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Composite image of the 2021 Perseid outburst on August 14 at Westmeath Lookout, Ontario in Canada (courtesy Pierre Martin)

- Perseid outburst
- Aurigids 2021
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- GMN shower discovery
- Visual meteor work
- Radio meteor work

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From memories of Prof. I. S. Astapovich

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This article describes the process of visual observations of meteor radiants according to the "Program-maximum" by Prof. I. S. Astapovich in Ashkhabad. 2021 marks 45 years since the day of his death.

1 Introduction

Among the many problems dealt with by I. S. Astapovich, we will only address one problem here – the visual study of meteor phenomena. He devoted most of his life to it and wrote hundreds of pages on it. During the Great Patriotic War, he was evacuated to Ashkhabad along with the Moscow University. In Ashkhabad the charm of the southern sky fascinated him so much that he stayed there for 17 years... He held observation every clear "moonless" night, while during the day he carried out extensive educational work at the Ashkhabad University, the Pedagogical Institute and others, preparing the Turkmen staff, as well as managing scientific work at the Ashkhabad Astrophysical Laboratory (AAL) that he had founded. In terms of the number of meteor observations he remained unsurpassed in the world taking into account such prominent meteor researchers as W. F. Denning, C. Hoffmeister and others.

2 "Program-maximum"

Observations were made according to "Program-maximum" that he had created. This is a method of visually studying meteors as they evolve, seeking to make the most of the properties of the eye, taking into account its errors. In a split second the sophisticated eye of a specialist is able to spot not only the main features of the meteor, but most importantly their change over the course of evolution. This was the first time that attention was drawn to this within our country. "Program-maximum" is set out in full on pages 89–112 (Astapovich, 1956).

But the enormous daytime workload and constant night-time observations could not help but take a toll on his health. When I. S. Astapovich decided to move from Ashkhabad, first to Odessa and then to Kiev, he was already very ill, although he continued to work.

I. S. Astapovich was a masterly observer, a romantic, sincerely devoted to the cause he loved. He wrote in vivid figurative language. We would like to convey to modern young people, who are keen on meteor observations, I. S. Astapovich's description of the process of observation of meteor radiants itself, we would also like to preserve his style and imagery of language, as far as translation will allow.

Figure 1 – Igor Stanislavovich Astapovich (1908–1976) (from the personal archive of A.Terentjeva).

Therefore, we quote this description in full (Astapovich, 1956, pages 115–117):

"After 5-10 minutes of observation, the eye becomes accustomed to the darkness and an experienced observer sees the sky as if it were alive with meteors: some radiants set, others rise, the appearance of meteors in the shower changes with the change of the radiant height; some showers show themselves after 20-30 minutes, others only after several hours of work. After 40-60 minutes, one gets

Figure 2 – I. S. Astapovich on vacation during a river cruise along the Volga, 1969 (from the personal archive of A.Terentjeva).

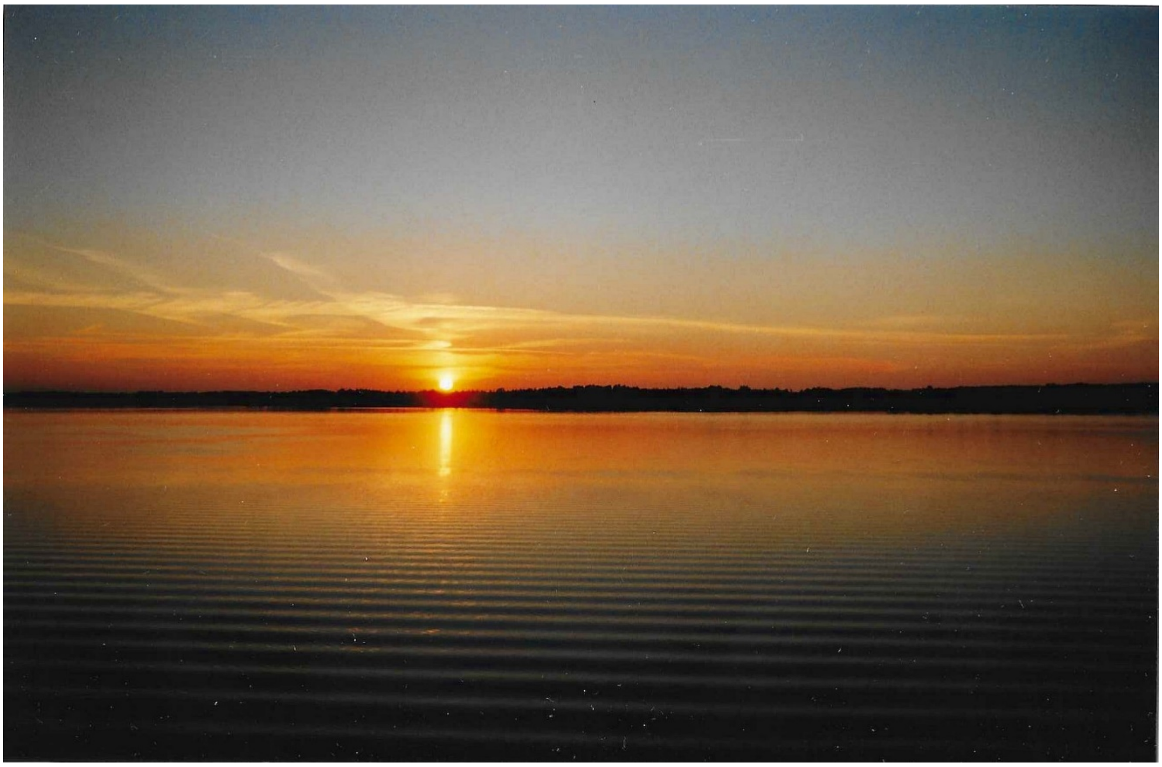

Figure 3 – Sunset over the Volga (the photo by A.Terentjeva).

an idea of how the meteor sky is "breathing" today; sometimes that "breath" remains for 2-3 nights in succession, changing in the same way from evening hours to morning hours, sometimes the following night has nothing in common with the preceding one, and new radiants completely replace those of the night before. Usually, however, the life of a meteor sky is marked by a reasonably smooth replacement of showers by other showers, littered with the chaotic presence of sporadic meteors "without kith or kin", or even sporadic radiants, those "caliphs for an hour" that appear once, sometimes in the brief splendor of a bunch of similar meteors, before disappearing forever. The reddish and orange slow meteors, prevalent in the early evening hours, are gradually ousted by the very swift white-blue meteors of the pre-morning showers, which constantly leave meteor trails. At first, as the radiant rises, the meteors are long and foggy: they pass at extreme altitudes, almost tangential to the Earth's atmosphere, and can easily exit again into interplanetary space. As the radiants rise, their fall becomes steeper, they become shorter and sharper. Because of the perspective contraction near the radiant, meteors are very short and slow, and reach their greatest length and velocity at elongation ψ = 90° from the radiant. But as the zenith distance of the meteor increases it moves away from us, its path and velocity decrease, the increased distance and the influence of the atmosphere will weaken it and make it yellowish and it will "disappear without a trace". By the end of the second hour, usually three to five of the main showers for a given part of the night have revealed themselves, but weak showers only hint at their existence with solitary meteors. We mentally find approximate "one-way" radiants from observations at one point, and the coincidence of these radiants is the first indication of the possibility of such a weak shower. When two hours have passed, over half of the suspected radiants have proved themselves in the meantime, and the rest either drift over the horizon, leaving the question open, or become silent, meaning they were either "caliphs", or a chance meeting of two sporadic radiants, or –occasionally – an unfortunate observation error. But reliable radiants, the existence of which is beyond doubt, unceasingly continue "providing" more and more meteors, as if on purpose. Occasionally an alien would fall into their company: it also passes through a common radiant, like the other members of this shower, and could formally claim kinship with them. But it is poorly disguised: it is swift when the others are slow, or it is green-blue when they are reddish. Its physical and kinematic data "bring it out into the open" and qualify it as sporadic material. Any given night, 6 to 8 good radiants may be found in 4 to 6 hours, some were working yesterday, some will remain until tomorrow, but in the summer and autumn nights, the number of active radiants is 2-3 times greater, and the observer will "have a hard time" then. And it is only afterwards possible to track 30 to 40 radiants on a few exceptional nights, using long, multi-day processing. Once or twice a year, a poor third-rate radiant, no better than most, suddenly comes to life for no apparent reason; it starts at first a little, then more often, and a few hours later quite well emitting meteors singly, in pairs, triples, and even full streams, for several minutes. Such a radiant, having occupied the first place in the sky, sets majestically, giving a chance to see its sudden transformation elsewhere on Earth, or it starts to wane and in two hours only an entry in the observation log remains of its former splendor. It happens that in the midst of observations, when the timidly hiding radiants of weak showers are retrieved and every meteor is of great value, the sky gets covered by clouds or becomes pale, dawn comes or the Moon rises, or suddenly the sky is lit up by a fireball: if it is not fast, you can take binoculars and capture it in flight offhand; every time something interesting is seen. If it has left a trail, say farewell to weak radiants: it will keep for about 10-15 minutes until it completely fades and then you have to record it for at least half an hour and the description of the fireball should be as detailed as possible: you cannot see it often!"

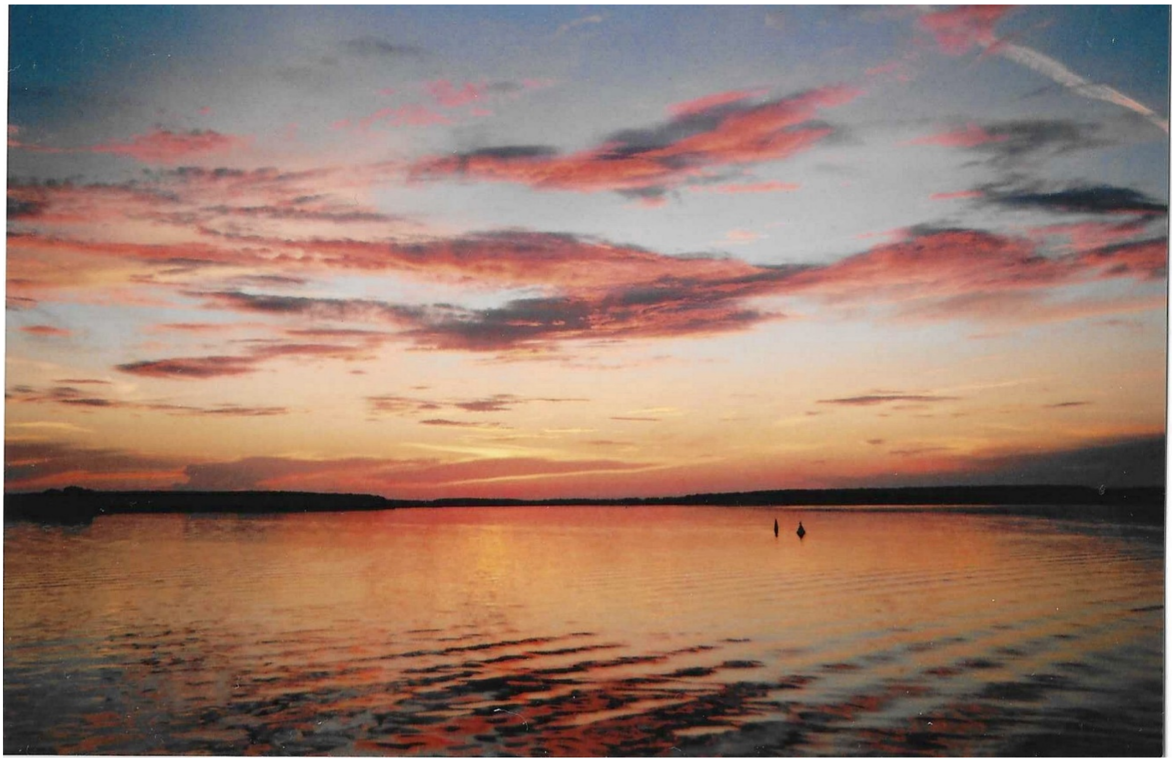

Figure 4 – Sunset over the Volga (the photo by A.Terentjeva).

The bibliography by I. S. Astapovich includes more than 800 works.

Extensive information on life and multifaceted scientific activities of Prof. I. S. Astapovich can be found in the works (Terentjeva, 2001), (Husárik et al., 2009), (Smirnov, 1999).

Acknowledgment

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The authors thank Paul Roggemans for his efforts enabling the preparation and publication of this paper.

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The big surprise: a late Perseid outburst on August 14, 2021!

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An unexpected Perseid outburst was observed over the North American continent on August 14, 2021 (Jenniskens and Miskotte, 2021; Jenniskens, 2021). This event was observed by visual- and radio observers. Also, the North American CAMS and AllSky 7 networks recorded the outburst. In this article we present the results of the visual- and radio observations.

1 Past years observations

2018

During the night of 2018 August 13–14 meteor observers witnessed a rich Perseid display above Europe, 24 hours after the annual maximum of the Perseids (Vandeputte, 2019; Gaarder, 2018). An analysis based on European data received by the IMO shows that there was a peak in activity profile (Miskotte, 2019). The night started with normal ZHRs around 50 but gradually a maximum ZHR of 85 was reached around $\lambda_\odot = 140.935°$ (August 14, 2021 at 00^h14^m UT), followed by a slow decline in ZHR to normal values at the end of the night (see *Figure 1*). This outburst featured a normal population index *r* of 2.1–2.2. The peak was less visible in the IMO on-the-fly graph[1], but relatively high ZHRs were achieved. This difference can be explained by the use of other parameters for the IMO on-the-fly graphs, such as, for example, limiting magnitude. Unfortunately, this peak could not be found in the radio data from RMOB (*Figure 2*).

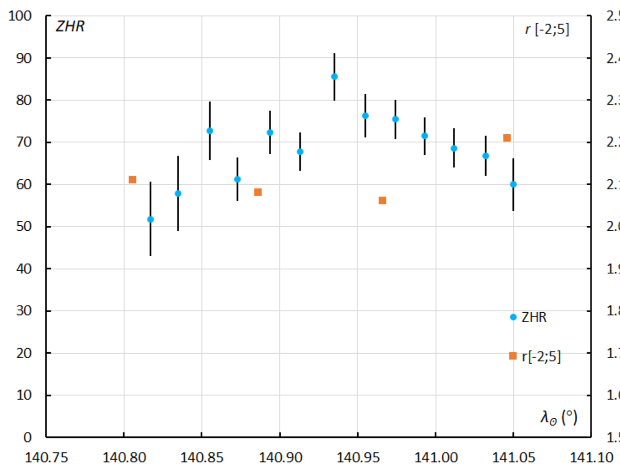

Figure 1 – The Perseid outburst of August 13–14, 2018 as observed visually above Europe.

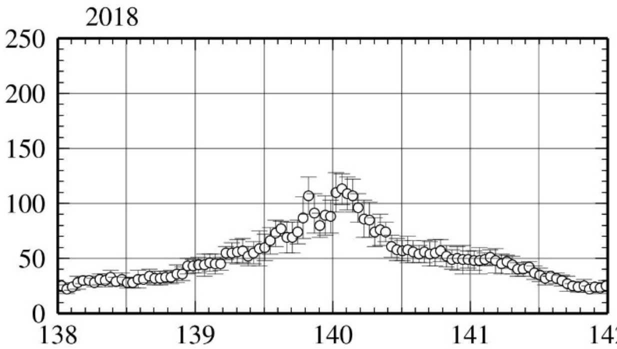

Figure 2 – The Perseid ZHR_r in 2018, based on radio observations (RMOB). No additional activity observed after the annual Perseid maximum.

2019

Also in 2019, an unexpected peak in activity around $\lambda_\odot = 141.02°$ has been reported (Miskotte and Vandeputte, 2020). Radio Meteor Observations captured this small outburst. The estimated ZHR_r was 82 ± 13 at $\lambda_\odot = 141.02°$ (August 14, 2019 8^h30^m UT), see also *Figures 3 and 4*. The 2019 peak was best visible over the Atlantic Ocean and eastern North America. Unfortunately, the peak was not well observed visually, only meteor observer Bruce McCurdy was able to make some observations around the time of maximum. His observations suffered a lot from smoke from the large wildfires that were raging at the time. Still, his observational data shows a peak at the same solar longitude as the radio observations. That peak is much lower than the radio peak, the difference is most likely caused by the large amount of smoke that caused lower limiting magnitudes and a greater atmospheric extinction

[1] https://www.imo.net/members/imo_live_shower?shower=PER&year=2018

(*Figure 4*). The start of the outburst might have been observed from Western Europe just at dusk by visual observers. This was mainly characterized by the appearance of relatively many bright Perseids. Radio observers also noticed this clearly with an increase in prolonged radio reflections around that period.

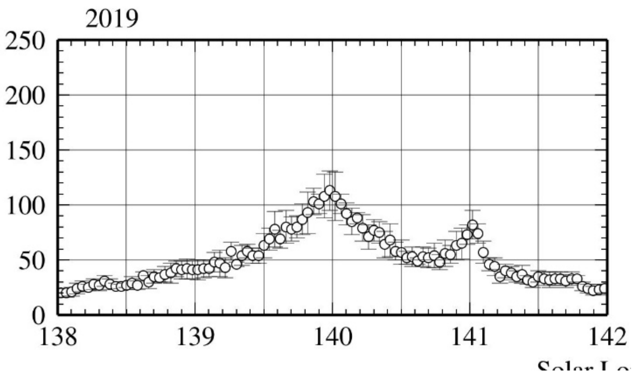

Figure 3 – The ZHR_r curve of the Perseids 2019 based on radio data from RMOB.

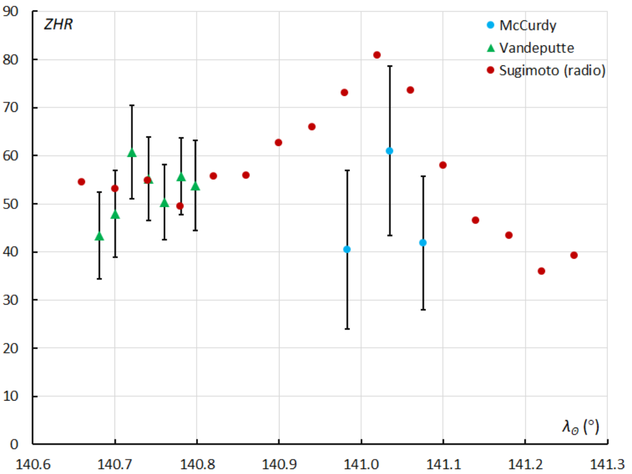

Figure 4 – Comparison of the visual *ZHR* and the radio estimated ZHR_r during the August 14, 2019 Perseid outburst. At the last ZHR point obtained by Michel Vandeputte (VANMC) many bright Perseids appeared.

2020

It was the Belgian radio observer Felix Verbelen who first reported via the VVS mailing list that he recorded many long-lasting reflections of the Perseids on August 14. The unexpected peak occurred at $\lambda_{\odot} = 140.77°$ (2021 August 13, 8^h30^m UT) with a $ZHR_r = 89$ based on radio data from RMOB.

It was visual meteor observer Paul Jones of the ACAC in Florida who was able to visually confirm the outburst, he wrote: "*WOW!!!! We had a very good Perseid display for an hour and a half for the ages this morning (8/13/20) from the Fairgrounds despite the clouds!! We had at least SIX Perseid fireballs and over twenty in all brighter than zero magnitude!*". Unfortunately, it was not possible for Paul Jones to make serious observations due to a rapidly changing cloud cover. An analysis by the first author appeared in Radiant and MeteorNews (Miskotte, 2020). Only much later it became clear that this outburst had been observed visually by the Canadian meteor observer Pierre Martin (Miskotte, 2021). He was the only one who observed this outburst visually under good conditions.

Pierre Martin observed multiple peaks at $\lambda_{\odot} = 140.632°$ (2020 August 13, 05^h00^m UT), $\lambda_{\odot} = 140.710°$ (2020 August 13, 07^h00^m UT and $\lambda_{\odot} = 140.765°$ (2020 August 13, 08^h20^m UT), with maximum ZHRs between 80 and 90. The ZHR graph looked very different than the graphs of the 2018 and 2019 outbursts (see *Figure 6*). The outburst was characterized by a relatively large number of bright Perseids at the start of the observations, later on with increasing population index *r* values. It is also striking that these 3 peaks appeared much earlier in solar longitude than the peaks from 2018 and 2019.

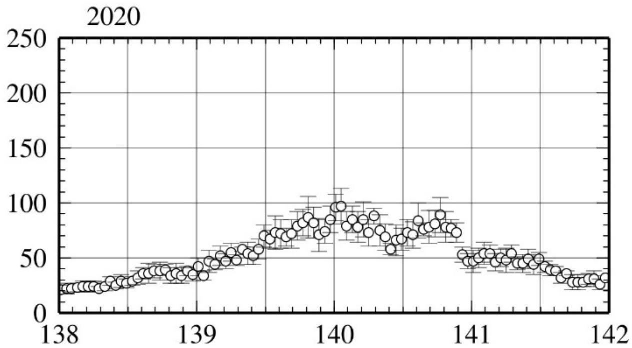

Figure 5 – The Perseid ZHR_r in 2020 based on radio observations collected by RMOB.

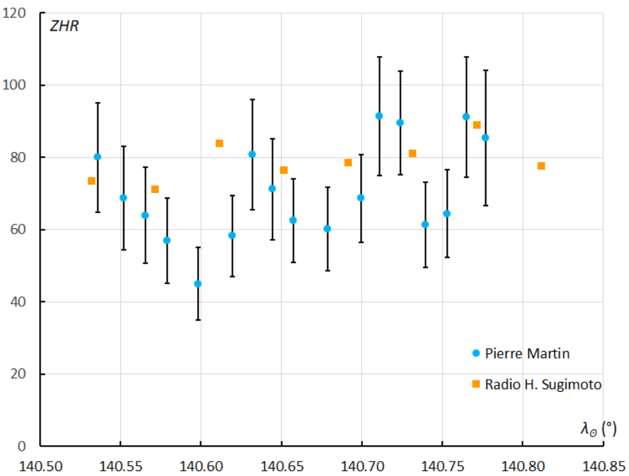

Figure 6 – Comparison between the visual *ZHR* and the radio estimated ZHR_r based on radio observations during 13–14 August 2020.

2 The big Perseid outburst of 2021

Saturday afternoon, August 14, around 2 pm, the first author received a striking message from the Canadian meteor observer Pierre Martin. He wrote: "*I just witnessed very strong Perseid activity August 13–14, 06^h–09^h UT. Multiples Perseids per minute with many bursts. Sometimes 3-4 in a second. Much busier than previous night but I had a great sky mag 6.7. Was this an unexpected outburst? I've never seen so many Perseids a full day after the normal peak. I think the rate might have been as high as 300/hr but I'll know more when I listen to the tape. Average brightness, perhaps a bit below average. There was a very large*

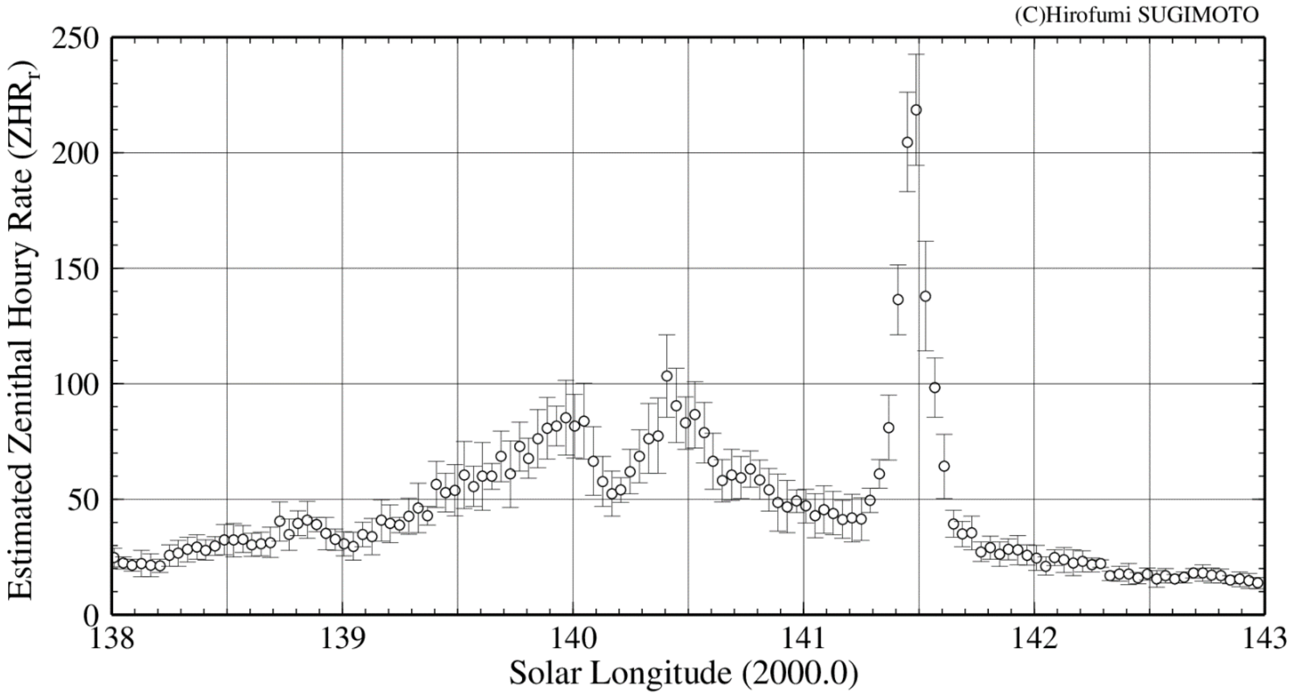

Figure 7 – The estimated ZHR_r of Perseids 2021 based on radio observations collected by RMOB.

number of mag 4 and 5 meteors but still good numbers of +1s and 0s. Brightest we're –3".

