are the fifth best during 10 years of CAMS BeNeLux.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The CAMS BeNeLux team was operated by the following volunteers during the month of January 2022:

Hans Betlem (Woold, CAMS 3071, 3072 and 3073), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Ludger Boergerding* (Holdorf, Germany, RMS 3801), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327, RMS 319, 328 and 329), *Giuseppe Canonaco* (Genk, RMS 3818, RMS 3819), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805 and 806), *Tammo Jan Dijkema* (Dwingeloo, Netherlands, RMS 3199), *Isabelle Ansseau, Jean-Paul Dumoulin, Dominique Guiot* and *Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 3814, RMS 3817), *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 811, 812 and 813), *Kees Habraken* (Kattendijke, Netherlands, RMS 378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 3100, 3101 and 3102), *Reinhard Kühn* (Flatzby, Germany, RMS 3802), *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 3051, 3052, 3053 and 3054), *Tim Polfliet* (Gent, Belgium, CAMS 396, RMS 3820), *Steve Rau* (Zillebeke, Belgium, CAMS 3850, 3852, RMS 3851, RMS 3853), *Paul and Adriana Roggemans* (Mechelen, Belgium, RMS 3830 and 3831, CAMS 3832, 3833, 3834, 3835, 3836 and 3837), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803).

Annual report 2021 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 year 2021 is presented. The year 2021 brought in general poor weather for astronomical observations. The best months of 2021 were the months August to November. 45985 orbits could be computed during 318 different nights which corresponds to 87% of all 365 nights in 2021. The months September and October had the best scores ever for these months.

1 Introduction

The first CAMS network started in October 2010 in California (Jenniskens et al., 2011) and CAMS BeNeLux was the first CAMS network outside the USA with 14–15 March 2012 as its starting date. Meanwhile we are almost 10 years later and the CAMS BeNeLux network has exceeded by far all expectations.

In CAMS BeNeLux all the cameras, optics, computers and other required equipment are bought and financed by the participants themselves. Operating cameras for the CAMS network also requires some time on a regular basis to confirm meteors, remove false detections and report the data. The commitment in such project requires a strong motivation which is crucial to maintain these efforts.

Until 2017 CAMS BeNeLux expanded fast in number of cameras while in recent years the total number of cameras did not change much. Some CAMS stations quit; few others joined the network. The total volume of the atmosphere covered by CAMS BeNeLux cameras gradually increased. In recent years the classic Watec H2 Ultimate cameras got less popular and all of the recently added cameras are all RMS which deliver data to both CAMS and Global Meteor Network. Using RMS cameras for the CAMS BeNeLux network has the advantage that these are fully automated and functioning 7 nights on 7.

2 CAMS BeNeLux 2021 statistics

The year 2021 started with an exceptionally poor week with as few as 31 orbits collected in 7 nights. Hopes for a weather improvement remained unfulfilled with not any single clear night in January, clear spells at best permitted to harvest a modest number of orbits. January 2021 was the poorest month of January in the CAMS BeNeLux history, while a record number of cameras were available. The poor weather persisted into February until the second week when an improvement occurred on 10 February with a series of mostly clear nights followed by variable weather with partial clear nights.

March continued the same weather pattern we got end of February, the first week of March 2021 had some clear nights and longer clear spells. The next ten nights were dominated by cloudy skies. The last period of March had variable circumstances with each night some clear skies, sometimes with almost complete clear nights. April started with one clear night followed by 9 mostly cloudy nights. Luckily the weather improved and remained stable until almost the end of the month. For the fourth year in a row, the CAMS BeNeLux network enjoyed clear sky during much of the Lyrid activity. Unfortunately, many cameras remained switched off during a number of nights, reducing the sky coverage during these nights.

May 2021 was an exceptional cold and rainy month with a lot of cloudy sky and therefore rather unfavorable weather for meteor work. Only 6 nights resulted in 100 or more orbits (against 18 in 2020). The lack of camera capacity affected especially the northern part of the network where the coverage was rather poor during many nights. May 2021 was the poorest month of May since 2016. The first half of June 2021 had a number of clear nights and several nights with partial clear sky. However, the second half of June came with exceptional poor weather, much too cold and totally overcast with a lot of rain. The worst possible weather pattern made astronomical observing almost impossible.

July 2021 got only few complete clear nights. A combination of unfavorable weather circumstances with less operational cameras available explains why this month was the least successful month of July since 2016. The weather was rather variable during the first week of August but luckily improved for the second week including the rich Perseid nights of 11–12–13–14–15 August. This saved the month since previous years the high scores were mainly obtained without perfect weather during the rich Perseid nights, so we have been lucky. Nobody would expect unforeseen surprises with the best studied and well-known meteor shower like the Perseid, but it did happen. August 13–14 produced a strong unpredicted Perseid outburst visible over Canada and the USA. CAMS BeNeLux recorded during this night as many as 1249 orbits, more than during August 12–13 with the traditional maximum. August 2021 brought less favorable weather than previous two years, but luckily the rich Perseid nights were mostly clear. Altogether it became the 4th best month of August in 10 years of CAMS BeNeLux.

September finally brought favorable weather and CAMS BeNeLux collected 7457 orbits. This is an absolute record for the month September, much better than the record of last year. This month counted as many as 26 nights with more than 100 orbits. The best September night was 7–8 with as many as 543 orbits in a single night, the best score in orbits ever for a September night. Not any single night remained without orbits. The larger number of cameras that were operational also provided better coverage compared to previous years with favorable weather.

Last year we got the worst-case weather scenario for the month October with not a single complete clear night for the entire network. October 2021 was a wet rainy month with a lot of cloud cover during the day, but with several clear nights and wide clear spells at night. For once we got lucky with this autumn month. 9669 orbits were collected (against 3305 in 2020) which is a new record for this month, doing slightly better than October 2018 when 9611 orbits were collected, including 1391 orbits in a single night with the Draconid outburst. Again, no favorable weather during the Orionids apart from some partial clear sky 20–21–22 October, but CAMS BeNeLux could confirm the discovery by the Global Meteor Network of a new shortly active meteor shower (Vida et al., 2021).

Table 1 – Statistics for each month of 2021.Total numbers of nights (*N*) with orbits, number of orbits, number of camera stations (*S*), maximum of cameras available (M_x), minimum of cameras available (M_i), average number of cameras (M_m), total number of meteors and percentage of multiple station meteors.

M	N	Orbits	S	M_x	M_i	M_m	Meteors	%
Jan	22	991	26	92	64	73.7	–	–
Feb	25	2136	26	91	60	78.6	–	–
Mar	28	1998	27	91	59	78.9	–	–
Apr	28	3061	27	91	59	82.1	–	–
May	28	1500	25	81	50	68.2	–	–
Jun	22	1389	26	81	54	73.3	–	–
Jul	28	2525	27	81	55	67.3	–	–
Aug	29	7496	27	89	65	80.2	–	–
Sep	30	7457	26	93	64	82.0	–	–
Oct	29	9669	26	94	70	82.2	51696	62%
Nov	24	4691	26	86	74	81.6	25832	55%
Dec	25	3072	25	84	67	76.0	19579	47%
	318	45985						

November 2021 brought fairly good autumn weather for the BeNeLux what resulted in a third-best November month during 10 years of CAMS BeNeLux. This month counted 14 nights with more than 100 orbits. Two nights produced more than 500 orbits in a single night. The best November night in 2021 was 21–22 with as many as 1810 multi-station meteors, good for 578 orbits in this single night. December 2021 brought barely better weather than the horrible poor month of December previous year. With more cameras operational 7 on 7 than previous years, mainly newly installed RMS cameras, the best could be derived from partial clear nights. December 2021 wasn't as bad as December 2020, but will remain one of the poorest months of December in the CAMS BeNeLux history.

An overview of the monthly statistics for CAMS BeNeLux during 2021 is presented in *Table 1*. January 2021 was the worst months of 2021 and the exceptional poor weather dominated the first three months, May, June and July as well as December. September 2021 was the best month of the year while October, August and November were good months too.

Good or bad weather determine the success of a camera network, but of course the hardware needs to be available. After a strong build-up of the network in 2017 we had a drop in the number of cameras in 2018 to about 80% of what was available before and the number was kept down throughout 2019 due to technical problems. This is visible in *Figure 1*, as a drop in the maximum (green line) and the average number (red line) of cameras available each month since 2018. The situation finally improved a lot in the first half of 2020 when less technical problems occurred and a few new cameras were added to the network. Unfortunately, since the summer of 2020 we see again a decline in the number of available cameras. No technical issues, but the variability of the motivation among amateur volunteers is sometimes a problem to maintain long-term projects such as CAMS BeNeLux. This explains why the number of available cameras fluctuates around the level achieved by the network since 2017 although new sites and cameras have been added to the network.

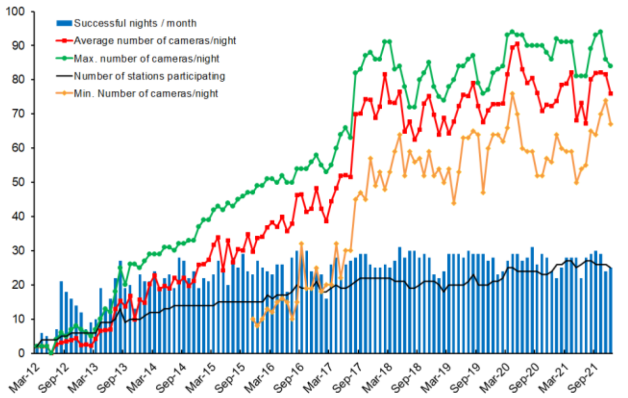

Figure 1 – CAMS BeNeLux performance at a glimpse. The blue bars represent the number of nights with orbits for each month. The black line is the number of operational CAMS stations, the green line the maximum number of operational cameras, the red line the average number of operational cameras and the yellow line the minimum number of operational cameras available.

Some new cameras were added to the CAMS BeNeLux network in 2021 at geometric strategic positions for the existing CAMS stations (see also *Figure 2*). All new cameras were RMS devices with 6mm optics and 54° × 30°

field of view. White dots and placenames in *Figure 2* indicate sites with only Watec cameras with 12mm/1.2 optics and a small field of view of 30° × 22°. Yellow dots with white placenames indicate a mixture of Watec and RMS cameras. Yellow placenames indicate sites with only RMS cameras. The orientation of the newly installed camera field can be seen in *Figure 3*, together with already existing RMS cameras of the network.

- RMS BE0006 alias CAMS 003816 got its first orbits during the night of 12–13 January 2021. This camera is installed at Lesve, Belgium and operated by *Pierre de Pontière*. This camera is pointed low towards the north and covers a large part of the Netherlands. The rich overlap with many other cameras explains its high score in number of orbits with 5369 orbits recorded in its first year.
- In March we could welcome *Ludger Boergerding* as new participant with his RMS DE000B, alias CAMS 003801 at Holdorf, Germany. Contributing CAMS data since 15–16 March, this camera has been pointed at the previously poorly covered region of Northern Netherlands and North West Germany. Although coverage on this region needs still enforcement, this camera obtained 2672 orbits.
- With the help of *Tammo Jan Dijkema*, *Reinhard Kühn* installed RMS DE000C, alias CAMS 3802 at Flatzby, northern Germany near the border with Denmark. This camera has been pointed south-west to cover the north-western part of Germany, a formerly poorly covered corner of the network. This camera had its first orbits May 27–28.
- RMS camera BE0005, alias CAMS 3817 became operational during the rich meteor night of August 13–14 at OCA, Grapfontaine thanks to the efforts of *Jean-Paul Dumoulin*, *Christian Wanlin* and *Kees Habraken*, This RMS with a 6 mm lens (54° × 30°) has been pointed low in western direction to give coverage on entire western Belgium, Norther France and Zeeland.
- Two new RMS cameras, BE0007 and BE0008 alias CAMS 3818 and 3819, were installed at Cosmodrome in Genk, both RMS cameras with 6 mm lenses with the help of *Giuseppe Canonaco*. CAMS 3819 is pointed low to the west to cover the western part of Belgium with large overlap with CAMS 3817 at Grapfontaine. CAMS 3818 has been pointed south-east to give coverage on the south-eastern part of Belgium and Luxembourg. Both cameras got their first orbits on August 14–15 for CAMS 3819 and on August 15–16 for CAMS 3818.
- RMS BE0003 formerly installed in Genk and replaced by BE0007, has been moved to AstroLab at Zillebeke, near Ypres in September. *Steve Rau* took care of the installation of CAMS 3853 (BE0003) pointed in eastern direction to cover central Belgium and Northern France. This RMS had its first orbits September 10–11.
- RMS BE0009 alias CAMS 3851 has been built by Steve Rau. This camera has been pointed north at Astrolab in Zillebeke to provide coverage on the North Sea and Zeeland, a poorly covered part of the network. This camera had its first orbits on September 24–25.
- RMS NL000B alias CAMS 319 has been pointed south-east by Martin Breukers at Hengelo and had its first orbits October 4–5. This region offers new possibilities to expand the network further eastwards.
- Poor weather postponed the installation of the last new camera for 2021, RMS BE000A alias CAMS 3820 installed in Gent, Belgium by *Tim Polfliet*. This camera has a 8mm lens with a FoV 22 × 41°and had its first orbits December 16–17.

Figure 2 – Locations of all the active CAMS BeNeLux stations and cameras during 2021. Yellow names are GMN RMS stations, yellow dots indicate mixed hardware Watecs and RMS cameras.

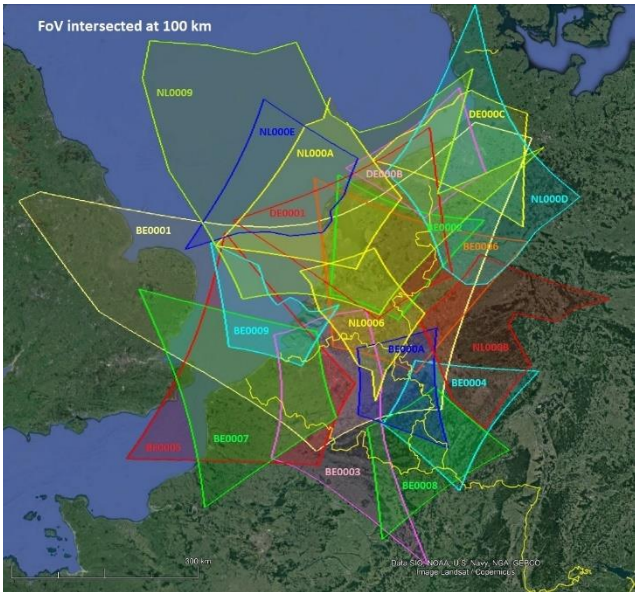

Figure 3 – Fields of View (FoV) of the RMS cameras that contributed to the CAMS BeNeLux network in 2021.

3 2021 compared to previous years

In total 45985 orbits were collected in 2021 (against 45743 orbits in 2020) which is a remarkable good result for a year with 8 months of unfavorable weather. Slightly more orbits than in 2020 and good for a second-best year after 2018 when as many as 49627 orbits were collected. *Figure* 4 compares the data from year to year and *Table 2* lists the numeric values. From *Table 2* we learn that 2021 brought slightly less favorable weather than previous three years with an average number of 26.5 nights with orbits per month. It was the poorest year since 2017. Also, the total number of nights that produced one or more orbits was less than previous three years with 318 nights. This number of nights with orbits is actually huge when considering the often-cloudy atmosphere over the BeNeLux region. More than 300 nights with observational results is something that most people expect for the Provence or other typical astronomical sites. The number of completely clear nights is indeed much less impressive and it would make a substantial difference if our cameras wouldn't be operated 7 nights on 7.

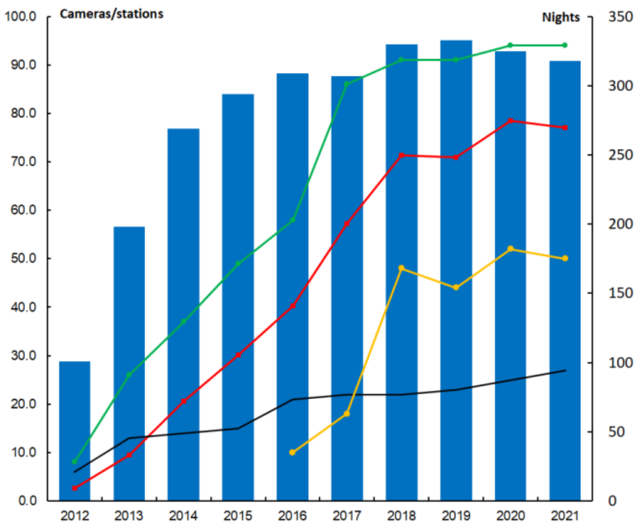

Figure 4 – The performance of the CAMS BeNeLux network from year to year. The blue bars represent the total number of nights during which orbits were obtained. The black line is the number of CAMS stations, the green line the maximum number of cameras available, the red line the average number of cameras available and the yellow line the minimal number of cameras.

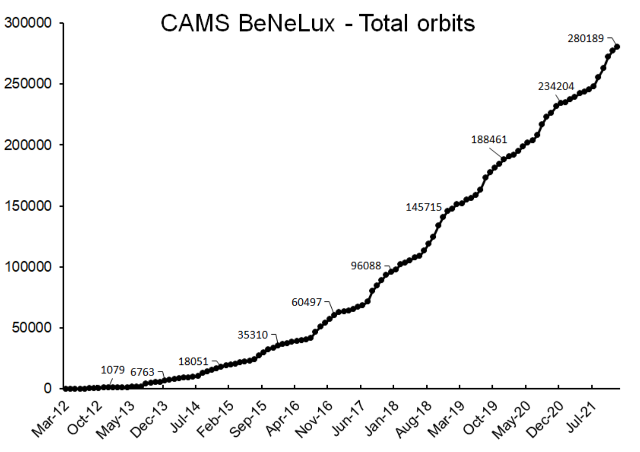

Figure 5 – The evolution of the number of orbits collected by the CAMS BeNeLux network.

Table 2 – Total numbers per year: average number of nights with orbits per month (D_m), orbits, average number of cameras per month (C_m), maximum number of operational cameras, number of operational stations and total number of nights with orbits.

Year	D_m	Orbits	C_m	Cameras	Stations	Nights
2012	10.1	1079	2.6	8	6	101
2013	16.5	5684	9.5	26	13	198
2014	22.4	11288	20.6	37	14	269
2015	24.5	17259	30.1	49	15	294
2016	25.8	25187	40.3	58	21	309
2017	25.6	35591	57.2	86	22	307
2018	27.5	49627	71.3	91	22	330
2019	27.8	42746	70.9	91	23	333
2020	27.1	45743	78.5	94	25	325
2021	26.5	45985	77.0	94	27	318
		280189				2784

The use of AutoCAMS for the Watecs and of course the new RMS cameras made the difference! The general bad weather during 2021 has been compensated by permanent coverage by many cameras taking advantage of clear spells during mostly cloudy nights which would be missed unless the cameras function regardless the weather circumstances. This is the basic principle behind meteor camera networks because clear sky proves in general to be pretty unpredictable.

The expansion of the network covering a larger surface than few years ago offered better chances for local clear sky in some regions while other parts of the network remained 100% cloudy. Amateurs who operate their cameras only during predicted clear sky are missing all the unforeseen periods with clear sky. For that reason, all meteor camera networks in the world keep their cameras recording, regardless the weather. The only reason for camera drop-outs are technical problems.

Looking at the accumulated number of orbits over the years in *Figure 5*, we see how CAMS BeNeLux took off after 2016 when AutoCAMS made it easy to run cameras 7 on 7 and the network got at full strength in 2017. The graph mentions the totals at the end of each year. 2021 ended with an accumulated total of 280189 orbits collected by CAMS BeNeLux. Ten years ago, nobody would ever have expected this to happen. A project like CAMS BeNeLux isn't a short-term project. The purpose is to keep it going as long as possible, keeping everyone motivated to invest in the maintenance of the network.

Figure 6 shows the number of orbits registered per month; the result often depends on luck with clear sky during major meteor shower activity. The graph shows the large fluctuations from month to month. Some months it may look like clear skies will never return, but even in the worst periods, orbits can be obtained. The CAMS project aims at the times of the year with poorly known meteor activity, away from shower maxima and poorly monitored nights in the past.

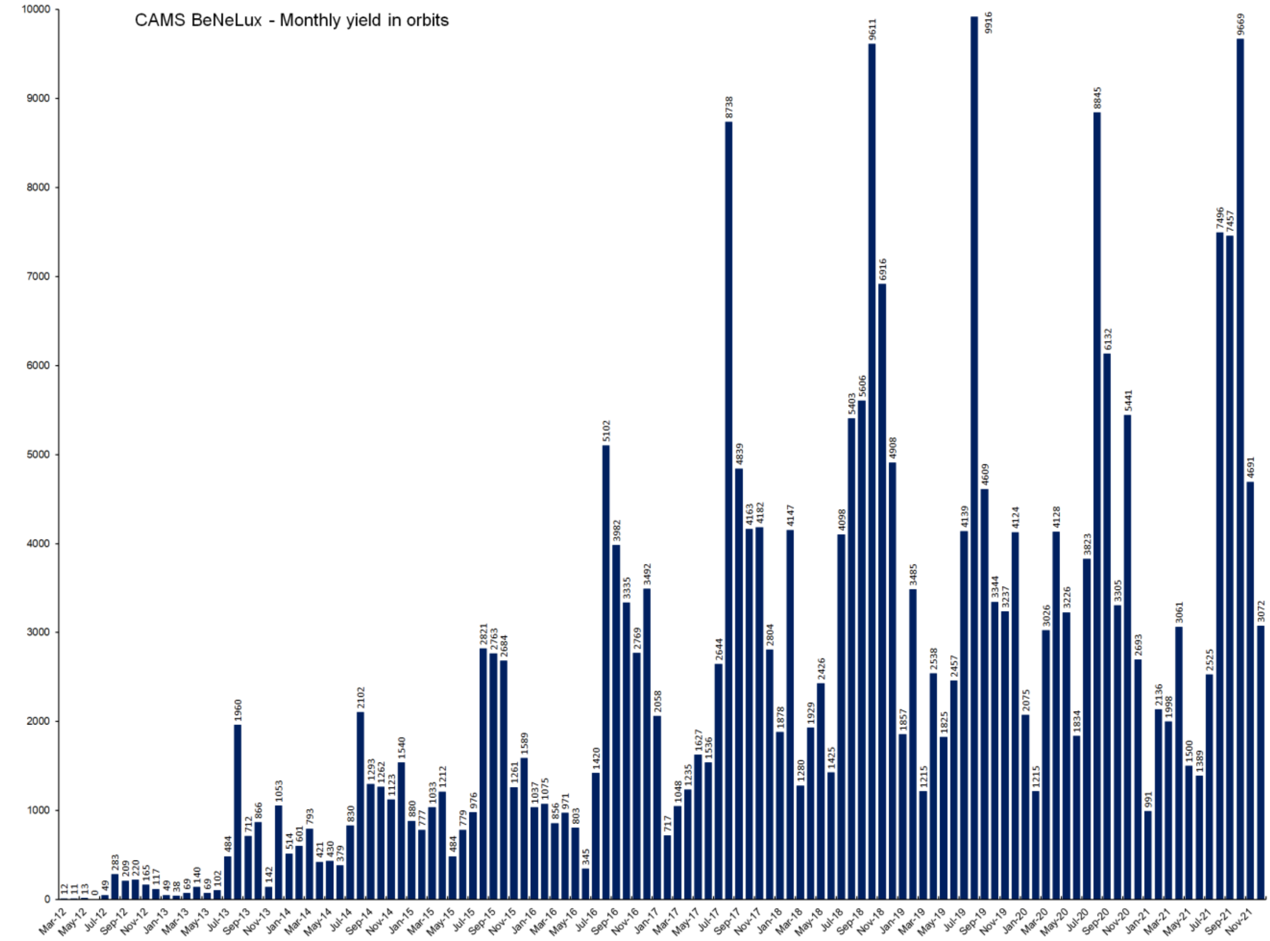

Figure 6 – The total number of orbits collected per month. August 2019 has the record with 9916 orbits in a single month.

TOTAL	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
January	111	400	1376	315	403	306	439	358	149	213	106	56	212	239	447	314
February	107	248	382	239	427	526	222	234	32	183	261	697	708	464	920	410
March	114	235	208	198	159	158	280	242	194	231	357	422	302	231	267	277
April	322	94	293	367	373	337	229	359	399	485	414	308	324	337	441	405
May	345	246	334	510	600	473	347	549	260	369	387	415	451	609	397	225
June	334	140	160	178	224	279	85	177	272	200	251	240	282	180	279	327
July	500	615	539	218	607	472	335	564	292	471	467	522	404	547	299	415
August	1299	1125	1176	1250	2128	2202	1536	1184	1563	2120	2294	4972	3049	1083	1701	717
September	1281	988	458	399	855	759	875	744	1533	887	806	731	1346	1355	862	1111
October	686	741	475	1157	941	300	648	1882	1019	1212	1066	915	1594	1119	1127	539
November	790	1307	1261	822	930	1596	1503	549	610	586	406	986	1076	783	798	1353
December	375	599	1037	1376	590	237	805	403	1206	1015	1234	2262	2048	991	569	458

TOTAL	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31	31-01	
January	586	630	841	866	538	135	5	69	203	238	55	244	247	127	120	10348
February	613	228	109	461	433	476	718	857	491	546	741	153	169			12055
March	333	334	167	283	380	464	345	581	354	402	347	307	422	310	428	9332
April	538	494	957	960	978	1030	521	156	297	401	225	268	101	172		12585
May	332	174	273	372	248	153	345	253	414	310	219	395	190	283	425	10903
June	268	375	241	426	418	432	346	291	450	322	334	485	532	329		8857
July	815	730	421	805	702	848	667	539	518	316	550	656	1128	1414	1087	18463
August	1252	1538	755	756	1114	1472	884	1181	1163	865	845	1134	942	771	1099	45170
September	1449	1301	1266	1299	1390	877	1041	1215	701	1237	730	1142	854	653		30145
October	783	988	979	925	845	1117	413	124	560	936	1613	548	1197	1274	1067	28790
November	1067	813	903	522	343	933	559	946	611	267	691	888	890	447		25236
December	544	837	515	812	24	177	183	421	342	346	782	648	859	324	301	22320
																234204

0 orbits:	0
>0 orbits:	366
>100 orbits	358
>500 orbits:	177
>1000 orbits:	69

TOTAL	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
January	132	403	1376	315	403	310	442	546	243	252	106	233	272	254	450	314
February	107	251	469	241	428	526	222	239	129	363	496	956	946	467	933	417
March	319	324	211	262	381	344	326	242	198	231	388	427	329	249	277	277
April	459	108	346	414	418	355	253	401	399	485	580	489	444	465	592	564
May	406	384	334	572	624	516	447	663	260	387	424	469	527	618	427	226
June	447	178	191	178	243	343	178	245	401	298	287	386	422	243	379	405
July	518	691	553	230	608	543	421	610	304	536	485	540	404	547	299	465
August	1452	1216	1352	1311	2176	2295	1569	1489	1717	2710	2888	6106	4298	1766	1946	978
September	1447	1443	793	759	1355	1035	1418	1221	1647	980	1024	999	1647	1362	1063	1372
October	736	741	582	1717	1075	562	1159	2387	1566	1338	1107	1312	1627	1261	1558	682
November	1194	1509	1461	1049	1256	1600	1767	960	1121	785	636	994	1076	851	798	1353
December	458	782	1037	1451	682	516	928	919	1284	1244	1245	2262	2048	991	594	508

TOTAL	17-18	18-19	19-20	20-21	21-22	22-23	23-24	24-25	25-26	26-27	27-28	28-29	29-30	30-31	31-01	
January	621	633	843	907	577	178	17	85	242	238	55	244	247	280	121	11339
February	625	419	129	547	558	537	861	948	495	617	837	259	169			14191
March	388	469	378	298	388	474	478	597	424	413	360	377	578	469	454	11330
April	663	598	1048	1086	1204	1369	686	279	432	481	337	273	172	246		15646
May	336	223	363	377	284	153	350	269	416	311	291	482	299	389	576	12403
June	271	448	241	426	418	432	348	331	454	362	345	485	532	329		10246
July	1013	900	559	992	836	1010	777	561	623	362	629	768	1413	1461	1330	20988
August	1255	1538	811	889	1137	1475	1245	1564	1183	1145	936	1222	942	902	1153	52666
September	1667	1525	1334	1479	1598	1174	1108	1392	812	1430	1149	1253	1299	817		37602
October	1233	988	1101	935	1436	1454	1339	839	823	971	2389	1366	1303	1373	1499	38459
November	1227	814	903	522	921	1389	608	1014	650	353	692	1062	915	447		29927
December	560	837	539	1180	583	199	186	440	530	348	795	648	861	399	338	25392
																280189

0 orbits:	0
>0 orbits:	366
>100 orbits	363
>500 orbits:	206
>1000 orbits:	102

Figure 7 – Day-by-day tally of the cumulated number of orbits per day collected by CAMS-BeNeLux. Top: the overview up to 31 December 2020, bottom: the situation on 31 December 2021.

Ten years ago, at the start of the CAMS project, the purpose of the project was to collect at least a hundred orbits for each calendar date to detect unknown minor showers caused by weak dust trails. This initial target proved to be too modest as meanwhile the BeNeLux Cams network alone almost accomplished this purpose. CAMS proved much more successful than ever expected. In 2021 all the CAMS networks together on average collected more than 1000 orbits per day!

Figure 7 shows the total number of orbits collected per calendar date since 2012 by CAMS BeNeLux alone, until end of 2020 (top) and until end of 2021 (bottom). End 2021 only 3 nights were left with less than 100 orbits with 23–24 January as the most miserable night since 2013 with as few as 17 orbits collected during all these years together. January seems to be the most challenging month for the weather.

End 2021 we had 206 nights with more than 500 orbits, 102 nights had more than 1000 orbits accumulated. The influence of the major meteor showers is reflected in the numbers of orbits: the Quadrantids 3–4 January, Lyrids 22–23 April, the delta Aquariids South end of July, most of the Perseid activity period with as best night 12–13 August with 6106 orbits for the Perseid maximum night. September proves to be a most rewarding meteor month although no major shower is active during this month. The 2387 orbits for 08–09 October were mainly due to the Draconid outburst in 2018. Past 10 years no really favorable circumstances occurred during the rich Orionid activity in October. Sooner or later our network should be lucky with this one! Of course, the Geminids provided large numbers of orbits, but a clear night for the Geminid maximum would change the numbers by a lot. From this overview it is very obvious how rich the meteor activity is in the second half of the year compared to the first half of the year.

4 Should we use more RMS cameras?

In 2019 the first RMS cameras were used to provide extra coverage to the CAMS BeNeLux network. Looking at *Table 3* we see that the best performing cameras are all RMS cameras. The main reason is the larger FoV combined with a very good resolution:

- RMS 36mm 47 × 88°, 3.9 arcmin/pix;
- RMS 6mm 30 × 54°, 2.5 arcmin/pix;
- RMS 8mm 22 × 41°, 1.9 arcmin/pix;
- Watec 12mm 22 × 30°, 2.6 arcmin/pix (PAL);
- Watec 12mm 22 × 30°, 2.8 arcmin/pix (NTSC).

The RMS with 8mm lens comes closest to the classic CAMS configuration with the 1.2/12mm lens. The small FoV proves ideal in light polluted areas. For darker areas the RMS 6mm is the best compromise with significant larger FoV and comparable in resolution to the CAMS standard optics. The RMS 36mm can be used only at very dark skies but the lens distortion is at the limit and therefore not recommended to be used within the CAMS network. The RMS doesn't need AutoCAMS and functions 7 nights on 7, apart from some occasional technical issues. RMS cameras can be home built for less than 200 euro for a complete system[24].

The most important advantage of the RMS is its calibration system. The classic CAMS system uses a single calibration for the entire night while the RMS system recalibrates for each single detection. The resolution of 2 to 4 arcmin/px isn't the only parameter to look at. During the night the plate center of a CAMS camera, if it is well fixed, wanders around the reference and may deviate 10, 12 or more arcminutes just because of the expansion, contraction of the camera support (arm, wall, mount, …) due to variations in temperature. The classic CAMS approach ignores this completely but the RMS system recalibrates for each individual detection. This is an absolute superior approach compared to the use of a single calibration for a whole night.

Table 3 – Selection of 20 cameras with the highest scores in orbits during the year 2021.

Camera	Total orbits	Nights active	Nights with orbits
003814 RMS Grapfontaine (B)	5725	348	189
003816 RMS Lesve (B)	5369	354	244
003830 RMS Mechelen (B)	3441	365	237
003817 RMS Grapfontaine (B)	3366	141	86
000378 RMS Kattendijke (Nl)	3301	365	212
003800 RMS Langenfeld (D)	3229	364	206
000816 Watec Humain (B)	2946	363	233
003801 RMS Holdorf (D)	2672	292	166
003833 Watec Mechelen (B)	2608	360	239
003836 Watec Mechelen (B)	2511	360	236
003891 Watec Mechelen (B)	2487	362	228
000380 Watec Wilderen (B)	2486	348	227
003831 RMS Mechelen (B)	2373	365	226
000394 Watec Dourbes (B)	2335	365	213
000814 Watec Grapfontaine (B)	2322	364	202
003837 Watec Mechelen (B)	2298	360	241
003834 Watec Mechelen (B)	2287	360	230
000806 Watec Zoersel (B)	2187	365	210
003890 Watec Mechelen (B)	2161	362	224
003035 Watec Oostkapelle (Nl)	2145	272	217

The Watec cameras are old technology, the required framegrabbers become expensive and difficult to purchase. The many Watec cameras used in CAMS BeNeLux are definitely not yet to be replaced, but it would be wise to rather buy RMS cameras for any future extensions. With the budget required for two CAMS configured Watecs, three

[24] https://globalmeteornetwork.org/wiki/index.php?title=Build_A_Camera

RMS cameras can be bought as plug & play or the components to build 6 homemade RMS cameras can be ordered.

In 2021 Steve Rau made the tool RMSgui.exe which is a great help to do the data reduction for CAMS. Before this was a bit a clumsy procedure with successive time-consuming steps. The new procedure makes it possible to combine data from several RMS cameras into a single procedure that takes less time to do than for an equivalent number of Watecs. This opens the possibility to install several RMS at one site without causing extra work to the camera operator.

5 CAMS BeNeLux in the world

CAMS is a global project in which different networks around the world participate all using the same CAMS software.