His highest 10-minute count was 42 Perseids with a radiant elevation of 61 degrees. Pierre made his observations from Westmeath Lookout, a dark site 80 km northwest of Ottawa, Canada. It appears to be the highest Perseid ZHR since the multiple outbursts during the night of 2016 August 11–12. On H. Sugimoto's website there was a significant peak in activity around $\lambda_\odot$ = 141.500° with a *ZHR* well above 200[2] An initial analysis of Pierre Martin's data soon led to a publication in Meteornews (Jenniskens and Miskotte, 2021) and in CBET[3] (Jenniskens, 2021).

CAMS

Based on data of the CAMS networks in Texas and California Peter Jenniskens found a maximum at $\lambda_\odot$ = 141.474 ± 0.005° with a ZHR of 130 ± 20 on top of the annual activity (ZHR 45). The Full-Width-at-Half-Maximum of the fitted Lorentzian profile is 0.08 ± 0.01 degrees solar longitude. The peak occurred $\lambda_\odot$ = 141.474 ± 0.005° (equinox J2000.0), corresponding to 8.2^h UTC on August 14.

Radio observations: Estimated Zenithal Hourly Rate

Figure 7 shows the estimated Zenithal Hourly Rate (ZHR_r) using data of 37 stations in nine countries (Sugimoto, 2017). The unexpected peak was recorded at $\lambda_\odot$ = 141.49° (August 14, 8^h UT) as *ZHRr* = 219 ± 24.

Table 1 – The estimated Zenithal Hourly Rate (ZHR_r) around the outburst peak. $\lambda_\odot$ is the Solar Longitude (2000.0), *N* is the number of analyzed data entries.

Time (UT)	$\lambda_\odot$ (°)	N	ZHR_r
August 14, 2^h	141.249	11	41 ± 9
August 14, 3^h	141.289	10	49 ± 5
August 14, 4^h	141.329	10	61 ± 6
August 14, 5^h	141.369	10	81 ± 14
August 14, 6^h	141.409	10	136 ± 15
August 14, 7^h	141.449	15	205 ± 22
August 14, 8^h	141.489	20	219 ± 24
August 14, 9^h	141.529	12	138 ± 24
August 14, 10^h	141.569	9	98 ± 13
August 14, 11^h	141.609	8	64 ± 14
August 14, 12^h	141.649	11	39 ± 6
August 14, 13^h	141.689	9	35 ± 6
August 14, 14^h	141.729	11	41 ± 9

Figure 8 shows the detailed activity for 10-minutes intervals by using four stations. The strong outburst began at $\lambda_\odot$ = 141.3° (2021 August 14, 3^{h}30^m UT) and the strong increase was clearly over at $\lambda_\odot$ = 141.42° (August 14, 6^{h}40^m). The peak was observed at $\lambda_\odot$ = 141.479° (August 14, 8^{h}15^m UT) with an estimated ZHR_r = 269 ± 6. The decreasing of the activity started after $\lambda_\odot$ = 141.492° (August 14, 8^{h}35^m UT).

[2] http://www5f.biglobe.ne.jp/~hro/Flash/2021/PER/index-e.htm

[3] http://www.cbat.eps.harvard.edu/iau/cbet/005000/CBET005016.txt

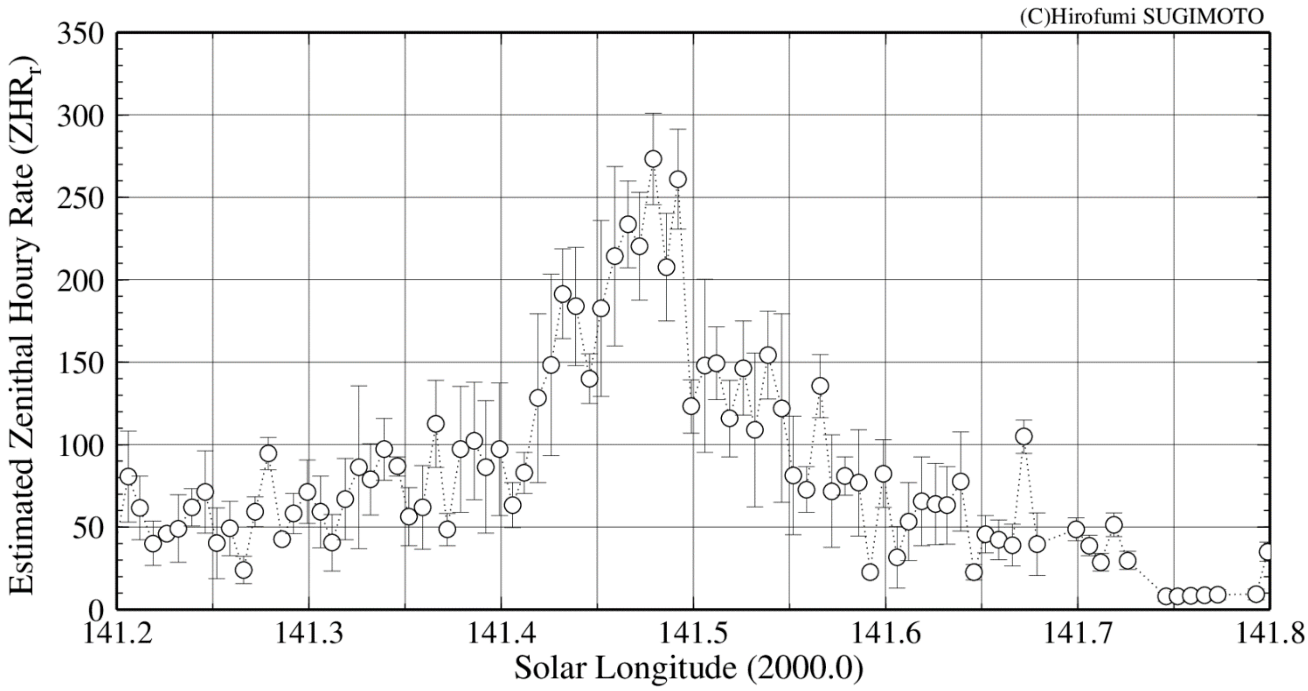

Figure 8 – A detailed estimated ZHR_r curve for the Perseids 2021, based on radio observations from Jochen Richert (Switzerland), Istvan Tepliczky (Hungary), Felix Verbelen (Belgium) and Giuseppe Massimo Bertani (Italy).

Table 2 – The population index *r* for the Perseids 2021 August 14, between 05^h50^m en 11^h47^m UT.

Period	$Time_m$	$\lambda_\odot$ (°)	*r* [–2;+5]	±	*r* [–1;+5]	±
05^h50^m–07^h00^m	6.42	141.405	2.29	0.28	2.55	0.28
07^h00^m–08^h00^m	7.50	141.448	2.39	0.15	2.54	0.15
08^h00^m–09^h00^m	8.50	141.488	2.55	0.13	2.62	0.13
09^h00^m–10^h10^m	9.58	141.532	–	–	3.09	0.19
10^h45^m–11^h47^m	11.27	141.599	–	–	2.66	0.47

3 Visual ZHR analysis

Using the visual observations of Pierre Martin, the first author obtained a provisionally determined maximum *ZHR* of 205 ± 20 (population index *r* based on CAMS data, this was *r* = 3.2). The *ZHR* is slightly higher than the *ZHR* based on CAMS data and somewhat lower than the *ZHR* based on radio observations. Six observers have observed the outburst, in addition to Pierre Martin, these were Robert Lunsford (California US, only the last part of the outburst), Terrence Ross (Texas, US), Gabriel Hickel (Brazil), Bruce McCurdy (Canada) and Paul Martsching (Iowa, US). Terrence Ross' observation around the maximum is also impressive: he counted 20 Perseids in 7 minutes with limiting magnitude 6.2 and a radiant height of only 38 degrees! Unfortunately, the observations of Bruce McCurdy and Gabriel Hickel do not meet the requirements for a good observational set (too low limiting magnitudes and/or too high coverage of clouds). McCurdy's observations unfortunately had too low limiting magnitudes caused by smoke from distant wildfires, just like in 2019. Using the data of the observers Lunsford, Martin, Martsching and Ross, both population index *r* and *ZHR* could be calculated.

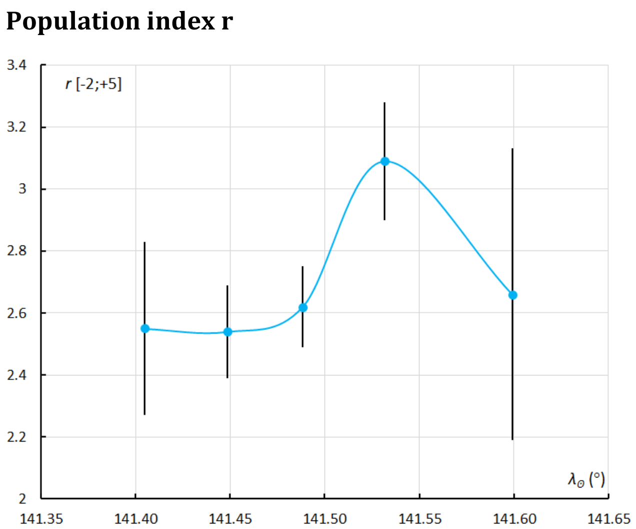

Figure 9 – Population index *r* Perseids August 14, between 05^h50^m and 11^h47^m UT.

To calculate the population index *r*, we first checked whether the observational data meets certain requirements, which are:

- The limiting magnitude must be, rounded off, at least 5.9.

- The difference between the limiting magnitude and the average magnitude of the meteors should not exceed 4 magnitudes.

Most of the data was satisfactory. For the analysis of the population index *r*, 636 Perseids could be used. The results are shown in *Table 2* and *Figure 9*.

Zenithal Hourly Rate

As with the determination of the population index *r*, the observational data must meet certain requirements for the ZHR calculations. These criteria are:

- The limiting magnitude *lm*, rounded off, had to be minimum 5.9 or better;
- The radiant elevation *h* has to be at least 25 degrees or higher;
- 15–20-minute counts were used for this analysis. Shorter consecutive counting periods were added together. Short isolated periods were not used;
- A known C_p was used or calculated for all observers whose data has been included in this analysis;
- Extreme outliers were removed.

A total of 831 Perseids were used in this ZHR analysis. The results of the calculations are shown in *Table 3* and *Figure 10*. To calculate the *ZHR* we use the formula:

$$ZHR = \frac{n \cdot r^{6.5-lm}}{(\sin h)^{\gamma} \cdot C_p \cdot T_{eff}}$$

The zenith exponent *γ* has been taken equal to 1.0. The above calculated population index *r* [–1;+5] was used for the ZHR calculations.

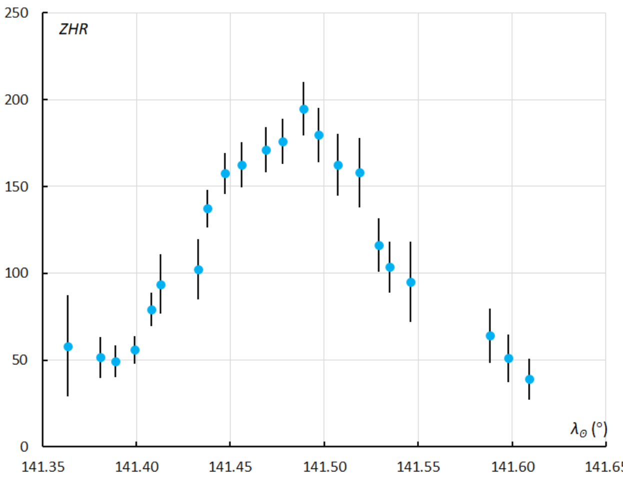

Figure 10 – ZHR values based on visual observations of the Perseids 2021 August 14, between 05h and 12h UT.

From these observations we calculated a maximum *ZHR* of 195 ± 15 at $\lambda_{\odot}$ = 141.489°. This is very close to the values found by CAMS and radio observations. Assuming a normal *ZHR* of 45 around this solar longitude, the extra activity due to the passage through this dust trail corresponds to a *ZHR* 140, in good agreement with the results based on CAMS, finding an extra *ZHR* of 130. In *Figure 11* we see the *ZHR* curve combined with the population index *r* [–1;+5]. This shows that the maximum consisted mainly of weak Perseids of +3, +4 and +5. At that moment, the *r* value was much higher than in the hours before and after the outburst.

Table 3 – ZHR values based on visual observations of the Perseids 2021 August 14, between 05h and 12h UT.

Hour UT	$\lambda_{\odot}$ (°)	*N*	*PER*	*ZHR*	±
5.38	141.363	1	4	58.1	29.1
5.82	141.381	3	19	51.5	11.8
6.01	141.389	4	28	49.2	9.3
6.27	141.399	5	47	55.8	8.1
6.48	141.408	5	66	79.2	9.7
6.63	141.413	2	30	93.7	17.1
7.10	141.433	2	35	102.4	17.3
7.23	141.438	5	161	137.3	10.8
7.47	141.447	6	180	157.6	11.7
7.73	141.456	5	154	162.4	13.1
8.03	141.469	5	174	171.1	13.0
8.25	141.478	6	180	176.0	13.1
8.51	141.489	7	157	194.8	15.5
8.72	141.497	7	131	179.7	15.7
8.98	141.507	5	84	162.5	17.7
9.26	141.519	4	62	157.9	20.1
9.50	141.529	5	56	116.2	15.5
9.68	141.535	4	50	103.5	14.6
9.93	141.546	1	17	95.3	23.1
11.00	141.588	2	17	64.0	15.5
11.25	141.598	2	14	51.0	13.6
11.51	141.609	2	11	39.0	11.8

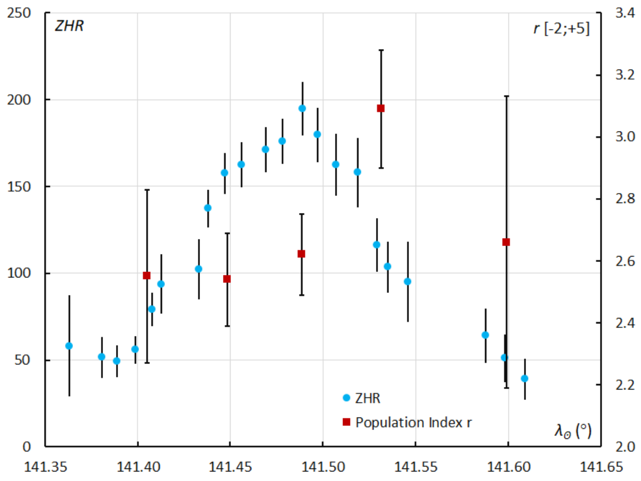

Figure 11 – Combined *ZHR* and population index *r* curve Perseids 2021 based on visual observations.

Photographic ZHR for the Perseids

Meteor observer Pierre Martin also used a camera during the Perseids outburst. The camera was a Canon 6D in combination with a Rokinon 14 mm F2.8 lens. The camera was set to iso 6400- and 20-seconds exposure time. The

Figure 12 – A magnificent composite image of the 2021 Perseid outburst on August 14 made by Pierre Martin at Westmeath Lookout, Ontario in Canada. Between 06^h50^m and 09^h00^m UT the camera took 364 continuous exposures on which 282 meteors were found (courtesy Pierre Martin).

camera worked completely automatically for the rest of the night. Between 06h50m and 09h00m UT the camera took 364 continuous exposures on which 282 meteors were found. These images were also the base for the magnificent composite image made by Pierre[4] (*Figure 12*).

Pierre also supplied a list with the number of Perseids per image with a time indication. To determine the photographic ZHR, the 20-second counts were summed to 15-minute counts. This way a ZHR determination was made every ten minutes in partially overlapping periods. Determining a photographic ZHR is only possible if the weather conditions remain exact the same. That means no clouds, haze, fog, moonlight or emerging twilight. The camera must be pointed exactly at the same point during the entire period (unguided) and settings may not be adjusted.

ZHR values may have been slightly higher after 8h10m UT due to a minimal increasing twilight. Corrections have only been made for radiant height and not for C_p, population index r and limiting magnitude lm. The purpose of this ZHR determination was not so much to determine the ZHR but more to see where the maximum photographically took place. The photographic maximum occurred at at $\lambda_{\odot} = 141.470°$ very close to the time of the visual and radio maxima. See also *Figure 13*.

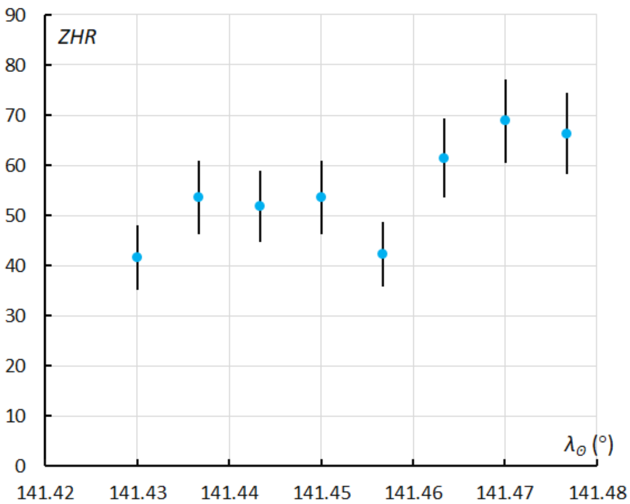

Figure 13 – The photographic ZHR for the Perseid outburst of 2021 August 14.

Comparison between the visual ZHR and radio estimated ZHRr's

Figure 14 was created from *Tables 1 and 3*, this graph shows both the radio estimated ZHR_r and the visual *ZHR* observations. How the radio estimated ZHR_r is determined is described in Sugimoto (2017). The excellent agreement between the two graphs is remarkable. It seems that with the Perseids it is quite possible to make comparisons between these two very different methods of observation. The ZHR_r's based on radio observations are slightly higher, but the characteristics of both curves are almost the same. It is possible that the higher ZHR_r was caused by other minor showers or different characteristics between radio and visual observing such as the observed portion of the sky and the limiting magnitude. The numbers of meteors observed with radio observations depend on several factors for example, the used radio frequency, the speed and size of the meteoroid, etc.

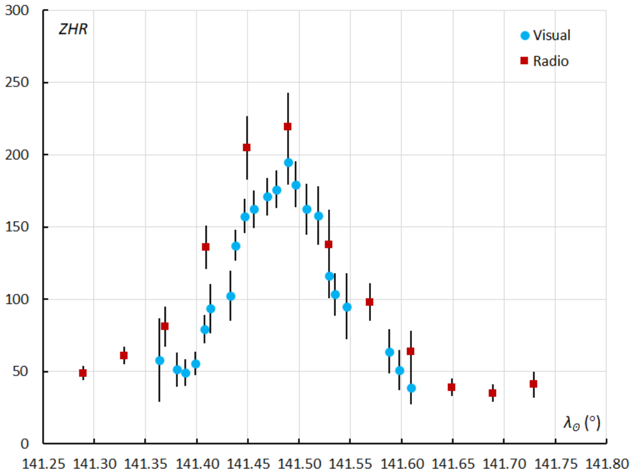

Figure 14 – Comparison of the visual *ZHR* and estimated radio ZHR_r.

Since Pierre Martin had the best conditions during his observations (high transparency and limiting magnitude 6.65), we also compared his calculated visual *ZHR* based on 10-minute counts, with the radio estimated ZHR_r based on 10-minute counts. The result is shown in *Figure 15*. Both methods find higher ZHRs and exact the same peak times. Just like in *Figure 14*, the radio estimated ZHR_r is about 10–15% higher.

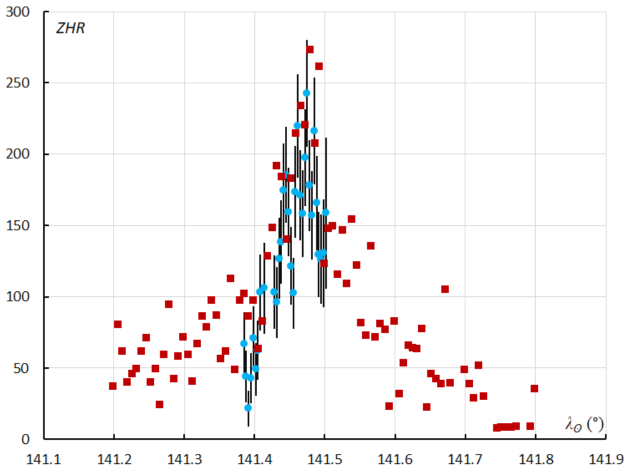

Figure 15 – Visual *ZHR* based on 10 minute counts from Pierre Martin (blue dots) compared with the radio estimated ZHR_r (orange dots) based on 10 minute counts of radio observations.

4 Discussion

It is difficult to determine from this dataset which structure (dust trail?) is responsible for this strong outburst. Is it the same structure that has started to cross the Earth's orbit since 2018, or are these different structures or dust trails that are active? Peter Jenniskens gives the appearance of the

[4] https://pmartin.smugmug.com/Astronomy/20211408-Perseids-at-Westmeath-Lookout-Ontario/

Table 4 – Overview outbursts of the Perseids in 2018–2021.

	Visual			Radio		
Year	$\lambda_{\odot}$ (°)	*ZHR*	Pop. index *r*	$\lambda_{\odot}$ (°)	ZHR_r	Remarks
2018	140.935	85.5±5.7	*r* [–2;+5] 2.06 ± 0.05	–	–	No trace of outburst in radio data!
2019	–	–	–	141.020	81 ± 4	No visual observations
2020	140.632	80 ± 15	*r* [–2;+5] 2.31 ± 0.28	140.612	84 ± 10	Three peaks Pierre Martin
	140.711	91 ± 16	*r* [–2;+5] 2.49 ± 0.30	140.772	89 ± 6	Three peaks Pierre Martin
	140.765	91 ± 17	*r* [–2;+5] 2.76 ± 0.28			Three peaks Pierre Martin
2021	141.489	195 ± 16	*r* [–1;+5] 2.76 ± 0.22	140.495	220 ± 20	CAMS, radio, visual observations

filament structure as a possible reason (Jenniskens, 2021). But what does this mean for the predictions for the filament structure in the Perseids meteoroid stream in the book by Jenniskens (Jenniskens, 2006, page 659 table 5d)?

Most of the peaks in *Table 4* and *Figure 15* appear to show similarities. First, the 2018 and 2019 outbursts, which are similar in maximum ZHR and duration. The 2020 outburst is different in that regard and is more like the 2016 August 11–12 Perseid outbursts when the Earth passed through multiple dust trails. It is noticeable that with each peak in 2020 the population index is higher than during the previous peak. If we disregard the outburst of 2020, it is noticeable that each peak of 2018, 2019 and 2021 falls somewhat later in solar longitude. For this reason, a search was done in the IMO visual database 2020 Perseids. However, no abnormal Perseid activity was found in 2020 during the interval $\lambda_{\odot}$ = 141.24° and 141.5° (European data).

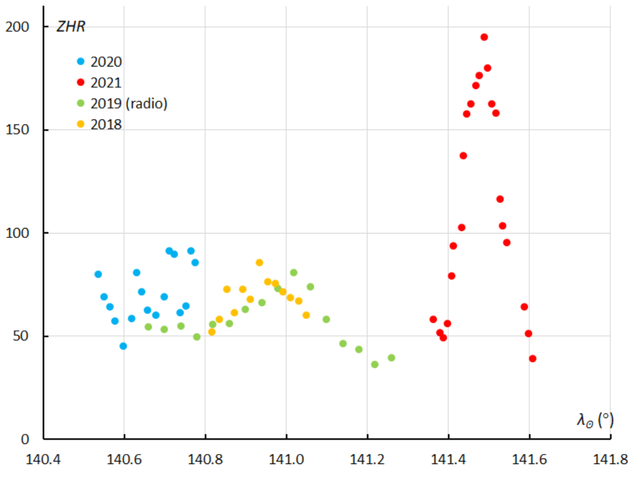

Figure 16 – A combined ZHR graph with the Perseid outbursts in 2018, 2019, 2020 and 2021.

5 Conclusion

In 2018, 2019 and 2020, the Perseids showed modest outbursts between $\lambda_{\odot}$ = 140.60° and 141.60°. In 2021, the Perseids showed a major outburst at $\lambda_{\odot}$ = 140.47°. It is not yet clear what mechanism(s) are behind these outburst(s). The Perseid meteor shower seems like a suitable meteor shower to combine both visual and radio observations.

Visual meteor observers are recommended to observe a little longer after the traditional Perseid maximum. You might be in for a surprise!

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A modest Aurigid outburst in 2021

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In this article the results are presented, based on visual observations of the Aurigids in 2021. The visually observed maximum was at $\lambda_{\odot}$ = 158.381° (August 31, 2021 at 21^h16^m UT) while the radio observations gave $\lambda_{\odot}$ = 158.402° (August 31, 2021 at 21^h45^m UT). Thus, the visual first maximum is close to the time predicted by Sato (August 31, 2021 at 21^h16^m UT), while the radio peak and the second visual peak are closer to the predicted time by Lyytinen and Vaubaillon (Rendtel et al., 2019).

1 Introduction

August 2021 turned out to be a special month for meteor observers. During this month, three meteor showers displayed increased activity, the Perseids showed a strong and unexpected outburst with a ZHR of 195 ± 20 on August 14 (Jenniskens and Miskotte, 2021a; Miskotte et al., 2021), the kappa Cygnids showed increased activity as expected (Jenniskens, 2021b), and the Aurigids showed a short outburst as expected on August 31 (Ogawa, 2021).

The Aurigids are a minor meteor shower with fast meteors (66 km/s) which has its maximum around August 31, usually with a ZHR of 5. In the past this meteor shower has shown several small outbursts, including in 1994 and 2007. In (Rendtel, 2019), a nice overview has been given. In 2019, the Aurigids showed another short outburst with a ZHR of 62 ± 12 at $\lambda_{\odot}$ = 157.918° (August 31, 2019 21^h22^m UT) (Rendtel et al., 2019). The outburst was also detected with radio and video observations. Based on model simulations, another outburst was predicted on August 31, 2021 between UT 21^h and 22^h UT. Indeed, the Aurigids displayed a moderate outburst once again, this article gives the results of the analysis.

2 Predictions

For 2021, independent predictions from different modelers, Jeremy Vaubaillon, Mikiya Sato, and Esko Lyytinen (†2020) were available. All modelers found a very short distance between the Earth and the dust trail. Determining the expected maximum ZHR turned out to be somewhat more difficult, because of the assumed ejection rates of the particles from the parent body. The expected maximum ZHR would be somewhere between 50 and 100.

The times shown in *Table 1* were especially favorable for Asia and eastern Europe, but the problem was that the Moon around the maximum was also above the horizon and even near the radiant. The problem for European observers was the very low radiant position, but they had the advantage that the Moon would only rise roughly a half hour after the expected maximum.

Table 1 – Predictions for the Aurigids in 2021.

	Distance AU	$\lambda_{\odot}$ (°)	Date and time UT
Sato	0.00054	158.383	2021 Aug.31, 21^h17^m
Lyytinen	0.00017	158.395	2021 Aug.31, 21^h35^m
Vaubaillon	0.0001	158.396	2021 Aug.31, 21^h35^m

3 Which data to use?

Looking at the website of the International Meteor Organization for data of the Aurigids, it appeared that it would be a difficult analysis. This is mainly due to the low radiant heights, although this has the advantage for visual observers that more earthgrazers can be seen. In standard ZHR analyses, calculations are usually made only for observations with a minimum radiant height of 25°. The data available on the IMO site was obtained with radiant positions between 3° and 15° during the period of maximum activity.

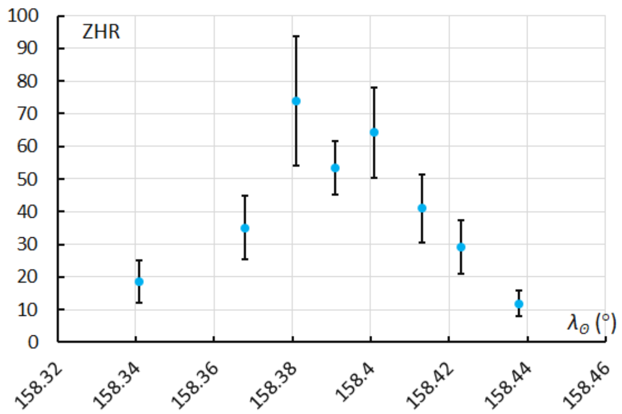

Figure 2 – On the fly curve from the IMO website of the Aurigids during maximum activity[5].

[5] https://www.imo.net/members/imo_live_shower?shower=AUR&year=2021. This image was generated on September 12, 2021 at 09^h45^m UT.

Figure 2 – A magnitude –4 Aurigid fireball, photographed August 31, 2021 at 21^h34^m UT. Photographer: Kai Gaarder from southern Norway.

Former experience with very low radiant positions learned that computing ZHRs only gives a somewhat reliable results if an observer has a reasonable number of shower meteors, the limiting magnitude is high and a good C_p determination is available for the observer. According to the data on the IMO website, 240 Aurigids were counted by 36 observers over the entire Aurigid activity period (August 30 to September 7, 2021). During the maximum, 129 Aurigids were seen. The IMO on the fly curve shows a nice activity profile, with an assumed population index *r* of 2.2 with a minimum limiting magnitude of 5.0. A maximum was found at λ_O = 158.381° (2021 August 31, 21^h17^m) with a ZHR of 74 ± 20. See *Figure 1*.

Because the graph in *Figure 1* has been generated using most data with a limiting magnitude of 5.0 or better, the author decided to do an analysis based on more restricted conditions. The data was selected using the following criteria:

- An observer must have observed at least 8 Aurigids during the maximum period.
- The minimum limiting magnitude must be 6.0 or better.
- No minimum radiant height was set due to the very limited data set.
- Data must be supplied in short counting periods around the maximum.
- Sky obstruction correction factor was accepted up to a maximum of *F* = 1.10.
- A reliable C_p must be known for the observer.
- The periods with 0 detections for the selected observers were also included in the calculations.

Unfortunately, of the 35 observers only 5 observers remained, who altogether observed 87 Aurigids.

4 Population index *r*

To determine the population index, the data must meet certain requirements. These are:

- The limiting magnitude rounded off, must be at least 6.0.
- The difference between the limiting magnitude and the mean magnitude of the meteor shower should be less than 4 magnitudes.

71 Aurigids met the criteria described above and the population index *r* was determined on the basis of this set. The dataset was too small to calculate a gradient. What the visual observers described is correct, relatively many Aurigids from –1 to +1 were seen. This, of course, results in a low population index *r*. *Table 2* presents the result of the population index *r* calculations.

Table 2 – Population index *r* for the Aurigids on 31 August 2021.

Range	r
r [–2;+5]	2.03 ± 0.27
r [–1;+5]	1.90 ± 0.27
r [–1;+4]	1.58 ± 0.30
r [0;+4]	1.6 ± 0.32
r [0;+5]	2.04 ± 0.29
r [+1;+5]	2.34 ± 0.32

For the ZHR calculations the range *r* [–1;+5] was used, with a population index $r = 1.90$.

5 Zenital Hourly Rate (ZHR)

With the calculated population index *r*, the ZHR could be calculated. The ZHR is calculated using the following formula:

$$ZHR = \frac{n \cdot r^{6.5-lm}}{(\sin h)^{\gamma} \cdot C_p \cdot T_{eff}}$$

The radiant height correction exponent γ was set to 1. This surprisingly yielded a very nice result, see *Table 3* and *Figure 3*. However, this result should be interpreted with caution because:

- The observations were made with very low radiant heights between 3° and 20°, see also the large error bars in the graph (*Figure 3*)
- The ZHR curve is based on “only” 87 Aurigids.
- Because the counting periods stated by the observers varied quite a bit (between 9 and 15 minutes), weighted average ZHRs were used.
- Overlapping periods have been calculated.

Table 3 – ZHR of the Aurigids on August 31, 2021 between 19^h and 23^h UT. *P* is the number of intervals.

Time UT	$\lambda_\odot$ (°)	*P*	AUR	ZHR	Obs.
19.834	158.324	2	2	27.1 ± 19.2	2
20.167	158.337	3	3	27.0 ± 15.6	3
20.375	158.345	4	3	24.3 ± 14.0	4
20.694	158.358	3	3	33.9 ± 19.6	3
20.859	158.365	5	3	34.9 ± 20.1	4
21.013	158.371	6	6	28.5 ± 11.6	4
21.133	158.376	6	15	72.8 ± 18.8	5
21.264	158.381	7	20	90.6 ± 20.3	4
21.364	158.385	8	22	84.4 ± 18.0	4
21.509	158.391	8	20	74.8 ± 16.7	4
21.633	158.396	7	14	60.1 ± 16.1	5
21.749	158.401	8	12	36.4 ± 10.5	6
21.868	158.406	6	6	21.4 ± 8.7	4
22.006	158.411	6	12	48.3 ± 13.9	6
22.108	158.415	4	12	68.3 ± 19.7	4
22.208	158.419	3	8	50.9 ± 18.0	3
22.406	158.427	3	4	18.2 ± 9.1	3
22.489	158.431	3	5	21.4 ± 9.6	3
22.663	158.438	3	6	25.1 ± 10.2	3
22.724	158.440	2	3	19.1 ± 11.0	2
22.919	158.448	3	3	8.6 ± 5.0	3

The ascending wing to the peak shows a kind of a plateau between $\lambda_\odot = 158.324°$ and 158.372° (this is on August 31, 2021 between 19^{h}50^m and 21^{h}00^m UT) with an average ZHR of 30. After that a double peak is clearly visible is at $\lambda_\odot = 158.381°$ (August 31, 2021 at 21^{h}16^m UT) and $\lambda_\odot = 158.415°$ (August 31, 2021 at 22^{h}06^m UT). This was already somewhat visible in the IMO curve (*Figure 1*), but appears somewhat extended in this analysis. The second peak of the IMO on the fly curve is also slightly earlier than in this analysis. Indeed, most observers temporarily saw fewer meteors between $\lambda_\odot = 158.40°$ and 158.41° (August 31, 2021 between 21^{h}45^m and 22^{h}00^m UT). After the second peak there was again a kind of (short-lived) plateau with ZHRs in the range of 20–25 between $\lambda_\odot = 158.427°$ and 158.440° (August 31, 2021 between 22^{h}25^m and 22^{h}45^m UT) after which a further decline seems to occur.

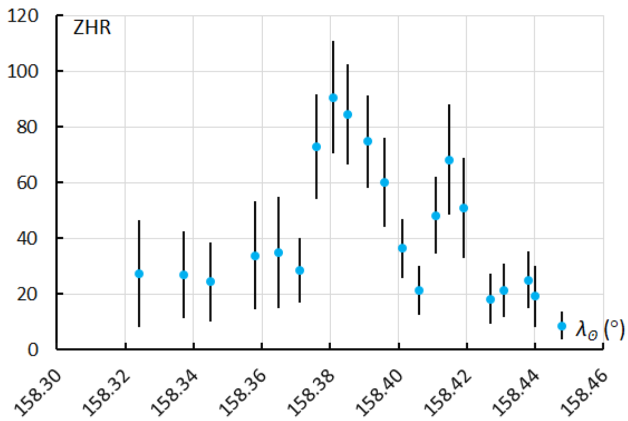

Figure 3 – ZHR profile Aurigids on August 31, 2021 based on 87 Aurigids.

A nice independent analysis has now also been published in WGN the Journal of the IMO (Rendtel et al., 2021). Slightly different parameters were used in this study and a minimal number of Aurigids was not considered. The limiting magnitude was set at 5.5. A population index $r = 1.65$ was found. This is lower than found in this analysis with an $r = 1.90$. The result of these calculations is shown in *Figure 4*. The maximum was found to be at $\lambda_\odot = 158.384°$, or 2021 August 31, 21^{h}18^m UT with a maximum ZHR of 74 ± 17. The ZHR is also somewhat lower than found in this analysis, so probably also some other parameters should be considered such as more 0 detection intervals and the lower population index *r*. The second peak in the IMO analysis is

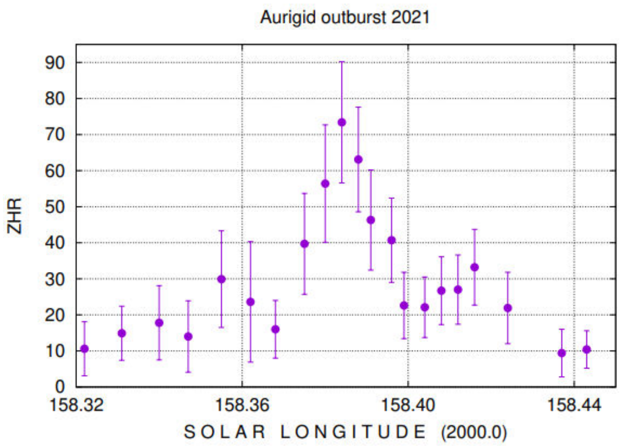

Figure 4 – ZHR profile of the Aurigid outburst based on visual observations sent to the VMDB. Some observers provided shorter counting periods than visible in the VMDB upon request.

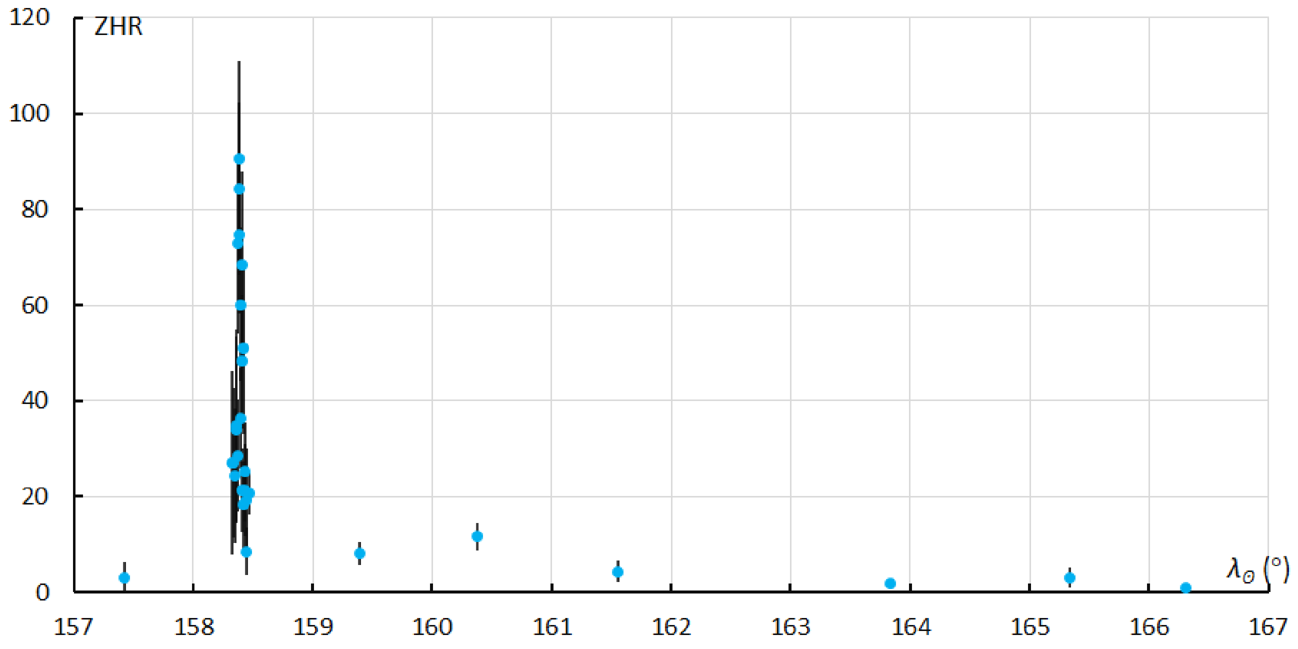

Figure 5 – The activity of the Aurigids between August 30 and September 9, 2021.

considerably lower than the one found in this analysis (ZHR 33 instead of 68). The explanation for this is that in the IMO analysis more observers were used who registered also more 0 detection intervals.

It is unfortunate that the email addresses of observers submitting data to the VMDB are unknown to the author. Some of the data in this analysis was not used due to excessively long observation periods and the author could have contacted the relevant observers to ask for shorter counting intervals.

Finally, the visual data that came in before and after the maximum night was also used for analysis. Because of the disturbing Moon, all observations with radiant heights of 10° or higher were used. The result is shown in *Figure 5*. It appears that the Aurigids still showed some above-normal activity on September 1 and 2 with ZHRs of 8 and 11, respectively.

6 Comparison with radio observations

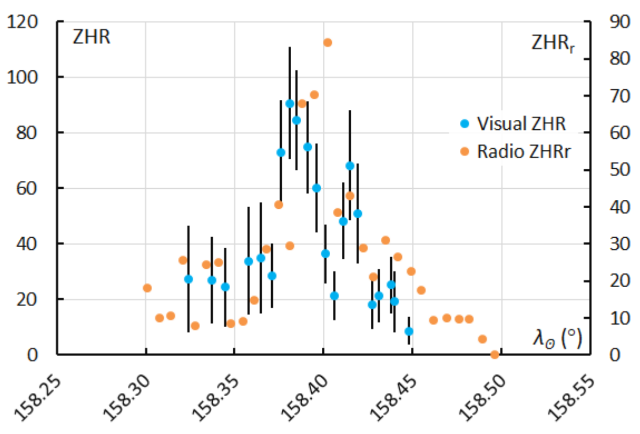

Figure 6 – Visual (ZHR) and radio (ZHR$_r$) observations combined in one figure.

Thanks to Hiroshi Ogawa and Hirofumi Sugimoto, the author received the radio observations (ZHR$_r$) from Japanese radio observers based on 10-minute counts (Ogawa, 2021). The way in which Sigumoto determines his ZHR_r is described in (Sugimoto, 2017). Some of the data overlaps with the visual data used in the above analysis. *Figure 6* shows the result.

This shows that there is a reasonably good agreement between the two graphs. In any case, it shows that the ZHR curve based on visual observations, despite the low radiant positions, is quite reliable. The visually observed maximum was at $\lambda_{\odot}$ = 158.381° (August 31, 2021 at 21^{h}16^m UT) and with radio at $\lambda_{\odot}$ = 158.402° (August 31, 2021 at 21^{h}45^m UT). Thus, the visual first maximum is close to the time predicted by Mikiya Sato (August 31, 2021 at 21^{h}16^m UT), while the radio peak and the second visual peak are closer to the predicted time by Esko Lyytinen and Jeremy Vaubaillon. But of course, we also have to bear in mind that the results of the models with only an 18-minute interval are very close to each other. The radio data also shows a second peak around the second visual peak. However, the "dip" between the two radio "peaks" is much less deep than the "dip" between the visual peaks.

7 Conclusion

All in all, a nice result considering that the observations were made with very low radiant heights. Good C_p determinations and observations done under good conditions are very important in cases like this. Comparison with radio observations gives good overall agreement, but looking at the details there are still differences (such as time of maximum). The low number of Aurigids used in this analysis may explain these small differences.

Acknowledgment

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First detection of the Arid (ARD, #1130) meteor shower from comet 15P/Finlay

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The predicted new meteor shower from crossing the 1988 and 1995 dust trails of Jupiter-family type comet 15P/Finlay on September 27–30, 2021, materialized and was recorded by CAMS video-based meteoroid orbit survey networks in New Zealand and Chile. The new shower is called the “Arids”, with meteors radiating from the constellation Ara, the Altar. The median radiant position of the first 13 shower members observed was at R.A. = 262.7 deg., Decl. = –57.5 deg. (Equinox J2000.0) with geocentric entry speed v_g = 10.8 km/s, but the shower was ongoing when this report was made. A potentially more intense shower is expected during the crossing of the 2014 dust trail on October 7, 2021.

1 Introduction

Jupiter-family comet 15P/Finlay does not pass far from Earth’s orbit but until now did not have an associated meteor shower (e.g., Beech et al., 1999). Indeed, dust trails created following past returns to the inner solar system did not wander into Earth’s path as far back as 1965, according to calculations by M. Maslov (2009)[6]. That changed this year. Calculations by S. Shanov and S. Dubrovski, reported in Jenniskens (2006), first predicted that dust tails would be in Earth’s path on 2021 September 27 around 6^h14^m UT (1988 dust trail) and on September 28, 18^h58^m UT (1995 dust trail). Since that time, better predictions were made by Maslov (2009), Sato (2009)[7], Ye et al. (2015), and Vaubaillon (2020).

The upcoming October 6 and 7 encounters with the 2014 dust trail are especially interesting. Ye et al. (2015) pointed out that comet 15P/Finlay had two cometary outbursts of activity during that return, which could translate into a more dense dust trail. As a result, their predictions for this year’s meteor shower have ZHR peak at 600–1100 per hour. The most recent update of expected rates is given in Ye et al. (2021).

2 The observations

These predictions have gotten more urgency now that in the past few nights CAMS video-based meteoroid orbit survey networks in New Zealand and Chile have detected the first two of these predicted encounters. These were meteor outburst caused by Earth encountering debris ejected from comet 15P/Finlay during its perihelion passage in 1988 and 1995. The shower was clearly detected from September 27 to 30. These are the first meteors observed from comet

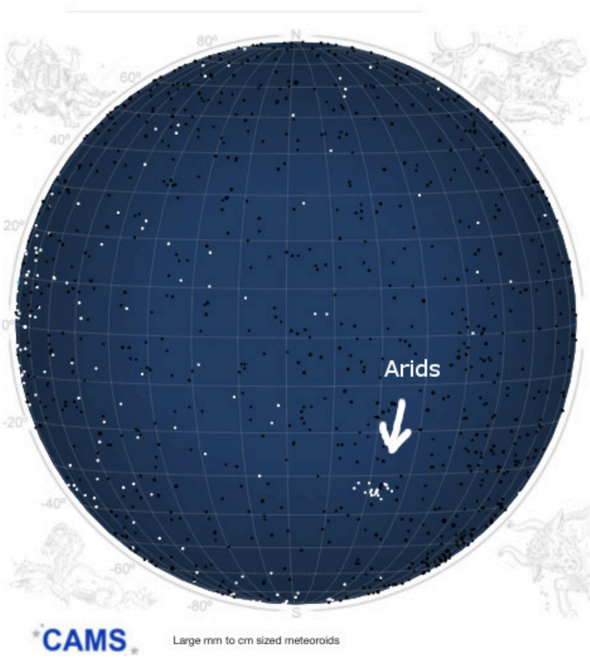

Figure 1 – The Arid radiants detected by CAMS 2021 September 29–30.

[6] http://feraj.ru/Radiants/Predictions/1901-2100eng/Finlayids1901-2100predeng.html (last accessed 2021-09-30)

[7] In a deleted post on a Yahoo group message board. (see: Ye et al. 2015).

15P/Finlay. The shower was added to the IAU Working List of Meteor Showers under number 1130 and name “Arids” (ARD), because the meteors radiated from the southern constellation Ara, the Altar[8].

In a recent CBET telegram (Jenniskens et al., 2021), we reported that CAMS New Zealand, with stations operated by I. Crumpton, C. Duncan, and N. Frost and the network coordinated by J. Baggaley of the University of Canterbury at Christchurch, triangulated 9 Arids between 2021 Sept. 28 08^h40^m and 17^h18^m UT, while CAMS Chile, with stations operated by J. Rojas, E. Jehin and T. Abbott and the network coordinated by S. Heathcote of AURA/Cerro Tololo, triangulated 4 Arids between 2021 Sept. 28, 23^h49^m and Sept. 29, 03^h45^m UT. Observations continued until 09^h33^m UT, but at that time the radiant had long set. Other southern hemisphere CAMS networks had poor weather. At the time of writing, the outburst was ongoing.

The meteors observed to that point radiated from R.A. = 262.7°, Decl. = –57.8° (Equinox J2000.0) with geocentric entry speed v_g = 10.8 km/s from a direction with few sporadic meteors (see *Figure 1*). The observed median orbital elements of the 13 meteors, centered on solar longitude 185.27°, are given in *Table 1* and are compared to the orbit of comet 15P/Finlay at the Epoch 2014-Nov–08.0 (TDB).

Table 1 – The orbit of the Arids (ARD#1130) compared to orbital elements comet 15P/Finlay had at Epoch 2014-Nov-08.0 (Equinox J2000.0).

	Arids	15P/Finlay
Epoch	2021-Sep-28.5	2014-Nov-08.0 TDB
a	3.53 AU	3.49 AU
q	1.0010 ± 0.0004 AU	0.976 AU
e	0.717 ± 0.042	0.720
i	9.10 ± 0.54°	6.80°
ω	356.1 ± 1.01°	347.55°
Ω	5.28 ± 0.29°	13.78°

Figure 2 – Two Arid meteors, caused by debris from comet 15P/Finlay entering Earth's atmosphere, captured by cameras of the Cerro Tololo station of the CAMS Chile network at 04^h51^m UT on 2021 September 29. Photo: P. Jenniskens/SETI Institute and S. Heathcote/AURA Cerro Tololo.

[8] http://cams.seti.org/FDL/ for dates of 2021 Sep. 29 and 30.

These meteors were mostly faint, with a magnitude distribution index of 4.7 ± 0.8. The shower was also detected by the SAAMER radar. Bruzzone et al. (2021) reported that activity lasted for about 3 hours and was centered on Sept. 29, 03^h32^m UT (solar longitude 185.92°). Over 100 Arids orbits were measured.

The meteors from the 1995 dust trail crossing were predicted to radiate from geocentric radiant R.A. = 261.1°, Decl. = –57.7°, with v_g = 10.8 km/s during Sept. 29, 02^h30^m to 04^h17^m UT by Maslov (2009)[1] and from R.A. = 260.8 ± 0.9°, Decl. = –57.4 ± 0.5°, with v_g = 10.807 km/s, during the peak on 2021 Sept. 29 at 08^h35^m UT by Vaubaillon et al. (2020). Those of the 1988 dust trail crossing were earlier, on September 27 between 13^h58^m and 16^h22^m UT according to Maslov (2009)[1]. The observed meteors by CAMS are what appear to be the 1995 dust trail crossing, with perhaps also a weak detection of the 1988 dust trail crossing.

The predictions for activity during the 2014 dust trail crossing vary a lot between the different models. Vaubaillon et al. (2020) has the 1995 dust trail crossing being the more intense. The 2008 dust trail would be crossed on 2021 Oct. 07, 00^h35^m UT, followed by an outburst from debris ejected in 2014 centered on 2021 Oct. 07, 03^h55^m UT.

Ye et al. (2015) expects high rates from the upcoming 2014 dust trail crossing on October 7. The expected encounter times are October 7 between 00^h34^m and 01^h09^m UT for the encounter with the first cometary outburst ejecta, and October 6 between 21^h59^m and 22^h33^m UT for the second cometary outburst ejecta.

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A second Arid shower outburst in 2021

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The predicted Arid meteor shower outburst on October 6–7, 2021, caused by Earth encountering the debris ejected by comet 15P/Finlay during its activity outbursts in 2014 and 2015, did materialize. The 2014 outburst dust was documented by CAMS low-light video networks in Chile. The observed activity was higher than that during the 1995-dust trail crossing, especially at small particle sizes, suggesting that the cometary activity had an influence on the density of the 2014 dust trail.

1 Introduction

Models of meteoroid stream formation and evolution predicted that debris from comet 15P/Finlay would move into Earth's path in 2021, possibly creating a number of meteor shower outbursts associated with its returns to perihelion of 1988, 1995, 2008 and 2014/15 (Jenniskens, 2006; Maslov, 2009[9]; Sato, 2009[10]; Ye et al., 2015; Vaubaillon et al. 2020). The first set of outbursts were detected by the CAMS low-light video meteor orbit survey project during September 27–30, 2021 (Jenniskens et al., 2021), and by the SAAMER meteor orbit radar in Argentina (Bruzzone et al., 2021).

The second set of outbursts were expected on October 6–7, 2021, when Earth was to cross the debris ejected in 2008 and 2014/15. Especially the latter was of interest, as Ye et al. (2015) pointed out that the comet had two activity outbursts (also see Ishiguro et al., 2016), an outburst in 2014 that could cause a peak around 00^{h}34^m–01^{h}09^m UT on Oct. 7, and an outburst in 2015 that could cause a peak about two hours earlier around 21^{h}59^m–22^{h}33^m UT on Oct 6. These outbursts could have increased the dust trail density by a factor of 10-20 (Ye et al., 2021). After correction for this, zenith hourly rates as high as 30–100 (M. Sato) and 600–1100 (Ye) meteors per hour were expected.