Altogether the CAMS networks collected about 470000 orbits in 2021 (against 418000 in 2020), the largest number of orbits in a single year and more orbits what CAMS collected from its start in October 2010 until end 2016. The different CAMS networks had the following numbers of orbits (raw data):

- CAMS Arkansas 15868 (14389 in 2020);
- CAMS Australia 54893 (31240 in 2020);
- CAMS BeNeLux 45985 (45743 in 2020);
- CAMS California 39683 (42281 in 2020);
- CAMS Chile 51350 (66556 in 2020);
- EXOSS Brazil 144 (399 in 2020);
- CAMS Florida 24554 (30303 in 2020);
- LOCAMS Arizona 76232 (44858 in 2020);
- CAMS Namibia 99659 (98581 in 2020);
- CAMS New Zealand 21661 (21561 in 2020);
- CAMS Northern California 272 (5413 in 2020);
- CAMS South Africa 8726 (13006 in 2020);
- UAZ-CN 16294 (24003 in 2019);
- CAMS MA tbd (992 in 2020);
- CAMS Texas 17449 (960 in 2020);
- CAMS Turkey 1323 (new network)
- Total 2021 ~470000 orbits (~418000 in 2020);

CAMS BeNeLux contributed almost 10% of the total score for 2021. Since the start of the CAMS project almost 2000000 video meteor orbits have been collected of which 280189 orbits by CAMS BeNeLux. This is currently the largest collection of optical orbits worldwide and the project is expected to be continued for more years to come.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. These statistics are based on the data published on the CAMS website[25]. In 2021, the CAMS BeNeLux team was operated by the following volunteers:

Hans Betlem (Woold, Netherlands, CAMS 3071, 3072 and 3073), *Felix Bettonvil* (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Ludger Boergerding* (Holdorf, Germany, RMS 3801), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326, 327, RMS 319, 328 and 329 *Giuseppe Canonaco* (Genk, RMS 3818 and 3819), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806 and 3888), *Tammo Jan Dijkema* (Dwingeloo, Netherlands, RMS 3199), *Isabelle Ansseau, Jean-Paul Dumoulin, Dominique Guiot and Christian Wanlin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 003814 and 003817), *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 / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822) , *Robert Haas* (Texel, Netherlands, CAMS 810, 811, 812 and 813), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 312, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005, after October 3100, 3101 and 3102), *Reinhard Kühn* (Flatzby, Germany, RMS 3802), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain, Belgium, CAMS 816), *Koen Miskotte* (Ermelo, Netherlands, CAMS 3051, 3052, 3053 and 3054), *Tim Polfliet* (Gent, Belgium, CAMS 396, RMS 3820), *Steve Rau* (Zillebeke, Belgium, CAMS 3850, 3852, RMS 3851, RMS 3853), *Paul and Adriana Roggemans* (Mechelen, Belgium, RMS 3830 and 3831, CAMS 3832, 3833, 3834, 3835, 3836 and 3837), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).

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Vida D., Šegon D., Roggemans P. (2021). "October zeta Perseid meteor shower (OZP#01131)". *eMetN*, **6**, 536–539.

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

Ursid activity 2021 by CAMS BeNeLux

Carl Johannink

Am Ollenkamp 4, 48599 Gronau, Germany
c.johannink@t-online.de

For the first time since the start of the CAMS BeNeLux network, the Ursid activity could be monitored successfully. As many as 165 Ursid orbits were collected between solar longitude 268.7° and 270.3°. No outburst was predicted for 2021, the Ursid orbits recorded this year did not show a very compact structure like in 2020 (Roggemans, 2021a, 2021b).

1 Introduction

Right in time for the Ursid maximum a high-pressure area dominated the weather pattern and resulted in clear skies over most parts of the BeNeLux.

Since the start of our network, collecting orbits during the Ursid maximum had always been hampered by cloudy skies. In the period 2012 – 2020 our network collected only 24 orbits during the night of December 21–22. Sixteen orbits in 2019, five in 2018 and three in 2015. In all other years, not a single orbit could be collected during this night. 2021 finally broke this ban, 559 orbits were obtained during this night.

An additional 368 orbits were registered during the night of December 20–21. This is an increase with more than 40% compared with the total number of orbits collected during this night during the period 2012–2020. In 2021 a total of 928 orbits were collected between solar longitude 268.7° and 270.3°.

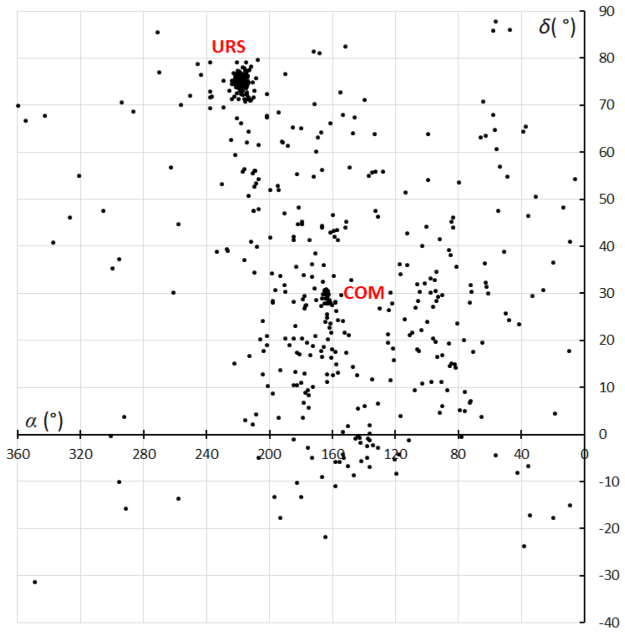

Figure 2 – All the 559 radiants plotted in equatorial coordinates during the night of December 21–22 (data CAMS BeNeLux).

2 Ursid identification

First of all, we show radiant plots for December 20–21 (*Figure 1*) and December 21–22 (*Figure 2*).

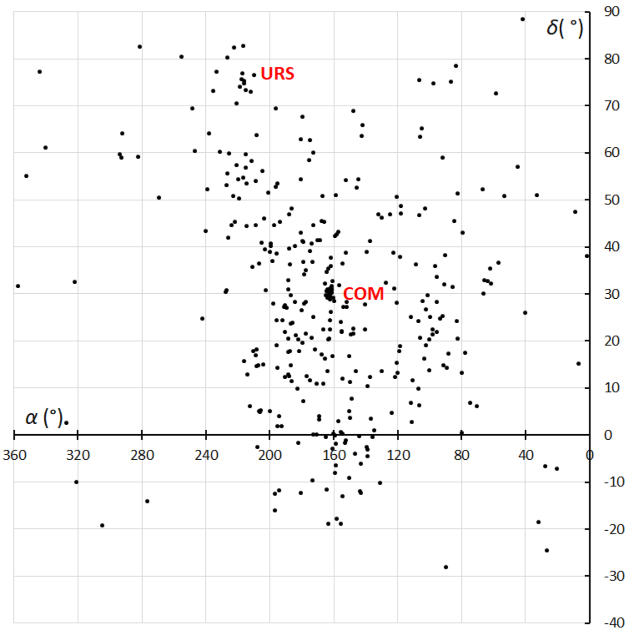

Figure 1 – All the 368 radiants plotted in equatorial coordinates during the night of December 20–21 (data CAMS BeNeLux).

During the night of December 20–21 the Ursid activity was very low. Some visual observers of the Dutch Meteor Society have noticed in the past that the Ursid activity during the post-maximum night was significantly higher than during the pre-maximum night. Unfortunately, until now we couldn't confirm or deny this from CAMS data, because the weather wasn't cooperating as mentioned earlier.

From the 927 orbits, the author identified 165 Ursid orbits based on the orbit similarity criteria explained in Roggemans et al. (2019). Because the dataset is small, the author used the Ursid orbit given by Jenniskens et al. (2016) as reference orbit to identify the Ursids.

Using the similarity criterion D_D of Drummond (1981), the author considered different classes of dispersion among the Ursid orbits. This helps to visualize the degree of dispersion and compactness within the meteoroid stream, and to compare the results of this year with those of 2020 given by Roggemans (2021a, 2021b).

The different classes of similarity are defined as follows:

- Low: $0.08 < D_D < 0.105$
- Medium low: $0.06 < D_D < 0.08$

- Medium high: $0.04 < D_D < 0.06$
- High: $0.02 < D_D < 0.04$
- Very high: $D_D < 0.02$

In *Table 1* the median values for 100 Ursid orbits with high threshold similarity ($D_D < 0.04$) are compared with the results by Jenniskens et al. (2016) and with the parent comet 8P/Tuttle.

Table 1 – The median orbit of 100 Ursid orbits with $D_D < 0.04$, compared with the reference orbit taken from Jenniskens et al. (2016) and the parent comet 8P/Tuttle.

	URS (2021) BeNeLux	URS (2016) Jenniskens et al.	8P/Tuttle (2008)
λ_O	270.14°	271.0°	–
α_g	217.9°	219.9°	–
δ_g	+75.1°	+75.4°	–
v_g	33.4 km/s	32.9 km/s	–
a	5.00 A.U.	4.87 A.U.	5.70 A.U.
q	0.9392 A.U.	0.940 A.U.	1.027 A.U.
e	0.8122	0.807	0.8199
ω	205.9°	205.6°	207.5°
Ω	270.1°	270.1°	270.3°
i	53.4°	52.6°	54.98°
Π	116.1°	115.7°	117.8°
N	100	62	

Figure 3 shows the radiant distribution in Sun-centered geocentric ecliptic coordinates to eliminate the radiant drift caused by the Earth moving on its own orbit around the Sun.

Figure 4 displays the same distribution but color coded with a gradient to show the variation in geocentric velocity v_g (km/s). A gradual increase in velocity in the direction of the Apex can be seen.

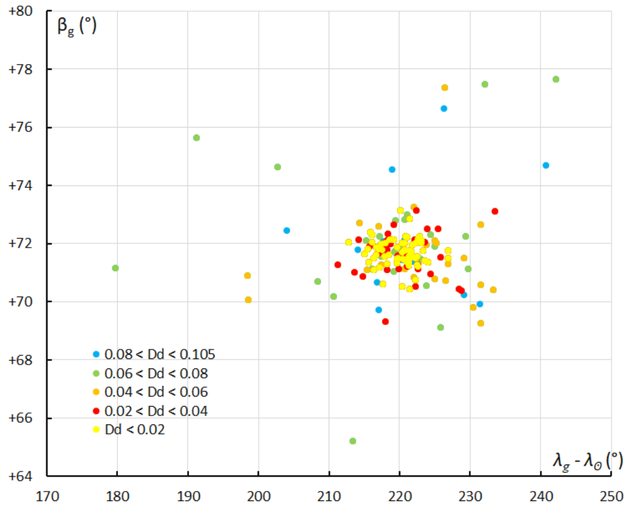

Figure 3 – The radiant distribution for all 165 Ursids fulfilling the Drummond similarity criterion D_D in Sun-centered geocentric ecliptic coordinates color coded for the different similarity classes (data CAMS BeNeLux, 2021).

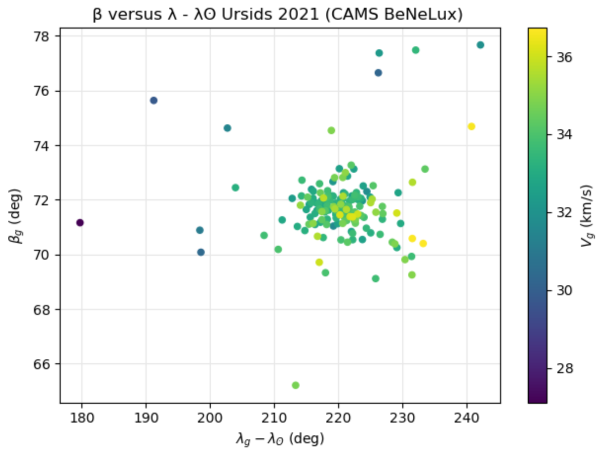

Figure 4 – The radiant distribution for all 165 Ursids fulfilling the Drummond similarity criterion D_D in Sun-centered geocentric ecliptic coordinates color coded with a gradient for the variation in the geocentric velocity v_g (data CAMS BeNeLux, 2021).

3 Ursid orbital elements

The distribution of the inclination i against the length of perihelion Π (*Figure 5*) shows a less compact concentration for a large majority of the Ursid orbits. This results from the dominance of a more dispersed annual component, unlike 2020 when the enhanced Ursid activity was caused mainly by a compact component with very similar orbits.

This dominance of a more dispersed annual component was also a reason to use the orbit given by Jenniskens as 'reference orbit' to identify the Ursids in this article.

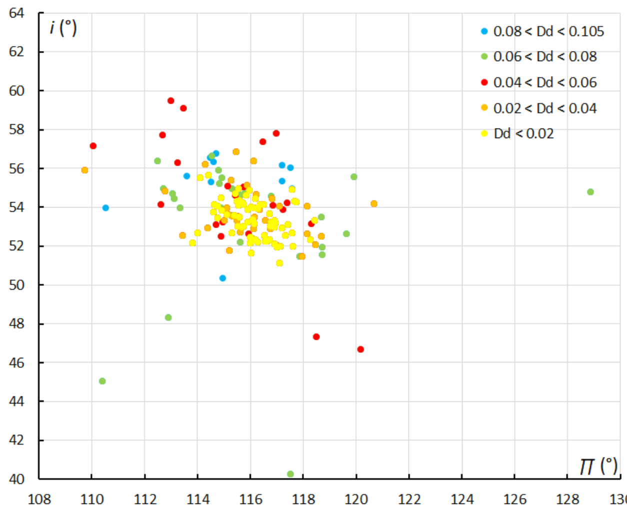

Figure 5 – The orbit distribution of Ursids with the inclination i against the length of perihelion Π (data CAMS BeNeLux).

When we look at the radiant distribution in Sun-centered ecliptic coordinates we see the fastest Ursids appear in the direction of the apex (bottom right corner of *Figure 4*) and slower Ursids away from the apex, as in Roggemans (2020a, 2020b).

The higher the inclination, the faster the Ursids, as can be seen in *Figure 6* where the inclination i is plotted against the length of perihelion Π.

In *Figure 7*, a plot of velocity v_g against inclination i, this is very obvious.

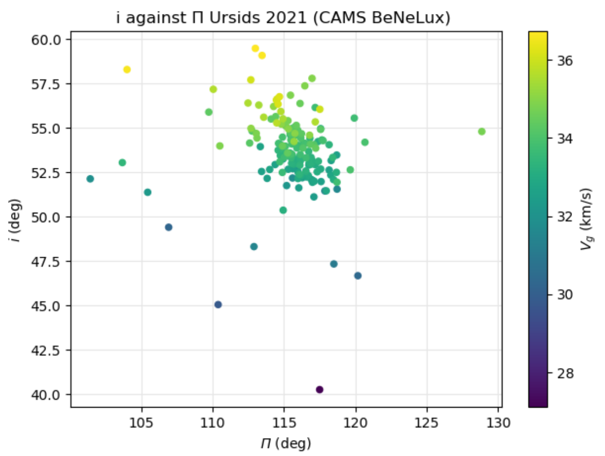

Figure 6 – The orbit distribution of Ursids with the inclination i against the length of perihelion Π color coded with a gradient for the variation in the geocentric velocity v_g (data CAMS BeNeLux).

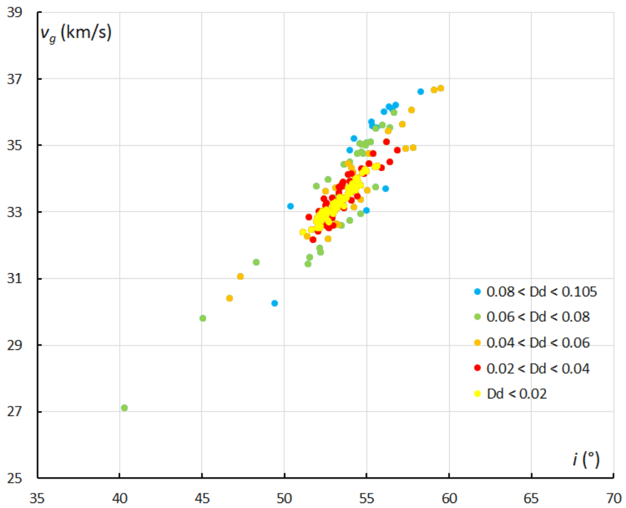

Figure 7 – The geocentric velocity v_g in function of the inclination i (data from CAMS BeNeLux).

4 Conclusion

The activity of the Ursids in 2021 was caused by the annual component. There are no indications for any other compact components with very similar orbits.

Acknowledgement

The author wants to thank all operators of the cameras in the CAMS BeNeLux network for their continuous efforts for delivering data.

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A comparison of TV and visual derived population indexes of some meteor showers

A. S. Betzler

Centro de Ciência e Tecnologia em Energia e Sustentabilidade, Universidade Federal do Recôncavo da Bahia, Feira de Santana, Bahia, 44.085-132, Brazil

betzler@ufrb.edu.br

The Brazilian Meteor Observation Network (BRAMON) is a meteor detection network that has been implemented in Brazil since 2014. BRAMON recorded about 27000 paired meteors with double or multiple stations between 2014 and 2021. A comparison between population indexes *r* obtained from visual observations and BRAMON data for the alpha Capricornid (CAP #00001), the eta Aquariid (ETA #00031), and the Geminid (GEM #00004) meteor showers suggests that this parameter is probably influenced by the difference in detection probability between visual and TV observational procedures, as well as by the zenith distance of the radiant of these meteor showers.

1 Introduction

One of the largest meteor monitoring networks regarding the number of stations (130) and covered surface area (1.3×10^6 km^2) in the southern hemisphere is the Brazilian Meteor Observation Network (BRAMON). The idea for the creation of BRAMON occurred in 2007 during a regional meeting of Brazilian amateur astronomers (Amaral et al., 2018). In 2013, some of these citizen scientists contacted members of the European networks UKMON ("United Kingdom Meteor Observation Network"), CEMeNt ("Central European video Meteor Network"), and EDMONd ("European viDeo Meteor Observation Network") to obtaining technical support for network implementation. BRAMON started operating with nine stations in the following year, and 23 cameras in 2015. Most stations are located in south-central Brazil, where the largest urban centers Rio de Janeiro and Sao Paulo are located, and the rest in the central, northeastern, and western regions of the country. The geographical disposition of the stations allowed the detection of meteors within a declination range between –90 and +70 degrees.

The stations are equipped with a TV camera capable of recording astrometric and photometric data from meteors, allowing the study of the dynamic and physical properties of the meteors. BRAMON recorded 26697 individual meteors registered at double or multiple stations, between August 2014 and February 2021, which could be identified with either 392 different meteor showers from the list of the International Astronomical Union Meteor Data Center (IAU MDC) or which were sporadic meteors.

I performed a comparison between the population index *r* of the alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers derived from this homogenous dynamic and photometric dataset obtained by BRAMON and from the Visual Meteor Database (VMDB) of the International Meteor Organization (IMO).

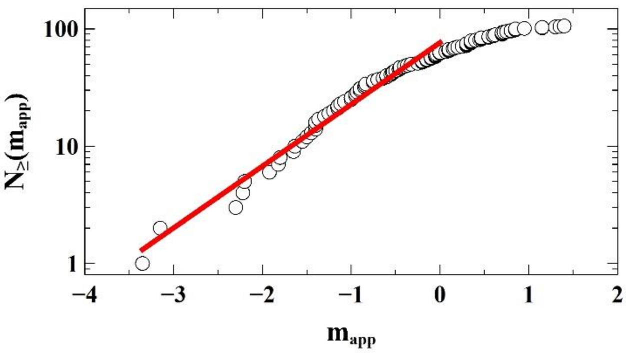

Figure 1 – Inverse cumulative distribution of the number of meteors as a function of the BRAMON apparent magnitude m_{app} of the eta Aquariid meteor shower observed in 2016. The observed distribution (circles) is modeled with Equation (1) (red line), with $C = 76 \pm 2$ and $r = 3.39 \pm 0.08$ for $m_{app} \leq 0$.

2 Meteor magnitude distribution

The statistical analysis of physical parameters is a relevant source of knowledge about objects of the solar system. The observational bias introduced by instrumental limitations (telescope plus detector), data collection, or analysis methods can influence the observed distributions. The origin of some of these distributions is associated with long-range gravitational interactions, fragmentation, among other complex phenomena.

The cumulative distribution of meteor magnitudes *M* is usually modeled by an exponential function (Baggaley, 1977) as

$$N_M = C \cdot r^M, \qquad (1)$$

where N_M is the cumulative flux of meteors brighter than magnitudes *M*, *C* is a constant, and *r* is the population index. The population index *r* is the ratio between the total number of meteors observed with magnitude *M* to those seen with magnitude *M + 1*. Equation (1) asymptotically models the observed meteor magnitude distribution (*Figure 1*).

Table 1 – Population indexes for the alpha Capricornid (CAP #00001) meteor shower. ΔT (UT) = observational period, r_{BR} = BRAMON population index, and r_v = visual VMDB population index.

Year	ΔT	r_{BR}	r_v
2015	Jul. 21.1–Aug. 04.2	3.24 ± 0.07	1.5 ± 0.1
2016	Jul. 22.4–Aug. 07.3	2.07 ± 0.04	3.4 ± 0.5
2017	Jul. 23.2–Aug. 06.3	1.95 ± 0.04	1.95 ± 0.04
2019	Jul. 23.2–Aug. 05.1	1.66 ± 0.08	1.66 ± 0.08
2020	Jul. 17.1–Aug. 07.1	3.24 ± 0.07	1.9 ± 0.2

3 The data

The main component of a meteor observation station is its camera whose efficiency is limited by its sensor, sky brightness, and detection software. A typical BRAMON station was equipped with a Samsung SCB 2000 camera, which uses a Sony Super HAD 1/3 CCD sensor, and is capable of registering light sources up to 0.05 lux in intensity. These cameras were modified having the infrared (IR) filter removed and were equipped with a Varifocal Ai 3–8mm Dc F1.0 Ltvr-3 lens. This lens provided a field of view (FOV) of ~70 × 60 degrees for the shortest focal length. Between 2014 and 2015, the 23 BRAMON operators had 27 stations, 60% of which were located in small urban centers, with a low level of light pollution.

Table 2 – Population indexes for the eta Aquariid (ETA #00031) meteor shower.

Year	ΔT	r_{BR}	r_v
2016	May 02.3 – May 27.3	3.39 ± 0.08	2.1 ± 0.1
2017	Apr. 26.3 – May 16.3	3.80 ± 0.09	2.2 ± 0.2
2019	Apr. 29.4 – May 16.3	3.5 ± 0.2	2.29 ± 0.05
2020	Apr. 28.3 – May 29.4	4.41 ± 0.08	2.40 ± 0.06

BRAMON uses the UFOCAPTURE software to detect meteors. The software records the detection in an AVI video, with a typical duration of 0.2 s. All phases of the temporal evolution of the apparent magnitude of each meteor are recorded in these videos, which may allow the composition of light curves. The UFOCAPTURE software works in conjunction with the UFOANALYSER and UFOORBIT that transfers the recorded image data into more suitable data for studying meteors.

Table 3 – Population indexes for the Geminid (GEM #00004) meteor shower.

Year	ΔT	r_{BR}	r_v
2015	Dec. 14.1 – Dec. 15.2	3.1 ± 0.2	2.6 ± 0.1
2016	Dec. 13.0 – Dec. 15.3	3.8 ± 0.4	2.3 ± 0.1
2017	Dec. 10.2 – Dec. 15.3	3.55 ± 0.08	2.35 ± 0.04
2019	Dec. 08.1 – Dec. 15.3	2.7 ± 0.2	2.5 ± 0.2

I modeled observed cumulative apparent magnitude distributions using Equation (1). The parameters C and r were obtained by optimization, using the non-linear generalized reduced gradient for the line search. The optimum values of distribution parameters minimize the Pearson chi-square coefficient.

The annual population indexes r have been calculated for the alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers, considering the same observational period in BRAMON and in the VMDB for each year.

I used independent sample t-tests to compare the means of the population indexes derived from BRAMON and VMDB databases as a criterion for testing their similarity ("null hypothesis"). A large p-value (greater than confidence level $\alpha = 5 \times 10^{-2}$) indicates weak evidence against the null hypothesis.

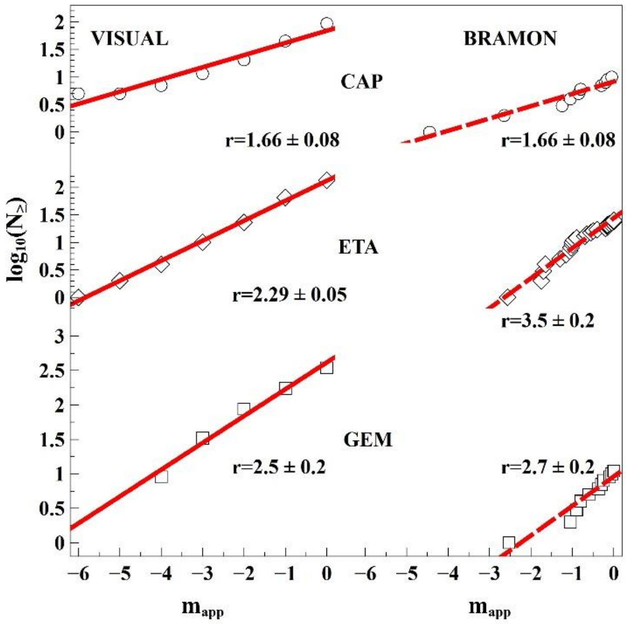

Figure 2 – Common logarithm of cumulative numerical distribution log10(N≥) of the apparent magnitudes m_{app} of the alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers observed by visual observers (VMDB) and BRAMON in 2019. The solid and dashed lines represent the adjustments of Equation (1) to the visual data and BRAMON for $m_{app} \leq 0$. The population index r is indicated next to the corresponding meteor shower.

4 TV and visual derived population indexes *r*

The population indexes r have been estimated for the alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers, between 2015 and 2020, for the $m_{app} \leq 0$ magnitude range (*Figure 2*). This magnitude range allows the detection of bright meteors, preventing limit magnitude lm restrictions between different observational sites.

The chi-square score suggests the same p-value ~ 1 for the fitting of the Equation (1) to the observed cumulative distribution of apparent magnitudes.

I used the t-test to compare the mean visual and BRAMON population indexes of *Tables 1* to *3*. The mean visual r

indexes of eta Aquariid (ETA #00031) and Geminid (GEM #00004) meteor showers are systematically lower than those obtained with BRAMON TV data (p-value = 3×10^{-4} and 5×10^{-3}). However, the mean visual and TV population indexes of the alpha Capricornid (CAP #00001) meteors are similar (p-value=0.5). Brown et al. (1998) suggests that the visually determined flux is tilted towards brighter meteors due to differences between the detection probability of the visual and TV observational procedures, justifying the dissimilarity. Another hypothesis is the possible dependence of the observed rate of meteors on the zenith distance of the radiant at the different observational sites (Zvolankova, 1983).

The alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers had a median altitude of the radiant above the horizon h_R of 65, 41 and 45 degrees respectively at the BRAMON observational sites in 2019.

The IMO VMDB observational campaign of the Geminid (GEM #00004) meteors in 2019 had 29 observers worldwide. From these, only five observers were from the southern hemisphere.

A similar zenith hourly rate (ZHR) could be presumably deducted by two distinctive observers with equal limiting magnitude lm, applying the correction F for obstructions in their field of view and the altitude of the radiant above the horizon $\sin(h_R)$. An hourly rate (HR) between 0.5/h and 0.7/h for the alpha Capricornid meteor shower for BRAMON sites or for a typical observer in central Europe or in the USA, with latitude 40 degrees North, generates the same ZHR, and it is compatible with the mean population indexes, admitting $F = 1$ and $lm = 0$.

The eta Aquariid and Geminid meteor showers observed by BRAMON should have about 6% and 7% of the HR obtained by an observer from the northern hemisphere to generate the same ZHR. These estimates are reasonable compared to the HR estimated from the BRAMON and VMDB datasets for the eta Aquariid (0.06 × 0.8/h) and Geminid meteor showers (0.07 × 4.1/h) in 2019. The ratio between the observed BRAMON and VMDB hourly rate for the alpha Capricornid meteor shower is 10% lower than the initial estimate of 70%.

I conclude that population indexes r of alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers are influenced probably by a combination of the detection probability of the detector (human eye or CCD) and the zenith distance of the radiant of the meteor shower at the different observational sites.

5 Conclusions

The population indexes r of alpha Capricornid (CAP #00001), eta Aquariid (ETA #00031), and Geminid (GEM #00004) meteor showers are probably influenced by a combination of the detection probability between visual and TV observational procedures and the zenith distance of the radiant of the meteor showers at the different observational sites. These factors can imply that the mean activity indexes of eta Aquariid (ETA #00031) and Geminid (GEM #00004) meteor showers obtained from the BRAMON apparent magnitudes $m_{app} \leq 0$ are systematically higher or equal to its equivalents obtained from IMO VMDB visual data.

Acknowledgment

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Fireball above lake Balaton, Hungary

Gábor Kővágó

fotospentax@gmail.com

A bright fireball appeared on 2021 October 21, at 16^h28^m UT over the Balaton Lake in Hungary. The trajectory, strewn field and orbit could be calculated. The results are presented in this article.

1 Introduction

On the evening of October 20, 2021, at 18^h28^m (local time), the lucky ones could see a bright fireball. Due to the early evening time, most meteor camera systems had not yet started. On the other hand, meteorological cameras and many car cameras, have successfully captured the phenomenon (*Figure 1*).

2 Initial data

According to the measurements, the meteor first appearance occurred at 91 km with an entrance angle of 68 degrees at a velocity of 17 km/s, it moved along a 67 km long trajectory through the atmosphere in just 4 seconds. The trajectory was situated between Padragkút to Révfülöp, where it was last seen at an altitude of 24.8 km. I used only the images of the meteorological cameras for the measurement, before the information calculated from the professional systems has been published. I used UFOAnalyser and UFOOrbit (Sonotaco, 2009) for the trajectory calculation.

3 Dynamical mass

By measuring the best recording of the end of the fireball trajectory, I was able to get closer to calculate the remaining mass. This picture was from one of the cameras on the VMETEO site (*Figure 2*), which recorded the end of the fall from close (from Veszprém, from a distance of 40 km). Bence Gucsik saved star background pictures from that camera and asked Mónika Landy-Gyebnár (camera operator) for the exact coordinates of the camera. The camera recorded the last moments of the fall on 7 frames, measuring them frame by frame provides the basis for the current mass and strewn field calculation.

As this camera was the closest to the fall, it could register the end better. The meteor could be tracked far more on the recording, than from another cameras, down to an altitude of 24.8 km. During this time, its speed decreased from 9 km/s to 3.75 km/s. Let’s not forget, that while this is the last light we recorded of the fall, it doesn’t mean the body has switched to dark flight at this point. The picture was taken at a clear sky and this camera is not so sensitive to dim lights. Therefore, the remaining mass probably got a few hundred meters deeper than that. Continuing the rate of deceleration, the assumed final altitude was 24.6 km at 2.5 km/s.

From the speed measured frame by frame, knowing the deceleration and the current altitude, one can calculate how

Figure 1 – Fireball 2021 October 21, at 16^h28^m UT, photo made by Schmall Rafael from Kaposfő, Hungary.

Figure 2 – Fireball 2021 October 21, at 16^h28^m UT[26].

much mass is required for this trajectory. (Halliday et al., 1996). Based on this, we obtain as result a 1.2 kg body on the last frame. Once again, this is not the end of the ablation, so it has fallen even further and ablated presumably until less than 1kg. However, based on the recording, this appears to be one body throughout the flight. If it was fragmented into several pieces at the end, this didn't happen at this distance (about 40 km). Continuing the ablation process, the Monte-Carlo modeling dispersed around 880 g.

4 Strewn field calculation

I modeled the dark flight with these data using two different wind profiles at 12^h UT and 00^h UT from Budapest (data came from University of Wyoming, Atmospheric sounding[27]). The remaining mass was given as 100 g – 1 kg. The beginning heights of the bodies varies from 25.1 km to 24.6 km, along the calculated trajectory. The gravitational deflection - the difference between the calculated straight-line path and the real curved trajectory - was not taken into account because it's negligible compared to e.g., wind measurement uncertainties (it was only 27m). My program doesn't handle in-flight fragmentation yet, so it's even possible to find smaller pieces at the 'large fragments' end of the strewn field, but it has to be still in the calculated field. Unfortunately, the results for the 12^h UT and 00^h UT models are very different. Since the fall was between the two, at 16^h28^m (UT), it can be assumed that the fragments that felt are likely to be between the two calculated strewn fields.

For this fireball, many parameters and the observed characteristics support the probability of meteorite fall. So, I posted a little article about it on Facebook. After this, there were some people who dedicated their time to search the area individually but this yielded no findings.

Czech professional astronomers (Spurný et al., 2021) have also calculated data from this fireball, based on images captured by cameras from the European Fireball Network. They have also published their results, from which much can be learned for a citizen scientist like me. Their calculated trajectory came out 800 meters west (yellow) from mine (white) (*Figure 3*), and the final altitude was calculated to be 26 km, instead of the 24.8 what I had calculated. Partly because of this, due to the difference in height, the center line of their calculated strewn field shifted 1.2 km to the SE compared to what I calculated. Based on their published information, I also calculated the strewn field, this can be seen at the edge of the yellow field they calculated. So, it can be seen that the strewn field started from above, gradually shifting into their strewn field result (yellow) (*Figure 4*). However, this alone is not enough to fully match the results. Unfortunately, I don't know what causes the extra difference, because I don't have either their exact starting data or the program, they're using to make their calculations. I use my own program to calculate the strewn field.

What is encouraging, however, is that there are no huge differences. They also gave a few hundred grams to the remaining mass. This proves that using the images and videos of meteorological cameras, a possible meteorite dropping can be approached within 1000 m.