2 CAMS detection of the 2014 dust trail

The CAMS video-based meteoroid orbit survey networks in Chile, Texas, Namibia and Australia detected this predicted Arid meteor shower outburst caused by Earth encountering the debris ejected by comet 15P/Finlay during its activity outbursts in 2014 and 2015. The night started out partially cloudy in Chile, with the first meteor detected at 23^{h}25^m UTC on Oct. 6. In partial clear skies, and based on the initial automatic reduction of data, a total of 31 Arids were triangulated by CAMS Chile (with network operated by J. Rojas, J. Vilaza, and T. Abbott), 16 by CAMS Namibia (network operated by T. Hanke, E. Fahl and R. van Wyk) , 6 by CAMS Texas (W. Cooney, D. Selle, F. Cyrway, and J. Brewer), and 2 by CAMS Australia (M. Towner, C. Redford and L. Toms) during 2021 Oct. 6, 11^{h}04^m and Oct. 7, 04^{h}10^m UTC[11], corresponding to the solar longitude range 193.12° to 193.83° (Equinox J2000.0).

Centered on solar longitude 193.68 ± 0.17° (Oct. 7, 00^{h}41^m UTC), these meteors radiated from a median geocentric radiant at R.A. = 256.8 ± 0.8°, Decl. = –48.3 ± 0.6°, with geocentric speed v_g = 10.5 ± 0.3 km/s, slightly north-west

[9] "Finlayids 1901–2001: Activity predictions". Website: http://feraj.ru/Radiants/Predictions/ 1901-2100eng/Finlayids1901-2100predeng.html (last accessed 2021-09-30).

[10] In a deleted post on a yahoo group message board. (see: Ye et al. 2015).

[11] http://cams.seti.org/FDL/ for dates of 2021 Oct. 7.

from the 1995-dust ejecta radiant (*Figure 1*), but still in the constellation of Ara. Median orbital elements are:

- a = 3.36 AU
- q = 0.991 ± 0.002 AU
- e = 0.705 ± 0.120
- i = 6.7 ± 1.3°
- ω = 348.3 ± 1.8°
- Ω = 13.69 ± 0.17°

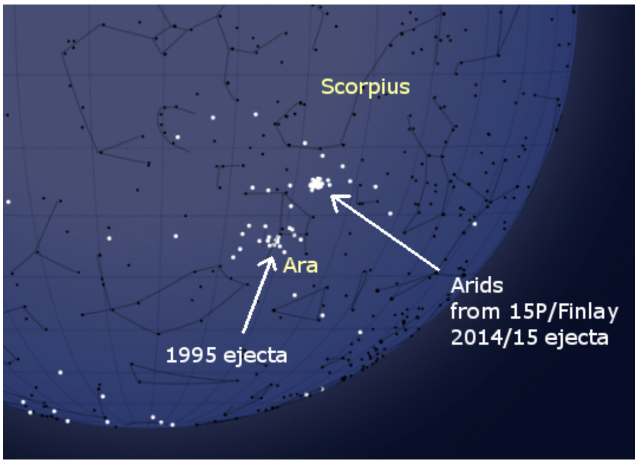

Figure 1 – The radiants caused by 2014 and 2015 comet activity outburst ejecta in CAMS data from October 7, 2021, compared to the radiants of the 1995 ejecta from September 29 (overlaid).

The predicted radiant was at R.A. = 256°, Decl. = –48°, and v_g = 10.7 km/s (Vaubaillon et al., 2020; Ye et al., 2021), in good agreement. Most meteors were faint. The magnitude distribution index was 4.2 ± 0.6. Visual observer T. Cooper, Astronomical Society of Southern Africa, described two +1 and +2 Arids as: "*Both very slow, noticeably orange, and sparkling appearance.*"

3 First impression of other reported observations

The outburst was also detected by radio forward meteor scatter observations, summarized by H. Sugimoto and H. Ogawa of The International Project for Radio Meteor Observations. Results show enhanced rates from solar longitude 193.50° to 193.75°, peaking at 193.7°, corresponding to Oct. 7^d, 01^h UTC[12]. Their preliminary Zenith Hourly Rate is about 80/h. This is in line with predictions by Sato (in Ye et al., 2021).

Visual observer P. Vera of the University of La Serena, in an observing campaign led by J. Vaubaillon of I.M.C.C.E., reported seeing 35 meteors from the constellation Ara between 00^{h}28^m and 01^{h}30^m UT from El Sauce observatory near La Serena in cloudy skies[13]. This may well be in agreement with the radio MS reported ZHR.

The University of Colorado SkiYMET meteor radar at McMurdo Sound in Antarctica detected a significant increase in the radar reflection count peaking around 23^h UT October 6[14]. The slightly earlier peak time is perhaps because of the 2015 cometary outburst having been richer in small particles.

In conclusion, it appears that the cometary outbursts significantly enhanced the dust density in the dust trail of comet 15P/Finlay. A more detailed analysis will be required to translate the observed dust densities and particle size distributions into better understanding the mass loss observed in 15P/Finlay cometary imaging in 2014 and 2015.

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[12] https://iprmo.org/flash/arids-2021.html
[13] https://www.imcce.fr/recherche/campagnes-observations/meteors/2021arids
[14] https://ccar.colorado.edu/meteors/meteors

October zeta Perseid meteor shower (OZP#01131)

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A new long-period meteor shower has been discovered by the Global Meteor Network. The shower experienced a sharp outburst at solar longitude 211.36°, and the peak lasted ~30 min. The median radiant is at R.A. = 58.19°, Decl. = +33.72°, geocentric velocity was v_g = 48.1 ± 0.8 km/s.

1 Introduction

During the night of 2021 October 24–25, more than 500 low-light video cameras of the Global Meteor Network[15] monitored meteor activity worldwide when some unexpected short-lived outburst occurred with a radiant in the constellation of Perseus. The radiant appeared on the radiant plot (*Figure 1*) once the reduction pipeline with the available uploaded camera data was completed. A preliminary investigation was made to verify the origin and nature of these orbits. Obviously, a previously unknown and peculiar meteoroid stream had encountered the Earth.

The shower was independently observed by cameras in 7 different countries (Czechia, Germany, Spain, France, Croatia, the Netherlands, and the UK). The first meteor was observed on Oct 24 at 19^h10^m UTC, and the last one at 22^h13^m UTC. The main bulk of activity was between 20^h30^m and 21^h00^m UTC. The skies were clear before and after, so more would be observed if there were any.

2 Observational data

In total 14 meteors were recorded for this new shower. The meteors (all brighter than magnitude 0) had a median radiant with coordinates R.A. = 58.19°, Decl. = +33.72°, within a circle with the standard deviation of ± 0.52° (equinox J2000.0). The median Sun-centered ecliptic coordinates were $\lambda - \lambda_\odot$ = 211.86°, β = +13.16° (*Figure 2*). The geocentric velocity was v_g = 48.1 ± 0.8 km/s. The mean radiant scatter (standard deviation of offsets from the median radiant) was only 0.52°.

The orbital elements (equinox J2000.0) are those of a sunskirting long-period comet:

- q = 0.082 ± 0.003 AU
- e = 0.998 ± 0.005
- i = 65.2 ± 2.5°
- ω = 326.8 ± 0.8°
- Ω = 211.377 ± 0.030°

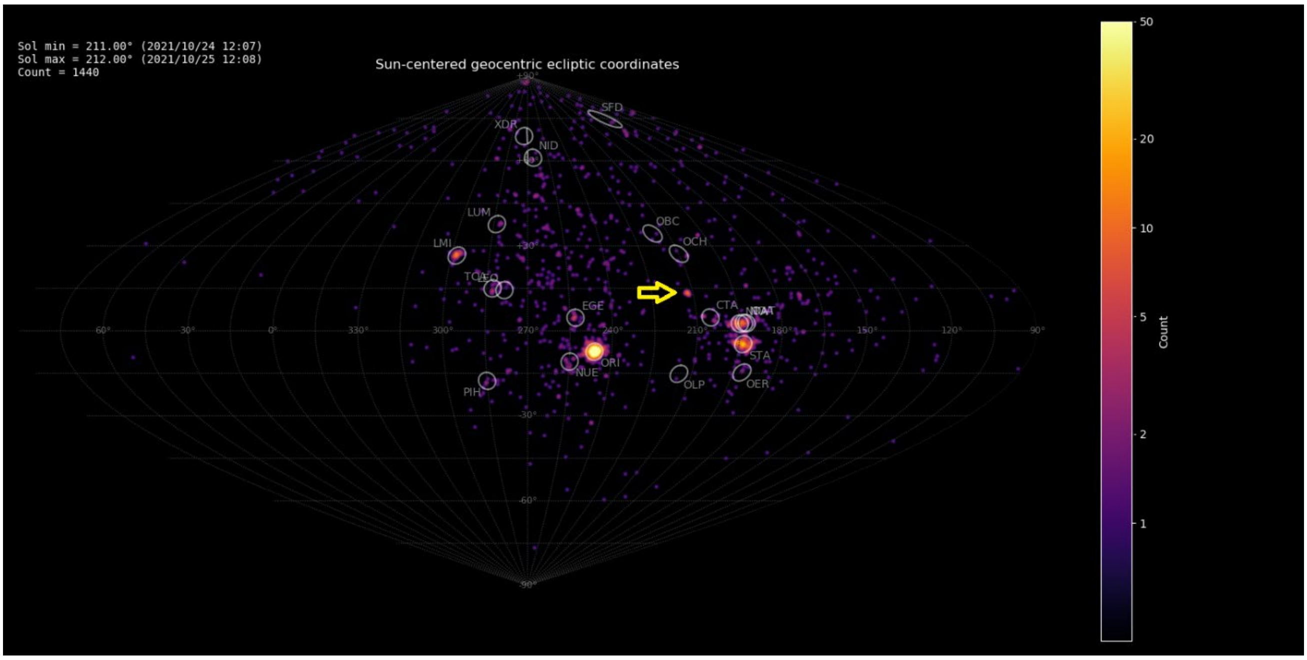

Figure 1 – The unexpected radiant appears as a compact dot at the Sun centered geocentric ecliptic coordinates $\lambda - \lambda_\odot$ = 212°, β = 13.5° on this plot (just above and left of CTA) marked with the yellow arrow.

[15] https://globalmeteornetwork.org

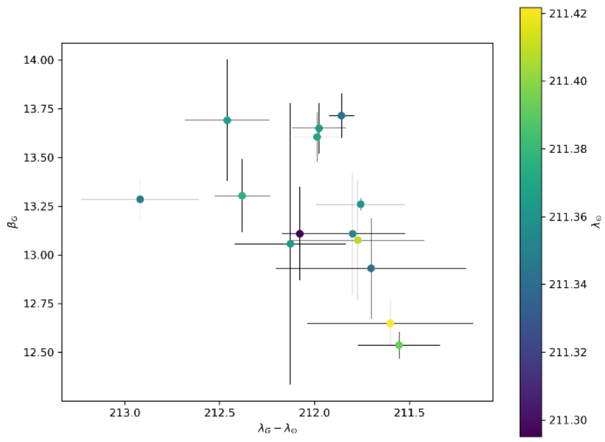

Figure 2 – The radiant distribution in Sun-centred ecliptic coordinates, together with the error bars.

All meteors appeared during the solar-longitude interval 211.30°–211.42°, with a sharp peak at 211.36°. 50% of meteors were observed in 30 minutes, while the whole activity lasted 3 hours (*Figure 3*).

The parent body search did not return any candidates (see *Table 1*). The shower is now listed as number 1131 in the IAU MDC shower database (Jenniskens et al., 2020; Jopek and Kaňuchová, 2017; Jopek and Jenniskens, 2011; Neslušan et al., 2020) and named the October zeta Perseids (OZP). GMN images are shown in *Figures 4 to 12*.

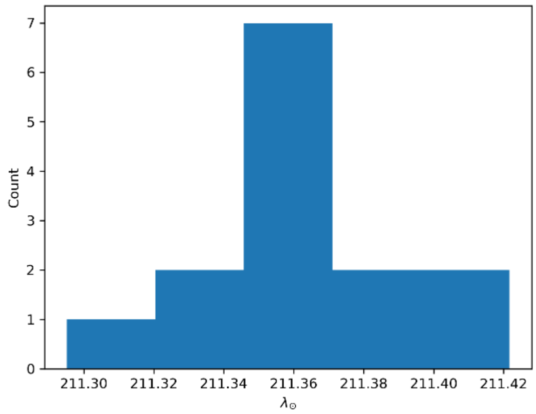

Figure 3 – There was a very sharp peak in activity centred at $\lambda_{O} = 211.36°$.

Table 1 – The top 5 matched sorted by the similarity criteria D_{SH} (Southworth and Hawkins, 1963).

Name	*q* (AU)	*e*	*i* (°)	ω (°)	*Ω* (°)	D_{SH}
C/2004 F4 (Bradfield)	0.168	0.999	63.16	332.786	222.778	0.28
C/2012 T5 (Bressi)	0.323	1.000	72.10	318.094	230.594	0.41
C/1786 P1 (Herschel)	0.411	1.000	50.89	325.052	197.400	0.49
C/1987 W1 (Ichimura)	0.200	1.000	41.62	329.293	226.528	0.51
C/1997 V9 (SOHO)	0.061	1.000	93.76	316.920	219.170	0.53

Table 2 – The 20 possible past detections of October zeta Perseid meteors, D_D is the similarity criteria according to Drummond (1981).

Ref.	MetCod	$\lambda - \lambda_{O}$ (°)	β_g (°)	v_g	*q* (AU)	*e*	*i* (°)	*Ω* (°)	*ω* (°)	D_D
CAMS1	20111028_095057	212.493	14.57	48.15	0.0955	0.9965	67.82	214.46	324.19	0.08
CAMS1	20131025_050721	210.396	12.78	48.01	0.0844	1.0034	59.58	211.76	325.80	0.04
CAMS1	20141024_131029	215.153	13.48	49.06	0.0767	0.9924	77.80	210.85	328.53	0.09
CAMS3	20151101_002811	211.643	13.22	47.00	0.0844	0.9919	60.90	218.04	326.87	0.05
CAMS3	20161022_194340	211.040	13.40	46.04	0.0900	0.9883	57.39	209.61	326.07	0.07
CAMS3	20161101_220616	211.990	14.25	46.56	0.0943	0.9872	61.93	219.69	325.26	0.09
CAMS7	20161030_163130	211.850	14.54	47.28	0.0976	0.9928	63.79	217.45	324.09	0.09
CAMS7	20161031_001752	213.086	14.31	47.17	0.0904	0.9873	66.57	217.78	326.07	0.07
SON	20071023_195831	210.629	13.98	46.42	0.0977	0.9924	58.14	209.92	324.15	0.10
SON	20081028_122944	212.057	14.00	48.53	0.0905	1.0006	66.93	215.34	324.81	0.06
SON	20081101_200903	211.815	13.43	44.52	0.0891	0.9757	55.17	219.66	327.47	0.09
SON	20121029_134257	211.842	13.32	50.64	0.0839	1.0148	71.19	216.37	324.86	0.06
SON	20181028_130055	212.455	14.38	47.85	0.0932	0.9944	66.81	214.80	324.83	0.07
SON	20191022_154529	222.225	16.00	40.37	0.0803	0.9284	70.91	208.67	335.44	0.07
EUS	20141012_233039	212.718	13.92	46.09	0.0877	0.9832	62.97	199.36	327.12	0.09
EUS	20141018_004842	215.789	15.34	46.70	0.0937	0.9740	73.95	204.36	326.72	0.09
EUS	20151024_182441	212.531	13.48	48.14	0.0830	0.9963	67.03	210.81	326.78	0.01
EUS	20151027_195358	210.190	13.37	48.25	0.0914	1.0065	60.36	213.86	324.11	0.06
SON	20201024_141728	213.148	12.80	48.64	0.0738	0.9970	69.59	211.35	328.69	0.06
SON	20201024_165630	214.240	13.49	47.25	0.0776	0.9855	69.64	211.46	329.04	0.04

Figure 4 – October zeta Perseid 2021, October 24, $20^{h}16^{m}07.8^{s}$ UT on CZ0003 at Prague, Czech Republic. (Operator Milan Kalina).

Figure 5 – October zeta Perseid 2021, October 24, $20^{h}16^{m}07.8^{s}$ UT on HR000M at Đakovo, Croatia. (Operator Danko Kočiš).

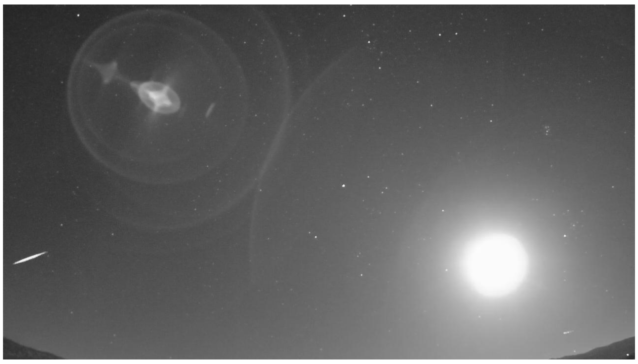

Figure 6 – October zeta Perseid 2021, October 24, $20^{h}16^{m}07.8^{s}$ UT on HR001Z at Hum, Croatia. (Operator Aleksandar Merlak).

Figure 7 – October zeta Perseid 2021, October 24, $20^{h}35^{m}42.1^{s}$ UT on NL000B at Hengelo, Netherlands. (Operator Martin Breukers).

Figure 8 – October zeta Perseid 2021, October 24, $20^{h}57^{m}29.6^{s}$ UT on HR000D at Čiovo, Croatia. (Operator Josip Belas).

Figure 9 – October zeta Perseid 2021, October 24, $20^{h}57^{m}29.6^{s}$ UT on HR000K at Zvjezdano selo Mosor, Croatia. (Operator Zoran Knez).

Figure 10 – October zeta Perseid 2021, October 24, $20^{h}57^{m}29.6^{s}$ UT on HR000M at Đakovo, Croatia. (Operator Danko Kočiš).

Figure 11 – October zeta Perseid 2021, October 24, $20^{h}57^{m}29.6^{s}$ UT on HR000P at Požega, Croatia. (Operator Nikola Gotovac).

Figure 12 – October zeta Perseid 2021, October 24, $20^h57^m29.6^s$ UT on HR000S at Virovitica, Croatia. (Operator Danijel Reponj).

3 Independent confirmation

Figure 13 – October zeta Perseid 2021, October 24, $20^h21^m10^s$ UT. CAMS Watec 3893 at Mechelen, Belgium (photo Luc Gobin).

Figure 14 – October zeta Perseid 2021, October 24, $20^h40^m18^s$ UT. CAMS Watec 379 at Wilderen, Belgium (photo Jean-Marie Biets).

CAMS BeNeLux coordinator Martin Breukers checked the available camera data for this network. A preliminary reduction of the night October 24–25 resulted in about 650 orbits. Only two matching orbits were found with a mean orbit at:

- q = 0.077 AU
- e = 0.994
- i = 68.6°
- ω = 328.21°
- Ω = 211.35°

Both meteors appeared on October 24, at $20^h21^m10^s$ UT ($\lambda_{\odot}$ = 211.344°) (*Figure 13*) and at $20^h40^m18^s$ UT ($\lambda_{\odot}$ = 211.357°) (*Figure 14*) registered by the same cameras stationed in Mechelen (Belgium) and Wilderen (Belgium). It is likely that more candidates may be found once all stations have reported their data. So far, no other CAMS networks detected any meteors from the new meteor shower because either daylight or bad weather interfered.

A search among 1326006 orbits collected by CAMS, EDMOND, SonotaCo and Global Meteor Network before 2021, resulted in 20 similar orbits, using the mean orbit for the 14 GMN orbits mentioned above as reference orbit. No significant activity has been detected in previous years. The 20 similar orbits are listed in *Table 2*, although the connection still needs to be confirmed.

Acknowledgment

The authors thank all participants in the Global Meteor Network community for their commitment and efforts to operate their cameras. Without their efforts this remarkable meteor shower would have passed probably completely unnoticed.

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The Chi Cygnids (CCY # 757) in 2020, a visual analysis

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In August and September 2020, the Chi Cygnids were active again. Several CAMS networks recorded these meteors. Visual observers also observed low numbers of CCY meteors. This article presents the results of the calculations made on the visual observations of the Chi Cygnids.

1 Introduction

The chi Cygnids (from now on referred to as CCY) were discovered in September 2015 by Peter Jenniskens, Martin Breukers and Carl Johannink. This happened during the processing of the CAMS data of the networks CAMS BeNeLux and CAMS California for the night 14–15 September 2015 (Jenniskens, 2015). A publication by Jakub Koukal et al. (2016) suggested that the meteor shower shows some additional activity every five years.

2 The CCY in 2020

On August 27, 2020, Peter Jenniskens reported that the CCY meteor shower was active again, some activity was detected by southern CAMS networks on August 21 (Jenniskens, 2020a). There was a possibility that a maximum would be reached around September 15. Indeed, a good number of CCY were recorded with CAMS (Jenniskens, 2020b; Johannink, 2020).

The question arose to the author how this would be visually observable. The author was able to observe 4 nights in September and 4 possible CCY meteors were seen (Miskotte, 2020a; Miskotte 2020b). Well-known Norwegian meteor observer Kai Gaarder (Gaarder, 2021) also wrote a report on his CCY observations.

This article gives the result of the calculations on the visual observations of the CCY in 2020. The problem here is of course that it concerns low level activity, in which the chance that sporadic meteors also line up with the large CCY radiant is quite high. On the other hand, It seems that there is little risk for much sporadic pollution because the area of the sky where the CCY radiant is situated produces little sporadic background activity. Any meteor shower popping up at this part of the sky stands out immediately.

3 Collecting the visual CCY data

Data was collected from the IMO website[16].

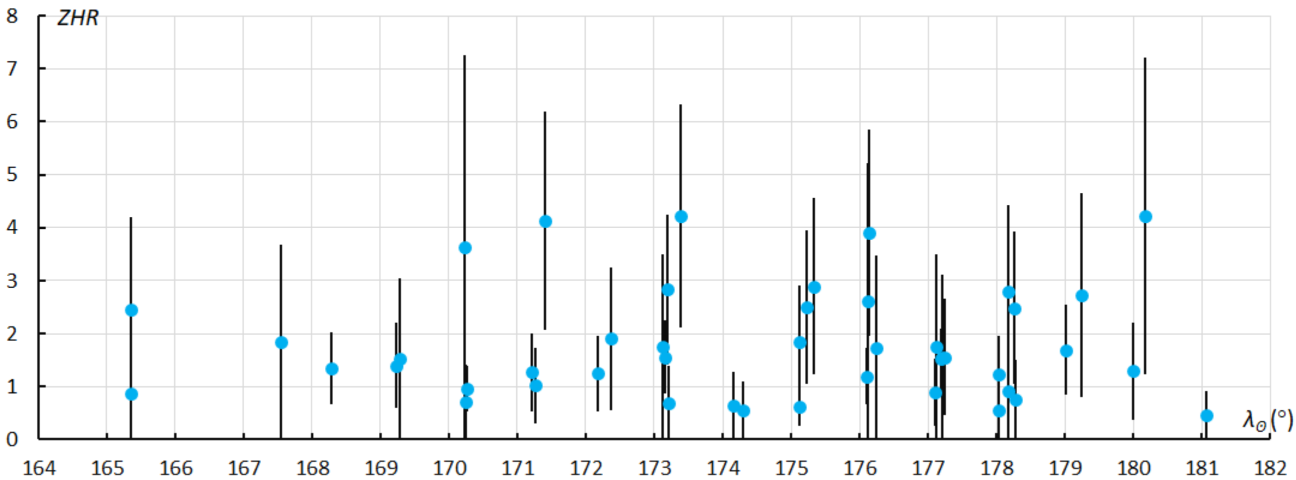

Figure 1 – Individual ZHR values of the CCY. The period shown is from 6 to 24 September 2020.

[16] https://www.imo.net/members/imo_live_shower?shower=CCY &year=2020

In total, 127 CCY were reported by 13 observers. The minimum hourly count was 0, maximum hourly counts were up to 7. The latter number was under very sublime circumstances (*lm* 6.8). The collected data was then checked for the following:

- The observations from CAMS BeNeLux in 2020 were used for the radiant positions.
- Radiant heights lower than 25 degrees were not used.
- Observations made with limiting magnitudes lower than 5.8 were not used.
- Very short single observation periods were not used.
- Short observation periods were merged if necessary and if possible.
- In the ZHR calculations an assumed population index *r* of 3.00 was used, because relatively little bright CCY meteors were seen.
- Of course, the weighted mean was calculated when averaging the individual ZHRs.
- A good C_p has been determined for most of the observers.

After this a total of 107 CCY remained for the analysis. The results of all calculations are shown in *Table 1* and *Figures 1, 2* and *3*.

Table 1 – ZHR of the CCY in September 2020, assuming *r* [–2,+5] = 3.0, date and time in UT.

Day, time	$\lambda_\odot$ (°)	Per	CCY	ZHR	OBS
07^d, 19.72^h	165.351	2	3	1.7 ± 0.6	2
10^d, 02.00^h	167.547	1	1	1.8 ± 1.8	1
10^d, 20.28^h	168.288	1	4	1.3 ± 0.3	1
11^d, 20.15^h	169.255	2	4	1.5 ± 0.4	2
12^d, 20.59^h	170.246	3	7	1.8 ± 0.3	3
13^d, 20.94^h	171.293	3	9	2.1 ± 0.2	3
14^d, 22.50^h	172.171	2	5	1.6 ± 0.3	2
15^d, 21.59^h	173.071	5	15	2.2 ± 0.1	5
16^d, 22.55^h	174.224	2	2	0.6 ± 0.3	2
17^d, 22.41^h	175.195	4	12	2.0 ± 0.2	4
18^d, 22.05^h	176.157	4	11	2.4 ± 0.2	4
19^d, 23.01^h	177.173	5	11	1.5 ± 0.1	5
20^d, 23.25^h	178.160	6	12	1.5 ± 0.1	6
21^d, 22.96^h	179.127	2	6	2.2 ± 0.4	2
22^d, 22.53^h	180.088	2	4	2.7 ± 0.7	2
23^d, 22.71^h	181.074	1	1	0.5 ± 0.5	1

In *Figure 1* we see all individual ZHR values of the observers. On average, these are between 1 and 4.

Figure 2 shows the result after averaging (weighted average) of the individual ZHR points per night. The result is a bit messy and some ZHR points show large error margins. After this, the author looked more critically at the ZHR points, see for example the point at $\lambda_\odot$ = 167.55°.

- ZHR values with an error margin larger than 0.5 were removed.
- ZHR values with error margins equal to the ZHR were removed.

This resulted in *Table 2* and *Figure 3* (based on 98 CCY).

Table 2 – ZHR for the CCY in September 2020 after removal of "critical" ZHR points, assuming *r* [–2,+5] = 3.0, date and time in UT.

Day, time	$\lambda_\odot$ (°)	Per	CCY	ZHR	OBS
10^d, 20.28^h	168.288	1	4	1.3 ± 0.3	1
11^d, 20.15^h	169.255	2	4	1.5 ± 0.4	2
12^d, 20.59^h	170.246	3	7	1.8 ± 0.3	3
13^d,20.94^h	171.293	3	9	2.1 ± 0.2	3
14^d, 22.50^h	172.171	2	5	1.6 ± 0.3	2
15^d, 21.59^h	173.071	5	15	2.2 ± 0.1	5
16^d, 22.55^h	174.224	2	2	0.6 ± 0.3	2
17^d, 22.41^h	175.195	4	12	2.0 ± 0.2	4
18^d, 22.05^h	176.157	4	11	2.4 ± 0.2	4
19^d, 23.01^h	177.173	5	11	1.5 ± 0.1	5
20^d, 23.25^h	178.160	6	12	1.5 ± 0.1	6
21^d, 22.96^h	179.127	2	6	2.2 ± 0.4	2

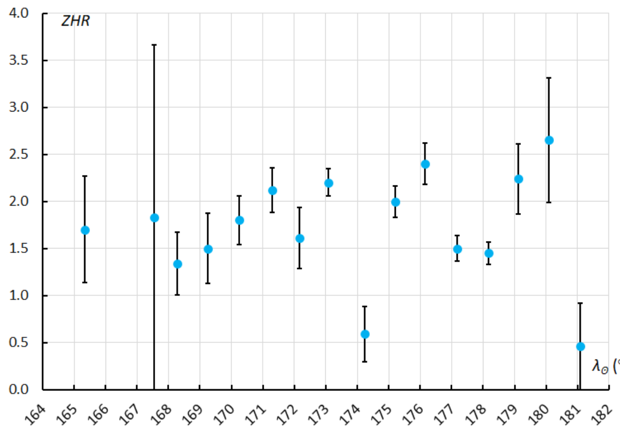

Figure 2 – ZHR distribution for the CCY 2020 per night. The period shown is from September 6 to 24, 2020. Based on Table 1 and 107 CCY.

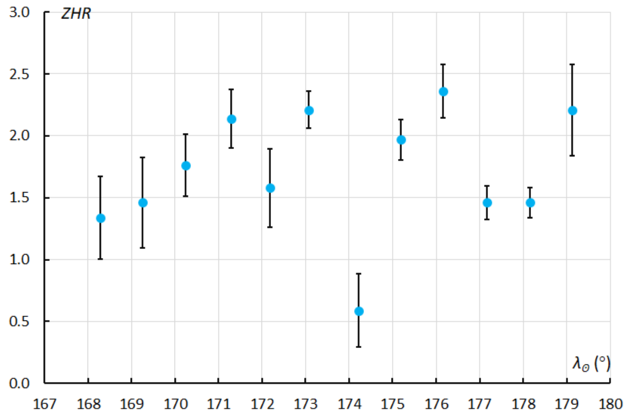

Figure 3 – The ZHR distribution for the CCY after removal of "critical" ZHR points. The period shown is September 10–21, 2020.

The result is a somewhat better graph. The ZHR increases regularly, but after this the distribution is somewhat variable. A dip is visible just after solar longitude 174°. If we compare *Figure 3* with *Figure 4* from the recent article about the CCY in 2020 by Peter Jenniskens (2020b), we also see a dip around solar longitude 174–175°! This gives some confidence in the end result of this analysis!

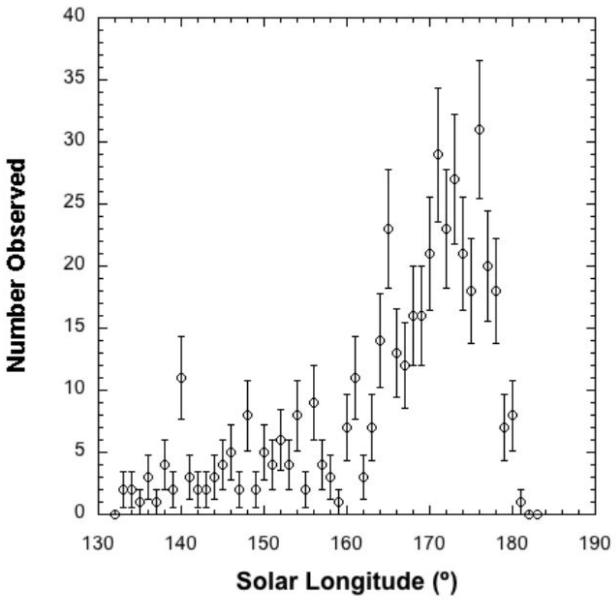

Figure 4 – Activity curve (no ZHR) of the detected Chi Cygnids by CAMS networks worldwide per 1 degree intervals. The figure comes from (Jenniskens, 2020b).

4 Conclusion

Obviously, in 2020 the ZHR of the CCY meteor shower was between 1 and 2.5. The problem of contamination by sporadic meteors radiating from the same area of the sky as the CCY meteors does not seem to play a role in this analysis. For example, the dip found around solar longitude 174–175° is visible in both the visual and CAMS analyzes. Individual ZHRs are between 1 and 4. The run-up is nicely increasing to the "maximum", after that activity becomes a bit variable. It is recommended to observe this meteor shower under sublime observing conditions.

Acknowledgment

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The possible rho Serpentids, single versus multiple station meteor work

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A possible new meteor shower had been recently reported based on single station camera images. The apparent radiant position was located near the star rho Ser with approximately coordinates at R.A. = 238º; Dec. = +18º on 13–14 August 2020, about: $\lambda_{\odot}$ = 141.2º. A search among 1.3 million video meteor orbits resulted in a dataset with 89 meteors from this radiant area, with a fair number of orbits fulfilling the discrimination criteria. However, no trace of any concentration could be detected. This case study proves that caution is required with impressions based on single station meteor observations. Meteoroid stream searches using D-criteria require caution too, especially for low inclination short orbits near the ecliptic, D-criteria may produce false positives.

1 Introduction

When watching the starry sky during a Perseid display some other, less active meteor showers manage to attract the attention of the visual observer. Every now and then a few sporadic meteors may confuse the observer when it looks like if these meteors come from a common area at the sky, suggesting a possible unknown meteor shower radiant. The random appearance of meteor trails at the sky has been often very misleading for single station observers. The only certainty a single station observer has, is that the radiant of the meteor is somewhere on its backwards produced trail. In case of a major meteor shower the radiant area will become visible as the area where many backwards produced trails cross each other at the sky. This makes it possible to assume the shower identification with a fair chance to have it right.

Unfortunately, the obvious effect of backwards produced intersections, which makes sense only in case of significant statistical numbers of events, was assumed to be also suitable to locate minor shower radiants. This way, the often randomly intersecting backwards produced meteor trails were assumed to define minor shower radiants which was the beginning of a long controversial polemic. It started in the 19th century with visual observers plotting meteor trails with chalk on a black stellar globe, later gnomonic star maps were used. Visually observing fast short-lived events like meteors is a real challenge for human eyes and brains. The plotting errors were believed to be rather small while in practice the errors on the direction of the trail as well as the beginning and ending points made the meteor plotting work questionable. Some visual observers from the past believed their eyes had a recording capacity and precision comparable to modern video meteor cameras while their brain flowless solved the complex geometrics which are today computed by powerful computers and carefully designed software applications. This resulted in long lists with discovered minor meteor streams, most of which were just fake, illusions created by randomly intersecting meteor trails combined with plotting errors.

Figure 1 – William Frederick Denning in the early 20th century with his black stellar sphere on which meteors were plotted with chalk.

When dedicated photographic and radar meteor observing campaigns revealed a quite different picture of the radiant distribution in the 1950s, the past visual observing efforts to define minor shower radiants lost credibility and with it, unfortunately all visual meteor work became unpopular. It took until the 1970s before a new generation of amateur astronomers resumed visual meteor observing, initially making the same assumptions and mistakes like in the late 19th, first half of the 20th century, but most amateurs soon understood the limitations imposed by human eyes and brains. Visual work focused on recording activity levels of major showers, based on statistical relevant numbers of events. However, some amateurs continued to believe in visual meteor plotting to determine minor shower radiants. Computer programs were made to visualize the hot spots of meteor intersections but at some point, it was understood that plotting errors diffused the picture. The problem with these plotting errors was solved when video meteor recording became affordable to amateurs. Instead of using multiple station video meteor work, the unfortunate mistake has been made to use single station data for shower identification, applying the same late 19th century methodology for visual observed plotted meteor trails on modern video recordings. The random pure chance intersections again produced plenty of fake minor shower candidates, making up long lists of spurious radiants. When video meteor observing got applied based on multiple station scale, permitting triangulations to determine the trajectory, radiant and orbit, the radiant distribution and existence of minor showers could finally be verified.

2 Video observational data

Never before the sky has been better guarded for meteor activity and fireballs than during past few years with several dedicated video camera networks operated worldwide. Daylight and bad weather can still interfere and prevent detection of unexpected short lived meteor showers, but anything active during several nights or recurrent during different years should have been observed by video cameras. Therefore, it is worthwhile to check if any activity has been detected of the low velocity Serpentids (Velkov, 2021).

In our orbit database we have 471582 orbits obtained by CAMS (Oct.2010–Dec.2016, Jenniskens et al., 2011), 663031 orbits obtained with UFOCapture (2006–2020, EDMOND, SonotaCo network, Kornoš et al., 2014; SonotaCo, 2009) and 191393 orbits obtained by GMN (Oct. 2018– Feb. 2021, Vida et al., 2021). Altogether, we have 1326006 orbits available.

In order to limit our search sample, we select all orbits collected around the time of the Serpentids appearance, a time bin of 10° in solar longitude centered at $\lambda_{\odot} = 141°$. 118843 orbits are available within this interval. The apparent radiant was given in equatorial coordinates at $\alpha = 238°$ and $\delta = +18°$ with a low velocity $v_g < 15$ km/s. Typical for meteor showers with such low velocity is that the zenith attraction has a great effect especially when the radiant is low, resulting in a huge radiant area. We select all radiants in within 15° around right ascension and declination, roughly a radiant with a diameter of 30° to account for the large spread in the apparent radiant positions. Only 89 orbits had their radiant in this area in the selected interval $136° < \lambda_{\odot} < 146°$, all of these had $v_g < 15$ km/s, since there aren't any fast meteors coming from this part of the sky where meteoroids have to hit the rear side of the Earth compensating the speed of Earth in its orbit around the Sun. With 89 meteors with the right speed coming from the suspected radiant area any single station meteor observer would be happy to confirm the existence of the rho Serpentids, statistically this looks like a relevant number of events. What about the orbits, are these orbits similar?

3 Comparing the orbits

In order to consider all the orbits with the same criteria an iterative procedure has been applied, using the mean orbit of the 89 selected orbits as the reference orbit to identify all similar orbits that may define the meteor shower. This method has been described before (Roggemans et al., 2019).

To calculate a reference orbit for a collection of similar orbits we do not use the median or average values of the orbital elements, but we compute the mean orbit according to the method described by Jopek et al. (2006). To compare orbits on similarity researchers established different discrimination criteria, often abbreviated as D-criteria. The D-criteria that we use are these of Southworth and Hawkins (1963), Drummond (1981) and Jopek (1993) combined. The oldest and most popular D-criterion, the one established by Southworth and Hawkins or D_{SH} proved often too tolerant and unsuitable for short period low inclination orbits near the ecliptic. It is not unusual that orbits which are very similar according to D_{SH}, fail for another D-criteria such as that of Drummond or D_D.

Taking the mean orbit of the selected 89 orbits as initial reference orbit, an iterative procedure recomputes the mean orbit for the orbits with D-criteria within a chosen threshold relative to the reference orbit. To limit the risk for pure chance similarity we took: $D_{SH} < 0.1$ & $D_D < 0.04$ & $D_H < 0.1$ as upper limits. The iterative procedure converges after a number of iterations with an orbit which is best representative as mean orbit for 27 orbits which respect the above-mentioned D-criteria:

- $\alpha_o = 237.9°$
- $\delta_o = +20.4°$
- $\alpha_g = 225.7°$
- $\delta_g = +12.9°$
- $v_g = 8.4$ km/s
- $a = 2.23$ AU
- $q = 1.0105$ AU
- $e = 0.553$
- $i = 6.1°$
- $\omega = 174.9°$
- $\Omega = 141.1°$

At this point we could shout "hurray" we confirmed the suspected new shower of the rho Serpentids. As many as 53 orbits respect the less strict D-criteria with $D_{SH} < 0.25$ & $D_D < 0.105$ & $D_H < 0.25$ which is often used in literature as acceptable to assume similarity between the orbits. On the other hand, 36 meteors which had their radiant in the suspected radiant area with the right speed fail in the D-criteria. Any single station observer, either a visual observer or any single station recording system would have counted all these meteors as rho Serpentids as coming from the right direction with the expected low velocity.

However, caution is required with this kind of low inclination short period orbits. Although we have a nice number of orbits fulfilling the similarity criteria, this only indicates that the orbits have similarity, it does not prove there is any physical relationship between these orbits. With only four almost identical orbits ($D_{SH} < 0.05$ & $D_D < 0.02$ & $D_H < 0.05$), it looks like there is no real concentration of these orbits.

4 Misleading D-criteria?

The D-criteria are helpful to check for similarity between orbits which is a useful criterium for most meteoroid streams with higher inclination, Jupiter family comet orbits or Halley comet orbits. The method can be very misleading for short period low inclination orbits as the Solar system is full of sporadics with such orbits near the ecliptic. To define a meteor shower it is not enough to find just similar orbits according to D-criteria, there must be a concentration visible in radiant positions are among the orbital elements.

For any single station observer all our selected orbits would have produced a rho Serpentid candidate, coming from the right radiant area with the expected speed. Looking at the plot of all 89 apparent radiant positions (*Figure 2*) we see a rather wide scatter. The black dots are radiants for orbits that fail in the D-criteria, the blue dots have low similarity and the red dots high similarity. Unfortunately, there is nothing that looks like a concentration of radiants as should be the case if there is a real meteor shower. The black, blue and red dots appear randomly distributed.

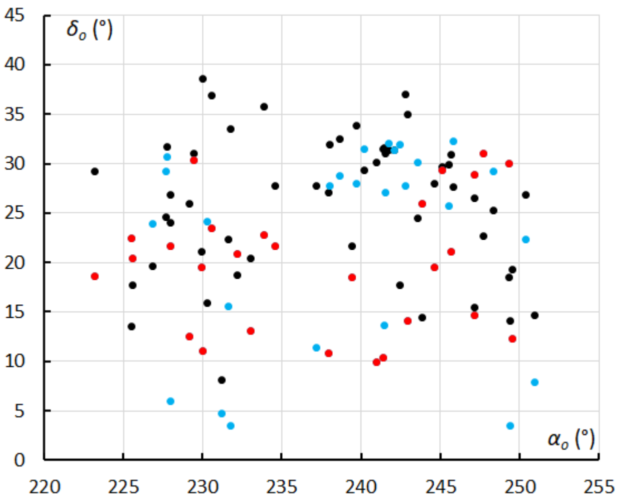

Figure 2 – The apparent radiant positions in equatorial coordinates, color coded with black for no orbit similarity, blue for weak orbit similarity and red for strong orbit similarity.

The apparent equatorial radiant positions suffer a large spread due to the Earth gravitation which has a large effect on slow velocity meteoroids especially when the zenith distance of the radiant is large. A more appropriate way to look at meteor shower radiant concentrations is to look at the plot of the computed Sun-centered geocentric ecliptic coordinates. By taking the difference between the ecliptic longitude λ and the solar longitude $\lambda_\odot$ we can neutralize the radiant drift due to the Earth's motion around the Sun. The result is shown in *Figure 3*. Still, there is no trace of anything like a concentration of radiants.

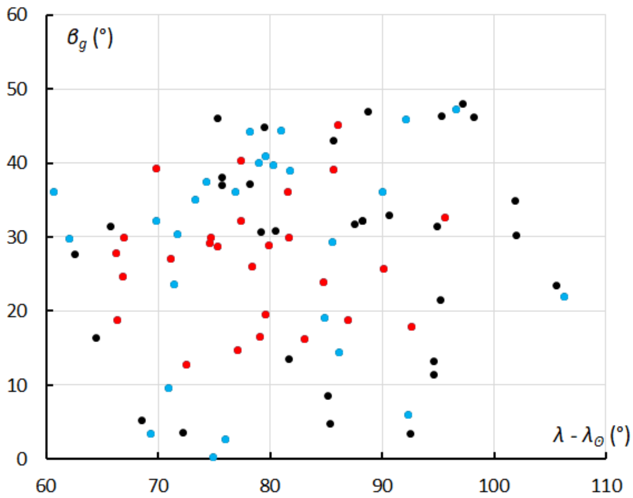

Figure 3 – The radiant positions in Sun-centered geocentric ecliptic coordinates, color coded with black for no orbit similarity, blue for weak orbit similarity and red for strong orbit similarity.

Another way to look for concentrations is to look at the orbital elements, for instance a plot of the inclination *i* against the length of perihelion *Π*. The result is shown in *Figure 4* and also here we see a random distribution of no similarity orbits, low and high similarity orbits, no trace of any concentration that could indicate the presence of a real meteor shower.

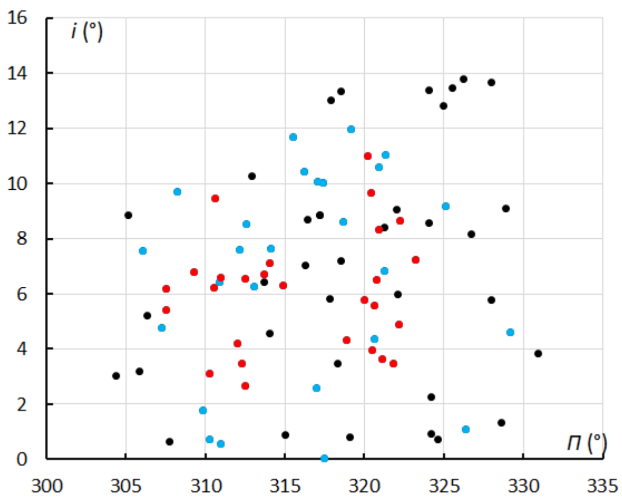

Figure 4 – The orbit inclination *i* against the length of perihelion *Π*, color coded with black for no orbit similarity, blue for weak orbit similarity and red for strong orbit similarity.

Looking for this type of orbits in the weeks ahead and after the suspected rho Serpentid activity, the same type of orbit appears, except for the ascending node which is time dependent, the same misleading positive matches for the D-criteria were found.

5 Conclusion

Whenever meteor observers report possible new shower activity, an in-depth study is required. Meteors and statistics make it pretty difficult to interpret visual impressions. When searching any kind of single station data sources, it will be easy to find meteor trails that confirm the impression. Thanks to the efforts of many amateurs and professional meteor workers worldwide a gold mine of meteor orbits became available. This way it became almost impossible for any new shower or unexpected meteor activity to escape attention.

The reported possible rho Serpentids situated in the western evening sky which produces only slow meteors heavily affected by the zenith attraction resulting in a huge radiant area are a nice example how misleading meteor appearances can be, especially for single station meteor work. But also using meteoroid orbits, caution is required as the available tools like D-criteria only indicate geometric similarity but do not prove any physical relationship between the orbits. If no concentration can be spotted in the radiant plots or orbital elements, then it is a case of pure statistical random coincidence, which is the case for the suspected rho Serpentids. We can safely conclude that there is no indication for the existence of the rho Serpentids.

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Remarkable bolides recorded along August 2021 in the framework of the Southwestern Europe Meteor Network

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The most remarkable fireballs observed along August 2021 in the framework of the Southwestern Europe Meteor Network (SWEMN) and the SMART project are presented in this work. These fireballs overflew the Iberian Peninsula and neighboring areas, and reached an absolute peak luminosity ranging between mag. –8 and –12. The emission spectra of some of these bright meteors are also discussed.

1 Introduction

The Southwestern Europe Meteor Network (SWEMN) is a research network coordinated in Spain by the Institute of Astrophysics of Andalusia (IAA-CSIC) with the aim to analyze the Earth's meteoric environment. Currently the 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). We also have support from the National Institute of Aerospace Technology (INTA), and receive input from amateur astronomers who collaborate with this meteor network.

The Spectroscopy of Meteoroids by means of Robotic Technologies (SMART) is being developed in the framework of the SWEMN network to identify and analyze meteors in the Earth's atmosphere. This systematic survey began in 2006 (Madiedo, 2014; Madiedo, 2017). To obtain a much more complete insight into the properties of the Earth-Moon meteoric environment, SMART works in close connection with another project conducted by the Institute of Astrophysics of Andalusia: The Moon Impacts Detection and Analysis System (MIDAS) (Ortiz et al., 2015; Madiedo et al., 2018). Thus, SMART employs our atmosphere as a detector to identify meteors generated by meteoroids crossing the Earth's orbit. At the same time, MIDAS considers the Moon as a laboratory that provides information about meteoroids hitting the lunar ground (Madiedo et al., 2019a). Previous works showed that there exists a strong synergy between both systems (Madiedo et al. 2015a,b; Madiedo et al. 2019b).

We present in this work an analysis of the most remarkable bolides recorded during August 2021 over Spain and neighboring areas by the Southwestern Europe Meteor Network. Their peak absolute magnitude ranges from –8 to –12 Their atmospheric path was triangulated and the orbit of the progenitor meteoroid was also obtained. We discuss also the emission spectrum recorded for some of these meteors.

2 Instrumentation and methods

The meteors described here 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 90 × 40 degrees. A detailed description of this hardware and the way it operates was given in previous works (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).

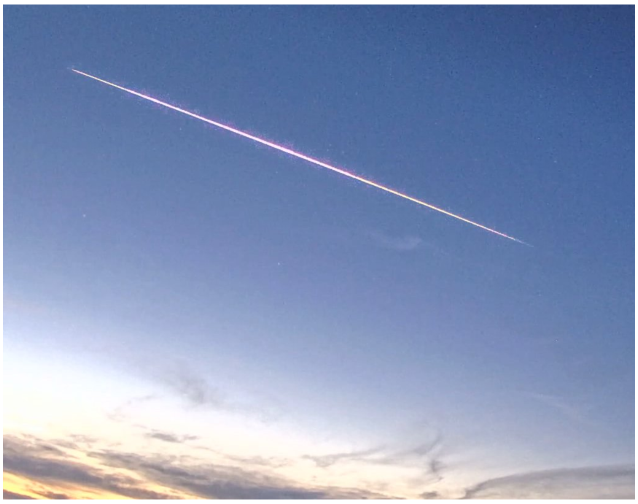

Figure 1 – Stacked image of the SWEMN20210803_195954 "Valdepeñas" fireball as recorded from the SWEMN meteor-observing station deployed at the Calar Alto Observatory.

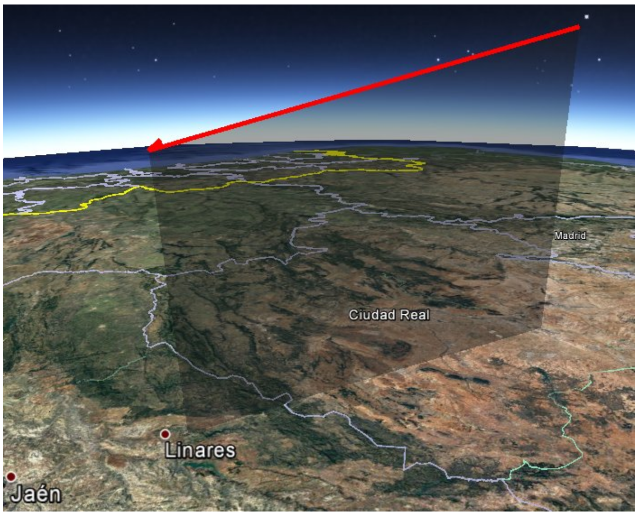

Figure 2 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210803_195954 "Valdepeñas" fireball.

3 The 2021 August 3 bolide

This fireball was a Perseid observed about 10 days before the activity peak of this meteor shower. The event was spotted at $19^h59^m54.3 \pm 0.1^s$ UTC on August 3 (*Figure 1*). It had a peak absolute magnitude of -8 ± 1, and was recorded by the cameras deployed at Calar Alto, La Sagra, La Hita, Sevilla, and El Arenosillo. We labeled it in the SWEMN meteor database with the code SWEMN20210803_195954.

Atmospheric trajectory, radiant and orbit

The atmospheric path of the bolide and its projection on the ground are shown in *Figure 2*. From the calculation of this trajectory, we obtained that it overflew the provinces of Ciudad Real (region of Castilla-La Mancha) and Jaén (Andalusia). The observed pre-atmospheric velocity of the meteoroid is $v_\infty = 59.4 \pm 0.3$ km/s, with the apparent radiant located at the equatorial coordinates $\alpha = 36.0°$, $\delta = +58.3°$. The meteor began at a height $H_b = 105.5 \pm 0.5$ km, and ended at an altitude $H_e = 78.4 \pm 0.5$ km. It overflew the town of Valdepeñas in the province of Ciudad Real, and so we named the bolide after this location.