[26] https://vmeteo.hu/
[27] University of Wyoming - http://weather.uwyo.edu/upperair/sounding.html

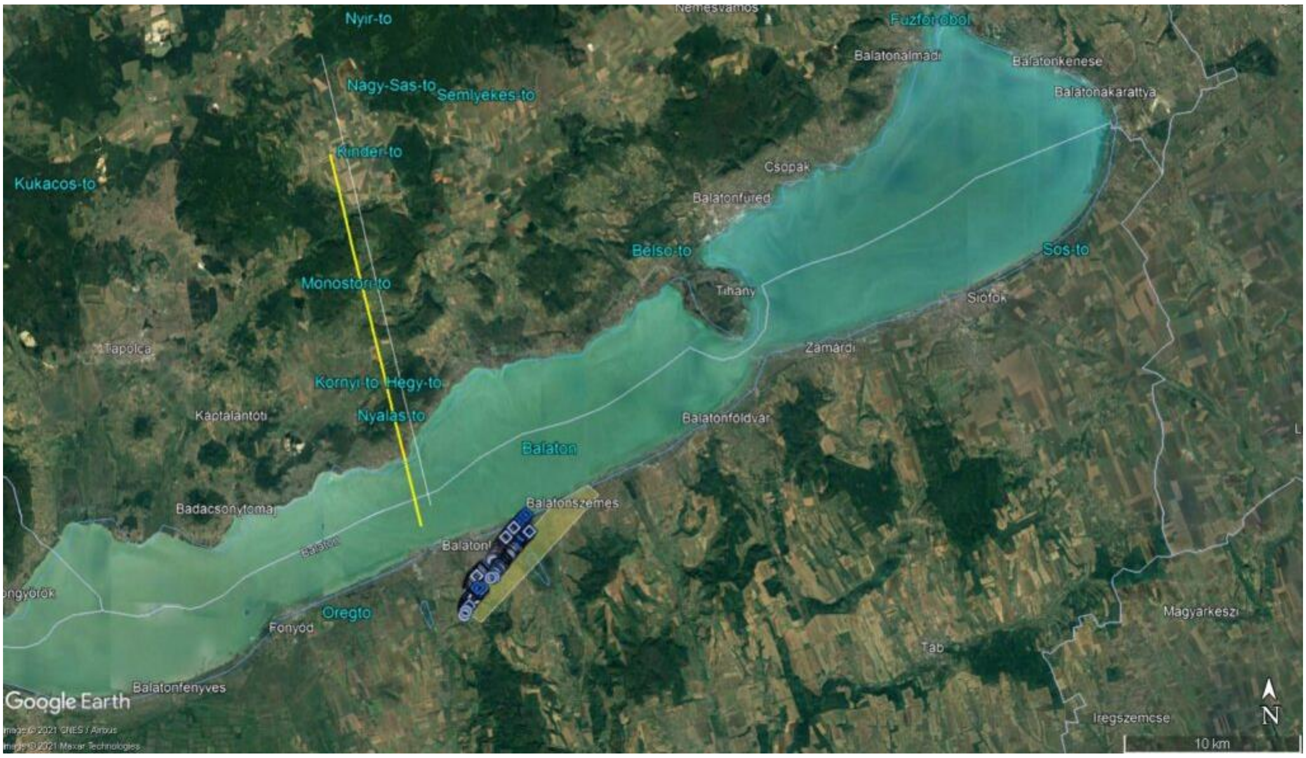

Figure 3 – Fireball 2021 October 21, at 16^h28^m UT, the two different trajectories.

Figure 4 – Fireball 2021 October 21, at 16^h28^m UT, different strewn field calculations.

5 Orbit

Before the collision with the Earth atmosphere this fragment followed a bit an unusual orbit around the Sun. In general, the fireballs come from between Mars and Jupiter, but this one barely reached the orbit of Mars. Therefore, this one was definitely a piece of the innermost part of the main asteroid belt. No known meteor shower could be associated.

The resulting orbital elements are:

- α = 273.9°
- δ = +68.6°
- a = 1.2 A.U.
- q = 0.993 A.U.
- e = 0.186
- ω = 191.2°
- Ω = 207.2°
- i = 24.2°

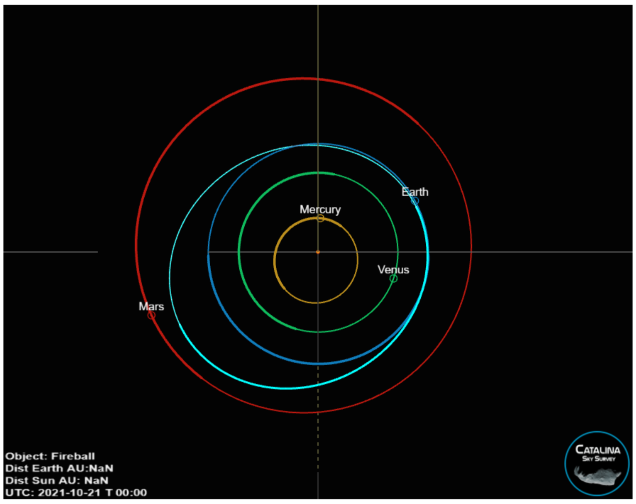

Figure 5 – Calculated orbit in UFOOrbit (Sonotaco, 2009) (Image credit: CSS, D. Rankin).

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RNDr. Pavel Spurný, CSc., RNDr. Jiří Borovička, CSc. a Mgr. Lukáš Shrbený, Ph.D. Oddělení meziplanetární hmoty Astronomický ústav AV ČR.

The Southwestern Europe Meteor Network: new advances and analysis of bright fireballs recorded from September to December 2021

J. M. Madiedo[1], J. L. Ortiz[1], J. Izquierdo[2], P. Santos-Sanz[1], J. Aceituno[3], E. de Guindos[3], P. Yanguas[4], J. Palacián[4], A. San Segundo[5] and D. Ávila[6]

[1] **Departamento de Sistema Solar, Instituto de Astrofísica de Andalucía (IAA-CSIC), 18080 Granada, Spain**
madiedo@cica.es, ortiz@iaa.es, psantos@iaa.es

[2] **Departamento de Física de la Tierra y Astrofísica, Universidad Complutense de Madrid, 28040 Madrid, Spain**
jizquierdo9@gmail.com

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

[4] **Departamento de Estadística, Informática y Matemáticas e Institute for Advanced Materials and Mathematics, Universidad Pública de Navarra, 31006 Pamplona, Navarra, Spain**
yanguas@unavarra.es, palacian@unavarra.es

[5] **Observatorio El Guijo (MPC J27), Galapagar, Madrid, Spain**
mpcj27@outlook.es

[6] **Estación de Meteoros de Ayora, Ayora, Valencia, Spain**
David_ayora007@hotmail.com

In this work we focus on some recent improvements performed in the framework of the Southwestern Europe Meteor Network (SWEMN) and the SMART project. Thus, by employing artificial intelligence methods, we have significantly enhanced the capabilities of our fireball database to automatically disseminate its most remarkable contents through social networks and other channels. This is the first digital database dedicated to meteor events recorded over Spain and neighboring areas. In addition, we have expanded our network by deploying new meteor cameras. We also present in this work the most relevant fireballs recorded by SWEMN from September to December 2021, including the emission spectrum of some of these events.

1 Introduction

The Southwestern Europe Meteor Network (SWEMN) is a research project coordinated from the Institute of Astrophysics of Andalusia (IAA-CSIC) with the aim to analyze the Earth's meteoric environment. This network is also integrated by researchers from the Complutense University of Madrid (UCM), the Public University of Navarre (UPNA), and the Calar Alto Observatory (CAHA). In order to identify and analyze meteors in the Earth's atmosphere, SWEMN develops the Spectroscopy of Meteoroids by means of Robotic Technologies (SMART) survey (Madiedo, 2014; Madiedo, 2017).

To improve our knowledge about the Earth-Moon meteoric environment, SMART works in close connection with another project conducted by IAA-CSIC: the MIDAS survey (Moon Impacts Detection and Analysis System). MIDAS uses the Moon as a laboratory that provides information about meteoroids hitting the lunar ground (Ortiz et al., 2015; Madiedo et al., 2015a, b). A strong synergy has been proved to exist between this survey and the SMART project (Madiedo et al., 2015a, b).

This work focuses on a series of advances performed in the framework of SWEMN along the end of last year and January 2022. The most important of these is related to the use of artificial intelligence methods to disseminate among the general public information about fireball events recorded by our meteor network. To do this, we employ as essential tools the SWEMN digital database containing information about bolides and meteors recorded over the Iberian Peninsula, but also our SAMIA software. Other advances have to do with the expansion of the SWEMN network. On the other hand, this work also presents some of the most remarkable fireballs recorded by our systems from September to December 2021.

2 New capabilities of the SWEMN digital database: use of artificial intelligence (AI) for dissemination in social networks and media

The SMART survey is currently co-funded by the Spanish Ministry for Science and Innovation. One of the objectives of this project is related to the dissemination of our scientific results among the general public. For this purpose, we employ several strategies. Thus, we disseminate this information through social networks (mainly Twitter and Facebook), information media, our website, and also YouTube. Thus, since the SMART project was started in

2006 the results obtained in the framework of this survey and the most remarkable fireballs recorded by our meteor stations have been widely disseminated to increase the interest of the public in Spain for meteor science. And, consequently, the number of amateur astronomers that expressed their interest in establishing some kind of collaboration with SMART also increased. The time consumed by this dissemination process was very significant, since all of the information necessary for this purpose was gathered manually, and the corresponding reports were also prepared by hand.

One important step taken in the framework of SWEMN along 2021 was the development of the first digital and interactive database containing meteors recorded and analyzed by the SMART project since this survey was started in 2006. This step included the development of a new dedicated software (the SAMIA software) to handle and exploit the contents of this database (Madiedo et al., 2021). AI methods were included in SAMIA to automatically derive valuable information from the events included in that database. And recently, those methods have been expanded to automatically perform most of the above-mentioned dissemination of information among the general public on social networks and media. This has two main advantages: first, it saves very valuable time to our team. And second, the information is disseminated much faster.

In relation to social networks, the first task that SAMIA could perform in this context was the automatic update of our website. More specifically, of the webpage containing information about the most relevant fireballs recorded and analyzed in the framework of the SMART project. In that way, the program adds for each new bolide a short description of the event, a stacked photo of the fireball as recorded from a given meteor station, and also a link to the video uploaded to YouTube explaining the main circumstances of the bolide. To do this, SAMIA edits the HTML code of the webpage dedicated to these fireballs, and once the new information is appended to that HTML page, the software automatically uploads the updated file to the server where the page is hosted. Besides, the AI in the SAMIA software also writes automatically Twitter threads describing the circumstances of a particular event. And it also writes the text necessary to inform about the same event on Facebook. By following this procedure, the information can be easily disseminated on both social networks. Currently, the text for Twitter and Facebook is written in Spanish only. But SAMIA also writes automatically text to describe the event on the YouTube channel we employ to disseminate fireball videos. In this case, the text is written in English and Spanish.

The last step taken in this automatic dissemination process consists on the preparation of press releases to inform about a particular event through the media (TV, radio, press, etc.). The use of a press release fully created by SAMIA's AI from the information contained in the SWEMN digital database was done for the first time in January 2022. Press releases are prepared by SAMIA in MS-Word DOC format, and in Spanish language. At this stage, the press release must be supervised by a human operator, who decides if the MS-Word file can be sent to the media, or if it needs some corrections before being submitted.

3 Expansion of the SWEMN network

Our meteor network went on growing during the second half of 2021 and the beginning of 2022. Thus, a new station named "El Aljarafe" started operation in October 2021. This station was setup by an amateur astronomer who joined the Pro-Am initiative that SWEMN started last year. The station was named after the area in which it was established, nearby to the city of Sevilla. It currently employs two HD CMOS cameras to monitor meteor activity during the night, but also the activity of bright fireballs during daytime.

On the other hand, we have expanded our video station in La Coruña (region of Galicia, NW of Spain). The first camera deployed there started operation on 2021 June 30, in commemoration of the International Asteroid Day. During the last week of 2021 and the first week of 2022 three additional video devices have been installed there.

It is also worth mentioning that SWEMN is planning the installation of a series of new professional meteor-observing stations along 2022. The first of these will be deployed in Mallorca, and it is expected to be fully operative along next spring. The cameras deployed at this location will significantly increase the coverage of our meteor network over the Mediterranean Sea, the south of France, and the north of Africa.

4 Instrumentation and methods

Below we present the most remarkable bright meteors recorded by our meteor-observing stations from September to December 2021. These events were recorded by means of analog CCD video cameras manufactured by Watec (models 902H and 902H2 Ultimate). Their field of view ranges from 62 × 50 degrees to 14 × 11 degrees. To record meteor spectra we have attached holographic diffraction gratings (1000 lines/mm) to the lens of some of these cameras. We have also employed digital CMOS color cameras (models Sony A7S and A7SII) operating in HD video mode (1920 × 1080 pixels). These cover a field of view of around 70 × 40 degrees. A detailed description of this hardware and the way it operates was given in previous work (Madiedo, 2017).

The atmospheric path and radiant of meteors, and also the orbit of their parent meteoroids, were obtained with the Amalthea software, developed by J. M. Madiedo (Madiedo, 2014). This program employs the planes-intersection method (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, 2015).

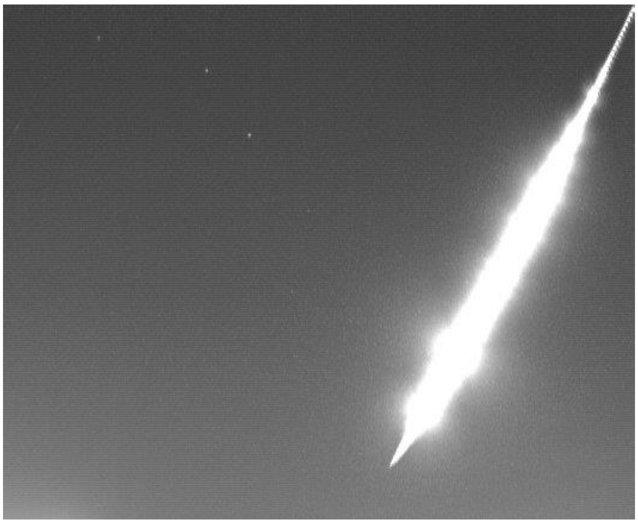

Figure 1 – Stacked image of SWEMN20210915_202553 "La Albuera" fireball as recorded from the SWEMN meteor-observing station at Sevilla.

Figure 2 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210915_202553 fireball.

5 The 2021 September 15 meteor event

On September 15, at $20^h25^m53.9 \pm 0.1^s$ UTC, our systems recorded an impressive fireball from the SWEMN meteor-observing stations operating at La Hita, La Sagra, Sierra Nevada, Sevilla, Calar Alto, and Huelva. It had a peak absolute magnitude of –12 ± 1 (*Figure 1*). This event was included in our meteor database with the code SWEMN20210915_202553. A video showing images of the fireball and its trajectory was uploaded to YouTube [28].

Table 1 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210915_202553 "La Albuera" fireball.

a (AU)	2.6 ± 0.1	*ω* (º)	246.62 ± 0.01
e	0.71 ± 0.01	Ω (º)	172.91443 ± 10^{-5}
q (AU)	0.753 ± 0.002	*i* (º)	8.0 ± 0.1

[28] https://youtu.be/qyE0iNzidvE

Atmospheric trajectory, radiant and orbit

By analyzing the recordings obtained from the meteor stations that observed this fireball, we found that this bright meteor overflew the province of Badajoz. Besides, we obtained a pre-atmospheric velocity for the progenitor meteoroid of v_∞ = 21.1 ± 0.3 km/s, with the position of the apparent radiant at the equatorial coordinates α = 335.5º, δ = +9.4º. The analysis of the atmospheric path also revealed that the meteor began at a height H_b = 91.9 ± 0.5 km, and ended at an altitude H_e = 22.2 ± 0.5 km. The zenith angle of this trajectory was of about 46 degrees. Since the terminal point of the bolide was almost over the vertical of the town of La Albuera, we named the fireball after this location. The atmospheric path of this deep-penetrating meteor and its projection on the ground are shown in *Figure 2*. The analysis of the terminal point of the atmospheric trajectory indicated that a small part of the meteoroid survived the ablation process and reached the ground as a meteorite. The derived total surviving mass, however, was very small, below 25 grams. In spite of that, an expedition was organized by the SWEMN network to the strewnfield determined from our calculations. Expeditions organized by amateurs were also organized to the same area. However, nothing was found.

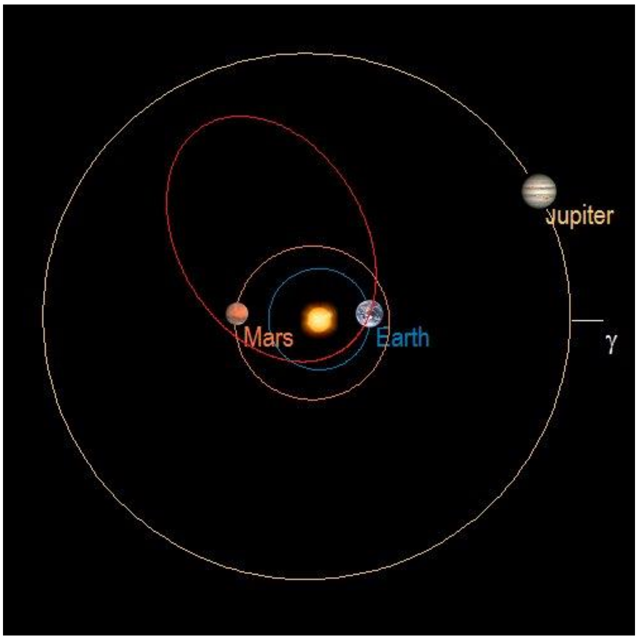

Figure 3 – Projection on the ecliptic of the orbit (red line) of the parent meteoroid of the SWEMN20210915_202553 fireball.

The geocentric velocity of the meteoroid was v_g = 17.7 ± 0.3 km/s. Its orbital parameters before its encounter with our planet are shown in *Table 1*, and this orbit is drawn in *Figure 3*. Radiant and orbital data do not match any of the meteoroid streams listed in the IAU meteor database[29]. So, we concluded that this event was produced by the sporadic background. According to the calculated value of the Tisserand parameter with respect to Jupiter (T_J = 3.0), the meteoroid followed an asteroidal orbit before impacting the Earth's atmosphere.

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

Emission spectrum

The emission spectrum of the SWEMN20210915_202553 meteor was recorded by our spectrographs from the astronomical observatories of Calar Alto and La Hita. We have analyzed it with the ChiMet software, which calibrates the signal in wavelength and then corrects it by taking into account the spectral sensitivity of the device (Madiedo, 2017). The resulting calibrated spectrum is shown in *Figure 4*, where the most remarkable emission lines have been highlighted. Most of these correspond to neutral iron, as usual in meteor spectra (Borovička, 1993; Madiedo, 2014). Thus, we have identified the emissions from Fe I-4, Fe I-42, Fe I-41, Fe I-318, and Fe I-15. The most important emissions are those of the Mg I-2 triplet (516.7 nm), and the Fe I-15 multiplet around 540 nm. The emission from the Na I-1 doublet (588.9 nm) is also remarkable, and the emission from Mg I-3 was also found. In addition, the contribution from atmospheric N2 is present in the red part of the spectrum.

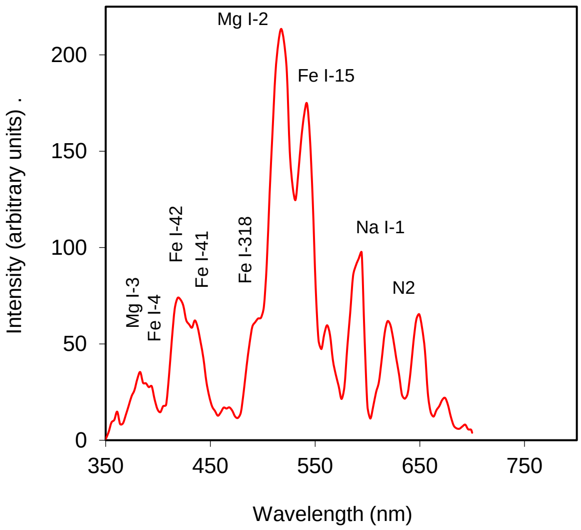

Figure 4 – Calibrated emission spectrum of the SWEMN20210915_202553 "La Albuera" fireball.

6 The 2021 October 20 fireball

This fireball was recorded from the SWEMN meteor-observing stations operating at La Sagra, La Hita, Madrid, Sevilla, Sierra Nevada, and El Guijo. The bolide can be viewed on this YouTube video[30]. It had a peak absolute magnitude of –9 ± 1 (*Figure 5*). It appeared at $23^h16^m07.1 \pm 0.1^s$ UTC, and so it was included in our database under the code SWEMN20211020_231607.

Atmospheric path, radiant and orbit

This fireball overflew the provinces of Segovia, Valladolid, and Avila (northwest of Spain). The meteoroid hit the atmosphere with an initial velocity $v_\infty = 66.2 \pm 0.4$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 94.0°$, $\delta = +32.0°$. The bolide began at an altitude $H_b = 135.1 \pm 0.5$ km over the northeast of the province of Segovia. The terminal point of its trajectory was reached at a height $H_e = 73.7 \pm 0.5$ km over the north of the province of Avila, near the vertical of the town of Madrigal de las Altas Torres. In our meteor database we named the event after this location. The calculated atmospheric path and its projection on the ground are shown in *Figure 6*.

Figure 5 – Stacked image of the SWEMN20211020_231607 "Madrigal de las Altas Torres" fireball as recorded from the SWEMN meteor-observing station located at La Hita.

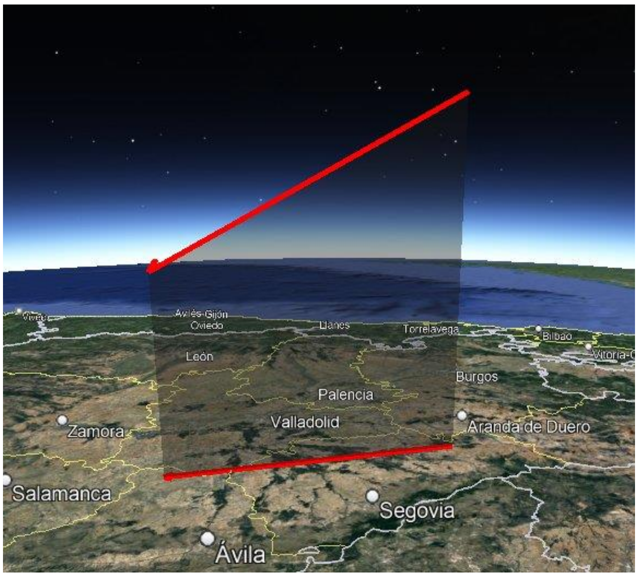

Figure 6 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20211020_231607 fireball.

Table 2 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20211020_231607 fireball.

a (AU)	5.8 ± 1.1	ω (°)	268 ± 1
e	0.90 ± 0.01	Ω (°)	207.48371 ± 10^{-5}
q (AU)	0.538 ± 0.008	i (°)	161.4 ± 0.1

The calculation of the orbital elements of the progenitor meteoroid yields the results listed in *Table 2*, and the corresponding heliocentric orbit is shown in *Figure 7*. The value derived for the geocentric velocity is $v_g = 64.9 \pm 0.4$ km/s. The value of the Tisserand parameter with respect to Jupiter ($T_J = 0.05$) shows that the meteoroid followed a

[30] https://youtu.be/Uq-TszJLnLY

cometary orbit. Calculated radiant and orbital data show that the meteoroid was associated with the κ-Aurigids (KAU#0537), according to the information listed in the IAU meteor database. The proposed parent body for this minor and poorly-known meteoroid stream is Comet C/1957U1(Latyshev-Wild-Burnham) (Šegon et al., 2014).

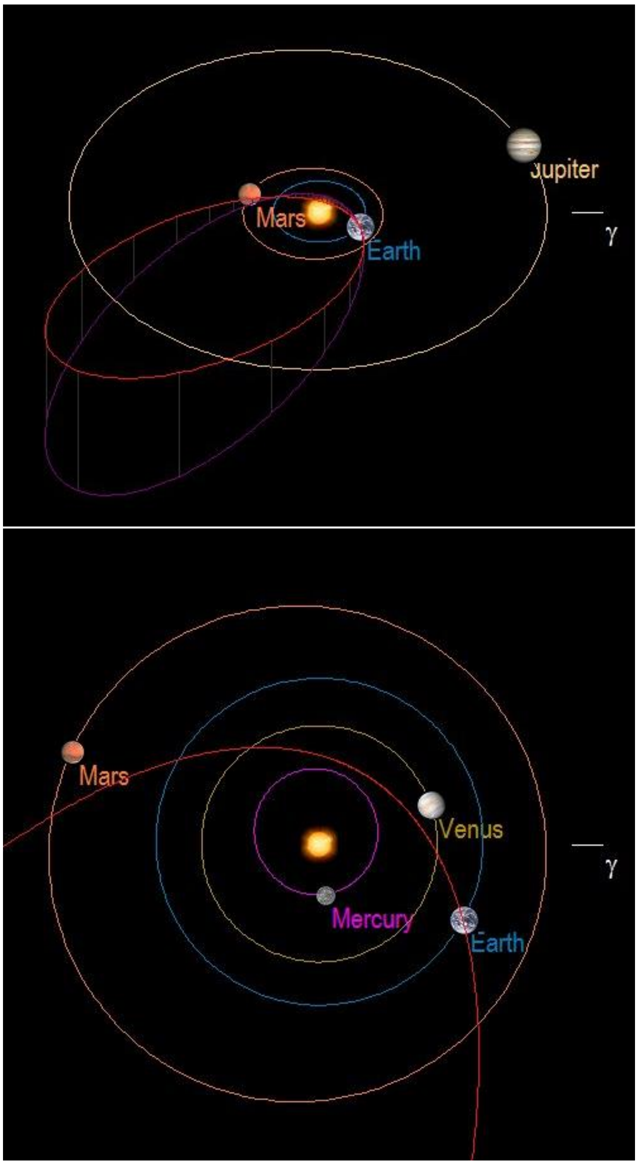

Figure 7 – Up: orbit (red line) of the parent meteoroid of the SWEMN20210404_214218 fireball, and projection of this orbit (violet line) on the ecliptic plane; Down: close-up view of the orbit.

7 The 2021 November 12 fireball

At $0^h34^m48.0 \pm 0.1^s$ UTC on November 12, we recorded a deep-penetrating bolide with a peak absolute magnitude of –13 ± 1 (*Figure 8*). The event was spotted from the meteor-observing stations located at El Guijo, Sierra Nevada, La Hita, and Sevilla. It was included in the SWEMN meteor database with the code SWEMN20211112_003448.

Atmospheric path, radiant and orbit

The analysis of the atmospheric trajectory of the event reveals that the luminous phase started at an altitude $H_b = 96.7 \pm 0.4$ km over the east of the province of Salamanca. The meteoroid stroke the atmosphere with a velocity v_∞ of about 28.5 km/s. The apparent radiant was located at the equatorial coordinates $\alpha = 55.6$º, $\delta = +16.5$º. The bolide penetrated the atmosphere till a final height $H_e = 25.0 \pm 0.4$ km over the same province.

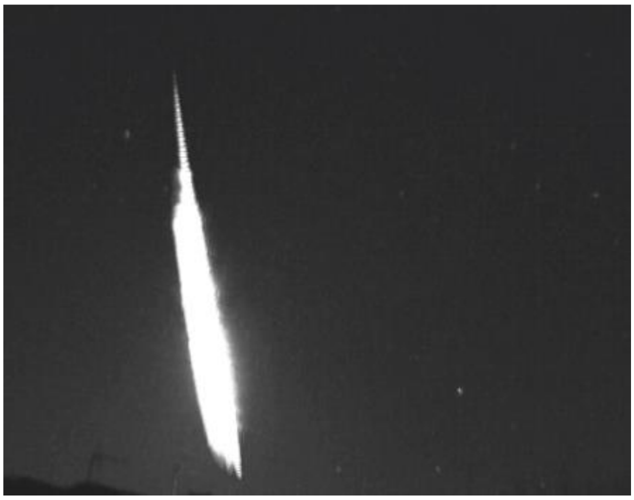

Figure 8 – Stacked image of the SWEMN20211112_003448 fireball as recorded from El Guijo Observatory.

Figure 9 – Projection on the ground of the trajectory of the SWEMN20211112_003448 fireball.

The projection on the ground of the atmospheric trajectory is shown in *Figure 9*. The parameters of the heliocentric orbit (*Figure 10*) followed by the meteoroid before its encounter with our planet are shown in *Table 3*. These data confirmed the association of the event with the Southern Taurid meteoroid stream (STA#0002).

The analysis of the lightcurve reveals that the fireball exhibited several flares along its path in the atmosphere. These flares took place as a consequence of the sudden disruption of the progenitor meteoroid when the aerodynamic pressure exceeded the tensile strength of the particle. From the analysis of these breakups we estimated that the tensile strength of the meteoroid was of about $(2.4 \pm 0.5)\cdot10^7$ dyn/cm^2.

Our calculations also reveal that the meteoroid was not completely ablated in the atmosphere, since at the terminal point of the luminous trajectory a mass of about 20 g survived the ablation process. The dark flight was also analyzed and the landing area of the surviving mass was determined. An expedition was organized to that area, where experts in meteorite recovery participated in collaboration with SWEMN. Unfortunately, part of the predicted landing area had just been plowed, and the meteorite was not found.

Table 3 – Orbital parameters (J2000) of the progenitor meteoroid of the SWEMN20211112_003448.

a (AU)	2.6 ± 0.1	*ω* (º)	101.6 ± 0.1
e	0.82 ± 0.01	Ω (º)	49.51242 ± 10^{-5}
q (AU)	0.455 ± 0.004	*i* (º)	3.7 ± 0.1

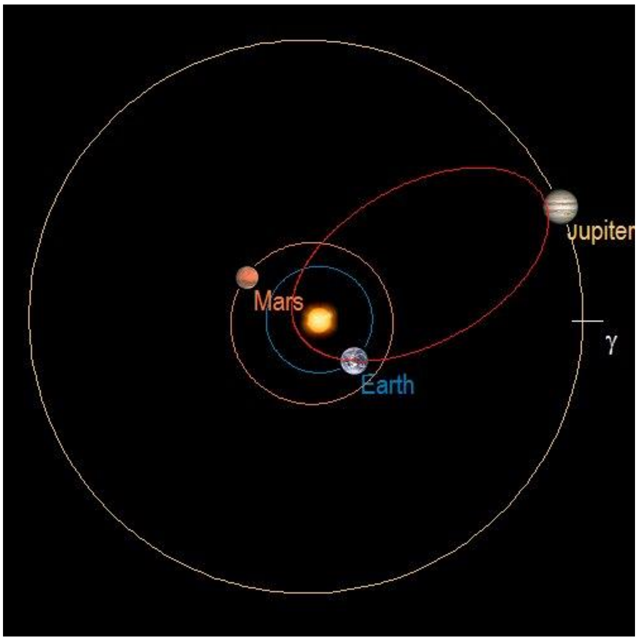

Figure 10 – Projection on the ecliptic plane of the orbit (red line) of the parent meteoroid of the SWEMN20211112_003448 fireball.

8 The 2021 November 28 fireball

This bolide was recorded at $22^h39^m04.4 \pm 0.1^s$ UTC on 2021 November 28 from the SWEMN meteor-observing stations located at La Hita, La Sagra, Calar Alto, Sevilla, Huelva, and Sierra Nevada. It reached a peak absolute magnitude of –12 ± 1 (*Figure 11*). A video about this fireball was uploaded to YouTube[31]. The meteor was included in the SWEMN meteor database with the code SWEMN20211128_223903.

Atmospheric path, radiant and orbit

According to our calculations, the meteoroid entered the atmosphere with an initial velocity $v_\infty = 20.1 \pm 0.3$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 16.8$º, $\delta = +57.9$º. The event overflew the Atlantic Ocean. It began at an altitude $H_b = 89.7 \pm 0.4$ km, and ended at a height $H_e = 45.7 \pm 0.4$ km over the sea. This atmospheric trajectory and its projection on the ground are shown in *Figure 12*.

Figure 11 – Stacked image of the SWEMN20211128_223903 fireball as recorded from Sevilla.

Table 4 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20211128_223903 fireball.

a (AU)	3.1 ± 0.2	*ω* (º)	216.6 ± 0.1
e	0.71 ± 0.01	Ω (º)	246.63159 ± 10^{-5}
q (AU)	0.904 ± 0.001	*i* (º)	19.5 ± 0.3

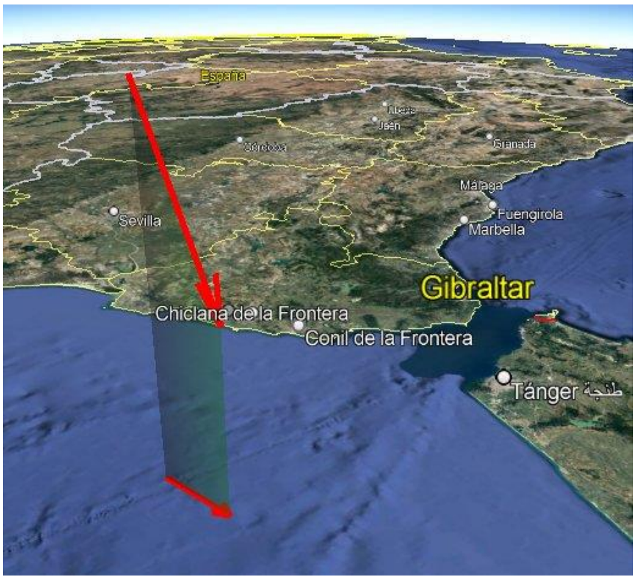

Figure 12 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20211128_223903 fireball.

Table 4 contains the orbital elements calculated for the parent meteoroid. This orbit is plotted in *Figure 13*. The calculated value of the geocentric velocity of this particle is $v_g = 16.8 \pm 0.3$ km/s. The Tisserand parameter with respect to Jupiter yields $T_J = 2.6$, which shows that this meteoroid followed a cometary orbit (JFC-type) before entering our atmosphere. In fact, according to the information found in the IAU meteor database, these results show that the fireball was a December ψ-Cassiopeiid (DPC#0446). This minor meteor shower, which is produced by meteoroids from

[31] https://youtu.be/PVyBB6-CTtg

Comet 3D/Biela, reaches its activity peak around December 4 (Jenniskens et al., 2016).