Table 1 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210803_195954 "Valdepeñas" fireball.

a (AU)	62 ± 98	ω (º)	149.3 ± 0.4
e	0.98 ± 0.02	Ω (º)	131.40337 ± 10^{-5}
q (AU)	0.944 ± 0.001	i (º)	109.4 ± 0.1

The geocentric velocity of the progenitor meteoroid yields $v_g = 58.2 \pm 0.3$ km/s, and its orbital parameters are listed in *Table 1*. This heliocentric orbit is drawn in *Figure 3*. Radiant and orbital data indicate a clear association with the Perseid meteoroid stream according to the information included in the IAU meteor database[17].

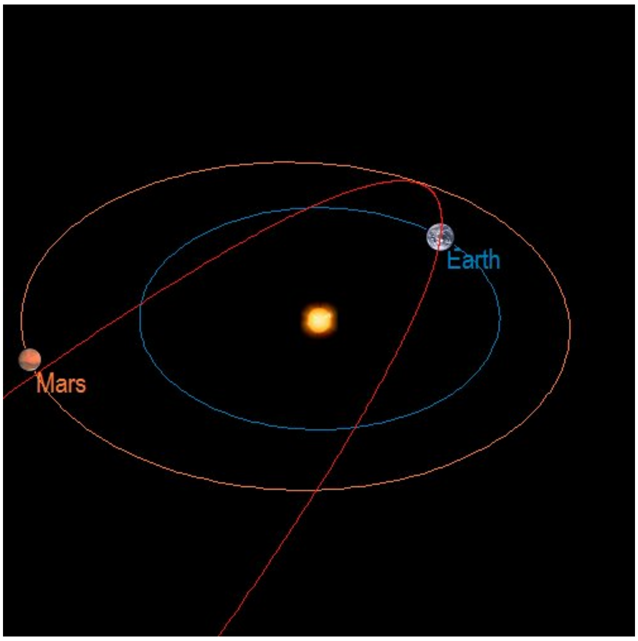

Figure 3 – Projection on the ecliptic plane of the orbit (red line) of the parent meteoroid of the SWEMN20210803_195954 fireball.

4 The 2021 August 5 fireball

This stunning bolide was recorded by our cameras on 2021 August 5 at $0^h22^m10.6 \pm 0.1^s$ UTC. It reached a peak absolute magnitude of -12 ± 1 as a consequence of a flare that occurred at the end of its atmospheric path (*Figure 5*). It was spotted from the SWEMN meteor-observing stations operating at La Sagra, Sierra Nevada, Calar Alto, La Hita, El Arenosillo, and Sevilla. The fireball, which can be viewed on this YouTube video[18], was included in the

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

[18] https://youtu.be/AcqysKKjn04

SWEMN meteor database under the code SWEMN20210805_002210.

Atmospheric path, radiant and orbit

The analysis of the images revealed that the fireball began over the Mediterranean Sea, next to the coast of the province of Almería (Andalusia). The parent meteoroid of this bolide entered the atmosphere with an initial velocity $v_\infty = 24.3 \pm 0.3$ km/s. The apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 311.9^o$, $\delta = -5.1^o$. The bolide began at an altitude $H_b = 104.4 \pm 0.5$ km over the sea, over the vertical of a point located at about 5 km of the coast of Spain. It moved northwest and overflew Almería, reaching its terminal point at a height $H_e = 73.1 \pm 0.5$ km over the north of this province. This trajectory and its projection on the ground are shown in *Figure 6*. We named this event "Villaricos", since the fireball overflew an area next to the vertical of this town.

Figure 5 – Stacked image of the SWEMN20210805_002210 "Villaricos" fireball as recorded from the Calar Alto Astronomical Observatory.

Figure 6 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210805_002210 "Villaricos" fireball.

The calculated orbit of the parent meteoroid is drawn in *Figure 7*, and the value of the corresponding orbital elements are included in *Table 2*. The geocentric velocity of the particle yields $v_g = 21.6 \pm 0.3$ km/s. Besides, the value of the Tisserand parameter with respect to Jupiter ($T_J = 2.9$) shows that this meteoroid followed a cometary orbit (JFC type). According to radiant and orbital information listed in the IAU Meteor Data Center, this particle belonged to the α-Capricornid stream (CAP#0001), whose parent body is Comet 169P/NEAT and produces an annual display of meteors with a peak activity around August 1 (Jenniskens et al., 2016).

Table 2 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210805_002210 "Villaricos" fireball.

a (AU)	2.48 ± 0.10	*ω* (º)	265.51 ± 0.03
e	0.75 ± 0.01	Ω (º)	132.51817 ± 10^{-5}
q (AU)	0.612 ± 0.003	*i* (º)	7.2 ± 0.1

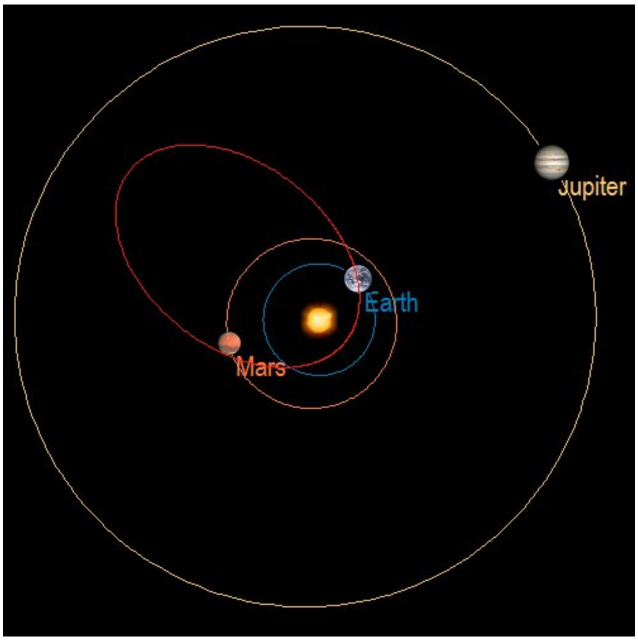

Figure 7 – Projection on the ecliptic plane of the orbit (red line) of the parent meteoroid of the SWEMN20210805_002210 fireball.

5 The 2021 August 10 fireball

A fireball with a peak luminosity equivalent to an absolute magnitude of -8 ± 1 was recorded by our systems on August 10, at $0^h55^m23.4 \pm 0.1^s$ UTC from the meteor-observing stations located at La Hita, Sierra Nevada, Calar Alto, La Sagra, and Sevilla (*Figure 8*). A video showing images of this event and information about its trajectory was uploaded to YouTube[19]. This bright meteor was included in the SWEMN digital database with the code SWEMN20210810_005523.

Atmospheric path, radiant and orbit

Our analysis shows that the event overflew the provinces of Ciudad Real and Albacete (region of Castilla-La Mancha). The pre-atmospheric velocity observed in this case was $v_\infty = 13.5 \pm 0.3$ km/s. The bolide began at an altitude $H_b = 79.2 \pm 0.5$ km over the southeast of the province of Ciudad Real and ended at a height $H_e = 45.6 \pm 0.5$ km over the west of the province of Albacete. We named this meteor "Viveros", since at this final stage the bolide was located

[19] https://youtu.be/OO8kGKtIhGA

almost over the vertical of this town. The apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 269.1^{\circ}$, $\delta = +1.4^{\circ}$. Its atmospheric trajectory and the corresponding projection on the ground are shown in *Figure 9*.

Figure 8 – Stacked image of the SWEMN20210810_005523 "Viveros" fireball as recorded from the Calar Alto Observatory.

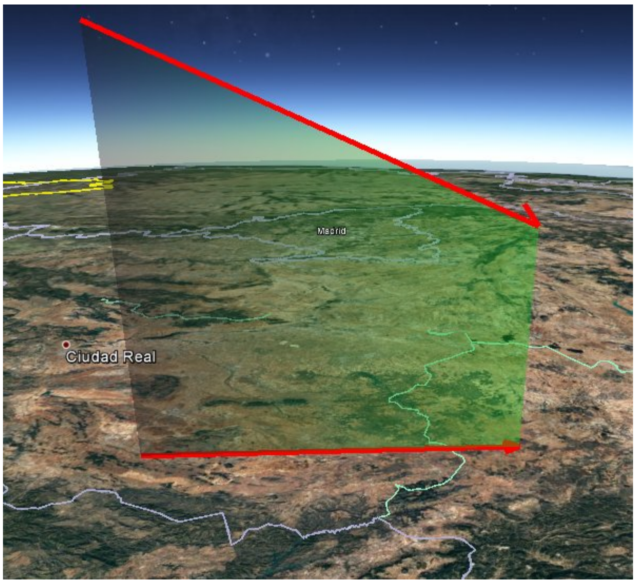

Figure 9 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210810_005523 fireball.

Table 3 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210810_005523 "Viveros" fireball.

a (AU)	2.3 ± 0.1	ω (º)	195.9 ± 0.6
e	0.56 ± 0.03	Ω (º)	137.30106 ± 10-5
q (AU)	0.999 ± 0.001	i (º)	2.3 ± 0.4

The heliocentric orbit of the progenitor meteoroid is shown in *Figure 10*, and the calculated orbital parameters are listed in *Table 3*. The geocentric velocity obtained for this particle is $v_g = 8.2 \pm 0.5$ km/s. According to these results we concluded that this meteoroid followed an asteroidal orbit before its encounter with our planet, since the Tisserand parameter with respect to Jupiter yields $T_J = 3.3$. In addition, since we found no match in the IAU meteor database, we associated this particle with the sporadic background.

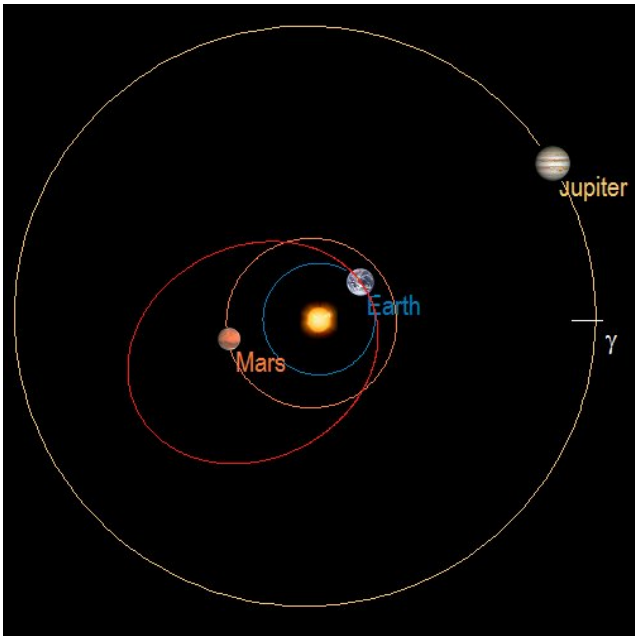

Figure 10 – Projection on the ecliptic plane of the orbit (red line) of the parent meteoroid of the SWEMN20210810_005523 fireball.

6 The 2021 August 12 fireball

A very bright Perseid bolide was recorded by the SWEMN network on the 12th of this month, at $21^{h}58^{m}32.1 \pm 0.1^{s}$ UTC. Besides, the fireball was observed by a wide number of eyewitnesses. Thus, many of them were observing the Perseids that night. The bolide reached a peak absolute magnitude of –12 ± 1 and, as can be seen in *Figure 11*, it exhibited several flares along its atmospheric trajectory as a consequence of the disruption of the meteoroid. The event was spotted from the meteor-observing stations operated by the SWEMN network at the astronomical observatories of La Hita, La Sagra, Sierra Nevada, Calar Alto, and El Arenosillo. It was included in our meteor database with the code SWEMN20210812_215832.

Atmospheric path, radiant and orbit

In this case the meteoroid hit the atmosphere with an initial velocity $v_\infty = 60.0 \pm 0.5$ km/s, and the apparent radiant was located at the equatorial coordinates $\alpha = 47.6^{\circ}$, $\delta = +59.2^{\circ}$. It overflew three provinces in central Spain: Segovia, Avila and Toledo. Thus, the bolide began at an altitude $H_b = 129.4 \pm 0.5$ km over the north of the province of Segovia. From that position it moved southwest and overflew the eastern part of the province of Avila and next the northwest of the province of Toledo. Finally, the fireball ended at a height $H_e = 75.1 \pm 0.5$ km over a point located near from the vertical of the town of Navamorcuende. We named the event after this location in the province of Toledo. *Figure 12* shows the atmospheric trajectory of this meteor and its projection on the ground.

In *Table 4* we have included the orbital elements of the meteoroid, and the heliocentric orbit is drawn in *Figure 13*.

The geocentric velocity of the particle yields $v_g = 58.8 \pm 0.5$ km/s. As in the case of the bolide recorded by our meteor network on August 3 and discussed above, the information provided by the IAU meteor database implies that that this fireball was a Perseid. It was, besides, the brightest Perseid observed over the Iberian Peninsula during the activity period of this meteor shower in 2021.

Table 4 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210812_215832 "Navamorcuende" fireball.

a (AU)	25 ± 27	ω (°)	150.1 ± 0.7
e	0.96 ± 0.02	Ω (°)	140.41044 ± 10^{-5}
q (AU)	0.947 ± 0.001	i (°)	111.6 ± 0.3

Figure 11 – Stacked image of the SWEMN20210812_215832 "Navamorcuende" fireball as recorded from La Hita Observatory.

Figure 12 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210812_215832 fireball.

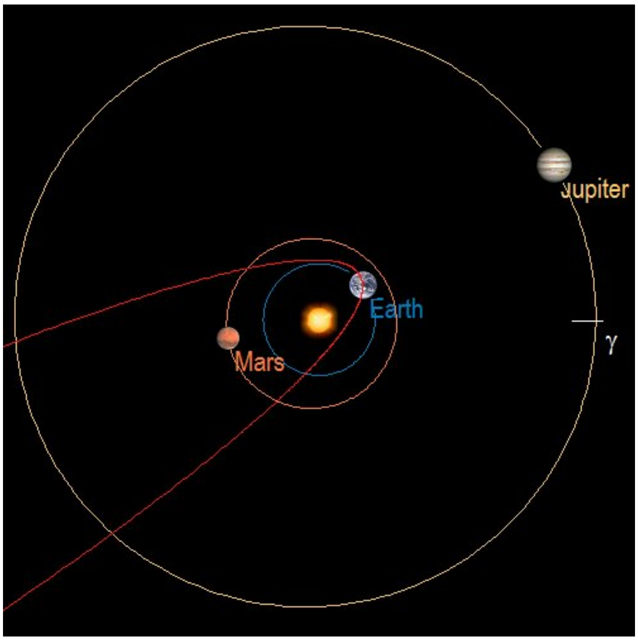

Figure 13 – Projection on the ecliptic plane of the orbit (red line) of the progenitor meteoroid of the SWEMN20210812_215832 fireball.

Emission spectrum

The emission spectrum of the fireball was obtained by our spectrographs located at La Hita. Calar Alto, and La Sagra meteor-observing stations. *Figure 14* shows the calibrated signal and the most important emissions in this spectrum. As usual in meteor spectra (Borovička, 1993), most lines correspond to neutral Fe emissions. Thus, we have identified the contributions from Fe I-5, Fe I-43, Fe I-41, Fe I-318 and Fe I-15. The most remarkable lines are those of Fe I-4 and Ca II-1, which appear blended, and the line of O I at 778 nm. The emissions from multiplets Ca I-2, Mg I-2 and Na I-1 are also present, together with the contributions from atmospheric nitrogen bands in the red region of the spectrum.

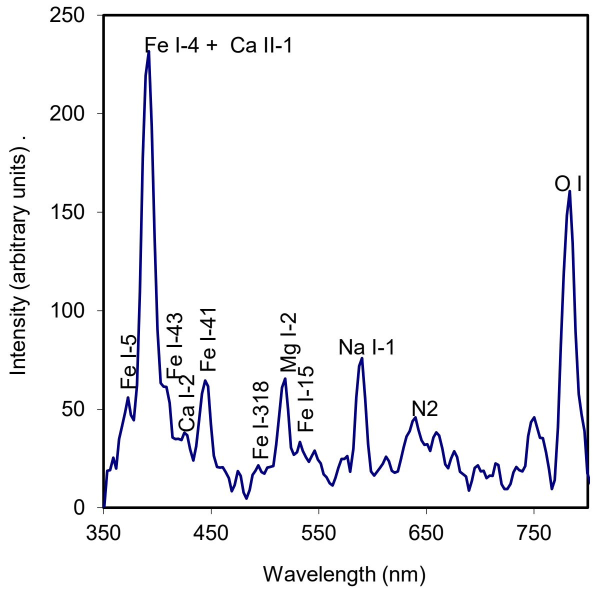

Figure 14 – Calibrated emission spectrum of the SWEMN20210812_215832 fireball.

7 The 2021 August 18 fireball

The bright meteor observed on the 18th of this month was detected at $0^h20^m16.2 \pm 0.1^s$ UTC, and reached a peak absolute magnitude of –9 ± 1 (*Figure 15*). The bolide was recorded from the SWEMN meteor-observing stations located at La Hita, La Sagra, Calar Alto, Sevilla, El Arenosillo, and Sierra Nevada. A video showing this fireball was uploaded to YouTube[20]. It was included in the SWEMN meteor database with the code SWEMN20210818_002016.

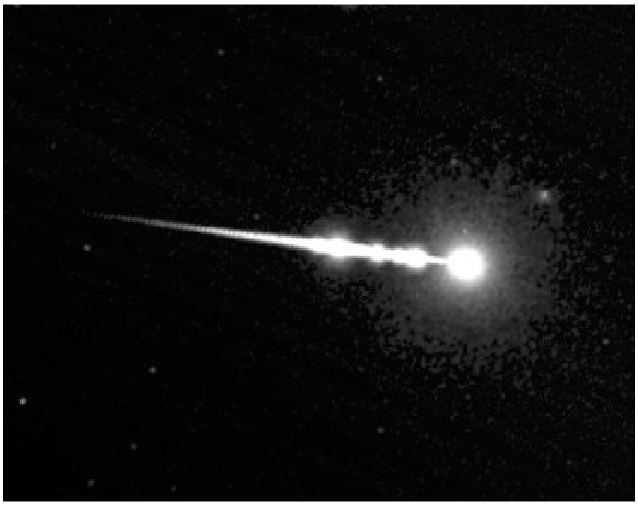

Figure 15 – Stacked image of the SWEMN20210818_002016 "Pajaroncillo" fireball as recorded from La Hita Observatory.

Atmospheric path, radiant and orbit

According to our analysis, the meteoroid hit the atmosphere with an initial velocity $v_\infty = 24.6 \pm 0.3$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 293.0°$, $\delta = +52.3°$. The fireball began at an altitude $H_b = 103.5 \pm 0.5$ km over the east of the province of Cuenca (region of Castilla-La Mancha), moved southeast, and ended over the same province, at a height $H_e = 67.5 \pm 0.5$ km. This meteor had its initial phase near from the vertical of the village of Pajaroncillo, and for this reason we named it after this place. *Figure 16* shows its atmospheric trajectory and the projection on the ground of this path.

Table 5 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210818_002016 "Pajaroncillo" fireball.

a (AU)	2.9 ± 0.1	ω (°)	205.6 ± 0.1
e	0.66 ± 0.01	Ω (°)	145.00469 ± 10-5
q (AU)	0.9724 ± 0.0002	i (°)	34.2 ± 0.3

From the analysis of the videos recorded for this bolide, we derived the values listed in *Table 5* for the orbital elements of the parent meteoroid. This orbit is plotted in *Figure 17*. The calculated value of the geocentric velocity of this particle yields $v_g = 22.1 \pm 0.3$ km/s. According to the information found in the IAU meteor database, our results show that the fireball was a κ-Cygnid (KCG#0012). This minor meteoroid stream produces every year a display of meteors peaking around August 18 (Jenniskens et al., 2016). So, this event was recorded during the maximum of this meteor shower. The Tisserand parameter with respect to Jupiter yields $T_J = 2.7$, which shows that this meteoroid followed a cometary orbit (JFC type) before entering our atmosphere.

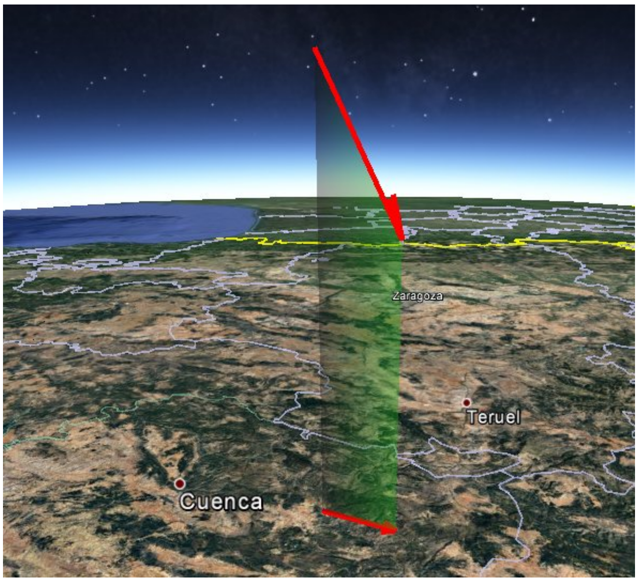

Figure 16 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210818_002016 fireball.

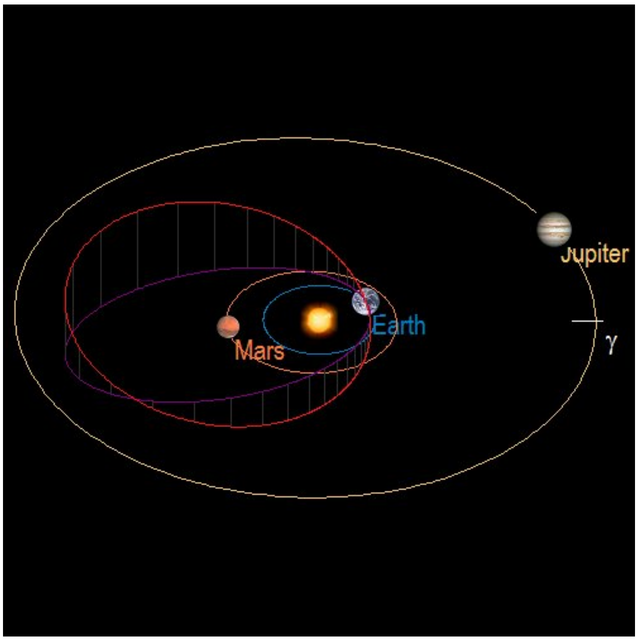

Figure 17 – Up: orbit (red line) of the parent meteoroid of the SWEMN20210818_002016 fireball, and its projection (violet line) on the ecliptic plane.

Emission spectrum

The spectrum of this κ-Cygnid was recorded by our spectrographs located at La Hita Observatory. *Figure 18* shows the calibrated signal, together with the most important emissions. As can be noticed, we have identified lines produced by several Fe I multiplets, as those of Fe I-23, Fe I-21, Fe I-4, Fe I-318 and Fe I-15. The most

[20] https://youtu.be/K3Y_kVikgPE

noticeable contributions to this spectrum are those of Na I-1, Mg I-2, and Fe I-4.

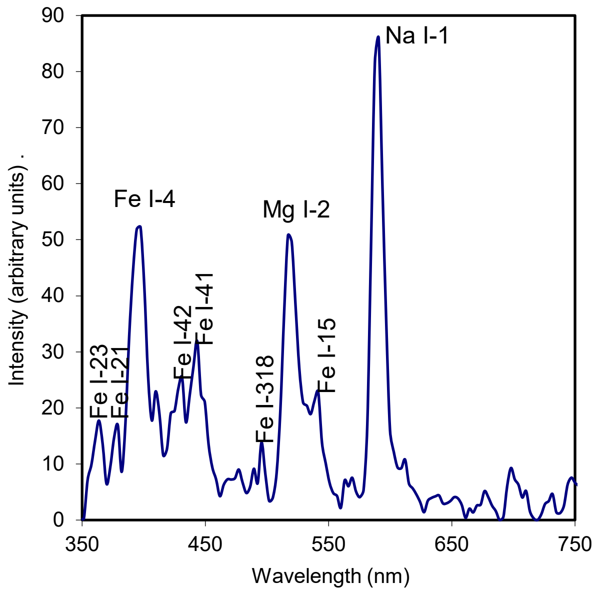

Figure 18 – Calibrated emission spectrum of the SWEMN20210818_002016 fireball.

A deeper analysis of this spectrum will be performed in order to obtain information about the composition of meteoroids in the κ-Cygnid stream. This will be compared with the information obtained previously in the framework of the SMART project for these meteoroids (Madiedo 2015a).

8 Conclusions

We have presented here the most remarkable bolides recorded during August 2021 in the framework of the Southwestern Europe Meteor Network (SWEMN). The absolute peak magnitude of these events ranged from –8 to –12. Their progenitor meteoroids belonged to the sporadic background, the Perseids, the α-Capricornids, and the κ-Cygnids.

The first relevant event recorded during the above-mentioned period was the "Valdepeñas" fireball, an early Perseid spotted on August 3 that reached a peak absolute magnitude of –8. It was recorded 9 days before the maximum of this meteor shower and overflew the provinces of Ciudad Real and Jaén.

The "Villaricos" fireball, recorded on August 5, overflew the Mediterranean Sea and the province of Almería, and reached a peak absolute magnitude of –12. It was produced by a meteoroid belonging to the α-Capricornid stream (CAP#0001). This bolide was detected four days after the peak of this meteor shower, which is produced by Comet 169P/NEAT. The event exhibited a sudden increase in luminosity at the end of its atmospheric path because of the sudden disruption of the meteoroid.

The "Viveros" bolide, spotted on August 10, overflew the provinces of Ciudad Real and Albacete. Its peak absolute magnitude was –8. The progenitor meteoroid belonged to the sporadic background and followed an asteroidal orbit before hitting the Earth's atmosphere.