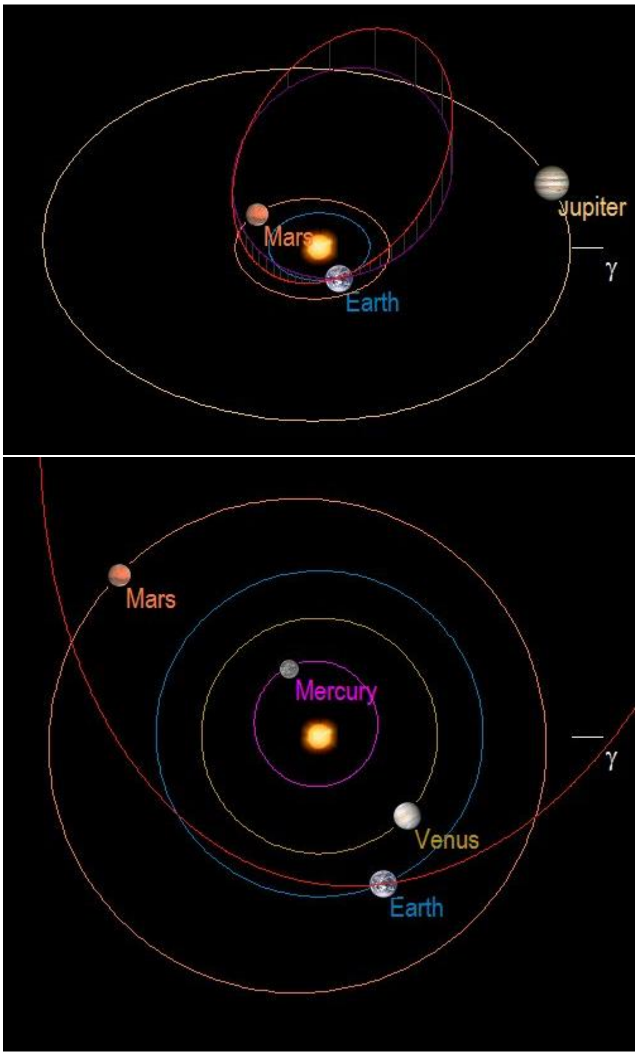

Figure 13 – Up: orbit (red line) of the parent meteoroid of the SWEMN20211128_223903 fireball, and its projection (violet line) on the ecliptic plane; Down: close-up view of the orbit.

9 The 2021 December 7 fireball

This bolide was recorded at $21^h31^m16.9 \pm 0.1^s$ UTC on 2021 December 7 from the SWEMN meteor-observing stations located at La Hita, La Sagra, Calar Alto, Sevilla, and Sierra Nevada. It reached a peak absolute magnitude of -12 ± 1 (*Figure 14*). A video about this fireball was uploaded to YouTube[32]. The meteor was included in the SWEMN meteor database with the code SWEMN20211207_213116.

Atmospheric path, radiant and orbit

According to our calculations, the meteoroid entered the atmosphere with an initial velocity $v_\infty = 22.0 \pm 0.3$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 69.0°$, $\delta = +14.7°$. The event overflew the province of Granada. It began at an altitude $H_b = 105.2 \pm 0.5$ km, and ended at a height $H_e = 31.9 \pm 0.5$ km. This atmospheric trajectory and its projection on the ground are shown in *Figure 15*. At its initial stage the event was located almost over the town of Gor, and so we named the bolide after this location.

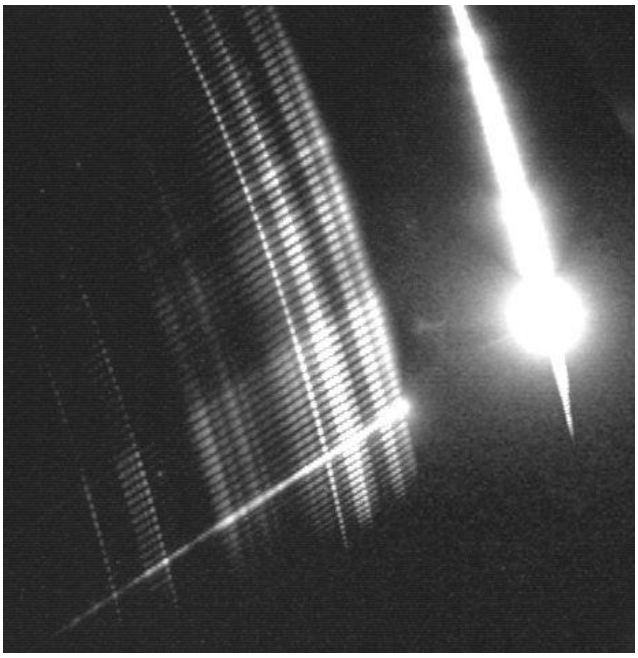

Figure 14 – Stacked image of the final stage of the SWEMN20211207_213116 "Gor" fireball as recorded from the Calar Alto Observatory. The image shows also the emission spectrum of the meteor.

Table 5 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20211207_213116 fireball.

a (AU)	2.24 ± 0.09	ω (°)	75.5 ± 0.3
e	0.69 ± 0.01	Ω (°)	75.67303 ± 10^{-5}
q (AU)	0.681 ± 0.003	i (°)	5.12 ± 0.05

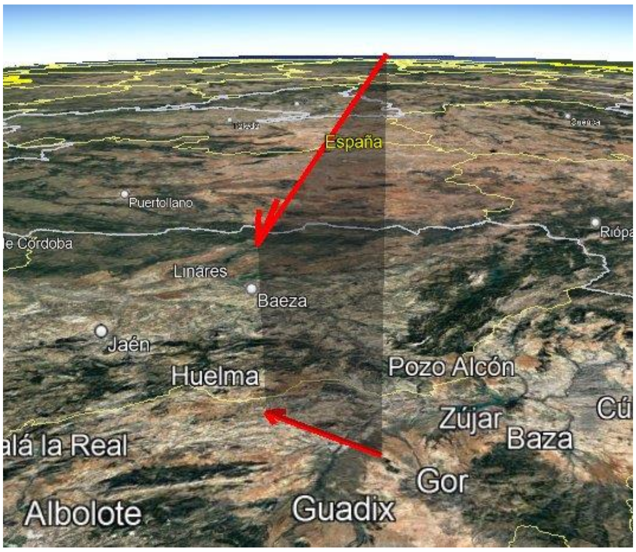

Figure 15 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20211207_213116 fireball.

Table 5 contains the orbital elements calculated for the parent meteoroid. This orbit is plotted in *Figure 16*. The calculated value of the geocentric velocity of this particle is $v_g = 18.7 \pm 0.3$ km/s. The Tisserand parameter with respect

[32] https://youtu.be/M2PE8AajxQM

to Jupiter yields $T_J = 3.2$, which shows that this meteoroid followed an asteroidal orbit before entering our atmosphere. Calculated radiant and orbital data do not match any of the meteoroid streams listed in the IAU meteor database. So, we classified this event as sporadic.

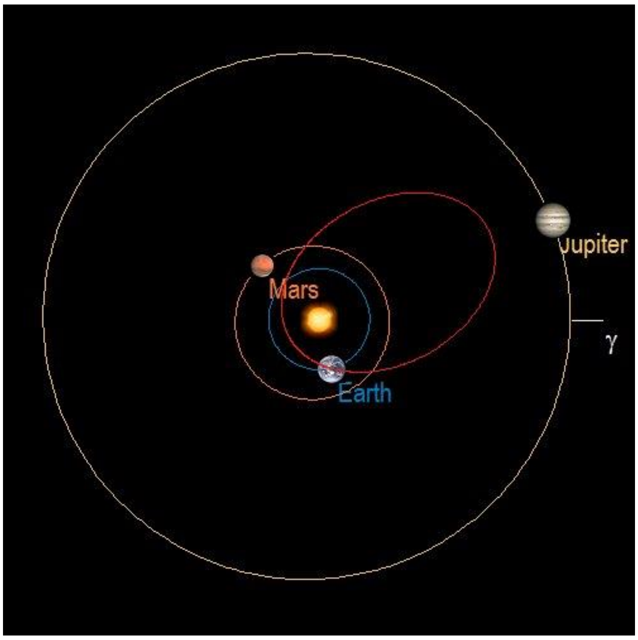

Figure 16 – Projection (red line) on the ecliptic of the orbit of the parent meteoroid of the SWEMN20211207_213116 fireball.

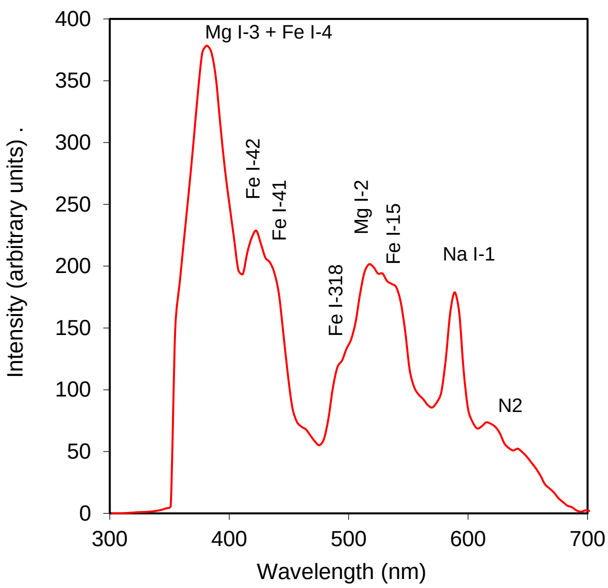

Figure 17 – Calibrated emission spectrum of the SWEMN20211207_213116 fireball.

Emission spectrum

One spectrograph located at Calar Alto recorded the emission spectrum of this event. The calibrated signal is shown in *Figure 17*, together with the most important emissions. The resolution of this spectrum is low, since there is a high degree of overlapping among the different multiplets. In spite of this, we have identified the emissions from Mg I-2, Fe I-15, Na I-2, Fe I-4, Mg I-3 and Fe I-318. Contributions from N2 bands are also present in the red region of the spectrum.

Figure 18 – Stacked image of the SWEMN20211214_001628 fireball as recorded from Calar Alto.

10 The 2021 December 14 fireball

This magnitude –12 ± 1 Geminid was recorded at $0^h16^m28.3 \pm 0.1^s$ UTC on 2021 December 14 from the SWEMN meteor-observing stations located at La Hita, La Sagra, Calar Alto, Sevilla, El Aljarafe, and Sierra Nevada (*Figure 18*). This is the brightest Geminid spotted from the Iberian Peninsula during the activity period of this shower in 2021. A video about this fireball was uploaded to YouTube [33]. The meteor was included in the SWEMN digital meteor database with the code SWEMN20211214_001628.

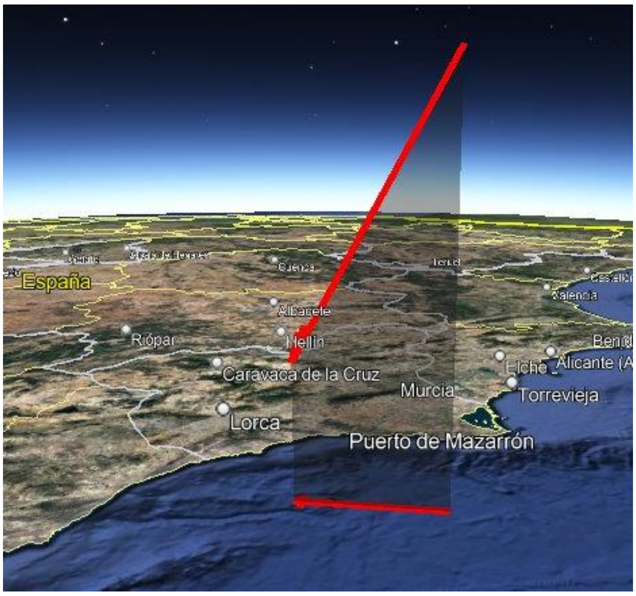

Figure 19 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20211214_001628 fireball.

[33] https://youtu.be/L_JjWkYCeJ8

Atmospheric path, radiant and orbit

According to our calculations, the meteoroid entered the atmosphere with an initial velocity $v_\infty = 36.4 \pm 0.3$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 118.9°$, $\delta = +30.5°$. The event overflew the Mediterranean Sea. It began at an altitude $H_b = 108.6 \pm 0.4$ km, and ended at a height $H_e = 35.6 \pm 0.4$ km over the sea. This atmospheric trajectory and its projection on the ground are shown in *Figure 19*.

Table 6 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20211214_001628 fireball.

a (AU)	1.10 ± 0.01	ω (°)	332.5 ± 0.1
e	0.910 ± 0.003	Ω (°)	261.92405 ± 10^{-5}
q (AU)	0.098 ± 0.003	i (°)	25.7 ± 0.5

Table 6 contains the orbital elements calculated for the parent meteoroid. This orbit is plotted in *Figure 20*. The calculated value of the geocentric velocity of this particle is $v_g = 34.4 \pm 0.3$ km/s. The Tisserand parameter with respect to Jupiter yields $T_J = 5.0$, which shows that this meteoroid followed an asteroidal orbit before entering our atmosphere. In fact, the information found in the IAU meteor database confirms that the meteoroid was associated with the Geminid stream (GEM#0004), whose parent body is Asteroid (3200) Phaethon.

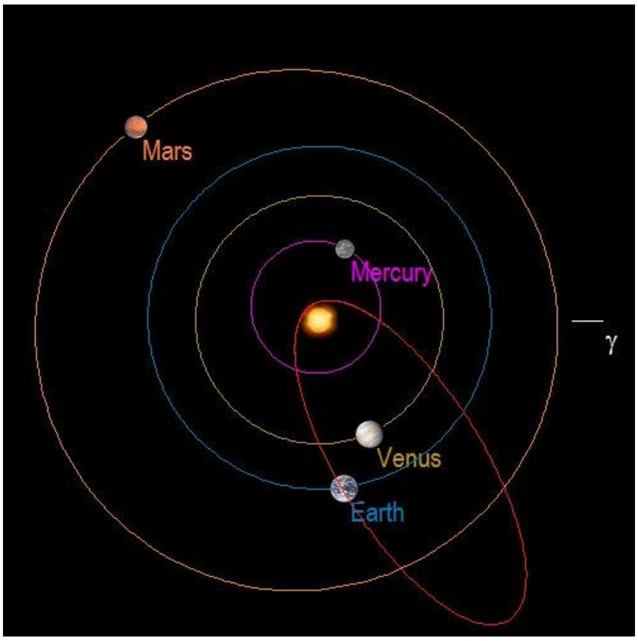

Figure 20 – Projection (red line) on the ecliptic of the orbit of the parent meteoroid of the SWEMN20211214_001628 fireball.

11 Conclusions

We have focused in this work on two new significant advances performed in the framework of the SWEMN network. One of them is related to the use of the SAMIA software and the AI in that program to automatically disseminate among the general public information about the most relevant fireballs recorded in the framework of the SMART project. Thus, by means of the information stored in the SWEMN digital database, SAMIA writes the texts necessary to disseminate this information on Twitter, Facebook, and YouTube. The software also can automatically write a press release to notify the media about these bolides.

The second advance discussed here has to do with the expansion of the SWEMN network during the last months. As a result of this, one new station named "El Aljarafe" entered operation near the city of Sevilla in October 2021. Besides, three additional video cameras were deployed between the last week of 2021 and the first week of 2022 at the meteor-observing station located at La Coruña (Galicia, NW of Spain). And currently, one new station is being setup at Mallorca to increase our coverage over the Mediterranean Sea, the south of France and the north of Africa.

We have also discussed the most remarkable fireballs recorded by our meteor-observing stations between September and December 2021. The peak absolute magnitude of these events ranged from –9 to –13.

The first of the bolides presented here was named "La Albuera". It was recorded on September 15, with a peak absolute magnitude of –12. This fireball, which was associated with the sporadic background, overflew the province of Badajoz and reached its final luminous stage with a non-zero terminal mass. The progenitor meteoroid followed an asteroidal orbit before entering our atmosphere. In the emission spectrum of this meteor we have identified the emissions from Fe I-4, Fe I-42, Fe I-41, Fe I-318, and Fe I-15, being the most prominent contributions those of the Mg I-2 triplet and the Fe I-15 multiplet. The emission from the Na I-1 is also remarkable, and the emission from Mg I-3 was also found.

The second fireball discussed in this work was the Madrigal de las Altas Torres event, which overflew the northwest of Spain on October 20 with a peak absolute magnitude of –9. Its progenitor meteoroid, which followed a long-period cometary orbit before entering the atmosphere, was associated with a poorly-known meteoroid stream: the κ-Aurigids (KAU#0537), whose proposed parent object is Comet C/1957U1(Latyshev-Wild-Burnham).

A deep-penetrating magnitude –13 Southern Taurid fireball was recorded on November 12. This event overflew the province of Salamanca, and reached a terminal height of about 25 km as a consequence of the high tensile strength of the meteoroid. Our calculations also reveal that the event exhibited a non-zero terminal mass (about 20 g) at the final stage of its luminous trajectory. An expedition was organized to the landing area of the surviving fragment(s), but unfortunately part of the area had just been plowed and the meteorite was not found.

Another bright fireball, with a peak absolute magnitude of –12, was recorded on November 28. The progenitor meteoroid was associated with Comet 3D/Biela. Thus, the event was a December ψ-Cassiopeiid (DPC#0446) that overflew the Atlantic Ocean around one week before the peak of this meteor shower.

The fireball named “Gor” was spotted on December 7. It was produced by a sporadic meteoroid following an asteroidal orbit. The bolide reached a peak absolute magnitude of –12 and overflew the province of Granada. The final height of this deep-penetrating event was of about 31 km. The emission spectrum of this meteor could be recorded. Despite its low resolution and high degree of line overlapping, we have identified in this signal the contributions from Mg I-2, Na I-1 and several neutral iron multiplets: Fe I-15, Fe I-4, Fe I-41, Fe I-42 and Fe I-318.

The last fireball we have included in this report is a magnitude –12 Geminid recorded by SWEMN stations on December 14. This bolide overflew the Mediterranean Sea and reached a final height of 35.3 km. This is the brightest Geminid observed from the Iberian Peninsula during the activity period of this shower in 2021.

Acknowledgment

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Meteors and bolides across the Caribbean

Yasmani Ceballos-Izquierdo[1], Dwayne Free[2], Ashley Hughes[3], Frankie Lucena[4], Eddie Irizarry[5] and Manuel E. Grullón[6]

[1] **Biblioteca Digital Cubana de Geociencias, Cuba**
yasmaniceballos@gmail.com

[2] **Spalding Allsky Camera Network, USA**

[3] **Florida Institute of Technology, 150 W University Boulevard, Melbourne, USA**

[4] **Caribbean TLE Observatory, Puerto Rico**

[5] **Sociedad de Astronomía del Caribe, Puerto Rico**

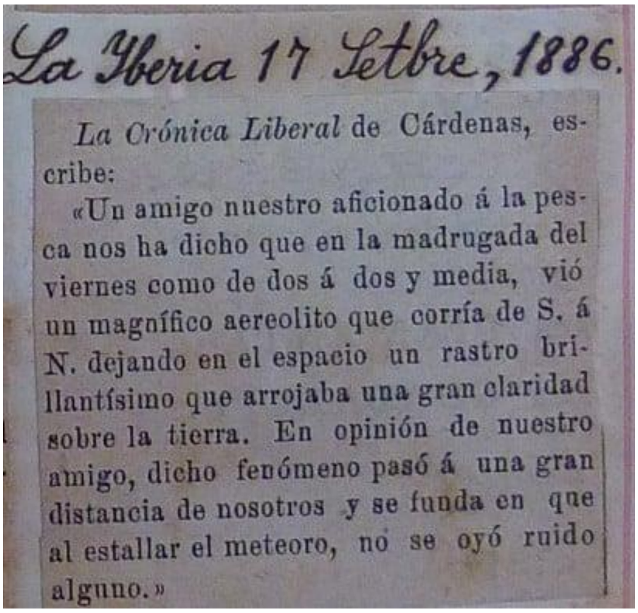
[6] **NOC DSA IAU Expresidente de la Sociedad Astronómica Dominicana, República Dominicana**

The meteor and fireball records of Cuba, Jamaica, Haiti, Dominican Republic and Puerto Rico, are reviewed, including records not listed in the American Meteor Society online fireball event database.

1 Introduction

Over the centuries many fireballs have been observed across the Caribbean. Some notable historical cases are: a meteor explosion near Antigua (November 9, 1839), a large meteor over St. Thomas's Island (March 20, 1821), a fireball seen over West Indies (August 20, 1821), and a brilliant meteor bursting over Martinique (November 14, 1867) (Greg, 1861). Early meteor observations in Cuba were made mostly in the second half of the 19th century (De la Sagra, 1867; Poey, 1862, 1864; Rodríguez-Ferrer, 1876; Viñes, 1886) (*Figure 1*). More recently, Lunsford (1995) reported Eta Aquariids and sporadic meteors, and Kartashova et al. (2017) reported on the observations of a Geminid meteor shower from the western portion of the island.

Bright fireballs from Cuba are poorly known inside and outside the island. The topic just gained more attention after the fall of Viñales on February 1, 2019, the Holguín bolide on March 19, 2021, and the Ramón de las Yaguas fall on July 10, 2021 (Ceballos-Izquierdo et al., 2021b and references therein). Consequently, a new wave of publications about fireballs over Cuba is starting to occur (e.g. Ceballos-Izquierdo, 2021; Ceballos-Izquierdo et al., 2021a, 2021b; Iturralde-Vinent and Arango-Arias, 2021; Zuluaga et al., 2019). Actually, the first trajectory estimations for a Cuban bolide were on the Viñales and the Holguín events (Ceballos-Izquierdo et al., 2021a, 2021b; Zuluaga et al., 2019). Concerning the Ramón de las Yaguas fall, some residents claim they saw a fireball[34] and its smoke trail, but only the seismic record of the explosion of the cosmic object is available, captured in three seismological stations in eastern Cuba (Iturralde-Vinent and Arango-Arias, 2021). Then, Ceballos-Izquierdo et al. (2021a) proposed the need of an implementation of a network for monitoring the sky using surveillance cameras that can record the passage of meteors through the atmosphere.


La Iberia 17 Setbre, 1886.

La Crónica Liberal de Cárdenas, escribe:

«Un amigo nuestro aficionado á la pesca nos ha dicho que en la madrugada del viernes como de dos á dos y media, vió un magnífico aereolito que corría de S. á N. dejando en el espacio un rastro brillantísimo que arrojaba una gran claridad sobre la tierra. En opinión de nuestro amigo, dicho fenómeno pasó á una gran distancia de nosotros y se funda en que al estallar el meteoro, no se oyó ruido alguno.»

Figure 1 – Chronicle of the crossing of a bright fireball in the Cuban sky, printed in a newspaper from September 1886 (Photo: L.E. Ramos-Guadalupe; used by permission).

On the other hand, the fireball record of Puerto Rico is far richer and perhaps better known, thanks to the diffusion work carried out by the Caribbean Astronomical Society (SAC) and amateur observers. In addition, a few fireballs have been recorded from the Dominican Republic as well. However, the information about all these events is scattered and there are also insufficient publications on the subject.

Here we review the meteor and fireball record of Cuba, Jamaica, Haiti, Dominican Republic and Puerto Rico, including records not listed in the American Meteor Society (AMS) online fireball event database. The available

[34] https://bit.ly/34jWZp3

information is summarized below, as a starting point for future research.

2 Cuban events

Sightings of the crossing of bright fireballs have been reported in the Cuban sky, but they are insufficiently studied (Ceballos-Izquierdo et al., 2021b). For example, between 2012 and 2022 several reports are logged at the online fireball event database (Event number 2206-2014, 414-2016, 1559-2016, 1497-2017, 4759-2018, 5025-2018, 5233-2018, 5955-2018, 513-2019, 1755-2021) of the AMS. The fireballs 1497-2017, 513-2019 and 4759-2018 are over Florida (USA), not Cuba. Excepting 513-2019 (Viñales) and 1755-2021 (the Holguín event), all the other Cuban events are from single observers only. If they were very bright fireballs, they would have been seen by more people.

Since the beginning of the use of the Geostationary Lightning Mapper (GLM) aboard the GOES 16 and GOES 17 satellites for detection of meteors in July 23, 2017 until the last update (December 16, 2021), there are 9 meteors reported over Cuba: 3 events of low confidence (2 from GLM-16 and 1 stereo), 3 events of medium confidence (1 from GLM-16 [the Holguín bolide] and 2 stereo), 2 event of high confidence (both stereo: one of them the Viñales meteorite fall).

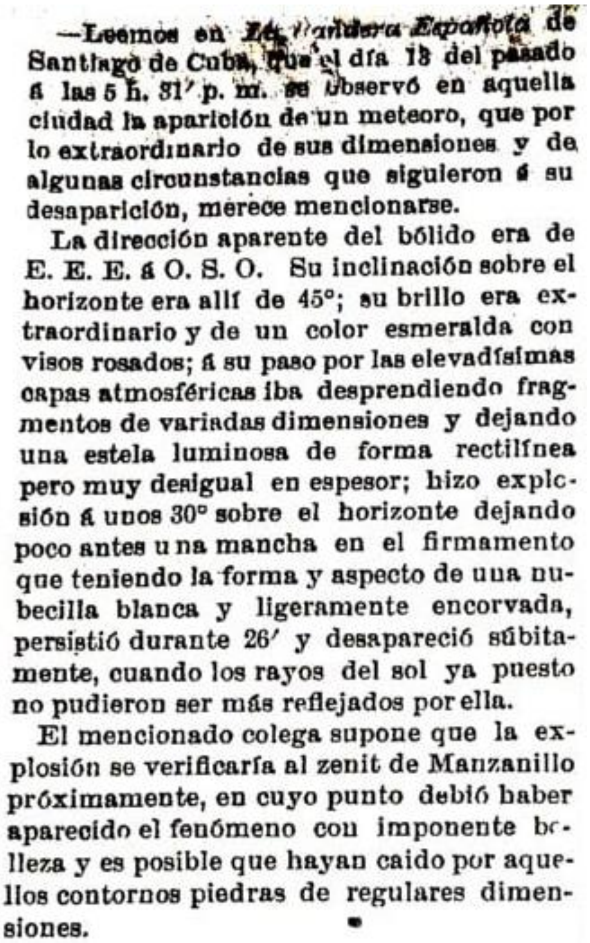
Recently, Ceballos-Izquierdo et al. (2021b) described the Viñales event and estimated the trajectory of the fireball, as an alternative to the Zuluaga et al. (2019) estimation, for that reason the fireball is not listed here.

Morón, 1867

Naranjo and Aguilar (1941) mentioned the occurrence of a probable meteorite that fell near the town of Morón (Ciego de Ávila province), on the night of November 24, 1867. These authors recount the tale of a suspected meteorite landfall based on the narration of Caridad Recino, who was an eyewitness: “she was with her family at the door of the house, when everything was illuminated, seeing how the sky was divided by a wide strip of fire, throwing sparks and stars, the bolide followed the north direction and fell with a fantastic crash, which produced a big alarm in Morón”. The fireball supposedly crossed over the northbound town and crashed causing an earthquake.

Havana, 1886

Viñes (1886) described what appears to be possibly a meteorite of great brightness and size that fell into the seafront of Havana city, causing panic in the neighbors. He pointed out that on Monday, May 10, 1886, approximately at 00^h30^m UTC, the inhabitants of Havana city witnessed a luminous object that was moving slowly in the sky, coming from the north. It produced such a commotion, that the Spanish authorities asked Viñes, director of the Observatory of the city, to publish a note explaining the phenomenon and in the next two days the main newspapers wrote about the event to calm the inhabitants. Based on the Viñes’ narration, Ramos-Guadalupe (2004) suggested a tentative magnitude around –10 for this fireball and estimated the meteor entered the atmosphere through a point located on the Gulf of Mexico, almost north of Havana, with part of its trajectory over the bay area.



—Leemos en La Bandera Española de Santiago de Cuba, que el día 18 del pasado á las 5 h. 31′ p. m. se observó en aquella ciudad la aparición de un meteoro, que por lo extraordinario de sus dimensiones y de algunas circunstancias que siguieron á su desaparición, merece mencionarse.

La dirección aparente del bólido era de E. E. E. á O. S. O. Su inclinación sobre el horizonte era allí de 45°; su brillo era extraordinario y de un color esmeralda con visos rosados; á su paso por las elevadísimas capas atmosféricas iba desprendiendo fragmentos de variadas dimensiones y dejando una estela luminosa de forma rectilínea pero muy desigual en espesor; hizo explosión á unos 30° sobre el horizonte dejando poco antes una mancha en el firmamento que teniendo la forma y aspecto de una nubecilla blanca y ligeramente encorvada, persistió durante 26′ y desapareció súbitamente, cuando los rayos del sol ya puesto no pudieron ser más reflejados por ella.

El mencionado colega supone que la explosión se verificaría al zenit de Manzanillo próximamente, en cuyo punto debió haber aparecido el fenómeno con imponente belleza y es posible que hayan caido por aquellos contornos piedras de regulares dimensiones.

Figure 2 – A very good description for the time of a fireball, on October 18, 1891 in eastern Cuba. (Photo: L.E. Ramos-Guadalupe).

DISCUSION”, VIERNES 5 DE AB

EL BOLIDO

CAIBARIEN, Abril 4.—Anoche serían las ocho cuando se vió un gran resplandor en la población. Se trataba de un meteoro ígneo que no pasó de dos segundos de duración.

FOMENTO, Abril 4.—En este barrio y en Güinía se pudo observar anoche el paso de un aerolito, que iluminó la bóveda celeste, ocasionando alarma entre los campesinos.

La Discusión, 5 de abril de 1907.

Figure 3 – Fireball in the Cuban sky, printed in a newspaper from April 1907 (Photo: L.E. Ramos-Guadalupe).

Consolación del Sur, 2010

On June 7, 2010, 03^h40^m UTC, a striking fireball was observed from Consolación del Sur (Pinar del Río province), but no meteorite was located. Peláez (2010) reported this rare event in the press and cited Efrén Jaimez-Salgado as a witness, saying that a huge and bright bolide crossed from north to south the sky of Pueblo Nuevo, near Consolación del Sur and could have fallen somewhere south of the town of Alonso de Rojas, or at sea, in waters of the Gulf of Batabanó. He also indicated that the object, apparently quite large, was leaving behind a huge bright greenish-white trail and a detonation was heard a few seconds later.

Calimete, 2013

An unidentified light phenomenon crossed the sky of Calimete (Matanzas province) at 1^h30^m UTC on February 5, 2013, and was sighted by dozens of residents of the town (Solís-Díaz, 2013). Eyewitnesses described the event as a reddish light source descending at high speed, crossing over the town from the northeast, and then in a descent in which it disappeared, caused a sound like an explosion. The locality of the alleged crashing could be a site near the contiguous town of Los Arabos; an area with unfavorable terrain conditions for recovery due to sugar cane plantations. Meteorites were not found.

Rodas, 2013

On February 14, 2013, a bright bolide was reported from several communities in Rodas, Cienfuegos province, central Cuba (Ceballos-Izquierdo, 2019). Local researcher Marcos Rodríguez-Matamoros described the event as a small bolide, without being able to verify a meteorite landfall with the collection of any fragment. According to Lobanovsky (2014), the bolide explosion occurred at a height of 18 – 21 km. Testimonies agreed that there was a very intense light that reached the size of a bus and exploded, and windows and walls shook following the explosion. According to the latter information, this was probably the first Cuban bolide that generated a seismological signature, but those records are not available.

Holguín, 2021

Recently, a rare event aroused attention when the National Seismological Service of Cuba reported in a note that, on the night of March 19, 2021, at 03^h06^m UTC, their stations in Oriente had registered vibrations that did not correspond with an earthquake (Iturralde-Vinent and Arango-Arias, 2021). Coinciding with the time of the anomaly, a natural phenomenon was observed in the eastern provinces of the island. The following day, the online fireball event database of the AMS recorded the event as 1755-2021, for a fireball sighted by various observers who reported it to this international platform, including witnesses from Jamaica and the west coast of Florida (USA). Based on a video recorded in Kingston (Jamaica) and the GLM / GOES-16 data, the space rock reached the Earth’s atmosphere at an angle of 42.7° relative to the ground and a speed of ~50000 km/h (Ceballos-Izquierdo et al., 2021a). The meteor appeared at an altitude of approximately 65.5 km between the town of La Maya and Los Reynaldos and continued for 3.7 seconds in a northerly direction until it disappeared at an altitude of 30.4 km, northeast of La Deseada (Ceballos-Izquierdo et al., 2021b). No meteorites from this bolide have been found thus far.

3 Jamaica events

Except for the Cuban bolide of March 19, 2021 which was also recorded from Kingston, there is not much footage material of meteors and fireballs sighted from Jamaica. However, there is remarkable historical information, including probably the oldest meteor documented for the Caribbean.

Jamaica, 1700 (?)

Barham (1717) noticed a large meteor landing at St. Jago de la Vega, Jamaica, about the year 1700. The publication referred to many deep holes in the ground, but no meteorites were found. This information is also listed in the catalog of Greg (1861).

Kingston, 1812

According to Darwin (1840) “At Kingston, in Jamaica, in November 1812, a large meteor appeared a few minutes previous to some alarming and tremendous concussions”.

Kingston, 1888

A very brilliant meteor was seen at Kingston, Jamaica, on the evening of November 10, 1888, at 0^h52^m local time (Hall, 1889). It appeared about 30° above the south-west horizon, crossed the heavens, and disappeared about 30° above the north-northeast horizon; and as Kingston is in lat. 18° N. The point of appearance was reported as the celestial coordinates R.A. 21^h24^m, N.P.D. 113°, and the point of disappearance R.A. 3^h45^m, N.P.D. 25° (Hall, 1889). According to eyewitness Mr. R. Johnstone cited by Hall (1889): “It was by far the brightest meteor I have ever seen, and it so lit up the sky as to cause consternation among many of the population. Exactly four minutes afterwards, I heard a sound as of a distant explosion, which was not quite so loud as the 9 o’clock gun at Port Royal, heard in due time about four minutes later. The sound was heard by other people in Kingston”.

4 Dominican Republic events

Several events are recorded for the Dominican Republic in the online fireball event database of the AMS (Event 3187-2019, 4892-2018, 3248-2018, 1243-2018, 656-2018, 754-2017, 4226-2015, 3702-2015, 2830-2015, 472-2014, 232-2013, 1479-2011, 1311-2011, 336-2011) but they are related to one or very few observers.

Confused reports of falling objects are disseminated on social networks also, but many of them are sunlit aircraft contrails[35], and rocket launches from Cape Coral like some

[35] https://bit.ly/3FeWycg, https://bit.ly/3FdH4Wb, https://bit.ly/3zHI3ww

zig-zag trails observed in western Cuba and explained by Ceballos-Izquierdo (2021). A luminous slow-moving phenomenon was seen from the Dominican Republic and Puerto Rico, crossing the whole sky, on January 21, 2020, and described on social networks as a meteorite that would have made landfall. However, it was likely a re-entry related to a rocket that China launched into space in 2017. We present a few interesting examples of meteors and fireballs from the Dominican Republic.

Santo Domingo, 2013

On August 05, 2013, a small meteor entering the Earth's atmosphere was recorded at J. F. Kennedy Ave before reaching the intersection with the A. Lincoln corner, Santo Domingo (coordinates: 18.4843°, –69.9387°). The meteor darted across the sky around 03^h35^m UTC, startling drivers who were lucky to have caught the ball of fire descending at a high rate of speed on their cameras.

Figure 4 – Meteor seen from Las Carreras, Bani, Dominican Republic, February 12, 2018 at 5^h01^m UTC (Photo: M.E.G.).

La Romana, 2020

On February 21, 2020, a small bolide blows up over the Caribbean after entering Earth's atmosphere. Preliminary GLM / GOES-16 satellite images suggest that it exploded over the southeast of the Dominican Republic, near La Romana at 07^h30^m UTC (*Figure 6*). Cameras operated by the SAC in Puerto Rico, and hurricane Nest cams in St. John (US Virgin Islands) also captured the event (*Figure 5*). Curiously it was the second meteor sighted from Puerto Rico during the same early morning hours in which another bright meteor was observed at around 6^h57^m UTC in an easterly direction, traveling with a north-south trajectory.

One of us (FL) recorded the fireball from Cabo Rojo, Puerto Rico. Based on the video taken from Cabo Rojo, the bolide certainly appears to have passed directly over the island heading in a West/South West direction. Actually, the GLM location data is affixed to an altitude conducive to cloud tops for lightning detection and the "grid" overlay of the Earth for that varies from around 7 km at nadir, to 14 km out on the edge of the FOV of the sensor. The bolide would have to have detonated somewhere close to a 14 km altitude for that location to be correct. So, if the bolide exploded at 14 km, it's possible there was a fall on land, but based on the GLM location, the ballistic trajectory would likely place the fall in the water. The GLM-16 Pixel Centroid Location is Latitude: 18.6°, Longitude: –68.9° at an altitude of 14 km placing the subpoint of the bolide detonation over water, if 14 km is the correct altitude (*Figure 7*). The Azimuth and Elevation from the 14 km location to the GLM-16 sensor is -198.336° and 68.021°, respectively. However, if say 28 km in altitude was a more reasonable altitude for the bolide detonation, it would be completely over water a good distance South from the Dominican Republic. Anyway, the very rudimentary ground track from the GLM latitude and longitude values, suggest that it's definitely traveling from northeast to southwest. We think that it has likely landed in the water, since the last of the flashes registering on the GLM places it off the coast. But there is wide room for error, as ±5 km error is map projection error for the GLM data (Jenniskens, 2018), so we can't completely rule out fragments on land.

Figure 5 – Bolide seen from St John (US Virgin Islands) on February 21, 2020 (Photo: Mark Sudduth).

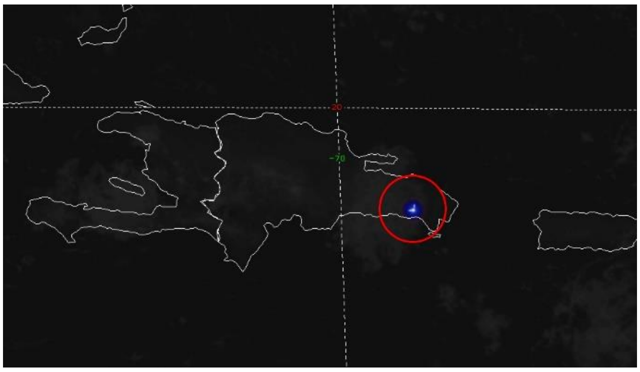


Figure 6 – Dominican Republic bolide of February 21, 2020 as captured by the GLM.

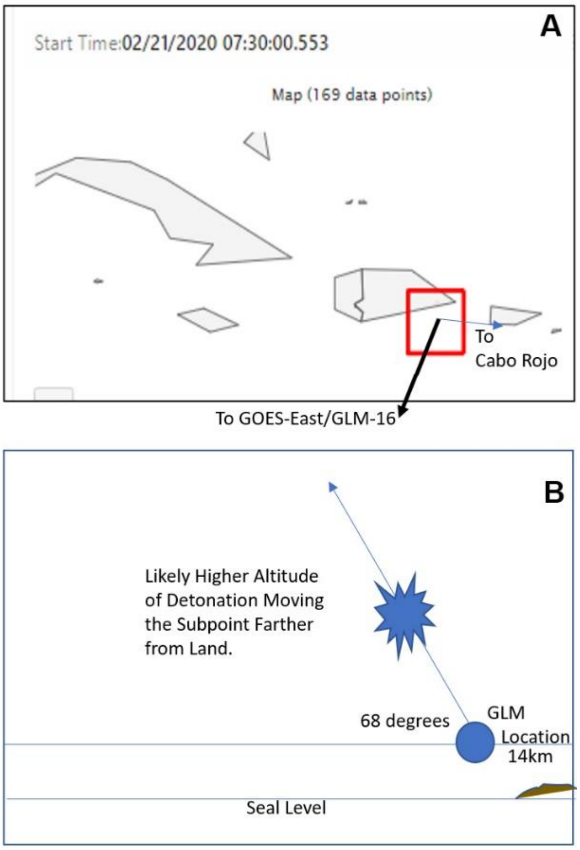


Figure 7 – A) GLM Pixel Centroid Location for the Dominican Republic bolide of February 21, 2020. B). Interpretation of the subpoint of the bolide detonation relative to the altitude.

Unfortunately, an astrometric calibration could not be performed on the two other videos (St. John and Fish Bay) because no positively identifiable stars could be extracted from background noise. Therefore, we cannot produce a precise trajectory of the fireball, because we cannot extract positional data from the videos. Light curve with calculated absolute magnitude vs. time, as done in the same fashion as Sankar et al. (2020) and Hughes et al. (2022) is presented in *Figure 8*. Temporal extent of the flash reading from GLM is 0.586 seconds. Max apparent magnitude is approximately –19, assuming a 6000K blackbody spectrum. Even this is variable depending on the temperature of the fireball, which can range from approximately 4000K (Borovička and Charvát, 2009) to 6000K (Brown et al., 2013). The estimated energy is about 14 Tons of TNT, following Brown et al. (2002) empirical relationship between luminous energy and total energy. Mass cannot be determined since we don't have a lock on the velocity.

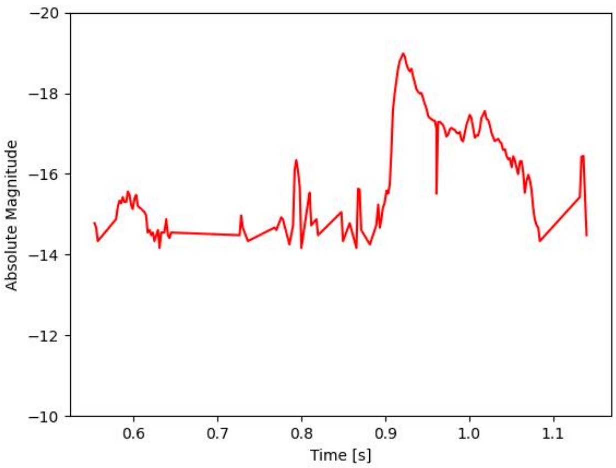


Figure 8 – Light curve with calculated absolute magnitude vs. time. Dominican Republic bolide of February 21, 2020.

Santo Domingo, 2020

A fireball was seen over Dominican Republic on May 2, 2020. The observed duration and speed, and the appearance in the available video are all consistent with a bright meteor. Sightings were reported in San Francisco de Macoris, Jarabacoa, Altagracia, Junumucú, Higüey and Santo Domingo.

5 Puerto Rico Events

In contrast to other territories of the Caribbean, Puerto Rico has a large visual record of meteors and bolides, offering a good opportunity to undertake future studies on these events (e.g. *Figures 14–31*). In addition to various amateur observers, a very nice initiative is the Puerto Rico Night Sky Network, which include eight Allsky cameras from different places on the island. The website[36] is maintained by Héctor Santini, an astrophotographer from the SAC, and display live images from the different stations and time lapse videos recorded from the night before.

For space reasons, this work only presents a brief description of the most notable meteors, the others that have an online record are listed in *Table 1*.

[36] https://bit.ly/3gCRMM7

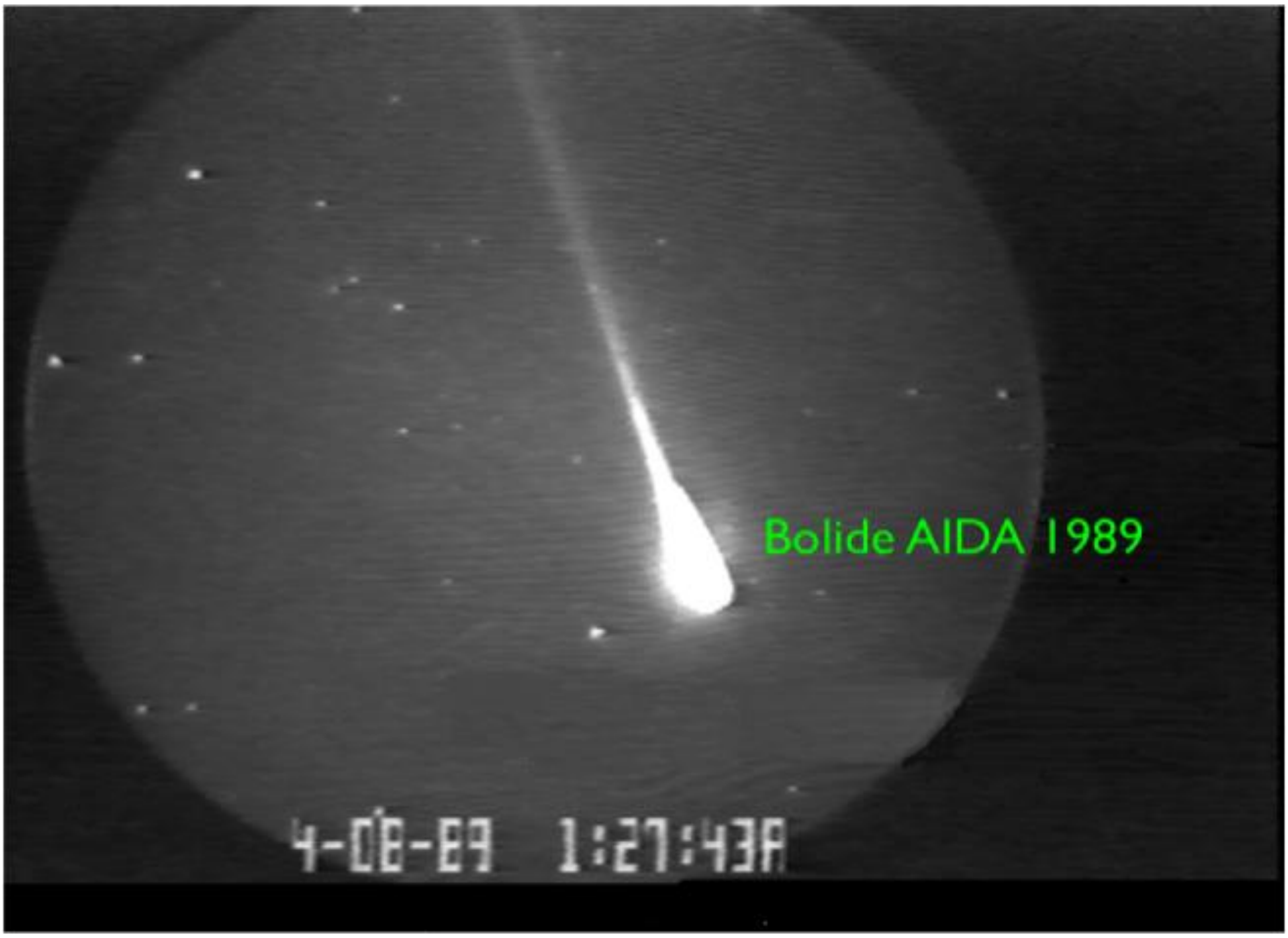


Figure 9 – Bolide AIDA captured from Arecibo Observatory (Puerto Rico) on April 8, 1989 at 05^h26^m UT (Photo: David Meisel).

Figure 10 – Huge meteor fireball flashing across the sky of Puerto Rico on January 17, 2020. Residents reported loud noise associated with the event.

Bolide AIDA, 1989

On April 8, 1989 at 05^h26^m UT, an aubritic composition meteoroid (~25 kg initial mass) produced a very bright (–10 visual magnitude) slow moving bolide (4-sec duration) which was observed from three locations in Puerto Rico (*Figure 9*).

Information was obtained with seven different instruments. Preliminary calculations indicate that the bolide entered the atmosphere on a steep trajectory, about 32° from vertical, and was luminous from 65 km altitude at 15.0 km/s velocity down to 25.6 km altitude and 1–2 km/s velocity. The date of occurrence and the apparent radiant (α = 190.8º; δ= –7.7°), and the orbit shows that the bolide probably belongs to the x-Virginid stream, which is connected with the Apollo Group asteroids (Getman et al., 1991; Meisel et al., 1995).

Towards the end of the observed trajectory, the bolide exploded into at least four large fragments, which were observed by the All-Sky camera and the video camera systems. Meteorites could be discovered in the jungles of the Arecibo River valley south of Arecibo.

2019 MO

A car-size asteroid exploded in the atmosphere over Caribbean waters 170 miles south of Puerto Rico, on June 22, 2019, near $21^h24^m45^s$ UTC. Weather satellite and radar captured the moment. Airwaves recorded by Bermuda infrasound station 2000 km north show periods which are consistent with a 5 kT bolide from a small multi-meter sized object NEA impact. UH's ATLAS and Pan-STARRS survey telescopes were able to identify 2019 MO on Saturday morning before it entered Earth's atmosphere, demonstrating that they can be used to provide advance warning for those that may be located at a possible impact site. The estimated path of 2019 MO was from east-to-west with an entry south of Puerto Rico, based on observations from the telescopes.

Following the impact of 2019 MO in the Earth's atmosphere, radar record signatures of falling meteorites were reported in data from the NEXRAD weather radar network operated by NOAA, the TJUA (San Juan, Puerto Rico) (Matlovič et al., 2020). The first appearance of falling meteorites on radar occurred at $21^h26^m15^s$ UTC and 10.6 km above sea level. Signatures consistent with falling meteorites appear in a total of four radar sweeps. It was estimated that all meteorites from this event ended up on the seafloor at a depth of approximately 4.8 km. Meteorite falls with enough mass to generate green pixels on weather radar are rare.

This event is not recorded by the AMS as there are no direct eyewitness reports. However, the bolide was detected by the GLM instrument on the GOES 16 weather satellite. US Department of Defense satellites also report the event[37] and calculate a total power of 6 kTons of TNT equivalent. A global infrasound network operated by the Preparatory Committee for the Comprehensive Nuclear Test Ban Treaty (CNTBT) also recorded this bolide and reports a total power of 5 kTons of TNT equivalent. Furthermore, the estimated size of 2019 MO was around 5 meters with a mass of about 200 T. This event is the third most powerful bolide recorded in the Caribbean and in the vicinity of North America since the US government sensors began reporting bolides in 1988.

Matlovič et al. (2020) suggest that the impact of the small asteroid 2019 MO, on June 22 near Puerto Rico, was not connected to the activity of the June epsilon Ophiuchids outburst.

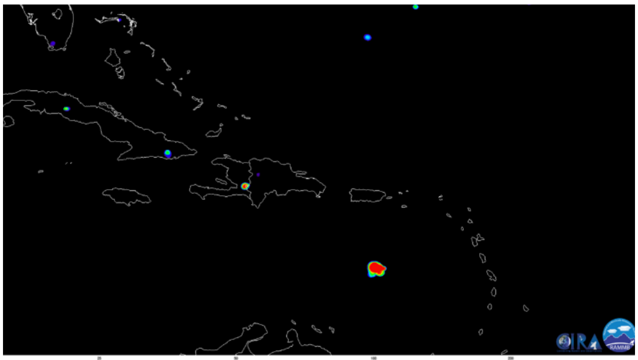


Figure 11 – NOAA satellite captured a multi-kiloton meteor explosion (2019 MO) just below Puerto Rico (Image: NOAA).

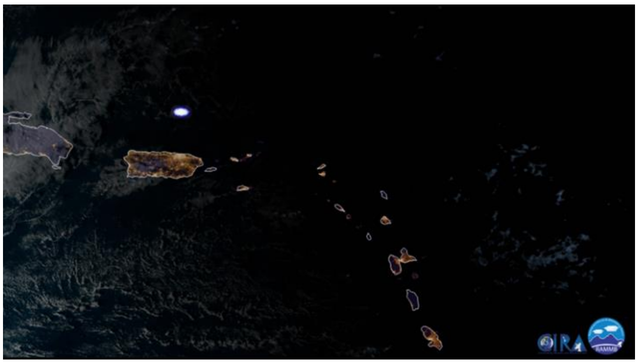


Figure 12 – Meteor flash just north of Puerto Rico at around 21^h30^m UTC on January 17, 2020 (Image: NOAA).

Caguas, 2020

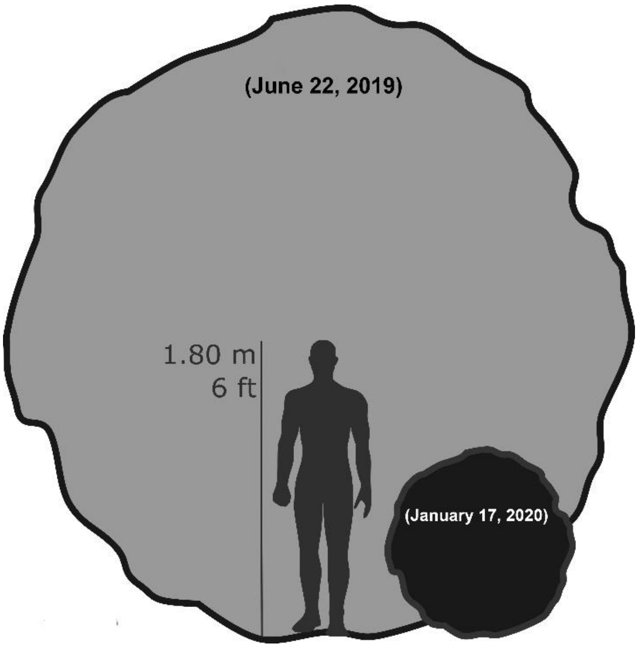


Figure 13 – Size comparison of the 2019 MO, the January 17, 2020 meteoroid and a human (Modified from imo.net).

[37] https://cneos.jpl.nasa.gov/fireballs/

A small asteroid entered the atmosphere just north of Puerto Rico at around 21^{h}30^m UTC on Friday January 17, 2020, which allowed many to witness this impressive daytime fireball from a large part of the island. Shortly after, users began posting video and images to social media sites and many reported to also hear a loud boom. A stele remained visible for several seconds, up to three minutes, some eyewitness reported. The AMS online fireball event database recorded the event as Event #2020-338 and counted 33 witness reports so far with the most distant coming from Anguilla.

The entrance of this large space rock into the atmosphere was detected by the NOAA weather satellites and infrasound stations in the Bermuda Islands, and the data collected indicates it was a small asteroid that was moving at a speed of 34673 miles per hour (55800 km/h) or about 15.5 km/s. The fireball was also detected with US government sensors, which published an entry time of 21^{h}29^{m}49^s UT, coordinates 19.4° N, 66.0° W, and an energy of the entering object of 0.29 kt TNT.

Figure 14 – Blazing meteor seen from Caguas (Puerto Rico) on January 17, 2020 (Photo: Rafael Emmanuelli Jiménez).

26 April, 2020

A bright fireball exploded over the Eastern Caribbean at around 00^{h}40^m UTC on April 27, 2020 lighting up the night skies between Martinique, Guadeloupe, Saint Martin, Saint Barthelemy, Gustavia, and Puerto Rico. The AMS online fireball event database received seven reports of the event, mainly from witnesses in Grande-Terre, Saint John, and Saint Thomas. The observers' description of the fireball's color varied, with some saying it looked purple and light blue, orange and yellow, or light green. One viewer mentioned that the object had a glowing orange train of debris and a green flash that lit up the sky very brightly. According to one report in Guadeloupe, the fireball was seen with a "big red trail with a very bright white ball ahead". Meanwhile, an observer in Antigua and Barbuda claimed that other people also witnessed the fireball in Saint Kitts and Florida. "No tail or fragmentation is seen-- just a super-bright flash that lit up the entire sky in every direction" he added.

Puerto Rico, 7 May 2021

A huge meteor was visible from Puerto Rico, the Dominican Republic, and Cuba around 0^{h}02^m ^{UTC}, May 7, 2021. Observers who were able to appreciate the event described it as a "huge greenish ball, with a long tail." Although it was visible looking towards the northwest, the trajectory of the meteor was from the North of the island descending towards the West, over the sea, as suggested by the SAC.

Figure 15 – Meteor streaks across Gurabo (Puerto Rico) on May 7, 2021 (Photo: Trinidad & Tobago Weather Center).

6 Conclusions

There are many cameras in Europe and the US but not too many in the Caribbean, even so there is a very rich historical record of meteors in the area that deserves more attention. Apparently, the territory with the scarcest record is Haiti, with only one entry of a fireball recorded in CNEOS, but no other record of casual footage from any observer could be located. Ceballos-Izquierdo et al. (2021a) proposed the need of an implementation of a meteor observation network for monitoring the sky in Cuba, but this is something that should be extended to other Caribbean islands to improve the fireball record, taking advantage of the potential offered by the cameras installed in Puerto Rico. Such initiatives could be integrated in the future with the Global Meteor Network[38] that currently does not have cameras in the Caribbean. Until then, we intend that this compilation serve as exploratory research for future work.

[38] https://globalmeteornetwork.org/

Figure 16 – Bright fireball captured on May 25, 2016 at 4^h35^m UTC. Taken in Cabo Rojo (Puerto Rico) (Photo: F.L.).

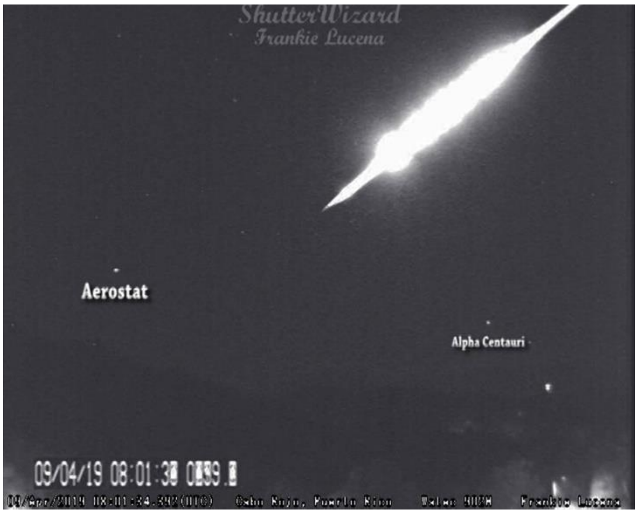


Figure 17 – Huge fireball captured on April 9, 2019 at 8^h01^m UTC facing south from Cabo Rojo (Puerto Rico) (Photo: F.L.).

Figure 18 – Perseid meteors and a fireball on August 11, 2019. Taken in Cabo Rojo (Puerto Rico) (Photo: F.L.).

Figure 19 – Meteor captured on September 11, 2020 at 2^h28^m UTC facing northwest from Cabo Rojo (Photo: F.L.).

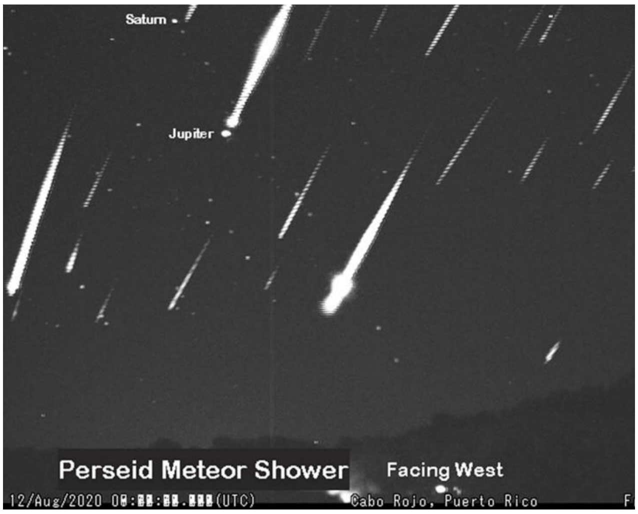


Figure 20 – Perseid meteor shower on August 12, 2020. Taken in Cabo Rojo (Puerto Rico) (Photo: F.L.).

Figure 21 – Taurid fireball lights up the night sky on November 13, 2020. Taken in Cabo Rojo (Puerto Rico) (Photo: F.L.).

Figure 22 – Sporadic meteor photographed on December 30, 2016 at 3^h15^m UTC Cabo Rojo (Puerto Rico) (Photo: F.L.).

Figure 23 – Colorful meteor taken during the Perseid meteor shower on August 12, 2017 at 7^h34^m (Photo: F.L.).

Figure 24 – Green meteor recorded on January 6, 2022 at 4^h28^m UTC in Cabo Rojo, Puerto Rico (Photo: F.L.).

Figure 25 – Meteor detected in Yauco, Puerto Rico, on July 01, 2020, at 2^h05^m UTC (Photo: Rafael Emmanuelli Jiménez).

Figure 26 – Meteor detected in Yauco, Puerto Rico, on August 18, 2020, at 8^h54^m UTC (Photo: Rafael Emmanuelli Jiménez).

Figure 27 – Meteor detected in Yauco, Puerto Rico, on October 19, 2020, at 2^h53^m UTC (Photo: Rafael Emmanuelli Jiménez).

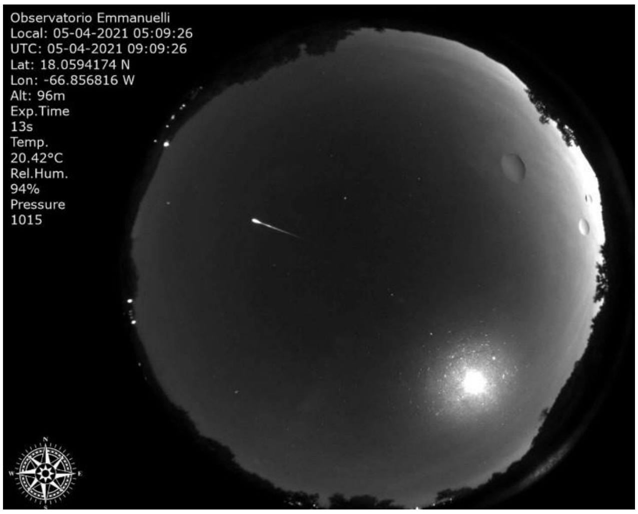


Figure 28 – Meteor detected in Yauco, Puerto Rico, on May 4, 2021, at 9^{h}09^m UTC (Photo: Rafael Emmanuelli Jiménez).

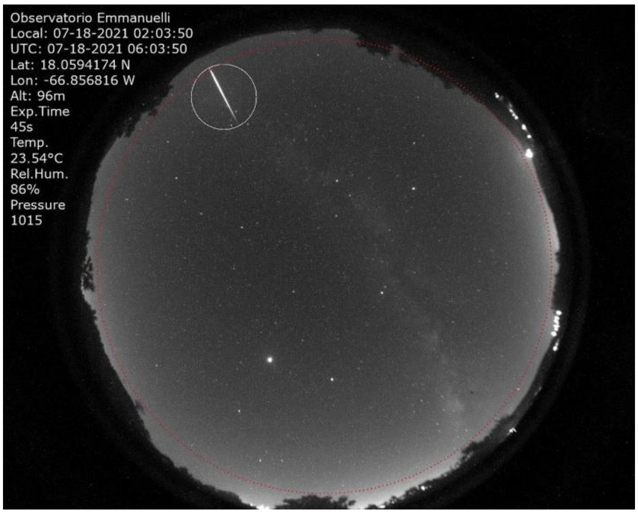


Figure 29 – Meteor detected in Yauco, Puerto Rico, on July 18, 2021, at 6^{h}03^m UTC (Photo: Rafael Emmanuelli Jiménez).

Figure 30 – Meteor detected in Yauco, Puerto Rico, on August 17, 2021, at 2^{h}05^m UTC (Photo: Rafael Emmanuelli Jiménez).

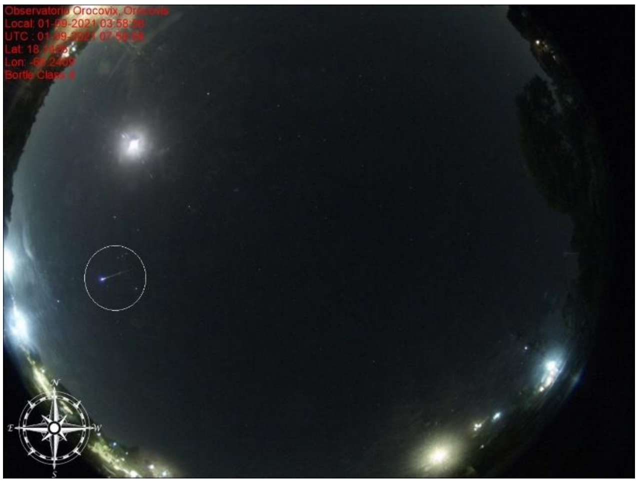


Figure 31 – Meteor detected in Orocovis, Puerto Rico, on September 1, 2021 at 7^{h}58^m UTC. (Photo: Orocovix Observatory).

Table 1 – Compilation of Caribbean meteor and bolides. Abbreviations: AO–Arecibo Observatory, CNEOS–Center for NEO Studies, GLM–Geostationary Lightning Mapper, FL–Frankie Lucena, SAC–Caribbean Astronomical Society.

#	Day	M	Year	UTC	Dur.	Location	Source	Comments	Online Footage
1	5	4	1989	0526	4s	Puerto Rico	AO	bolide AIDA	https://bit.ly/3oG2Oof
2	14	12	2011	0413		Puerto Rico	SAC	Geminid	https://bit.ly/3qw2Wqe
3	4	1	2012	0708		Puerto Rico	SAC	Quadrantid	https://bit.ly/3HdRPJj
4	15	2	2012	0140		W and SW of PR	SAC	slow bright meteor	https://bit.ly/3EAkF4W
5	10	3	2012	0900	10s	Puerto Rico	SAC	bolide over PR	https://bit.ly/32zBGPw
6	11	4	2012	0622		Puerto Rico	SAC	bolide over PR	https://bit.ly/3HcLbTO
7	21	4	2012	0357		Puerto Rico	SAC	Lyrid meteors	https://bit.ly/32rtyAV
8	2	5	2012	0111		Puerto Rico	SAC	meteor behind the clouds	https://bit.ly/32tZK6K
9	10	8	2012	0136	14s	Rincón, PR	SAC	slow meteor	https://bit.ly/3pvn90f
10	11	8	2012	0336		Puerto Rico	SAC	Perseids	https://bit.ly/3yZIOAV
11	2	11	2012	0025	3s	Puerto Rico	SAC	meteors	https://bit.ly/3mDnGLH
12	4	11	2012	0351	2s	Puerto Rico	SAC	meteors	https://bit.ly/3mDnGLH
13	5	11	2012	0755		Puerto Rico	SAC	meteors	https://bit.ly/3mDnGLH
14	17	11	2012	0729		Puerto Rico	SAC	Leonid meteors	https://bit.ly/3mBnjRV
15	13	12	2012	0525		Puerto Rico	SAC	Geminid meteors	https://bit.ly/3eu4Z8U
16	3	1	2013	0740		Puerto Rico	SAC	Quadrantid meteors	https://bit.ly/3Er4M0R

#	Day	M	Year	UTC	Dur.	Location	Source	Comments	Online Footage
17	14	2	2013	?		Rodas, Cuba	?	bright meteor	https://bit.ly/3rENY3c
18	5	3	2013	0240	4s	Puerto Rico	SAC	bright meteor	https://bit.ly/3Ha2zZg
19	22	4	2013	0915		Puerto Rico	SAC	Lyrid	https://bit.ly/311qUkC
20	6	5	2013	0824		Puerto Rico	SAC	Eta-Aquariid	https://bit.ly/3Ez6I7r
21	21	7	2013	0548		Puerto Rico	SAC	bright meteor	https://bit.ly/32CA0VA
22	1	8	2013	0423		Puerto Rico	SAC	Perseid	https://bit.ly/3pvFIBp
23	5	8	2013			Dominican Republic	?	meteor	https://bit.ly/3oG3ZEb
24	5	8	2013	0455	2s	Puerto Rico	SAC	Perseid	https://bit.ly/3Ev3DW4
25	7	8	2013	0858	1s	Puerto Rico	SAC	Perseid	https://bit.ly/3Ev3DW4
26	12	8	2013	0444	4s	Puerto Rico	SAC	Perseid	https://bit.ly/3Ev3DW4
27	13	8	2013	0754		Puerto Rico	SAC	Perseid	https://bit.ly/3Ev3DW4
28	18	1	2014	0943	5s	San Juan, Arecibo, Ponce y Aguadilla, PR	SAC	bright meteor	https://bit.ly/3z21wru
29	18	2	2014	1058		Puerto Rico	SAC	bright meteor	https://bit.ly/3qlWous
30	30	4	2014	0145		Puerto Rico	SAC	bright meteor	https://bit.ly/3Ey2n4z
31	23	5	2014	0635		Puerto Rico	SAC	Camelopardalid meteor	https://bit.ly/3FxLwjD
32	23	5	2014	0626		Puerto Rico	SAC	meteor	https://bit.ly/3EwCAJX
33	17	6	2014	0154		Puerto Rico	SAC	meteor	https://bit.ly/3JeNbN4
34	13	7	2014	0210	4s	Puerto Rico	SAC	Slow bright meteor	https://bit.ly/3ptwgP6
35	18	7	2014	0307	3s	Puerto Rico	SAC	bright meteor	https://bit.ly/311rKxM
36	28	7	2014	0827		Puerto Rico	SAC	Perseid	https://bit.ly/3JeNhEq
37	7	8	2014	0711		Puerto Rico	SAC	Perseid	https://bit.ly/3Jm3fgg
38	13	8	2014	0456		Puerto Rico	SAC	Perseid	https://bit.ly/312JOaV
39	19	8	2014	0440		Puerto Rico	SAC	meteor	https://bit.ly/3qqxYA1
40	22	10	2014	0549		Puerto Rico	SAC	Orionid	https://bit.ly/3qvHK3M
41	18	11	2014	0530		Puerto Rico	SAC	Leonid	https://bit.ly/3FwKK6n
42	13	12	2014	0540		Puerto Rico	SAC	Geminid	https://bit.ly/3qqho37
43	28	12	2014	0618	44s	Puerto Rico	SAC	slow meteor probably space trash	https://bit.ly/3mxyYRx
44	3	4	2015	2342		Camuy, PR	SAC	bright meteor	https://bit.ly/3HcEpxp
45	15	4	2015	0224		Puerto Rico	SAC	meteor	https://bit.ly/3qsdHKv
46	31	5	2015	0315		Puerto Rico	SAC	meteor with sonic boom	https://bit.ly/3mB0AFu
47	10	8	2015	0439		Puerto Rico	SAC	Perseid	https://bit.ly/3118mkr
48	13	8	2015	0631		Puerto Rico	SAC	Perseid	https://bit.ly/3z1gCO1
49	20	8	2015	0129	4s	Puerto Rico	SAC	bright meteor	https://bit.ly/3Er5Ku1
50	27	9	2015	0358	3s	Puerto Rico	SAC	bright meteor	https://bit.ly/32CAV8u
51	21	10	2015	0832		Puerto Rico	SAC	Orionid	https://bit.ly/3Hka5kx
52	12	11	2015	0134	6s	Puerto Rico	SAC	bright meteor	https://bit.ly/3mDXwZr
53	15	12	2015	0720		Puerto Rico	SAC	Geminid	https://bit.ly/3eqgVZc
54	25	5	2016	0435	3s	Cabo Rojo, PR	FL	Caribbean fireball	https://bit.ly/3szlOYl
55	2	6	2016	0003	5s	Cabo Rojo, PR	FL	Earth Grazing Fireball	https://bit.ly/3z3mEh8
56	2	6	2016	0106	1s	Puerto Rico	SAC	meteor	https://bit.ly/3mC9Nxs
57	13	7	2016	0006	4s	Cabo Rojo, PR	FL	audible meteor	https://bit.ly/3qwr63Y
58	26	7	2016	0109		Puerto Rico	SAC	green meteor	https://bit.ly/3pux2v6
59	26	7	2016	0249		Cabo Rojo, PR	FL	meteor explodes 3 times	https://bit.ly/3Ex8OET
60	12	8	2016	0603		Puerto Rico	SAC	Perseid	https://bit.ly/3EDzYtW
61	13	9	2016	2321		Puerto Rico	SAC	bright meteor	https://bit.ly/32zDNmq
62	11	10	2016	0930	6s	Puerto Rico	SAC	meteor	https://bit.ly/3HclC5e
63	1	12	2016	0402		Puerto Rico	SAC	meteor	https://bit.ly/3pwqvQM