Another remarkable Perseid fireball was recorded on August 12, during the activity peak of this meteor shower. With an absolute magnitude of –12, this event was the brightest Perseid spotted over the Iberian Peninsula in 2021. We named this event "Navamorcuende". It overflew the provinces of Segovia, Avila and Toledo. In the spectrum of this meteor we have identified the emissions from Fe I-5, Fe I-43, Fe I-41, Fe I-318 and Fe I-15. The most remarkable lines are those of Fe I-4, Ca II-1, and O I. The emissions from multiplets Ca I-2, Mg I-2 and Na I-1 were also found.

The last fireball presented in this report is a mag. –9 κ-Cygnid recorded on August 18, during the peak of this minor meteor shower. It overflew the province of Cuenca, and the progenitor meteoroid followed a JFC orbit before entering our atmosphere. The most significant contributions found in the emission spectrum of this meteor are those of Na I-1, Mg I-2, and Fe I-4.

Acknowledgment

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The bolide of March 19, 2021 in eastern Cuba and comments on historical Cuban bright fireballs

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On the night of March 19, 2021, at 22^h06^m (02^h06^m UTC), the Cuban seismological stations registered signals that did not match with an earthquake. A bolide was observed in the eastern provinces of the island at this time. Based on a video recorded in Kingston (Jamaica) and the GLM / GOES-16 data, the Cuban bolide reached the Earth's atmosphere at an angle of 42.7° relative to the ground and a speed of ~50000 km/h. The meteor appeared at an altitude of approximately 65.5 km between the town of La Maya and Los Reynaldos (eastern Cuba) and continued for 3.7 seconds in a northerly direction until it disappeared at an altitude of 30.4 km, northeast of La Deseada (eastern Cuba).

1 Introduction

Since the 19th century or earlier, important naturalists observed different celestial phenomena from the island of Cuba, including bright fireballs and meteor showers (De la Sagra, 1867; Poey, 1862, 1864; Rodríguez-Ferrer, 1876; and other publications). But without doubt, it was the fall of "Viñales" in 2019 that accelerated interest in meteorites among the Cuban scientific community in a race against time.

Recently, an event produced similar attention when the National Seismological Service of Cuba reported in a note that, on the night of March 19, 2021, at 22^h06^m (02^h06^m UTC), several seismological stations registered signals that did not match with an earthquake (Arango-Arias, 2021; Iturralde-Vinent and Arango-Arias, 2021).

However, a luminous phenomenon was observed at this time in the eastern provinces of the island, which was quickly disseminated on social networks as a meteorite fall, along with several non-authentic videos and photos. The next day, the online fireball database of the American Meteor Society recorded the event 1755–2021, for a fireball sighted by various observers, including reports from Jamaica and from the west coast of the United States.

2 Fireball trajectory estimation

From the video of Jamaica (*Figure 1*), we see that the Cuban event was not a re-entry as the bolide moved very quickly and ended with an explosion. There are no reentry objects that could have produced the characteristics of this fireball, nor information that can be associated with this specific event[21].

A reentry can cause an artificial bolide that is distinct from a meteoric bolide (Trigo-Rodríguez et al., 2000, 2005). Although the visual appearance is similar, they differ especially in speed and duration of the observed object. The low speed that characterizes a reentry (around 28500 km/h, compared to the range of 40000–250000 km/h for a fireball), slowly wears down the spacecraft so that the artificial bolide can last as long as several minutes, in contrast to the duration of a few seconds for a meteoric bolide. In addition, a spacecraft generally includes multiple structures of various materials that are usually seen separating from the main body during its atmospheric reentry (Trigo-Rodríguez et al., 2005).

Figure 1 – Composition from images of the appearance of the Cuban bolide in the video of Jamaica, made with the UFOAnalyzer software.

[21] https://www.space-track.org/

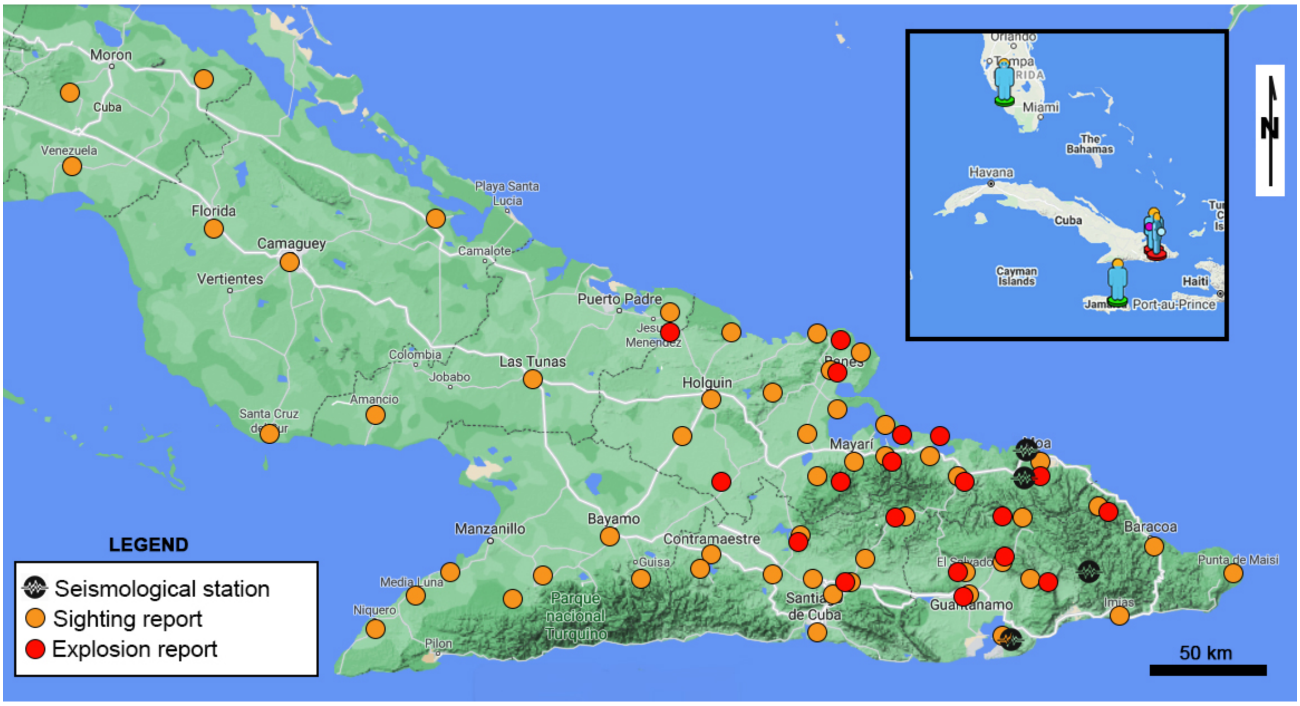

Figure 2 – Map of eastern Cuba with the locations of sightings according to the testimonies of users on the internet, and in the small box according to the official website of the American Meteor Society.

According to Trigo-Rodríguez et al. (2005) other elements such as fuel or water ejection from spacecrafts and traces emitted by aircrafts commonly cause confusion, but they also differ from a natural fireball. Ceballos-Izquierdo (2020) mentions that there have been sightings of luminous phenomena in Cuba that have been erroneously interpreted as meteoric bolides, while these were related to rocket launches in Florida. However, the analysis of the video from Jamaica rules out such assumption.

The duration of the event captured by the camera was about 4.2 seconds and the main explosion reached certainly a magnitude brighter than the Full Moon (–12), probably reaching around –17, an estimation based on the Kingston video (*Figure 1*).

From the GOES-16 satellite flash it was a very energetic event, with the potential to drop meteorites, which does not necessarily mean that this happened.

Table 1 – Videos that captured the appearance of the Cuban bolide (the videos are public online).

#	Location	Coordinates (°)	
1	Guardalavaca, Cuba	–75.8291	21.12523
4	Kingston, Jamaica	–76.843783	18.013435

According to the GLM data from GOES-16, the flash was detected on a north-south trajectory, which suggests the bolide followed a trajectory towards the interior of the island, not to the sea. The start and end coordinates of the path direction are published on the GLM website[22]. It is not the complete trajectory of the fireball, but the explosive phase (final section of the trajectory), for which the energy was recorded by GOES.

On the other hand, the only account of a direct witness on the island in the American Meteor Society reports describes the fireball crossing from left to right, which agrees with the trajectory of GLM, in this case consistent with the hypothesis that the bolide traveled towards the interior of the island. Based on this data, if meteorites had fallen, they should have fallen in the Pico Cristal National Park region. However, the GLM trajectory data does not match the video from Jamaica.

In the video, shot near Kingston, the bolide crossed from high right to low left, suggesting a south-north trajectory, contrary to the GOES-16 data. This divergence is explained by the fact that the GOES-16 satellite is located at the geostationary slot at longitude 75.2° West, 35780 km above the equator.

The GLM view is two-dimensional, therefore, to estimate the coordinates of a flash, the satellite system applies a parallax correction considering that the flash occurred at an altitude of 16 km, which is the average altitude of the upper part of the clouds of storms.

The fireball occurred at longitude –75.6°, practically the same as the satellite, and at latitude 20.6° and since the initial altitude of the bolide is greater than the final altitude and both are probably greater than 16 km, it is necessary to recalculate the coordinates of the flash to correct the difference in parallax along its path. Therefore, depending on the initial and final altitudes of a bolide, it can be

[22] https://neo-bolide.ndc.nasa.gov/

perceived by the GLM in a different trajectory, even contrary to its real trajectory.

To figure out which would be the most realistic trajectory with the data available so far, one of us (di Pietro) found the exact location from where the Jamaica video was made. To do this, the roads on the outskirts of Kingston were reviewed with reference to the mountains in the background of the video and the Google Earth images, until the exact point of the footage was found.

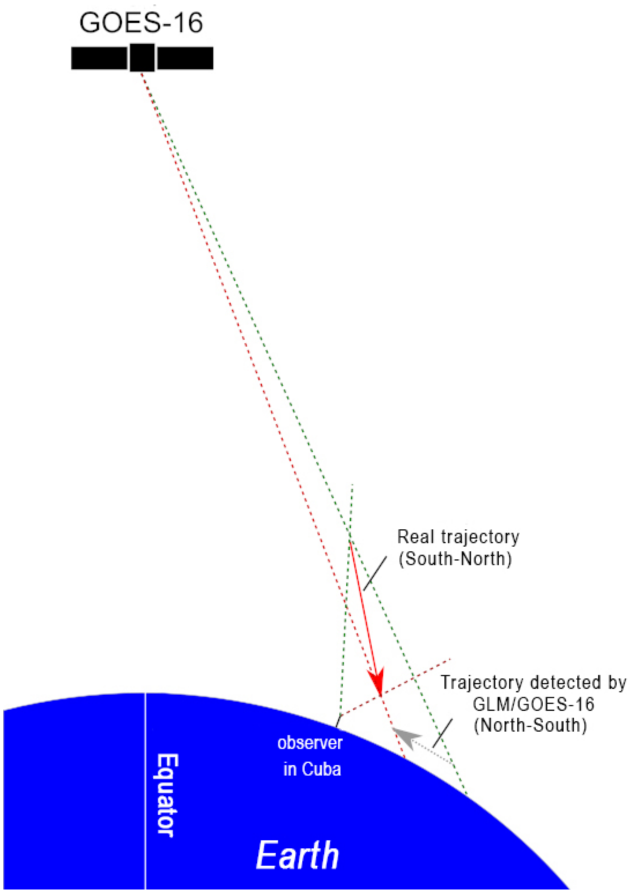

Figure 3 – How the parallax difference can interfere with the direction of the bolide detected by GOES-16. The green lines are the observation directions of the starting point of the bolide. The red lines are the directions of the end point.

With the coordinates it was possible to plot a more precise trajectory. It is practically the opposite direction to the GLM trajectory (*Figure 3*), but much more reliable since it was obtained through the video of Jamaica. The bolide crossed from ~ Southeast to Northwest, which means that, if meteorites had fallen, the strewn field could still be in the Pico Cristal region, although this is just an estimate, as only one informative video is available.

In addition, it is necessary to check the strength and direction of the wind at 30 km of altitude (average altitude from the beginning of the "dark flight" of the meteorites) to the ground, to know where the fragments would have fallen. Another point is that, if the entry angle of the bolide is very shallow, the area of dispersion can extend for tens of kilometers on its longitudinal axis, 40 km or more. In this case the density of fragments per m^2 on the ground would be very low and finding a meteorite would require a miracle. Anyway, the dispersion area is roughly the entire Pico Cristal region, but it is hard to achieve more precision with the information we have (*Figure 4*). A video with enough parallax would be necessary for a good triangulation of the trajectory. Ideally a new video from the opposite point of the existing video would help a lot, although any new record that appears will be useful, even from Jamaica.

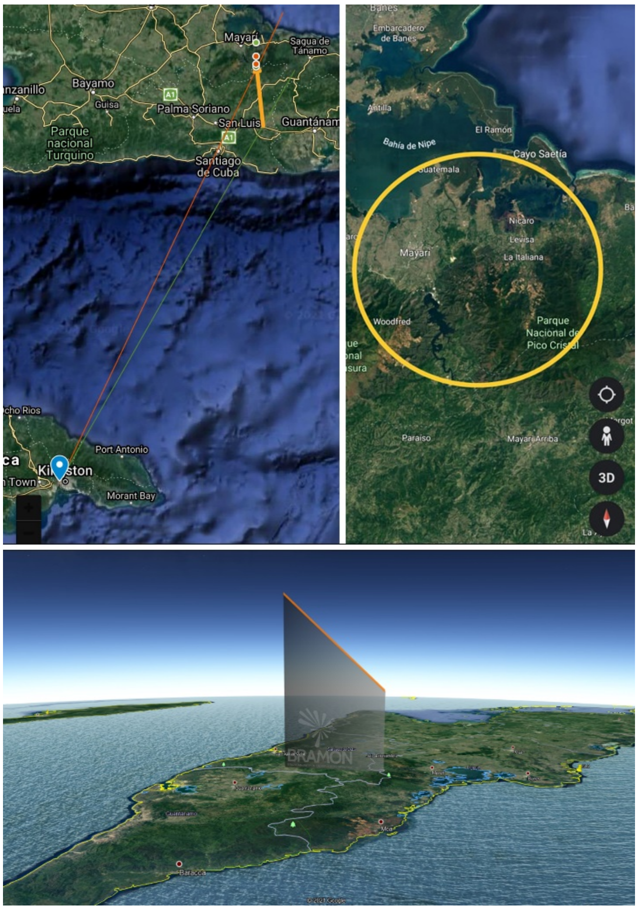

Figure 4 – Above, the yellow arrow represents the preliminary trajectory of the bolide with the available data, while the yellow circle represents the strewnfield if meteorites had fallen. Below, the trajectory of the Cuban bolide from a 3D perspective.

However, if the speed of the bolide was greater than 27 km/s, there is no chance for meteorites as the material is completely volatilized. Also, if the fireball exploded at a high altitude (more than 40 km), the chances for meteorites are minimal. Therefore, so far it is only possible to affirm that the phenomenon observed in eastern Cuba corresponds to the passage of a fireball or meteoric bolide, probably associated to the encounter of our planet with a small group or swarm of meteoroids, which disintegrated at great height. This information is consistent with that offered by the American Meteor Society on meteoric activity in the week of March 13 to 19 (Lunsford, 2021)[23].

[23] https://www.amsmeteors.org/2021/03/meteor-activity-outlook-for-march-13-19-2021.

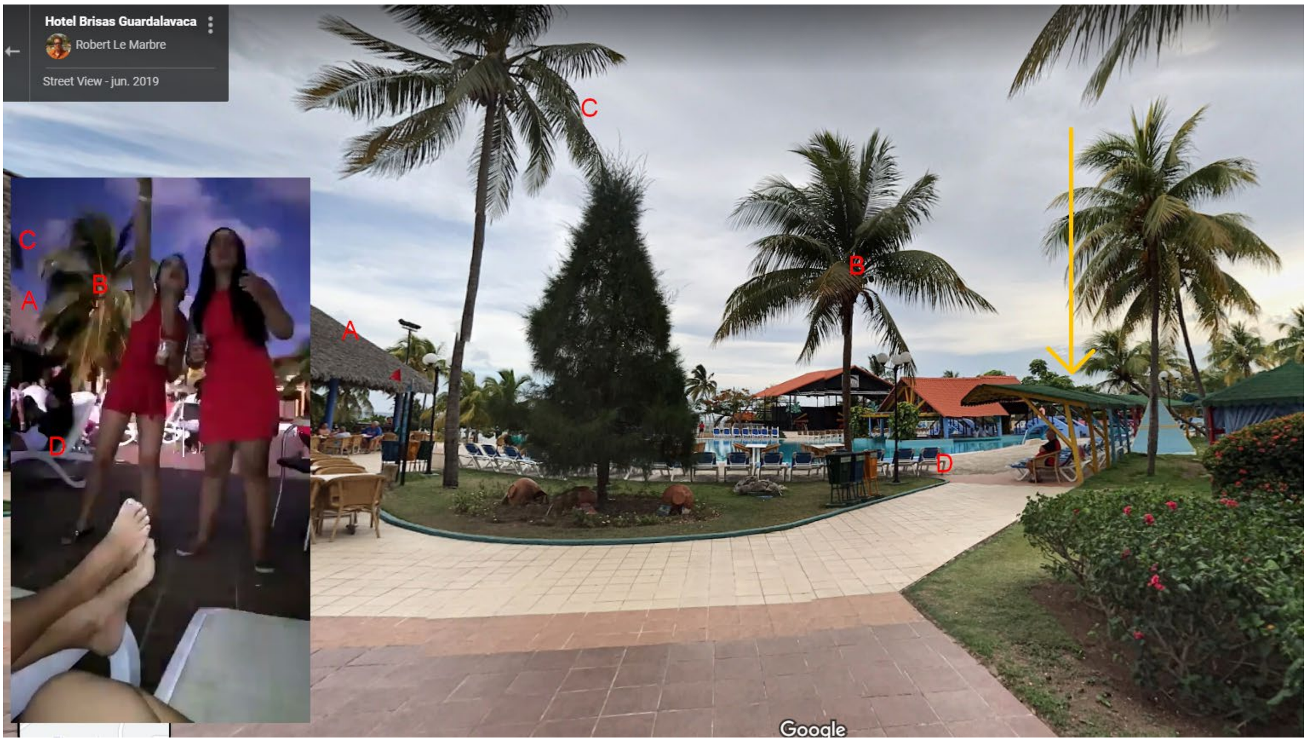

Figure 5 – Reference points that suggest that the location from where the Guardalavaca video was filmed is the one indicated by the yellow arrow.

Table 2 – Preliminary data on the trajectory of the Cuban bolide, M20210320_Cuba. *GD* = ground distance, *HD* = height distance, *D* = Distance, *ZA* = Zenith angle, *A* = Angle.

Point	Coordinates			Dur. (s)	*GD* (m)	*HD* (m)	*D* (m)	*V* (km/s)	*ZA* (°)	*A* (°)
	Lat. (°)	Long. (°)	Alt. (m)							
P1	20.17188	–75.54225	65.50	3.700	38.070	35.10	51.781	13.995	47.324	42.676
P2	20.51176	–75.58620	30.40							

The other video (*Table 1*, *Figure 5*), filmed from Guardalavaca (eastern Cuba), does not seem to provide information, but it does. Guardalavaca is about 66 km from the end point of the bolide (final explosion) of our preliminary trajectory. Assuming that the final altitude of the bolide was about 30 km, the elevation above the horizon for an observer in Guardalavaca would be above 50° probably up to an elevation of 70°. This is the elevation the young woman seems to be aiming for long before the bolide explodes. In a way, this video serves to support our trajectory, making the research work much more valid. There is no way to tell exactly how tall the young woman pointed. On the other hand, with this video we know that the bolide was visible from a region with many hotels, perhaps some of them have cameras that may have recorded the event.

The fact that the other tangible evidence is a seismographic report is not surprising. According to Tapia and Trigo-Rodríguez (2013) the airblast or airburst is an energetic phenomenon that creates sonic waves with enough potential to generate seismic waves, but true generation of seismic waves can also occur by the impact on the ground of meteorites. However, the latter case is rare as large craters do not occur often. From the information offered by the National Seismological Service of Cuba for the Institute of Geophysics and Astronomy (first figure in Arango Arias, 2021) it is possible to infer that there was no true generation of seismic waves, instead these were produced by the sonic waves of the airburst:

1) because the meteoroid completely disintegrated by progressive sublimation as suggested in Note 2 of the Ministry of Science, Technology and Environment (2021), or
2) because in case of an impact, it was too small to produce perceptible records on nearby seismic stations. Some witnesses report having heard two explosions, which is confirmed by the energy variation recorded by the GOES satellite and it also seems to be reflected in the seismograms (where a first initial peak is observed followed by a relatively minor peak).

In addition, the fact of having records of the event in more than two seismic stations, could offer a perspective for further investigations (Tapia and Trigo-Rodríguez, 2013). However, it is possible to use seismological data to find the epicenter of the bolide explosion, but sometimes the error can be large. In case of the 2018 Michigan bolide the error was more than 60 km, in Zambia the error was more than 300 km.

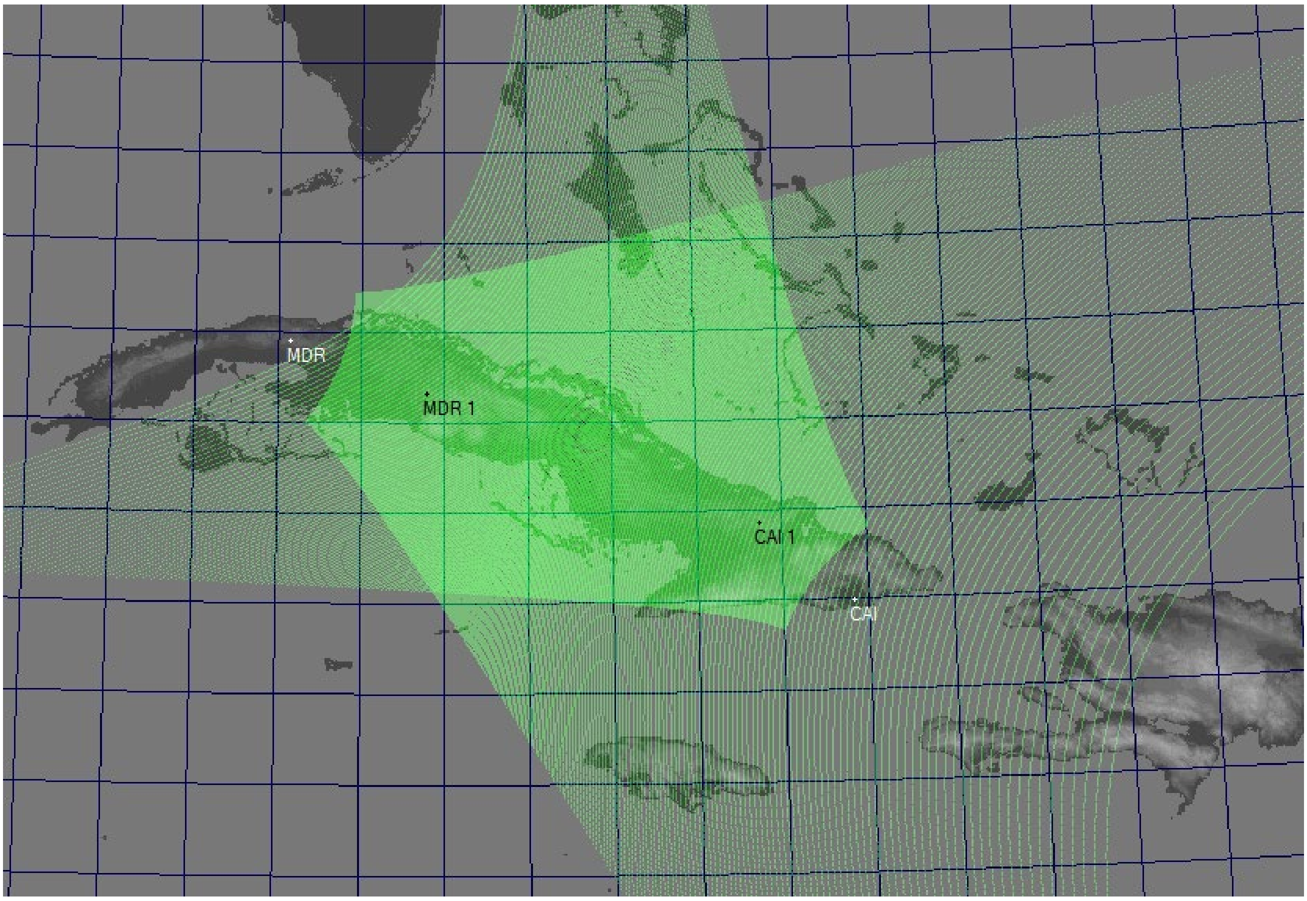

Figure 6 – Basic network proposal for monitoring the sky using surveillance cameras. Two cameras would be enough to cover a large part of Cuban territory.

3 Historical comments

Traditionally six meteorites have been listed for Cuba, all from the year 1938. However, the landfall of a shower of rocks on February 1, 2019, in the Viñales Valley, in Pinar del Río (western Cuba), added a seventh record, and the investigation that would come later on it yielded two meteorites from the 19th century.

The eighth and ninth records are "Las Canas" that fell in 1844, and a meteorite discovered in the eastern part of the island before 1871 (Solano y Eulate, 1872), and which fragments are labeled as "Cuba" in various museums worldwide. Only "Cuba" and "Viñales" are official meteorites recorded in the Meteoritical Society online database (Muñoz-Espadas et al., 2002; Gattacceca et al., 2020).

Being critical with unofficial ones, the information is not available to the international scientific community since little has been published in journals with limited circulation in Cuba, there are no publications available with good quality photos of these materials that can be evaluated and some specimens have been lost or not deposited in museums or institutions. Along with the sparse information available, these facts are in contradiction with the requirements for an adequate modern verification.