#	Day	M	Year	UTC	Dur.	Location	Source	Comments	Online Footage
64	13	12	2016	0935		Puerto Rico	SAC	Geminid	https://bit.ly/3EJAlTP
65	14	12	2016	0636		Cabo Rojo, PR	FL	huge Geminid fireball	https://bit.ly/3Jk7VmB
66	12	1	2017	0911		Cabo Rojo, PR	FL	fireball explodes near Southern Cross	https://bit.ly/3evymrw
67	8	3	2017	0942		San Juan, PR	SAC	meteor	https://bit.ly/3EwgdEk
68	9	8	2017	0909		Cabo Rojo, PR	FL	Perseid fireball	https://bit.ly/3z11v7n
69	12	8	2017	0734		Cabo Rojo, PR	FL	Perseid fireball	https://bit.ly/3qwYk3p
70	25	12	2017	0932		Cabo Rojo, PR	FL	meteor	https://bit.ly/3JoE6S4
71	18	1	2018	0253	12s	Cabo Rojo, PR	FL	Rare Earth-grazer Meteor	https://bit.ly/3eroEWP
72	3	2	2018	0055		Cabo Rojo, PR	FL	Huge Meteor	https://bit.ly/3FzvSEk
73	1	5	2018	0508		Cabo Rojo, PR	FL	Fragmenting Meteor	https://bit.ly/3FyxUoh
74	29	8	2018	0630	3s	Cabo Rojo, PR	FL	Fireball	https://bit.ly/3euRLZy
75	29	8	2018	0634	3s	Cabo Rojo, PR	SAC	meteor	https://bit.ly/3FsX5Zf
76	3	11	2018	0334	3s	Cabo Rojo, PR	FL	large meteor	https://bit.ly/3ErRr8x
77	27	11	2018	0633	4s	Cabo Rojo, PR	FL	two fireballs	https://bit.ly/32p8Cuu
78	1	2	2019			Viñales, Cuba	public	meteorite fall	http://bit.ly/2UJ18c2
79	9	4	2019	0801	5s	Cabo Rojo, PR	FL	Huge Meteor	https://bit.ly/3FA9z1l
80	14	4	2019	?		west of Haiti	CNEOS	0.1 kt fireball	
81	22	6	2019	2125		south of PR	GLM	Asteroid 2019 MO	https://bit.ly/33Xg401
82	14	7	2019	0122	4s	Puerto Rico	SAC	bright fireball	https://bit.ly/3mBE53e
83	22	7	2019	0846		Cabo Rojo, PR	FL	Perseid	https://bit.ly/33RkiX0
84	5	8	2019	0935	2s	Cabo Rojo, PR	FL	early morning fireball	https://bit.ly/3HfRVQO
85	31	8	2019	0102		Cabo Rojo, PR	FL	meteor	https://bit.ly/3FMthXu
86	11	9	2019	0228	4s	Cabo Rojo, PR	FL	fireball over PR	https://bit.ly/3pyxvMZ
87	12	12	2019	0905	2s	Cabo Rojo, PR	FL	Geminid meteor near Lajas	https://bit.ly/32onqJT
88	13	12	2019	0504		Puerto Rico	SAC	Geminid	https://bit.ly/3z2NNRe
89	21	12	2019	0939	2s	Cabo Rojo, PR	FL	Geminid meteor near Lajas	https://bit.ly/3pwl2tc
90	22	12	2019	0520	2s	Cabo Rojo, PR	FL	Geminid meteor near Lajas	https://bit.ly/3mGn2gF
91	23	12	2019	0058	6s	Puerto Rico	SAC	bright green meteor	https://bit.ly/3H7g4Jk
92	12	1	2020	0831	4s	Cabo Rojo, PR	FL	slow moving fireball	https://bit.ly/3mEl8wN
93	17	1	2020	2130		Caguas, PR	SAC	very bright bolide	https://bit.ly/311nP3Y
94	21	2	2020	0657	3s	Puerto Rico	SAC	slow green meteor	https://bit.ly/3qmBlYI
95	21	2	2020	0731		Puerto Rico	SAC	bright meteor #2	https://bit.ly/3eq0vQG
96	21	2	2020	0730		Cabo Rojo, PR	FL	bolide west of PR	https://bit.ly/3mBEumc
97	26	2	2020	0331	5s	Cabo Rojo, PR	FL	fireball west of PR	https://bit.ly/3qoiRqM
98	15	4	2020	0416	2s	Cabo Rojo, PR	FL	meteor	https://bit.ly/3mD31HL
99	23	4	2020			Cabo Rojo, PR	FL	meteors	https://bit.ly/3z23b0k
100	26	4	2020	0039	2s	Puerto Rico	SAC	bright meteor	https://bit.ly/3qMlLWH
101	2	5	2020	?	5s	Dominican Republic	?	meteor	https://bit.ly/3GMujCA
102	15	5	2020	0428	3s	Cabo Rojo, PR	FL	fireball south of PR	https://bit.ly/3JlRlCR
103	16	6	2020	0440		Cabo Rojo, PR	FL	3 bright meteors	https://bit.ly/3FCnL9R
104	1	7	2020	0855	6s	Puerto Rico	SAC	bright meteor	https://bit.ly/33RNcq0
105	1	7	2020	0857	4s	Cabo Rojo, PR	FL	large fireball	https://bit.ly/3pARZ7y
106	31	7	2020	1148	4s	Puerto Rico	SAC	meteor	https://bit.ly/3px7mOH
107	12	8	2020			Cabo Rojo, PR	FL	Perseid meteors	https://bit.ly/3ExgeYz
108	13	8	2020	0803	1s	Puerto Rico	SAC	Perseid	https://bit.ly/3z0ZSX8
109	17	10	2020	0744	5s	Puerto Rico	SAC	very bright meteor	https://bit.ly/32GPuI8
110	21	10	2020	0322	3s	Cabo Rojo, PR	FL	Taurid fireball	https://bit.ly/3Hlpocq
111	17	11	2020	0615	4s	Puerto Rico	SAC	Leonid	https://bit.ly/3mBeWpy

#	Day	M	Year	UTC	Dur.	Location	Source	Comments	Online Footage
112	13	12	2020	0953	2s	Puerto Rico	SAC	Geminid	https://bit.ly/3qqixYF
113	15	12	2020		2s	Cabo Rojo, PR	FL	Geminid	https://bit.ly/3sDyVYo
114	11	1	2021	1108	4s	Puerto Rico	SAC	meteor	https://bit.ly/341LdQa
115	24	1	2021	0320	5s	Puerto Rico	SAC	bright meteor	https://bit.ly/313GcoZ
116	4	3	2021	0825	6s	Puerto Rico	SAC	meteor	https://bit.ly/3z37GYl
117	19	3	2021	0206	4.2s	Kingston, Jamaica	public	bright meteor	https://cutt.ly/jco8Nt7
118	21	4	2021	0254	3s	Cabo Rojo, PR	FL	meteor	https://bit.ly/32onysR
119	5	5	2021	0808	9s	Puerto Rico	SAC	meteor	https://bit.ly/346lE0t
120	7	5	2021			Gurabo, PR	public	meteor	https://bit.ly/3gHFOkb
121	19	5	2021	0218	5s	Puerto Rico	SAC	meteor	https://bit.ly/3JgxV2p
122	15	7	2021	0855	20s	Puerto Rico	SAC	slow meteor	https://bit.ly/3mBiOa1
123	28	7	2021	0908		Puerto Rico	SAC	meteors	https://bit.ly/33PKD7R
124	31	7	2021	0753	2s	Puerto Rico	SAC	meteor	https://bit.ly/3mBOJHm
125	8	8	2021	0139	2s	Cabo Rojo, PR	FL	bright meteor	https://bit.ly/32tSR5n
126	10	8	2021			Cabo Rojo, PR	FL	Perseid meteor	https://bit.ly/3JlJjdf
127	10	8	2021	0737		Puerto Rico	SAC	Perseid	https://bit.ly/3FKs8ja
128	13	8	2021	0824		Puerto Rico	SAC	Perseid	https://bit.ly/32DlOM2
129	17	8	2021	0205	4s	Puerto Rico	SAC	bright meteor	https://bit.ly/3JoVbvd
130	1	10	2021	0628	4s	Puerto Rico	SAC	South Taurid meteor	https://bit.ly/343sCDl
131	26	10	2021	0659	2s	Puerto Rico	SAC	Orionid meteor	https://bit.ly/3FDr9RZ
132	13	11	2021	0206		Puerto Rico	SAC	North Taurid meteor	https://bit.ly/3qxIqG5
133	23	11	2021	0901		Puerto Rico	SAC	meteor	https://bit.ly/3sD4ul3
134	19	11	2021	0900		Cabo Rojo, PR	FL	meteor	https://bit.ly/3Ez3gtw
135	19	11	2021	0508		Cabo Rojo, PR	FL	meteor	https://bit.ly/32wlOxA
136	14	12	2021	0730		Puerto Rico	SAC	Geminid	https://bit.ly/3HwtLBV
137	28	12	2021	0123		Cabo Rojo, PR	FL	meteor near Jupiter	https://bit.ly/3Hp0qcu
138	3-4	1	2022				SAC	Quadrantid meteors	https://bit.ly/3HMrzXl
139	6	1	2022	0428		Cabo Rojo, PR	FL	Green meteor	https://bit.ly/3sC7lcy

Acknowledgment

Luis E. Ramos Guadalupe is thanked for kindly provided historical newspapers of Cuban meteors. *David Meisel* provided literature and photos of bolide AIDA. *Mark Sudduth* and *Brent Lynn* kindly provided footage and information on the fireball of February 21, 2020, over the southeast of the Dominican Republic. *Rafael Emmanuelli Jiménez, Observatorio Orocovix,* and *Gastón Junca Vega* kindly provided original footage of meteors. Special thanks to *Paul Roggemans* for his help in the lay-out and the correction of this article.

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Radio observations in December 2021

Ivan Sergei

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

This article presents the results of radio observations made in December 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.

2 Automatic observations

Three intervals with increased Geminid (GEM, #0004) activity during the period of maximum activity were registered (*Figure 1*). The first, a brief peak on December 13 from 14h30m to 16h UT, the second from 21h UT on December 13 to 01h UT on December 14, and the third from 05h to 08h UT on December 14. These intervals are within the range of the predicted peak activity according to IMO data (Rendtel, 2021).

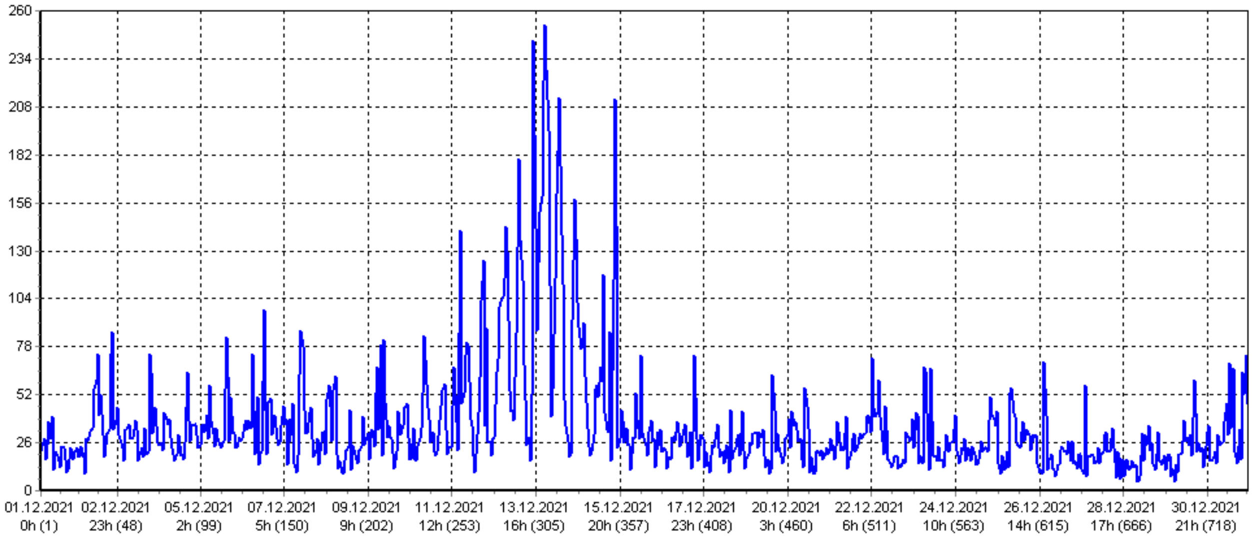

Figure 1 – Radio meteor echo counts recorded at 88.6 MHz during December 2021.

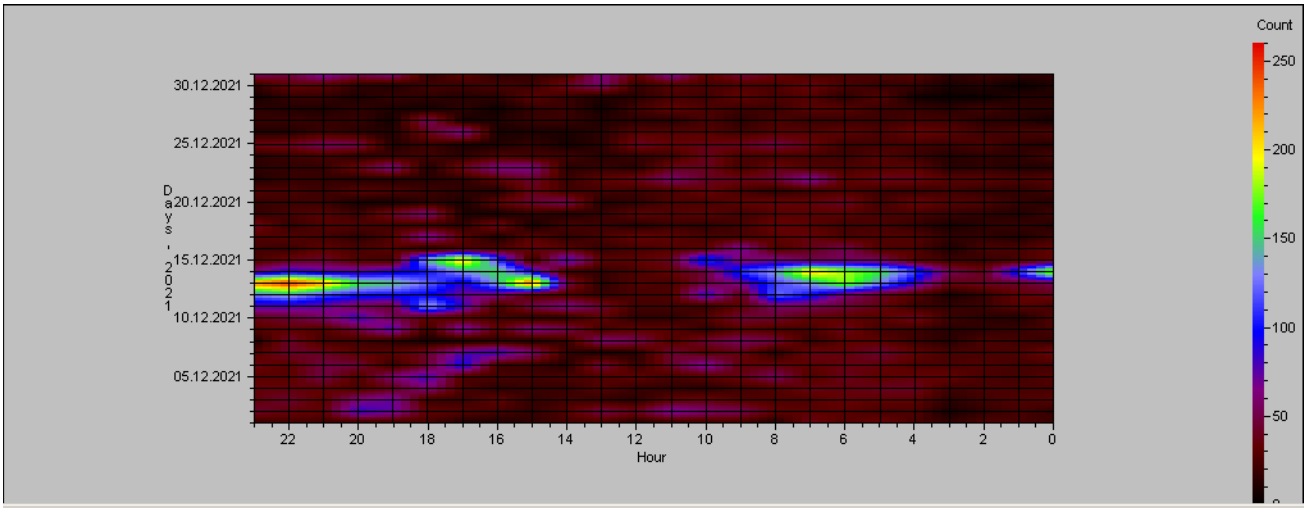

Figure 2 – Heatmap for radio meteor echo counts recorded at 88.6 MHz during December 2021.

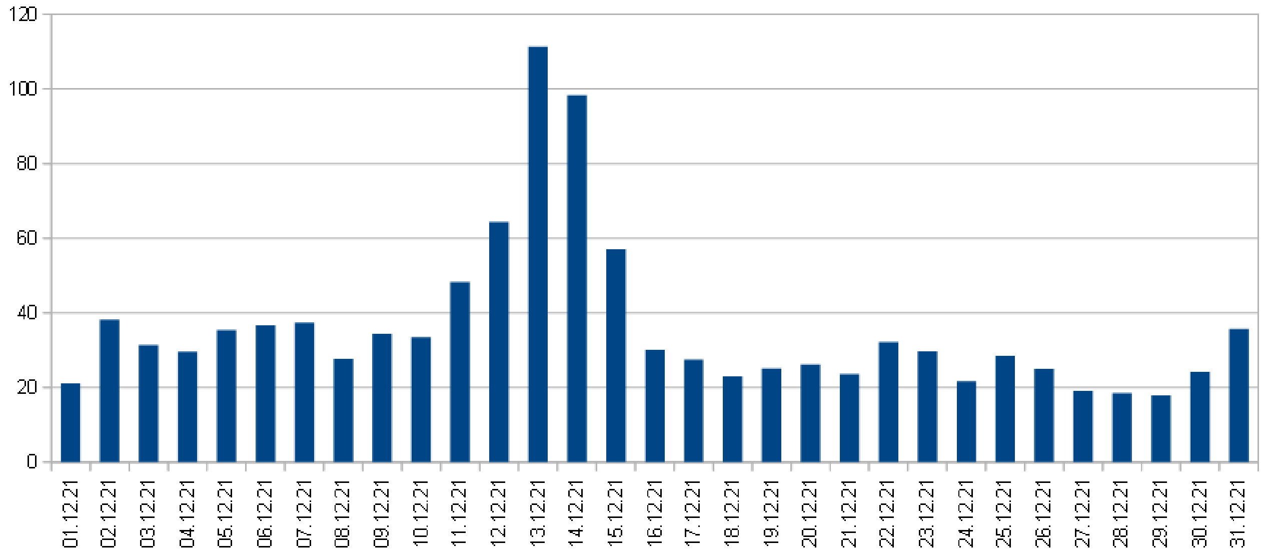

Figure 3 – Average hourly activity of meteor radio echo signals at 88.6 MHz in December 2021.

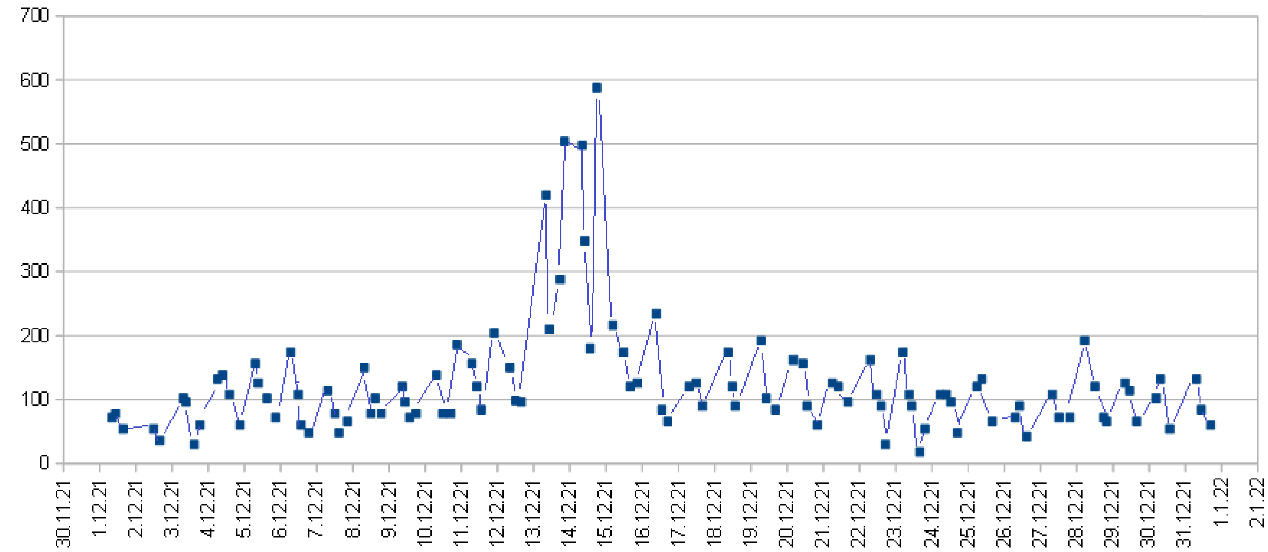

Figure 4 – The result with the calculated hourly numbers of meteor radio echoes by listening to the radio signals during December 2021.

The profile of the average hourly activity shows a weak peak on December 2 (*Figure 3*). It may belong to the peak activity of Phoenicid (#0254). A slight increase in activity on 6–7 December may be due to the maximum activity of Puppid-Velids (#0301). The maxima of the minor showers Monocerotids (MON, #0019) and sigma-Hyrids (HYD, #0016) are almost invisible in the activity profile and get lost within the sporadic background activity.

The minor shower maxima of Comae Berenicids (COM, #0020) on December 16 and December Leonis Minorids (DLM, #0032) on December 19 cannot be resolved on the profile of the average hourly rates. On December 22, there is a slight increase in the level of average hourly signal activity, which is probably due to the increased Ursid activity (URS, #0015). Also, there is an unidentified weak peak on December 31. For the identification of the peak on December 25, see CAMS data section.

3 Listening to radio echoes on 88.6 MHz

In order to save observation time and to increase the efficiency of listening to the radio meteor echoes in order to obtain a more complete observation series, I made a modification to the method with the introduction of a definition of "synthetic" hourly rate numbers (*Figure 4*).

Listening to the radio signals for 10 minutes with extrapolation of the data to 1 hour was done about 3 to 5 times a day. this was done in order to control the level of the hourly rates as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 110 synthetic hours.

The peak around December 6 can be explained by the Puppid_Velid (PUP, #0301) maximum. The maximum Geminid activity (GEM, #0004) was recorded on December

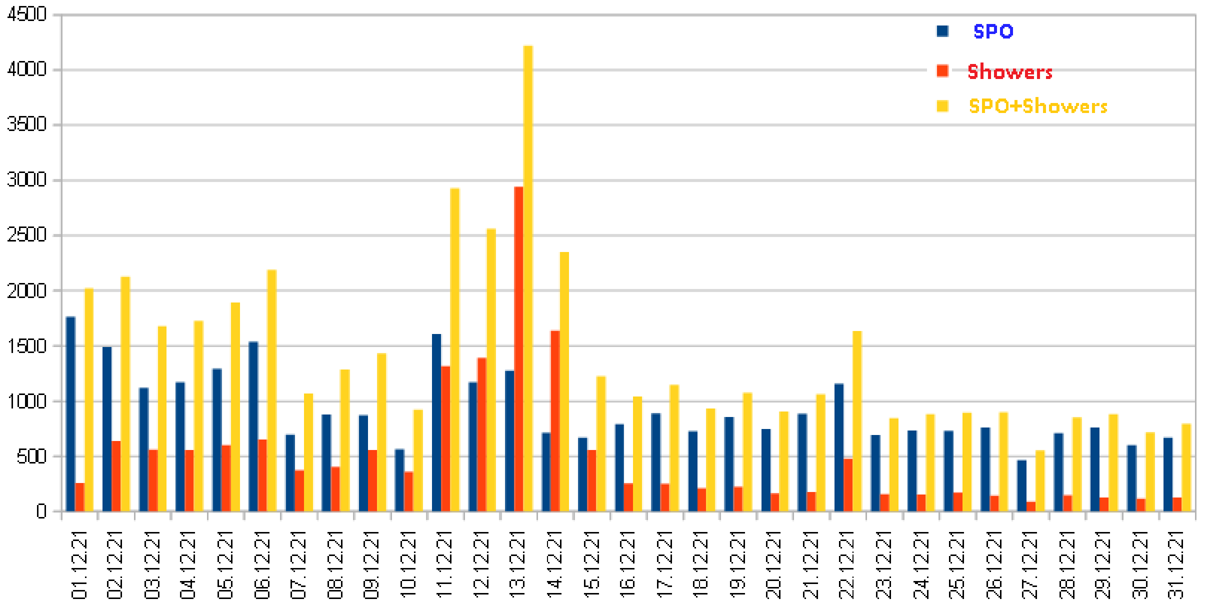

Figure 5 – Daily number of orbits recorded by CAMS video networks in December 2021, yellow bars are the total number of orbits.

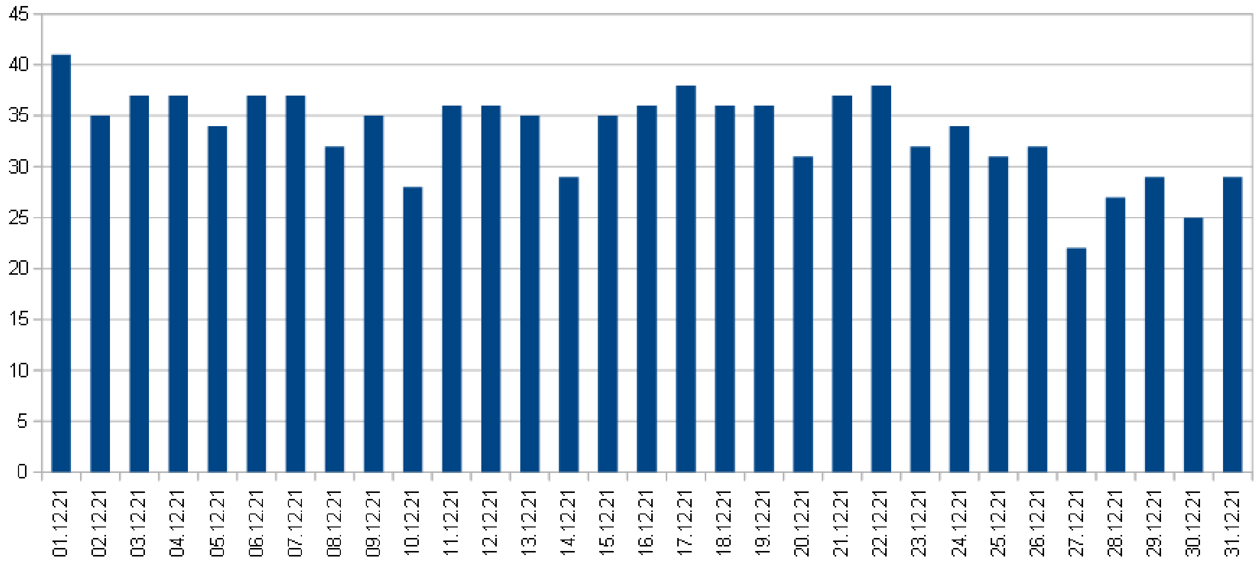

Figure 6 – Numbers of meteor showers detected by CAMS video networks in December 2021.

14–15 at 500–600 signals per hour. The Ursid (URS, #0015) maximum barely appears above the general sporadic background activity, indicating a very short peak activity, we could not locate the exact time of the peak activity). A very weak peak around December 19 may belong to the maximum of the December Leonis Minorids (DLM, #0032) meteor shower. For the identification of the peak on December 28, see CAMS data.

4 Preliminary CAMS Data

Figure 5 shows the total daily activity of meteor orbits obtained by the CAMS video networks data (Jenniskens et al., 2011). For December there is a noticeable correlation between the activity level of sporadic meteors and the activity level of shower meteors. I used the preliminary CAMS data as available on the website on January 3, 2022.In addition to the Geminid peak on December 13, video network data shows the following maxima in number of orbits with varying intensities: December 2, 6, 9, 22, 25, 28. A slight increase in Geminid activity is noticeable on December 2, as well as a nearly three-fold increase in December kappa Draconids (DKD, #0336) activity. On December 6, an increase in the activity of the number of detected showers was registered, as well as an increase in the activity of Geminids, Monocerotids, November Orionids (NOO, #0250). On December 9 the situation is similar to the previous peak, plus some increase in the activity of December alpha Draconids (DAD, #0334), Northern chi Orionids (ORN, #0256). On December 22, there was a burst of Ursid activity. On December 25, there was a noticeable increase in the activity of the December Leonis Minorids (DLM, #0032) and a number of minor showers. This peak is probably the same as the one detected by radio observations with automatic signal detection.

On December 28, there was an increase in Alfa Hydrids (AHY, #0331) activity and an increase in the number of detected showers. This peak corresponds probably to the one detected by radio observations using the method of radio echo.

5 Conclusion

The method of listening to the radio meteor echoes is about 3 times more sensitive than the method using automatic detection of meteor echo signals with music or speech. The maximum of the Geminids occurred on December 14–15, shifted by 1 to 2 days compared to the maximum according to the method of automatic detection and the orbit data obtained by CAMS video networks. This shift in the time of the maximum can be explained by the fact that the smaller and fainter particles cross the Earth 1 to 2 days later than the larger particles. Some dates of peak activity of minor showers or dates with increased numbers of detected shower radiants by CAMS video-networks are in close agreement with data obtained by radio-listening and automatic registration of meteor signals.

Acknowledgment

I would like to thank *Sergey Dubrovsky* for the software he developed for data analysis and 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.

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Radio observations in January 2022

Ivan Sergei

Mira Str.40-2, 222307, Molodechno, Belarus

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This article presents the results of radio observations made in January 2022. 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.

2 Automatic observations

The primary maximum of the Quadrantids (#0010) was recorded at the interval 12^h–14^h UT on 03 January 2022 (*Figure 1*). The secondary peak occurred at the interval 22^h–00^h UT on the night of January 3 to 4. This secondary peak coincides with that predicted by the IMO (Rendtel, 2021).

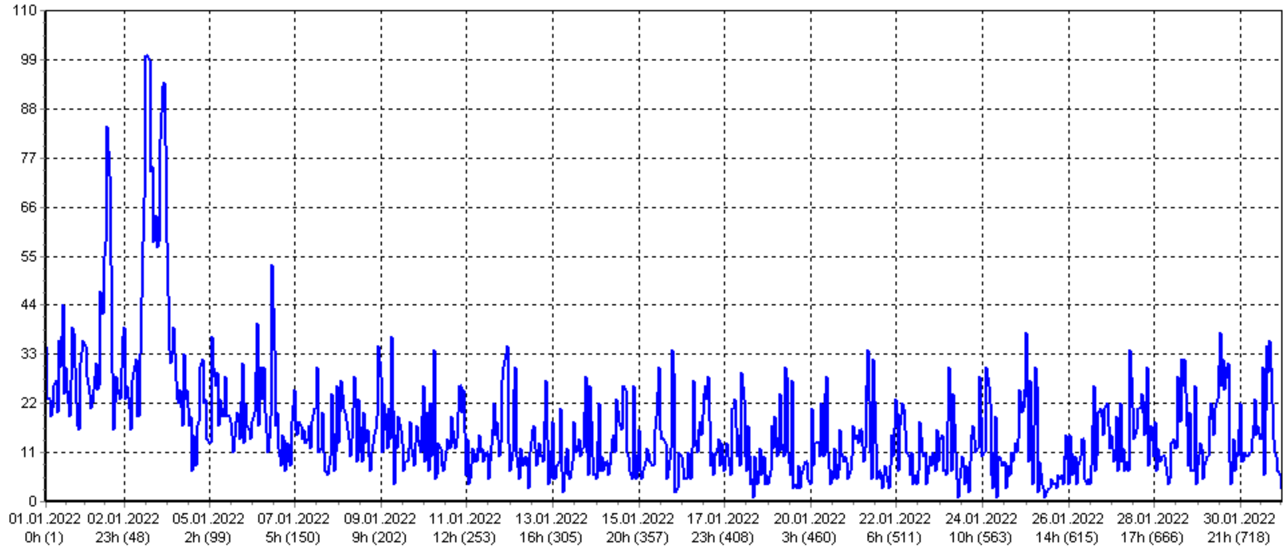

Figure 1 – Radio meteor echo counts recorded at 88.6 MHz during January 2022.

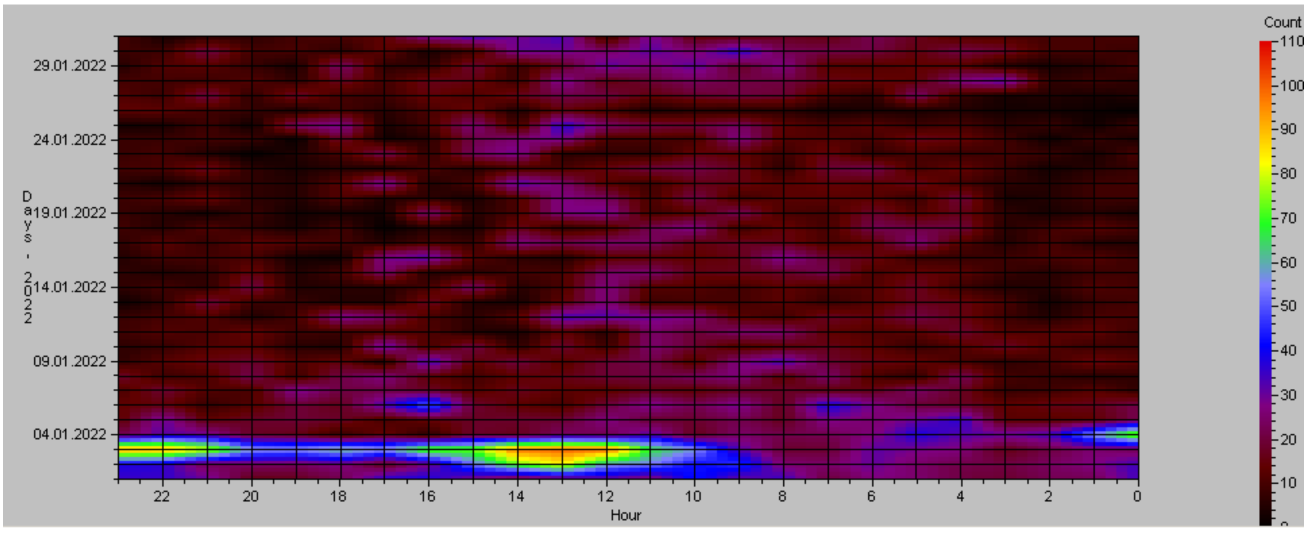

Figure 2 – Heatmap for radio meteor echo counts recorded at 88.6 MHz during January 2022.

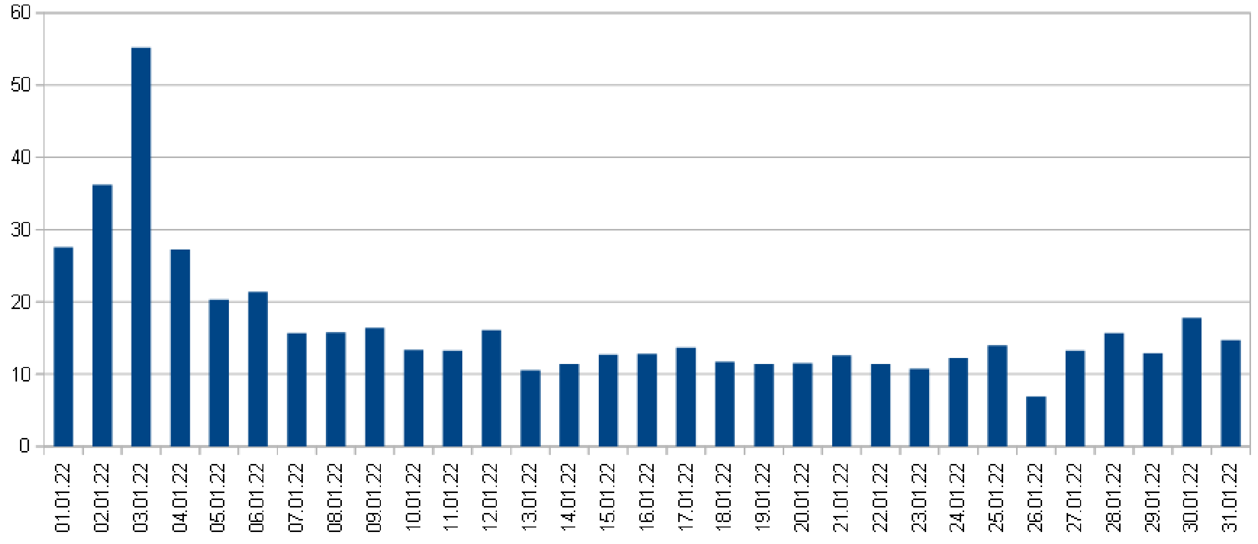

Figure 3 – Average hourly activity of meteor radio echo signals at 88.6 MHz in January 2022.

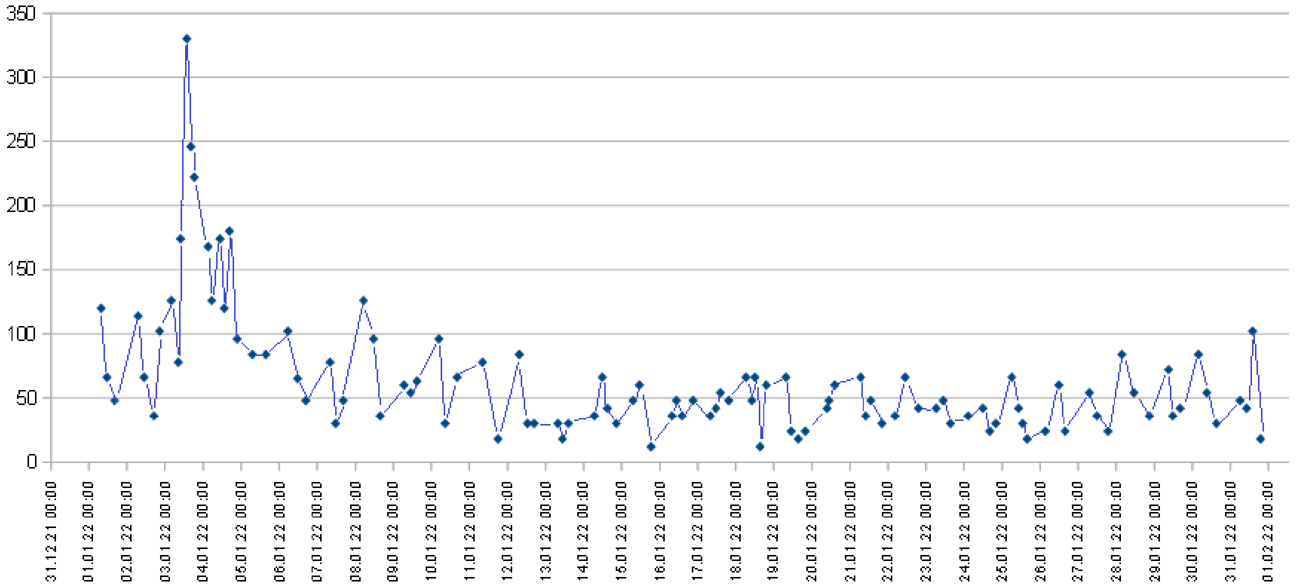

Figure 4 – The result with the calculated hourly numbers of meteor radio echoes by listening to the radio signals during January 2022.

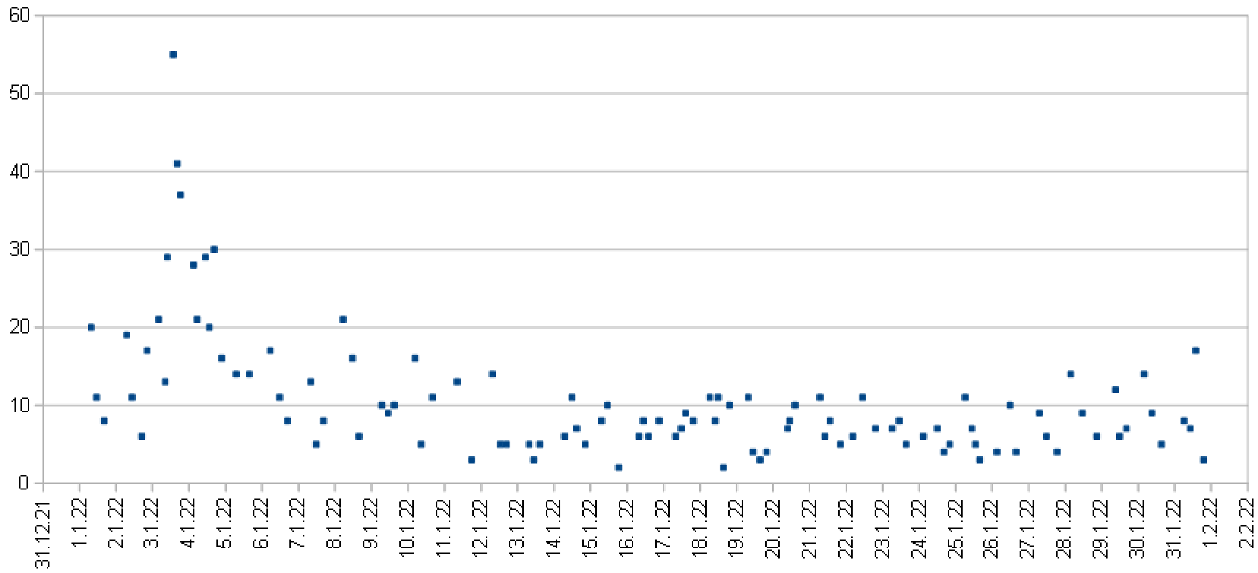

Figure 5 – The result with the actual ten-minute meteor echoes when listening to radio signals during January 2022.

3 Listening to radio echoes on 88.6 MHz

In order to save observation time and to increase the efficiency of listening to the radio meteor echoes in order to obtain a more complete observation series, I made a modification to the method with the introduction of a definition of “synthetic” hourly rate numbers (*Figure 4*).

Listening to the radio signals for 10 minutes with extrapolation of the data to 1 hour was done about 3 to 5 times a day. This was done in order to control the level of the hourly rates as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 108 synthetic hours. The hourly calculated data are given in order to compare with the hourly activity values obtained by the method of automatic hourly signal detection.

The maximum signal activity was recorded in the afternoon of January 3. This could mean that the Earth first crosses parts of the meteoroid stream dominated by mainly very small particles.

4 Preliminary CAMS Data

Figure 6 shows the total daily activity of meteor orbits obtained by the CAMS video networks data (Jenniskens et al., 2011). For January there is a noticeable correlation between the activity level of sporadic meteors and the activity level of shower meteors. I used the preliminary CAMS data as available on the website on February 23, 2022. In addition to the traditional Quadrantids (QUA, #0010) high on January 3, the chart shows weak peaks in showers activity on January 13, 21,28–29.

The weak peak on January 13 is caused by a small increase in the activity of some minor meteor streams. The weak peak on January 21 is caused by the peak activity of the minor shower gamma-Ursae Minorids (GUM, #0404), despite the fact that the IMO tabular data gives a peak date of January 19, and needs to be clarified. A weak increase in shower activity on January 28–29 is caused by the peak activity of the minor shower ACB (#0429), as well as a small increase in the activity of several minor showers.

Interestingly, the CAMS data show minimal activity on January 16–19, which agrees well with the minimal activity on January 16–20 recorded by the radio echoes listening method and correlates satisfactorily with the minimal activity interval on January 15–22 by the automatic radio signal registration method.

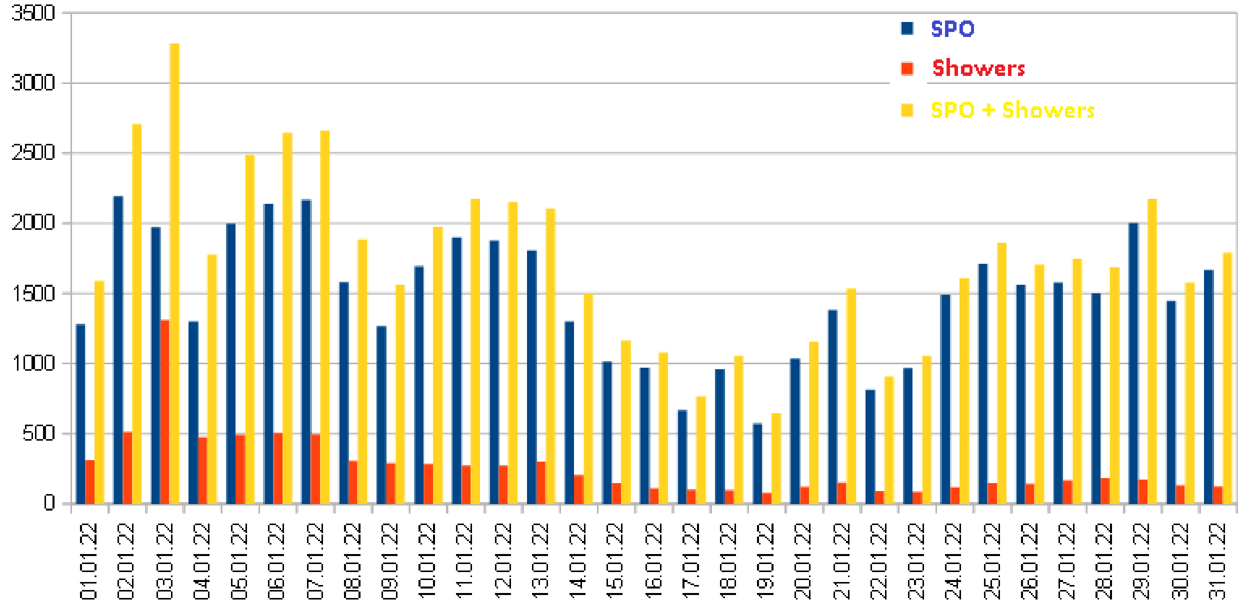

Figure 6 – Daily video meteor orbit activity in January 2022 according to CAMS video networks.

5 Conclusion

The method of listening to the radio meteor echoes is about 3 times more sensitive than the method using automatic detection of meteor echo signals with music or speech. The averaged data of radio signal activity obtained by the two methods correlate satisfactorily with each other, as well as with CAMS video network data.

Acknowledgment

I would like to thank Sergey Dubrovsky for the software he developed for data analysis and 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.

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Radio meteors December 2021

Felix Verbelen

Vereniging voor Sterrenkunde & Volkssterrenwacht MIRA, Grimbergen, Belgium

felix.verbelen@skynet.be

An overview of the radio observations during December 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 December 2021.

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

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

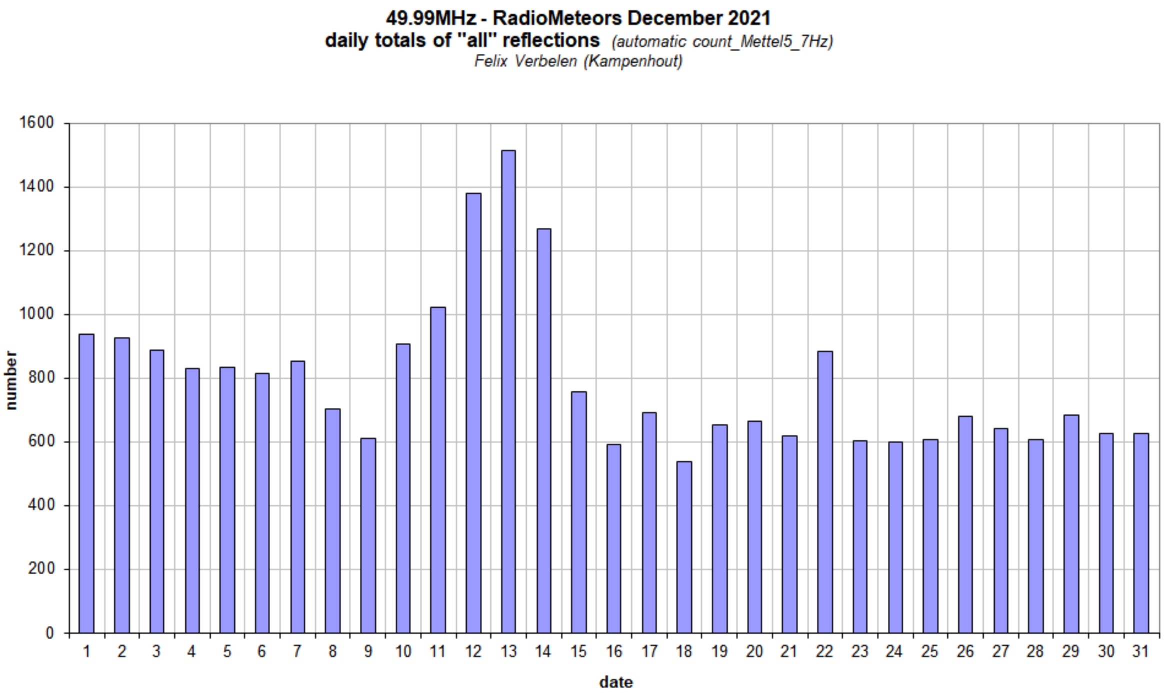
Local interference and unidentified noise remained moderate or low for most of the month and no lightning activity was detected. Due to maintenance work in the vicinity of the beacon antenna, our beacon had to be switched off on December 8th between 12^h08^m and 14^h37^m UT and on December 9th between 07^h38^m and 10^h31^m UT; data is missing for those short periods.

The eye-catchers of the month were, of course, the Geminids, but the Ursids were also prominent on December 22nd.

This month, only 6 reflections longer than 1 minute were observed here, all in the first half of the month. A selection of these, along with some other interesting registrations, are displayed in *Figures 5 to 9*.In addition to the usual graphs, you will also find the raw counts in cvs-format[39] from which the graphs are derived.

The table contains the following columns: day of the month, hour of the day, day + decimals, solar longitude (epoch J2000), counts of "all" reflections, overdense reflections, reflections longer than 10 seconds and reflections longer than 1 minute, the numbers being the observed reflections of the past hour.

[39] https://www.meteornews.net/wp-content/uploads/2022/01/202112_49990_FV_rawcounts.csv



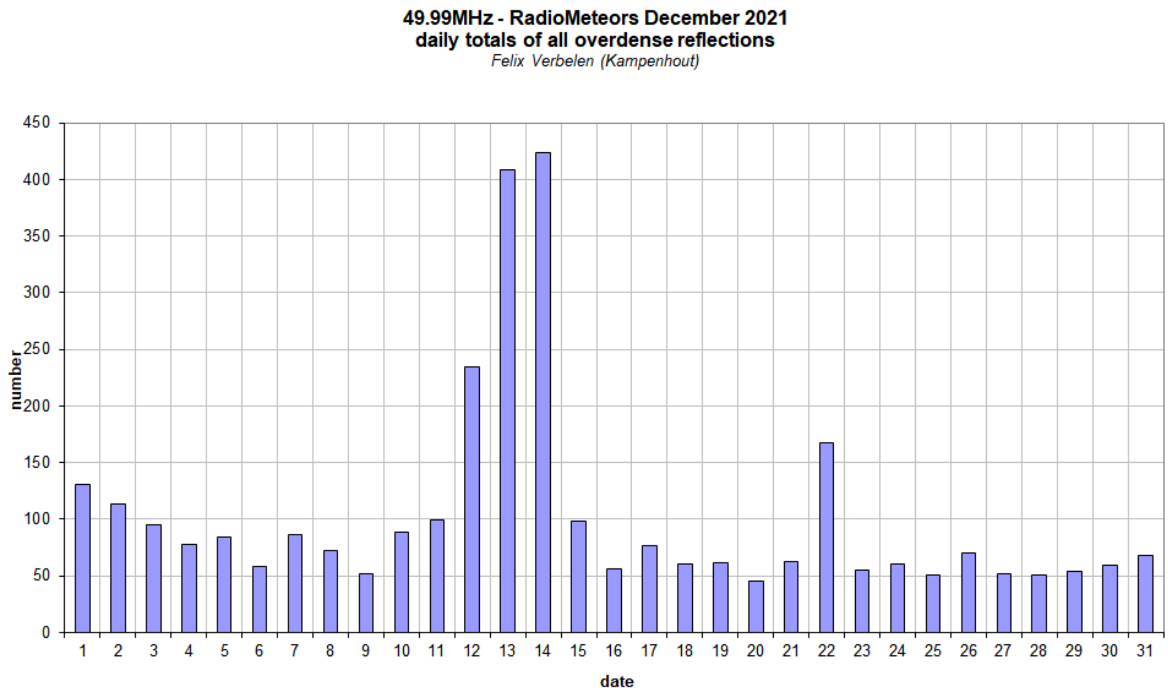
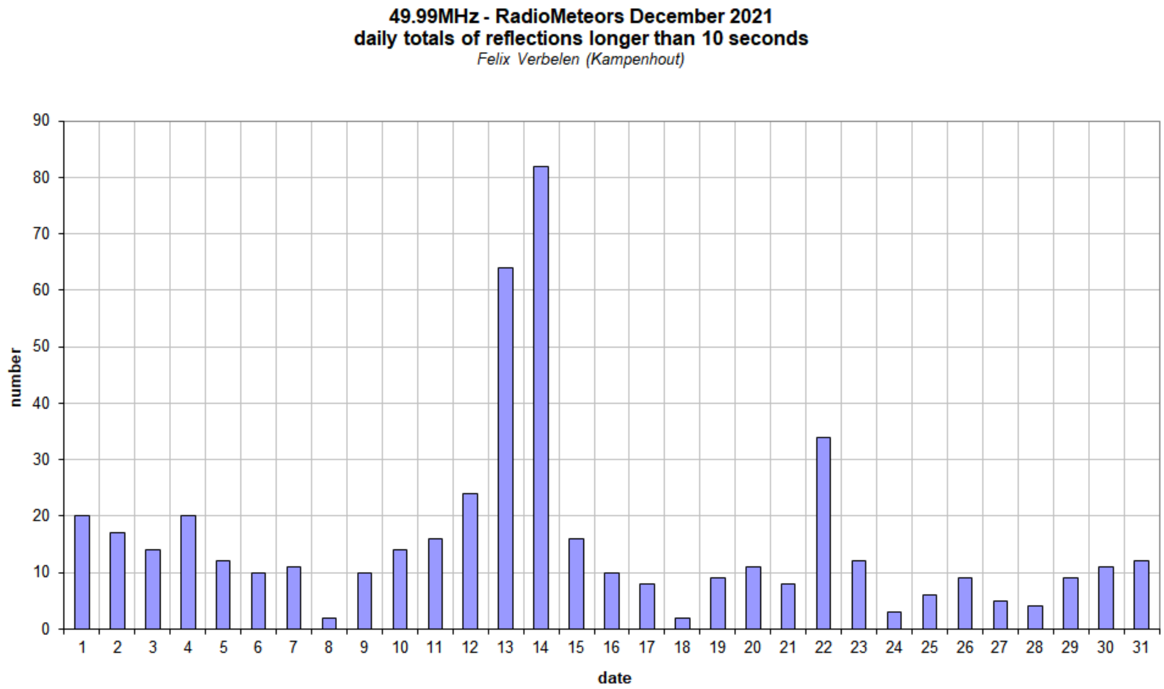


Figure 1 – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2021.



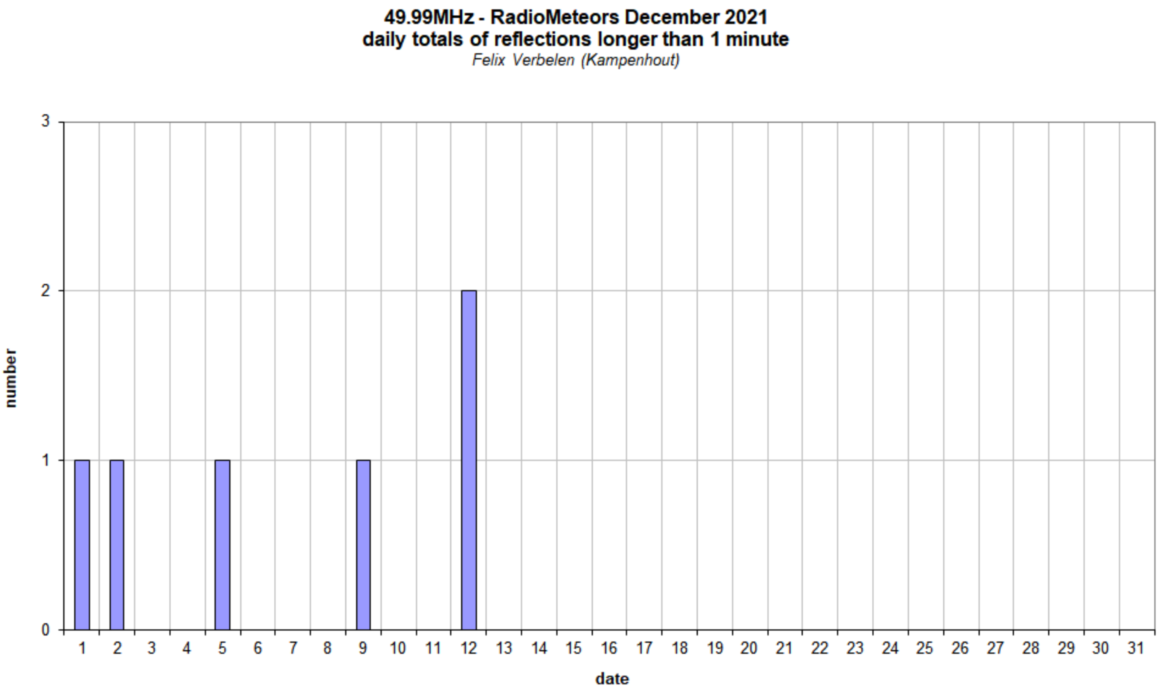
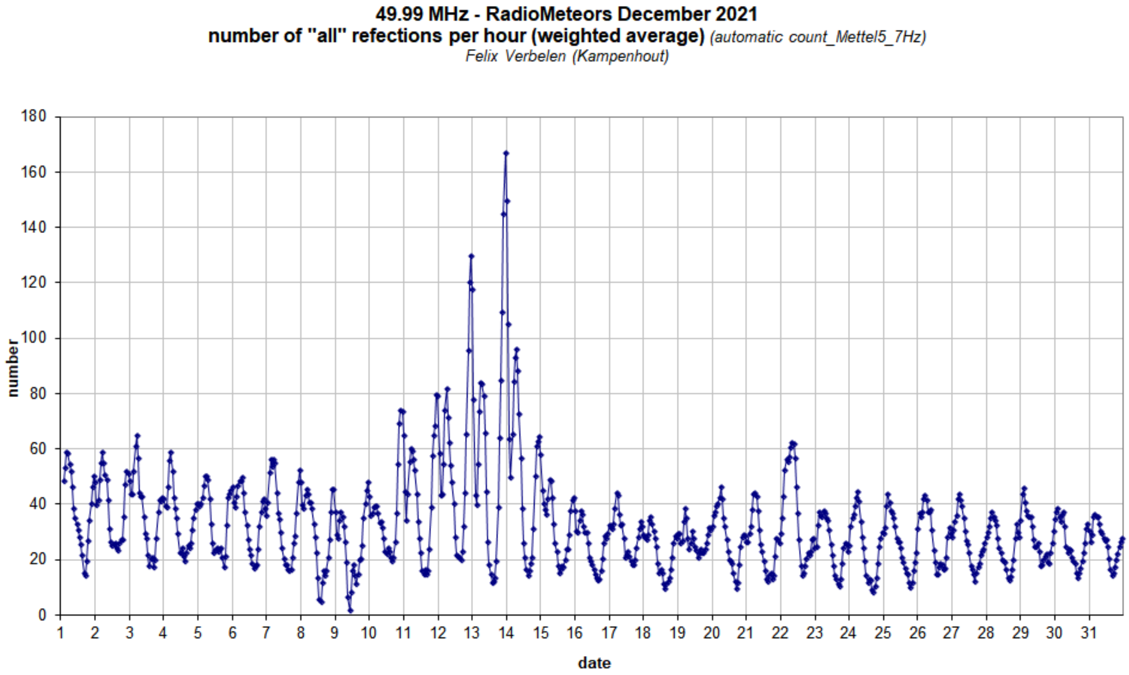


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2021.



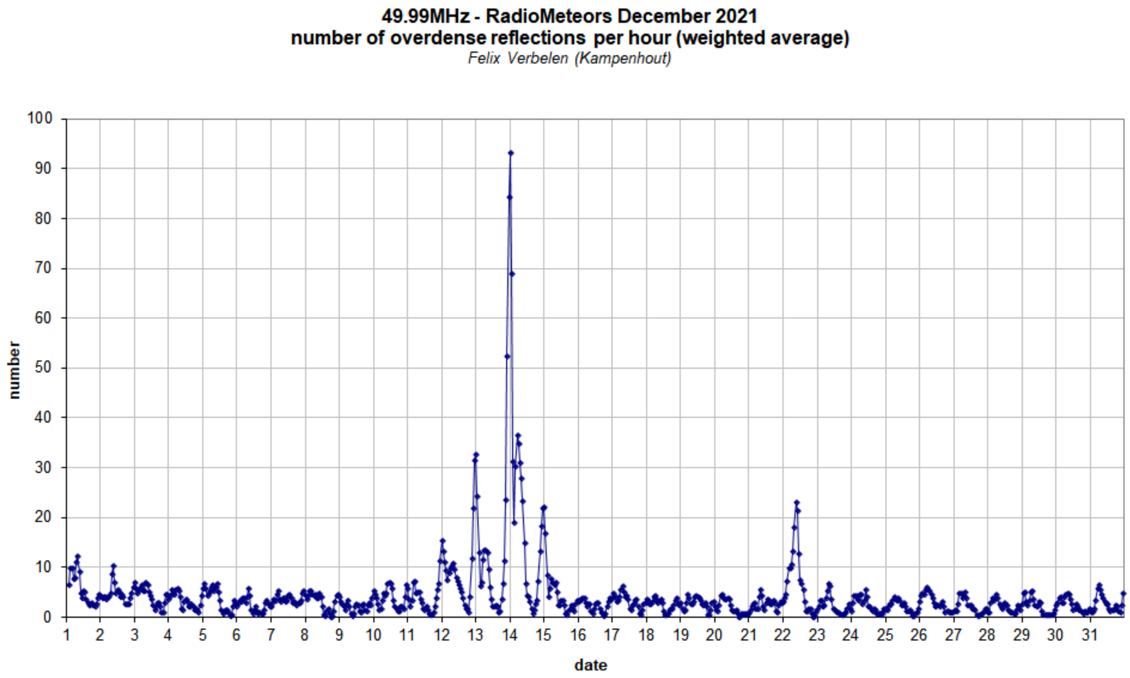
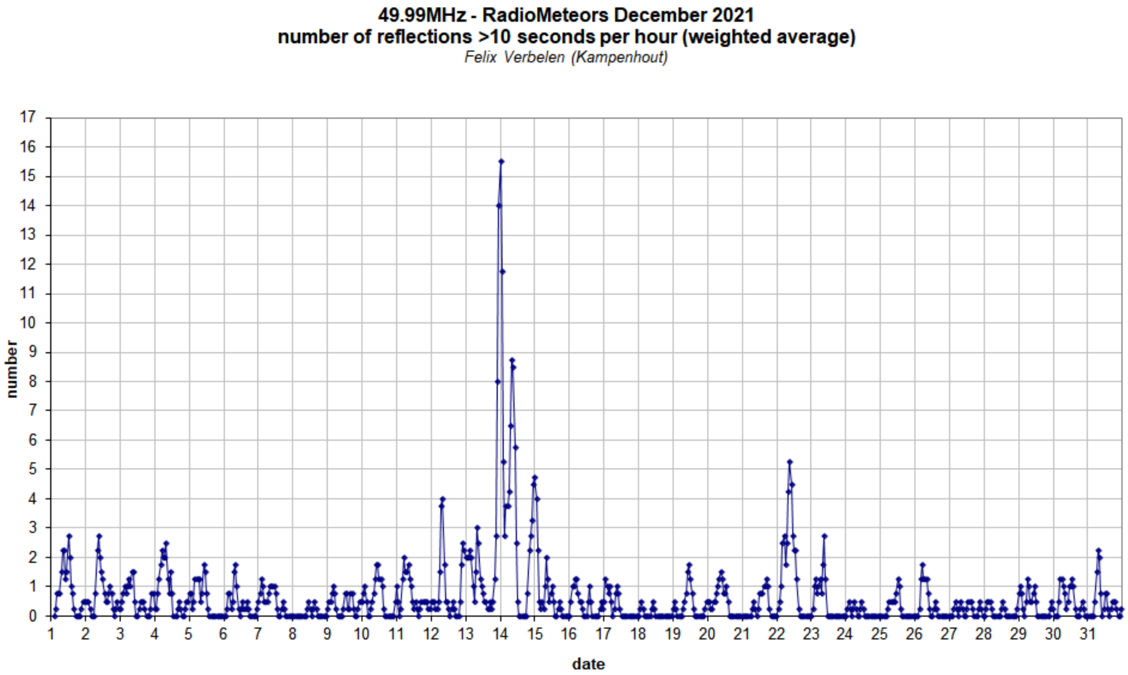


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2021.



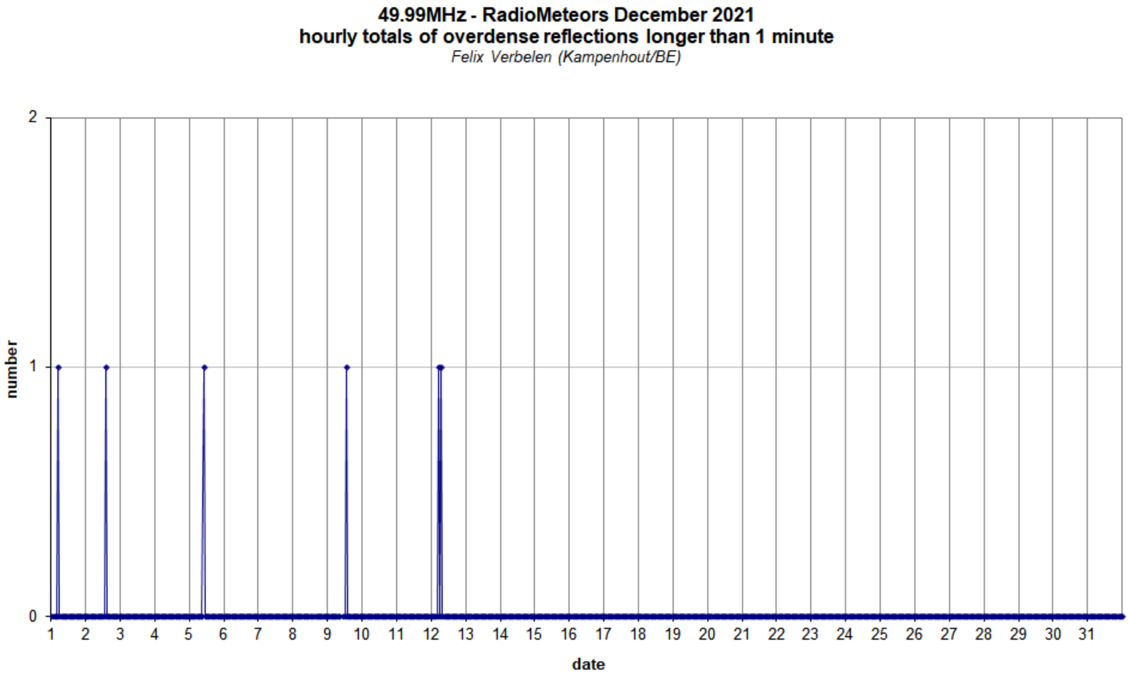


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during December 2021.

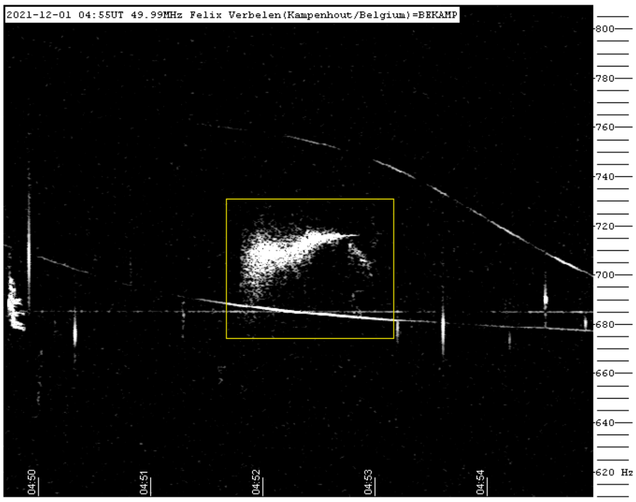


Figure 5 – Meteor reflection 1 December 2021, 04^{h}55^m UT.

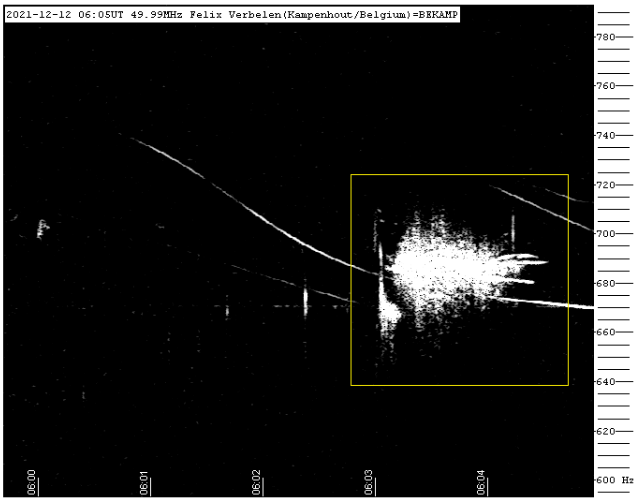


Figure 8 – Meteor reflection 12 December 2021, 06^{h}05^m UT.

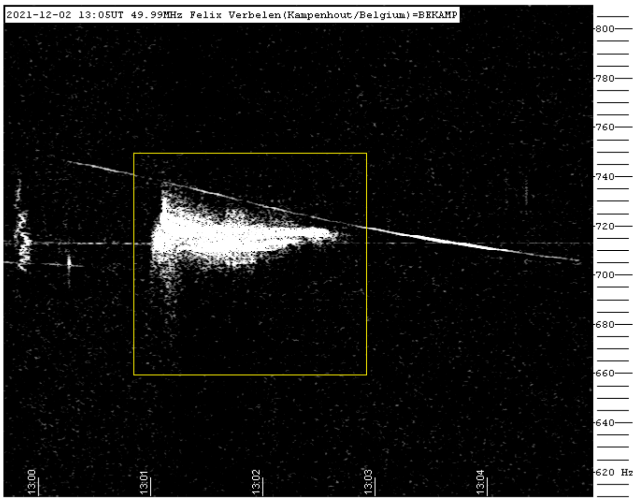


Figure 6 – Meteor reflection 2 December 2021, 13^{h}05^m UT.

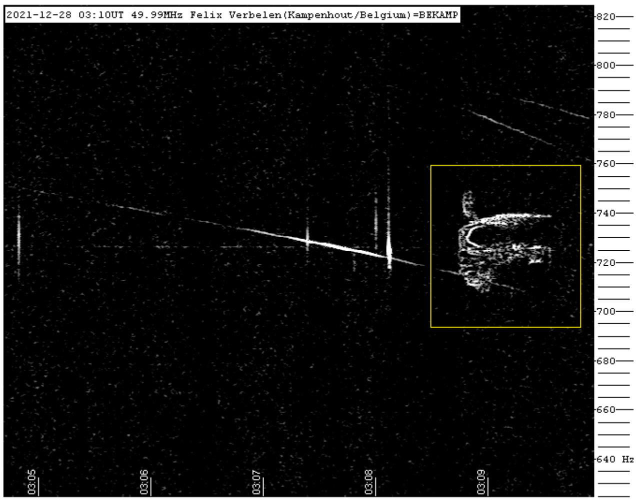


Figure 9 – Meteor reflection 28 December 2021, 03^{h}10^m UT.

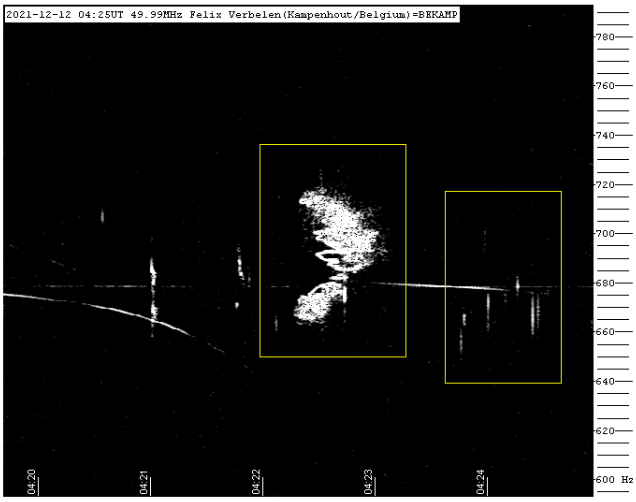


Figure 7 – Meteor reflection 12 December 2021, 04^{h}25^m UT.

Radio meteors January 2022

Felix Verbelen

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

An overview of the radio observations during January 2022 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 2022.

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

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

The highlights of the month were, of course, the Quadrantids/Bootids, which apparently peaked on January 4th, but were also very active on January 3th, especially in terms of overdense reflections. *Figure 5* shows the hourly totals for the January 1–7 period, as well as some SpecLab screen-dumps giving an idea of the intensity of the shower.

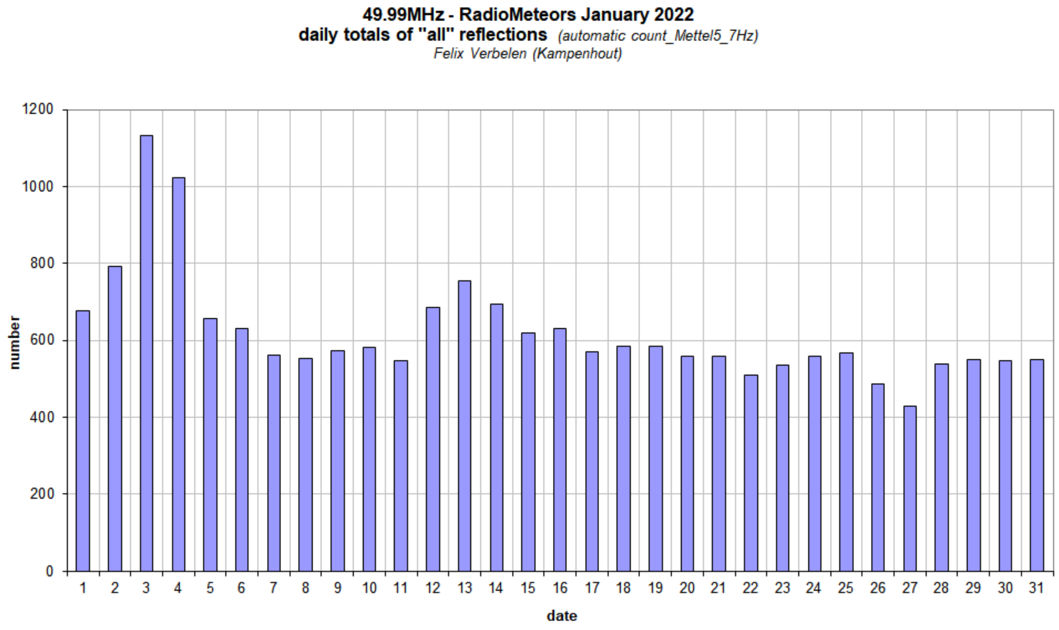
The rest of the month was fairly calm as usual, but with a clear increase in mostly underdense reflections during the days before and after January 14th (294°–295° solar longitude).

In addition, on the frequency of our beacon, solar outbursts mainly of type III were registered almost daily, as was the re-entry of Starlink-1204d on January 21st.

This month, only 4 reflections longer than 1 minute were observed here. A selection of these, along with a few other interesting registrations, are displayed in *Figures 6 to 14*. In addition to the usual graphs, you will also find the raw counts in cvs-format[40] from which the graphs are derived.

The table contains the following columns: day of the month, hour of the day, day + decimals, solar longitude (epoch J2000), counts of "all" reflections, overdense reflections, reflections longer than 10 seconds and reflections longer than 1 minute, the numbers being the observed reflections of the past hour.

[40] https://www.meteornews.net/wp-content/uploads/2022/02/202201_49990_FV_rawcounts.csv



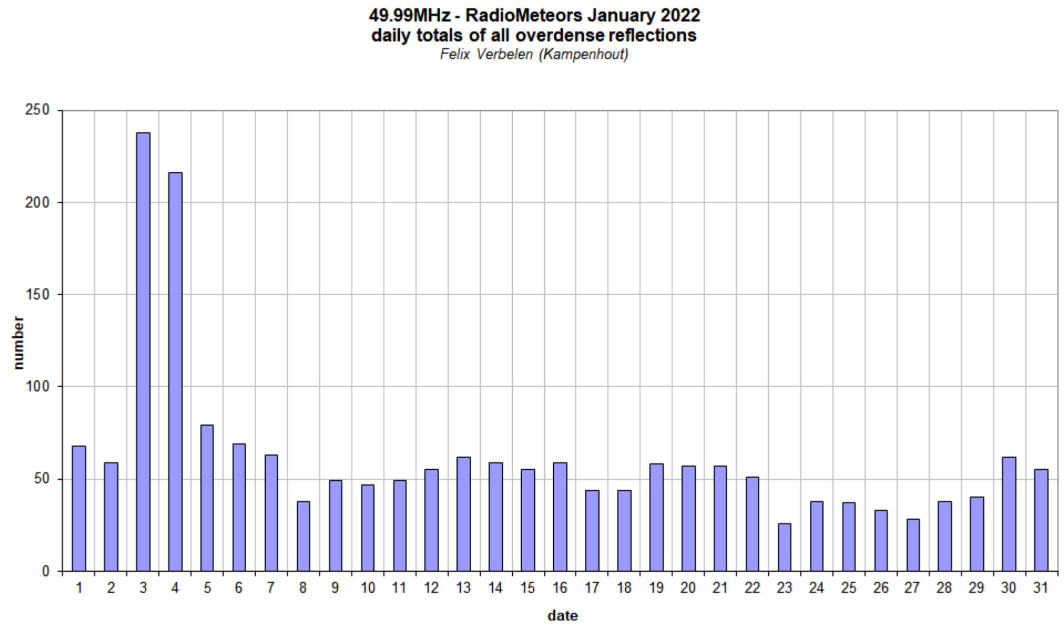
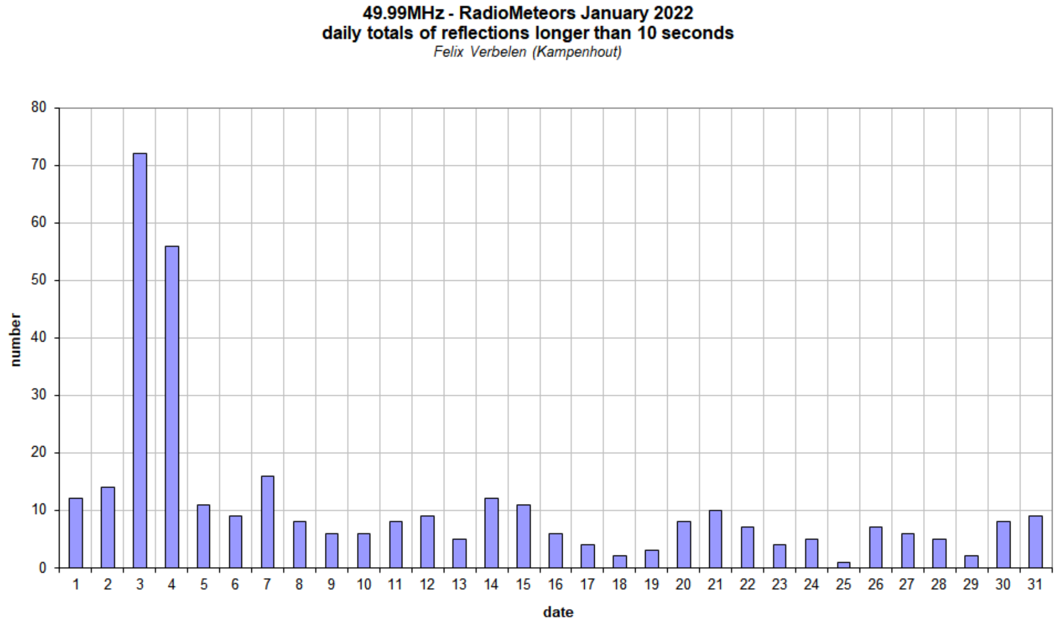


Figure 1 – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2022.



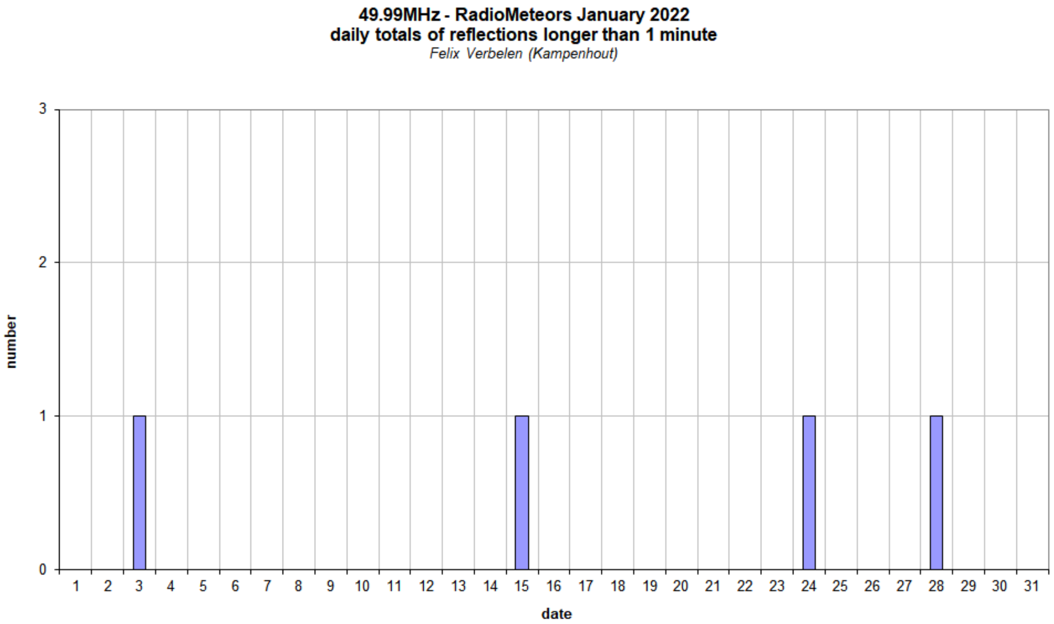
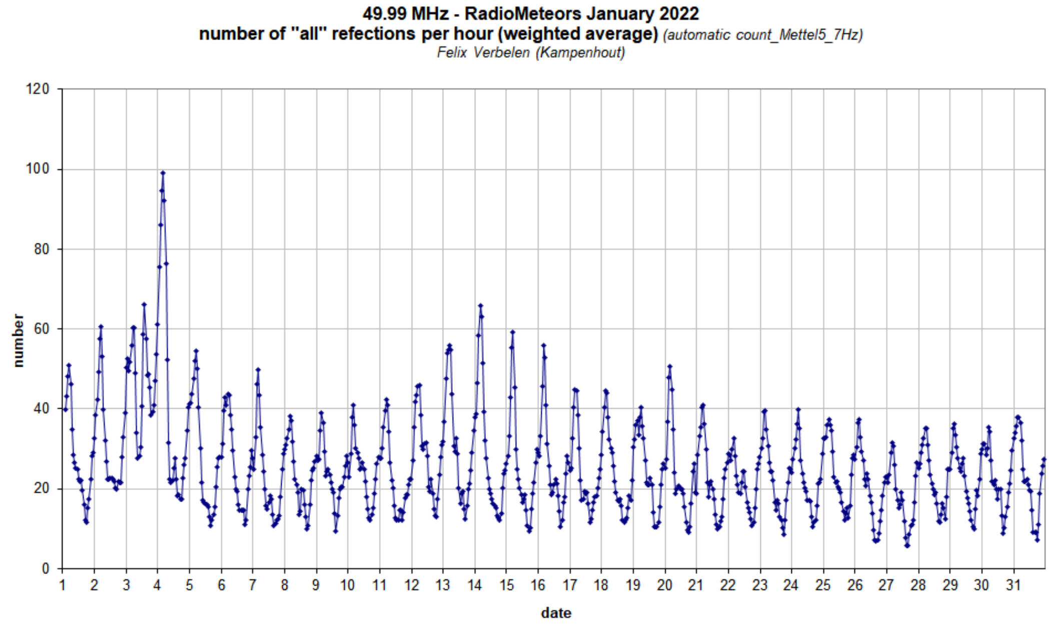


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2022.



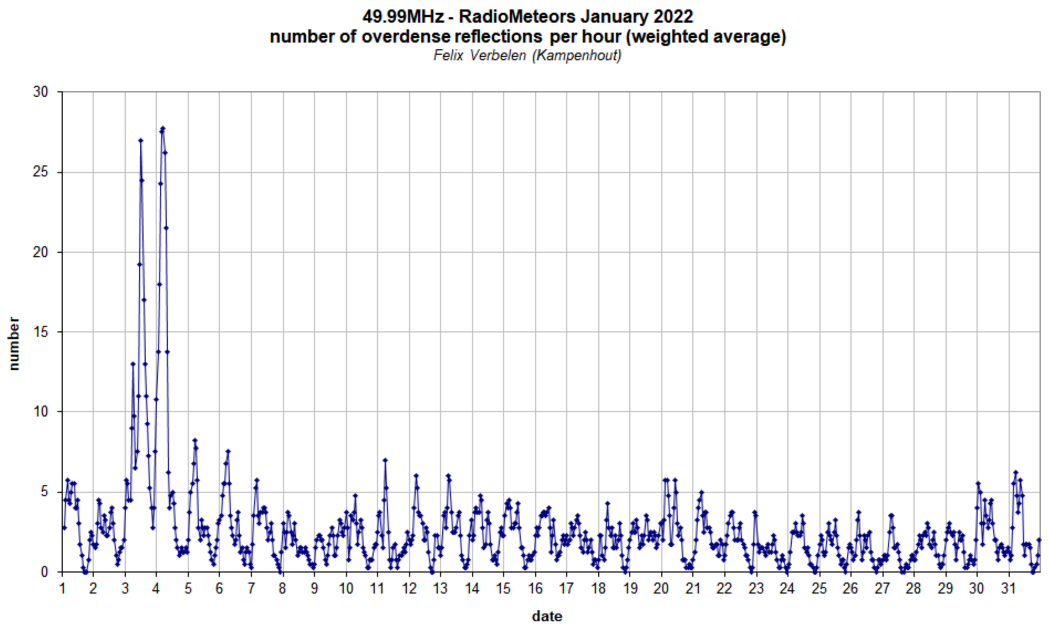
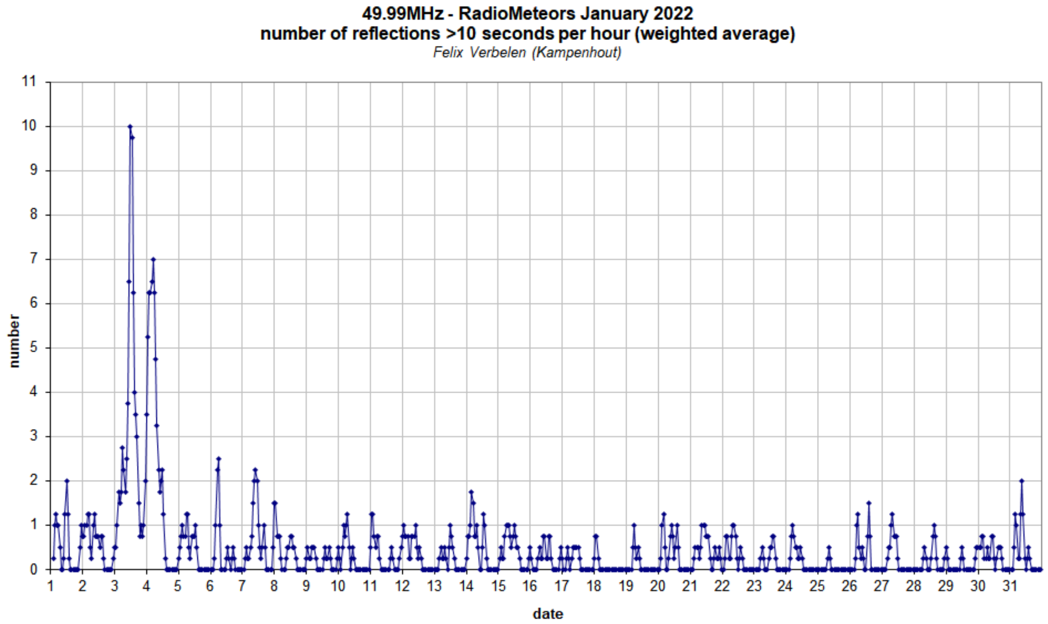


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2022.



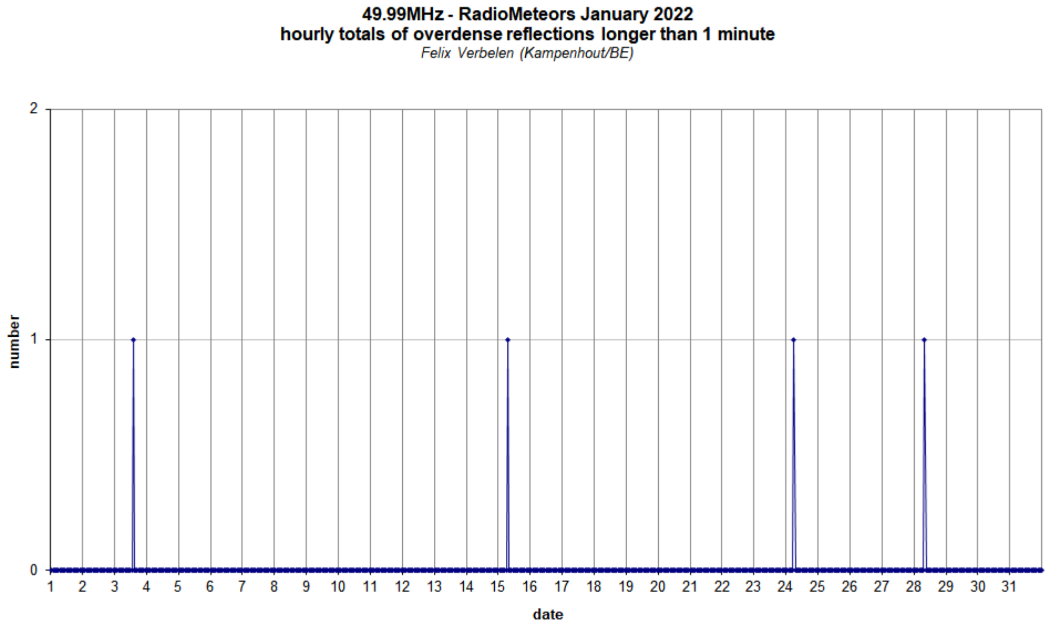


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during January 2022.

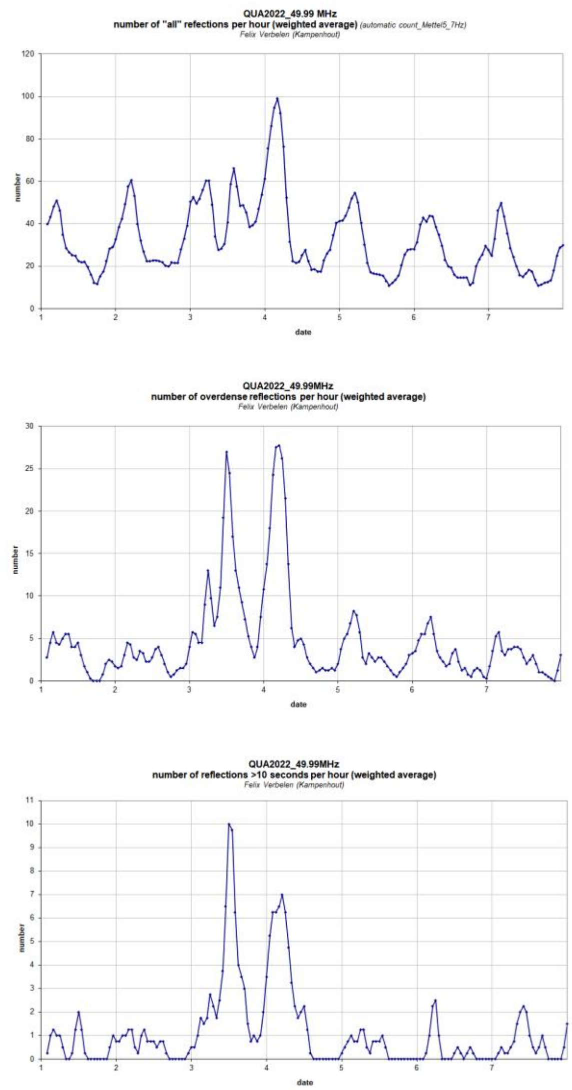


Figure 5 – Quadrantids radio activity January 2022.

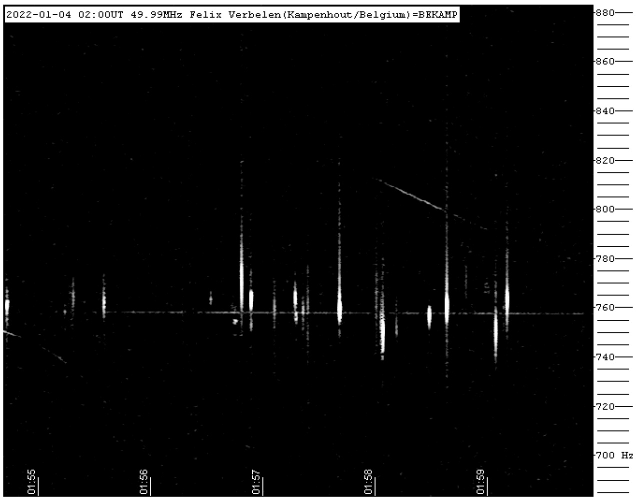


Figure 6 – Meteor reflections 4 January 2022, 02^h00^m UT.

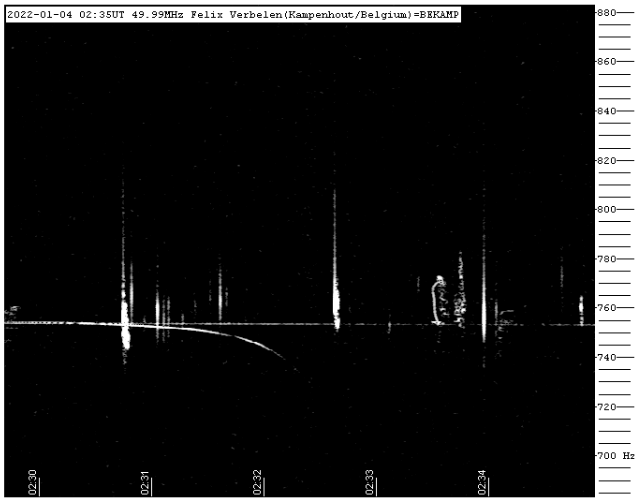


Figure 7 – Meteor reflections 4 January 2022, 02^h35^m UT.

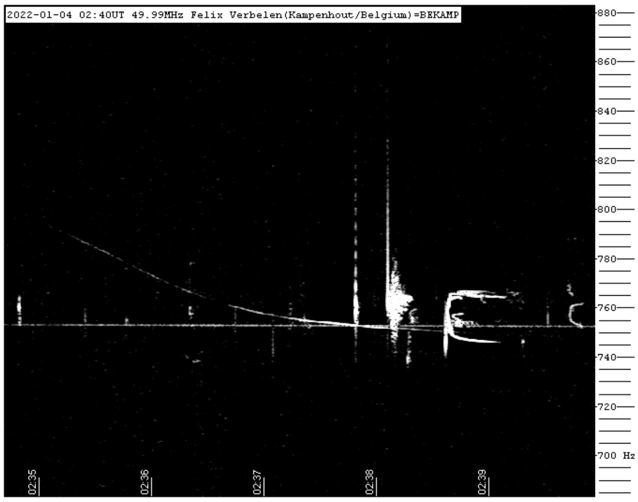


Figure 8 – Meteor reflections 4 January 2022, 02^h40^m UT.

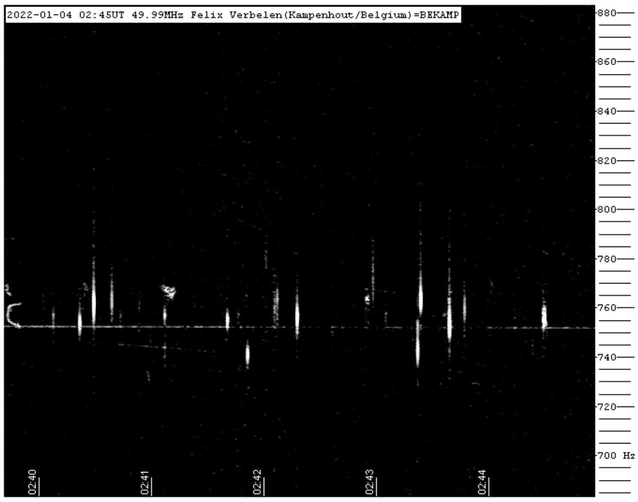


Figure 9 – Meteor reflections 4 January 2022, 02^h45^m UT.

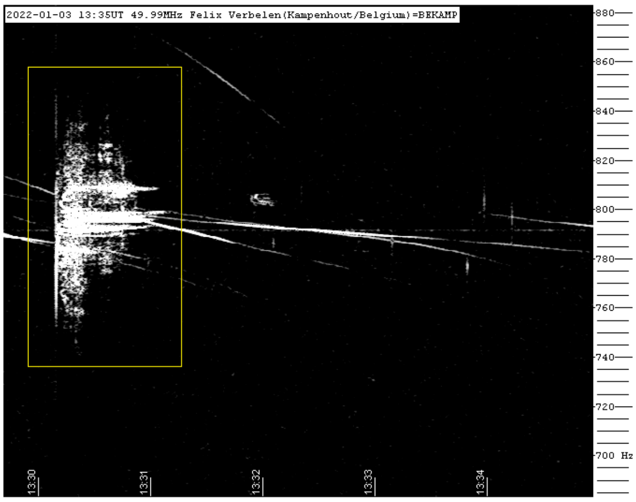


Figure 10 – Meteor reflection 3 January 2022, 13ʰ35ᵐ UT.

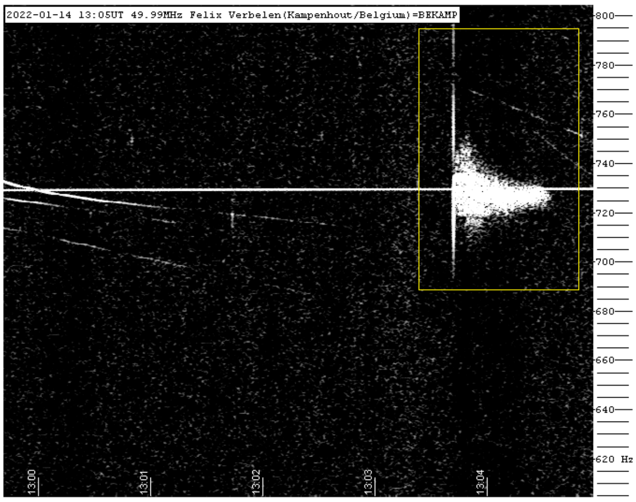


Figure 11 – Meteor reflection 14 January 2022, 13ʰ05ᵐ UT.

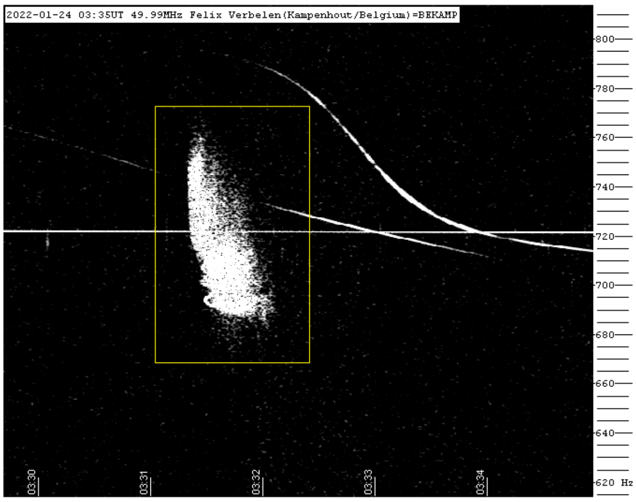


Figure 12 – Meteor reflection 24 January 2022, 03ʰ35ᵐ UT.

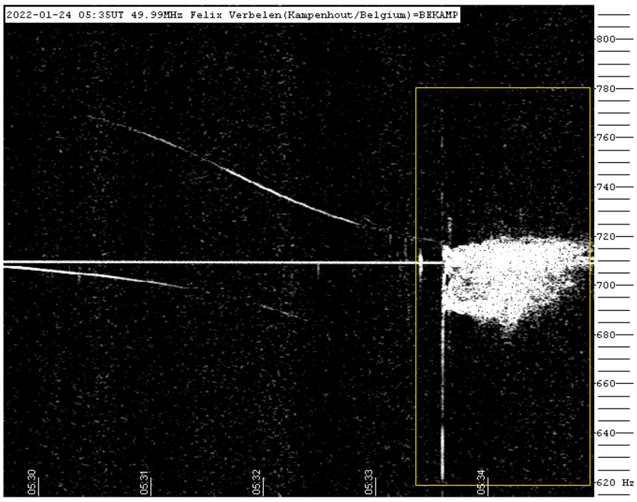


Figure 13 – Meteor reflection 24 January 2022, 05ʰ35ᵐ UT.

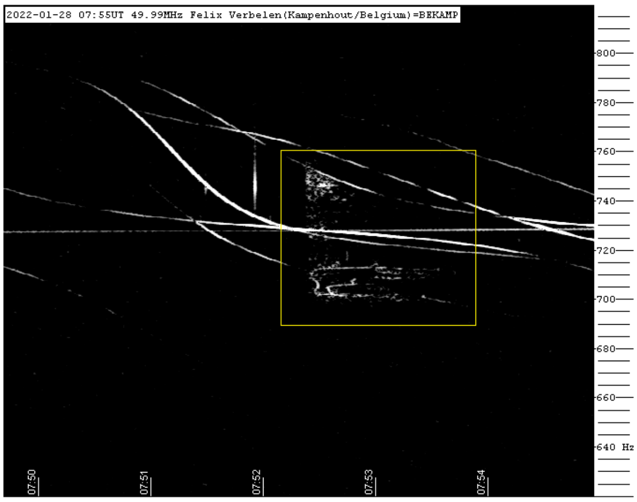


Figure 14 – Meteor reflection 28 January 2022, 07ʰ55ᵐ UT.

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