Only "Las Canas", under study since 2019, has the possibility to be the next internationally recognized Cuban meteorite, since it is available in an international public institution, and isotope analysis and modern tests allowed to classify it as a Eucrite or Howardite. The handwritten museum label, the fall before a famous hurricane on the island, and several publications support its fall in Cuba (Greg, 1854; Harris, 1859; and others). The event was described as an "explosive aerolitic", evoking the progenitor fireball.

Except for "Viñales" and "Las Canas", only one other Cuban meteorite appears documented in the literature as its entrance produced a fireball with several explosions, this is the "Santa Isabel de las Lajas" meteorite, a specimen shaped like a projectile, oriented, and with a fine black fusion crust.

Up to now, no evidence has been recovered from the recent event in eastern Cuba that would allow us to speak of a meteorite, but even in that case it would not be the first occurrence of a meteorite or a fireball documented in that region. In addition to the 1871 "Cuba" meteorite, Lores (1977) referred to the fact that almost four decades earlier, on August 14, 1833, the impact of a meteorite destroyed part of the Baracoa parish church, and on November 12 in that same year an impressive meteor shower was observed in Sancti Spíritus, according to the naturalist Ramón de la Sagra (1867). In the book "Nature and civilization of the great Island of Cuba", published in 1876, the author, Miguel Rodríguez-Ferrer, provided two old records of meteorite falls, unfortunately without a date or available specimens that can be verified: one was referred to as a meteorite that fell "two leagues from Cienfuegos, near the confluence of the Saladito stream and the Salado river" and the other to a meteorite that fell in Baracoa, which caused great damage and was accompanied by fireballs in heaven. The latter is likely the event described by Lores (1977).

More recently, on April 25, 2019 in Moa, several observers reported the landing of an unusual object in broad daylight. However, no sounds were reported and no fragmentation of the object was observed. A recent analysis of the video record and low-resolution photographs from two different locations leads to the conclusion that it was neither a fireball nor a reentry. The speed is too low even for a re-entry, and also because of the twisted smoke trail. The smoke trail from a bolide or a re-entry takes time to be blown by the wind until it twists, in Moa's video an irregular path of the object itself is observed, leaving the twisted trail in its wake. It is not possible to clarify exactly what it is, but it does not appear to be a meteor or a re-entry.

Based on these historical and, mainly, on recent falls, the implementation of a network for monitoring the sky using surveillance cameras that can record the passage of meteors through the atmosphere would be very useful. Networks like this exist in Europe, USA and Japan since the end of the 20th century and in Brazil since 2015, and are excellent tools in the study of meteors and in determining the trajectory of fireballs, helping the recovery of eventual meteorites. Such a network could be composed of low-cost cameras, hosted at universities and educational institutions, or encouraged by institutions to be hosted and operated by students and amateur astronomers, in a citizen science approach. As shown in *Figure 6*, just two cameras would be enough to cover a large part of Cuban territory.

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Optimizing Camera Orientation for the New Mexico Meteor Array

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The Global Meteor Network consists of over 450 video cameras in 30 countries. Most of these cameras are part of various regional networks. A significant challenge is to optimally orient the cameras within a regional network to maximize the volume of atmosphere that is observed by at least two cameras. We demonstrate the use of an integer linear programming approach to optimize camera coverage for the New Mexico Meteor Array.

1 Introduction

The Global Meteor Network consists of over 450 video cameras in 30 countries that are observing and measuring meteor activity on a nightly basis (Vida et al., 2021). Achieving valid meteor trajectories requires that meteors be observed by at least two cameras. A significant challenge is to optimally orient the individual cameras within a regional network of cameras so as to maximize the volume atmosphere that is within the field of view of least two cameras.

The Art Gallery Problem is a well-known problem in computational geometry. It addresses the problem of guarding an art gallery with the minimum number of guards who can keep every piece of art within the gallery under their constant gaze. It is a special case of the more general problem of maximizing surveillance of selected targets by a limited number of sensors. There is an extensive literature on this topic (Mavrinac and Chen, 2013). However, we found little in the literature that is directly applicable to the unique requirements associated with meteor monitoring. Here, the challenge is not to keep a few selected targets always in view with the minimum number of sensors, but to find the largest volume of contiguous space that can be kept within the constant view of two or more cameras. Furthermore, because these cameras are operated by volunteer owners, it is generally not possible to optimally choose the location of the camera, nor is it always possible to use what might be the optimal azimuth and elevation angle due to obstruction by terrain, trees, buildings, utility poles, etc.

2 Approach

We employ the Target in Sector (TIS) approach to the problem of optimizing multi-camera coverage of multiple targets by a network of directional cameras as described by Sadik et al. (2015). This is commonly referred to as the *k*-coverage problem, where *k* refers to the number of cameras covering a target.

A target is deemed coverable by a camera if it is within the angular sector defined by the field of view of the camera and within the sensing range of the camera. Conducting TIS tests over every possible orientation of every camera for each target leads to a 3-dimensional coverage matrix of M targets and N cameras with P orientations where each binary element of the matrix is assigned a value of 1 when target M_m is covered by camera N_n at orientation P_p or, otherwise, the matrix element is assigned the value of zero.

For meteor detection, the targets are the gridpoints of a three-dimensional Cartesian grid that covers the altitude layer where meteors are typically observed above a geographical region of interest. While the magnitude of the horizontal dimensions is limited only by the computational power that it takes to numerically solve the optimization problem, we have generally limited the Cartesian grid to less than 1000 km × 1000 km at 10 km resolution. The vertical dimension of the grid is between 70 km and 120 km at 10 km resolution. This region is referred to as the Region of Optimization (RoO).

We define 24 possible orientations for each camera by designating 8 azimuths (N, NE, E, SE, S, SW, W, NW) and up to 3 user-selectable elevation angles for each elevation. The most common camera/lens arrangement in the GMN network uses the IMX291 camera fitted with a 3.6mm f/0.95 lens. This combination yields a nominal 88° × 48° field of view (Vida et al., 2021). It is also conveniently suitable for the computation of the binary coverage matrix via the TIS method described above.

The effective sensing range of the cameras was estimated from an analysis of over 45000 meteor observations made by all 23 stations in the New Mexico Meteor Array (NMMA) during December 2020. Analysis of those observations revealed that 99% of meteors detected were within 320 km of the stations detecting them.

The software that processes the meteor observations detected by the cameras, RMS, also calculates a polygon representing the field of view at 100 km altitude from the stellar astrometric calibration data that accounts for lens distortion and asymmetry. In a similar way, the field of view can also be visualized by plotting the projected location of meteor observations in the horizontal plane at 100 km altitude from the azimuth and altitude of the observations. In *Figure 1*, the blue polygon represents the RMS-calculated field of view at 100 km and the grey markers are the projected locations of 7238 meteor observations (made in December 2020) at 100 km for one camera in the network, US000J. Several features are apparent. Because meteors exhibit a wide range of magnitudes, the density of observations decreases with increasing distance from the station due to atmospheric scattering and extinction of light from the fainter meteors. Some (4.4%) observations fall outside of the polygon. The reason for this is not clear. The asymmetry of both the polygon and the distribution of observations may be the result of lens asymmetry or because the camera is not perfectly level.

Figure 1 also shows (in yellow) the nominal 88° × 48° field of view as computed by the TIS test as described above. This field of view encompasses 71.9% of the observations. We found that increasing the horizontal width to 96° was a better match to the width of the RMS-polygon. We decreased the vertical height of the field of view from 48° to 46° because all the platepar files we examined from the cameras in the Lowell and NMMA networks reported a vertical field of view of 46°. The resulting field of view of 96° × 46° at 100 km and limited to a range of 320 km as computed by the TIS test is shown in green in *Figure 1*. This field of view encompasses 74.2% of the observations and is used for all of the results presented below.

Many camera owners rely on the 3DFOV tool provided on the GMN website[24] to aid pointing of cameras. *Figure 1* shows that field of view in red. Note that 64% percent of the meteor observations are within that trapezoidal polygon.

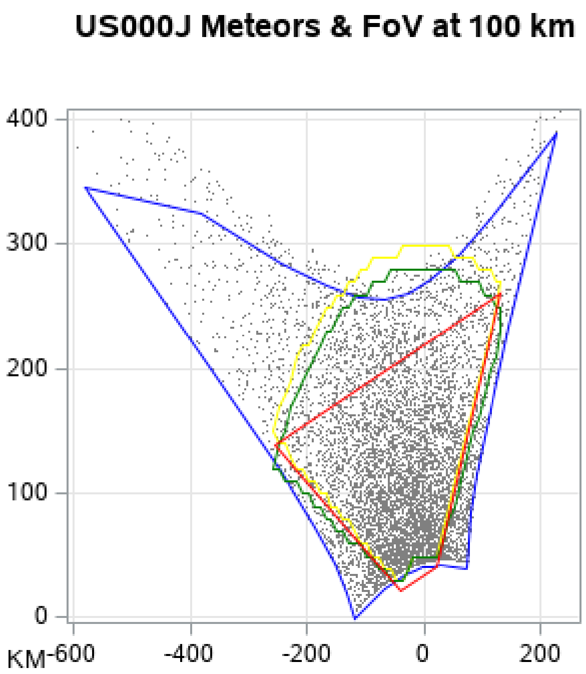

Figure 1 – Meteors detected at 100 km by US000J and representations of the field of view: RMS (blue), FOV3D (red), 88° × 48° sector (yellow), 96° × 46° sector (green). See text for details.

After the binary coverage matrix has been created by the TIS test, the next step is to formulate an objective function that can be numerically solved using integer linear programming techniques.

The objective function is the function to be maximized by the numerical solver. Although a meteor trajectory and orbit can be calculated with a minimum of two observations from two stations, it is desirable to have at least three camera coverage for a more robust solution. Therefore, the objective function maximizes the number of targets covered by three or more cameras ($k \geq 3$).

Implementation of the model is performed with SAS® software[25]. Specifically, SAS software generates the binary coverage matrix. The SAS OPTMODEL Procedure implements a mixed integer linear programming solver that finds the optimal orientation of each camera that maximizes the objective function. SAS software is also used to analyze and display the results. SAS software is a cloud-based service freely available through SAS OnDemand for Academics.

Figures of Merit

An important use of the model is to explore of how the addition of new or hypothetical cameras or relocation or re-aiming of existing cameras might affect the overall coverage. A key question is how to measure the quality of one proposed solution versus another. There are several ways to evaluate a solution.

The simplest metric is the Objective Value. This is the value of the function being maximized by the model. It is simply the number of gridpoints covered by 3 or more cameras ($k \geq 3$).

Sadik et al. (2015) proposed what they call a Balancing Index. It combines the concept of a Fairness Index that measures the uniformity or fairness of coverage with an additional metric that measures the extent to which the desired goal of 3-camera coverage has been met. Mathematically, the Fairness Index is expressed as:

$$FI = \left(\sum_{t=1}^{m} \psi_t\right)^2 \Big/ \left(m \sum_{t=1}^{m} \psi_t^2\right)$$

where m is the number of targets, and ψ_t is the number of times target t is covered. Note that ψ_t is restricted to less than or equal to k to avoid biasing the result by targets with $> k$ camera coverage. Sadik et al. (2015) recognized that this metric is imperfect because it favors solutions that yield uniform coverage.

Consider a simple case (adapted from Sadik et al. (2015)) with only 3 targets and where 3 camera coverage ($k = 3$) of each target is desired. A solution where each target is covered twice (2, 2, 2) is fairer than a solution where two targets are covered twice and one target covered three times

[24] https://globalmeteornetwork.org/fov3d/

[25] The output for this paper was generated using SAS software. Copyright © 2021 SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

(2, 3, 2). The Fairness Index FI for both solutions is given below:

$$FI = \left(\frac{(2+2+2)^2}{(3\cdot(2^2+2^2+2^2))}\right) = 1.0$$

$$FI = \left(\frac{(2+3+2)^2}{(3\cdot(2^2+3^2+2^2))}\right) = 0.97$$

The (2, 2, 2) solution, while fairer than the (2, 3, 2) solution, fails to achieve the desired 3-camera coverage for any of the targets. Sadik et al. (2015) modify the concept of the Fairness Index by introducing a term that measures the achieved coverage as a fraction of the maximum possible coverage. Mathematically, the Balancing Index is given by:

$$BI = FI \cdot \left(\sum_{t=1}^{m} \psi_t\right) \Big/ (k\cdot m)$$

where km is the product of the desired optimal coverage ($k = 3$) and the total number of targets m.

Using the example from above, the Balancing Index for the two solutions is:

$$BI = \left(\frac{(2+2+2)^2}{(3\cdot(2^2+2^2+2^2))}\right)\cdot\left(\frac{(2+2+2)}{(3\cdot 3)}\right) = 0.666$$

$$BI = \left(\frac{(2+3+2)^2}{(3\cdot(2^2+3^2+2^2))}\right)\cdot\left(\frac{(2+3+2)}{(3\cdot 3)}\right) = 0.747$$

The Balancing Index favors the (2, 3, 2) solution and is a more useful metric for evaluating possible solutions. Note that this metric, like the Objective Value, is based on the number of gridpoints covered and the number of times each gridpoint is covered.

In meteor science the quality of the coverage is as important, if not more so, as the extent of the coverage. Quality of coverage can be measured by the convergence angle. From geometry, on a 3-dimensional grid, a plane can be defined by a line and a point. The convergence angle, Q_c, is defined as the angle between two planes where each plane is defined by the linear track of the meteor and the location of each of two stations. A meteor trajectory obtained from a pair of observations by two stations with a high convergence angle is, all else being equal, superior to a solution from a pair of observations with a low convergence angle.

From the model output, we identify the subsets of gridpoints within the Region of Optimization that are within the joint field of view of every unique combination of cameras. For each subset, 100 random meteors[26] are generated within the bounds of that region. The mean convergence angle among the cameras that hold that region within their joint field of view is calculated. If a region is within the view of only two cameras, then the Q_c Score for the region is calculated as the mean of the convergence angle for the 100 meteors weighted by the number of gridpoints within that region. If three or more cameras cover the region, then for each of the 100 random meteors we identify the camera pair with the maximum Q_c value. The Q_c Score for that region is defined as the mean of the maximum Q_c values for the 100 meteors weighted by the number of gridpoints within the region. The final Q_c Score for the entire Region of Optimization is then taken as the mean of the Q_c Score for all sub-regions. Note that the Q_c Score is a relative measure that can only be used for evaluating the coverage of one possible arrangement of cameras vs other possible arrangements within a given RoO.

3 Results

Two-station network

The simplest of networks consists of two cameras. This is the minimum number of cameras necessary to compute a meteor trajectory and orbit. For eight possible azimuths, there are four possible camera orientations (*Figure 2*). The optimal choice depends on the elevation angle of the cameras and the distance between the stations. The optimal elevation angle is the lowest angle that has a clear view of the sky for both cameras. The optimization model was used to determine the optimal orientation as a function of the

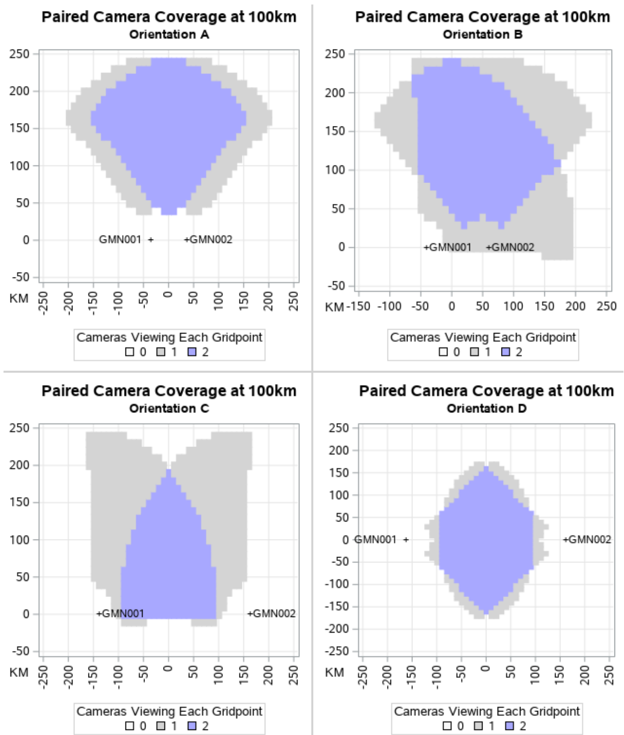

Figure 2 – Four possible camera orientations for a two-station network. For Orientation A, GMN001 & GMN002 are both aimed perpendicular to the line between the two stations. For Orientation B, GMN001 is oriented perpendicular to the line whereas GMN002 is at a 45° angle toward GMN001. For Orientation C, each camera is oriented at a 45° angle towards each other. For Orientation D, the two cameras are aimed toward each other.

[26] Random meteors are generated between start altitudes of 90–120 km and end altitudes of 70–100 km while ensuring that the start altitude is higher than the end altitude. The track is at least 10 km in length and the entry angle is between 15 and 90 degrees.

distance between the stations. *Table 1* shows the recommended orientation as a function of the elevation angle and the distance between the stations.

Table 1 – Two-camera orientation as function of elevation angle and distance between hypothetical stations GMN001 and GMN002. See *Figure 2* for a description of orientations A through D.

	Elevation Angle			
Orientation	35 °	40 °	45 °	50 °
A	<100 km	<80 km	<70 km	<60 km
B	100-190 km	80-180 km	70-135 km	60-110 km
C	190-320 km	180-290 km	135-270 km	110-200 km
D	>320 km	>290 km	>270 km	>200 km

Small Network

A more complex challenge was to optimize the pointing of a small network of three stations located in Southern California. Initially, each station hosted a single camera. In 2021, the Lowell Observatory began installing and activating a network of cameras throughout Arizona. The field of view of some of these cameras extends westward into Southern California. *Figure 3* shows the initial state of the coverage of the Lowell network and the three stations in Southern California at an altitude of 100 km.

Two of the three California stations were in the process of being upgraded with the addition of a second camera. So, the challenge became to optimize the pointing of five cameras at three locations so as to maximize the intersection with the field of view of the Lowell cameras. The fields of view of the Lowell cameras were treated as fixed and the Southern California cameras were optimized to maximize the volume of atmosphere covered by at least three cameras from both networks.

The first optimization calculations produced a result where both cameras co-located at a single location were oriented on the same azimuth and elevation. Although this produces two observations of a meteor by two cameras, there is no separation between the cameras. The convergence angle is zero and no trajectory solution is possible.

In these cases, the co-located cameras were treated within the optimization model as a single "virtual camera" with a horizontal field of view that is twice the width of a single camera. The model solves the optimization problem for the virtual camera. The physical cameras are aimed so that the boundaries of their respective fields of view overlap slightly at the azimuth recommended by the model for the virtual camera. *Figure 4* shows the optimized coverage. The blue box shows the region where coverage is optimized by the model. Stations designated with the prefix VS are virtual stations with two co-located physical cameras. VS0S1R is a composite of physical cameras US000S and US001R. Whereas VS0V1Q is a composite of physical cameras US000V and US001Q. In this case, the optimal result was for US001E, VS0S1R and VS0V1Q to all be aimed at the 135° azimuth at 35° elevation. For the virtual station VS0S1R, the two physical cameras (US000S and US001R) were pointed at 180° and 90° respectively. The same holds true for virtual station VS0V1Q where the two physical cameras US000V and US001Q were also pointed at azimuths of 180° and 90°. The improvement in coverage is clearly evident in *Figure 4*. The figures of merit as represented by the Objective Value, Balancing Index and Q_c Score as shown in *Table 2* provide a more quantitative way to comparatively judge coverage pre- and post-optimization.

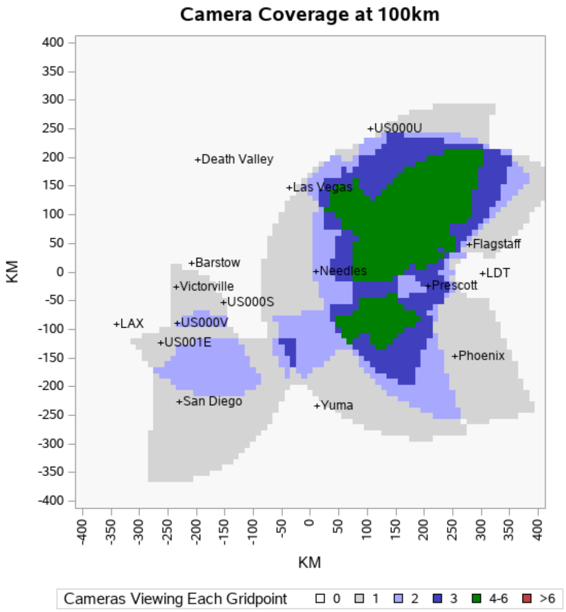

Figure 3 – Coverage at 100 km by the Southern California network and Lowell network before optimization.

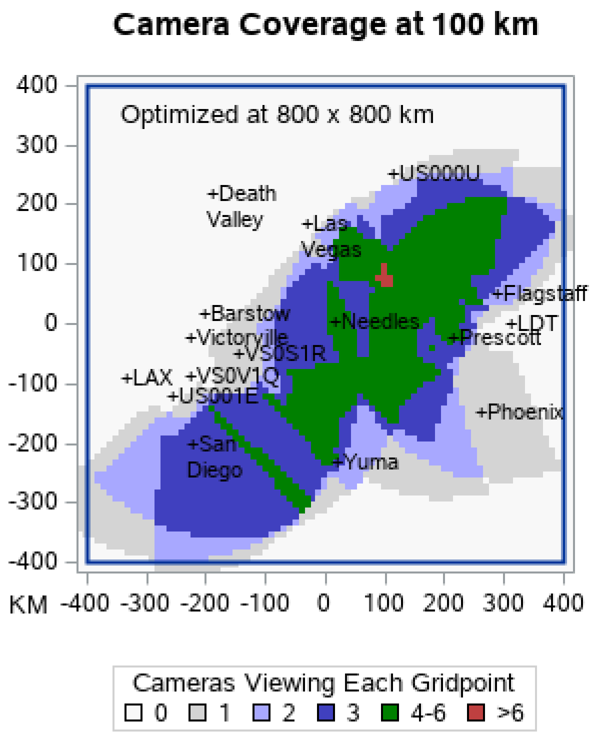

Figure 4 – Coverage at 100 km by the Southern California network and Lowell network after optimization.

While in this instance it's clear from inspection of *Figure 4* that the coverage after optimization is a dramatic improvement, it may not always be so clear.

Consider the hypothetical possibility that US001E could alternatively be located in Victorville, CA. It would be useful to know how this would affect network coverage. We ran the model for this configuration and found that the recommended camera orientations would be unchanged. But the entry for "Victorville option" in *Table 2* shows that all the figure of merit scores are lower. Locating the camera in Victorville would not be an improvement over the current location.

The cameras of this network were re-aimed and re-calibrated in the summer of 2021 and are now aligned and operating as indicated in *Figure 4*.

Table 2 – Figures of merit for region of optimization.

Figure of Merit	Pre-Optimization	Post-Optimization	Victorville option
Objective Value	4592	10048	9620
Balancing Index	0.044	0.100	0.098
Q_c Score	55	71	65

Large Network

Building on the success of the Southern California network, we moved to a similar problem but on a larger scale with the 23 cameras that comprise the New Mexico Meteor Array (NMMA). Here, too, the goal was to optimize the pointing of the NMMA cameras to maximize intersection with the cameras of the Lowell network whose fields of view extend eastward into New Mexico. In addition, a goal of the NMMA is to maximize coverage over the state of New Mexico.

Figure 5 shows the coverage at 100 km for the cameras in the Lowell network in eastern Arizona and extending into western New Mexico. *Figure 6* shows the combined coverage at 100 km of the NMMA, as currently configured, with the Lowell network. The current coverage evolved prior to the establishment of the Lowell network. It was originally designed with the primary goal of maximizing coverage over the Albuquerque metropolitan area. The blue box is a 540 km by 700 km area that indicates the region designated for optimization. It covers most of the state of New Mexico and a bit beyond. It overlaps the outer limits of coverage from the Lowell network where there is less than 3-camera coverage.

As before, the orientation of the Lowell cameras was held constant while the orientation of the NMMA cameras were subject to optimization. If a given orientation of a camera results in an obstructed field of view, then that orientation becomes a forbidden orientation within the model. The three allowed elevation angles are 35, 45 and 55 degrees. *Figure 7* show the coverage at 100 km after optimization. *Table 3* gives the figures of merit for the Region of Optimization shown in *Figures 6* and *7*. Although the improvement is obvious from the figures, the increases in the figures of merit confirm the improvement. Work is presently underway to re-orient the NMMA cameras to their optimal orientations and establish the required new calibrations.

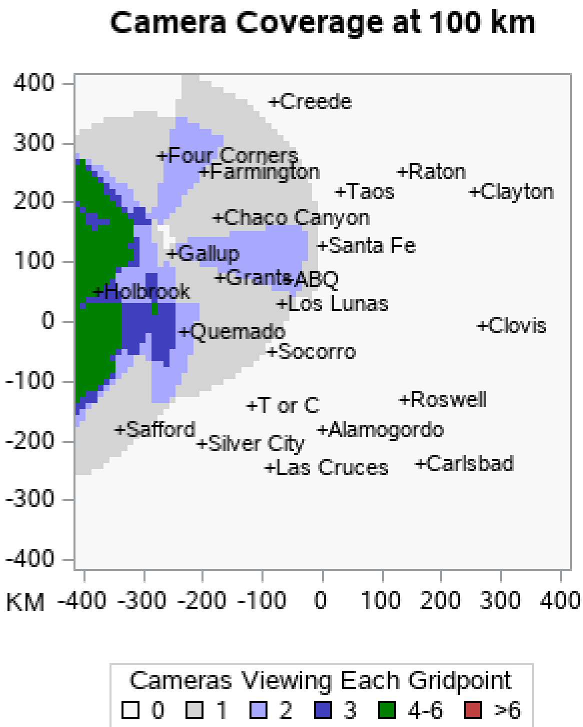

Figure 5 – Extension of coverage at 100 km by the Lowell Network into New Mexico.

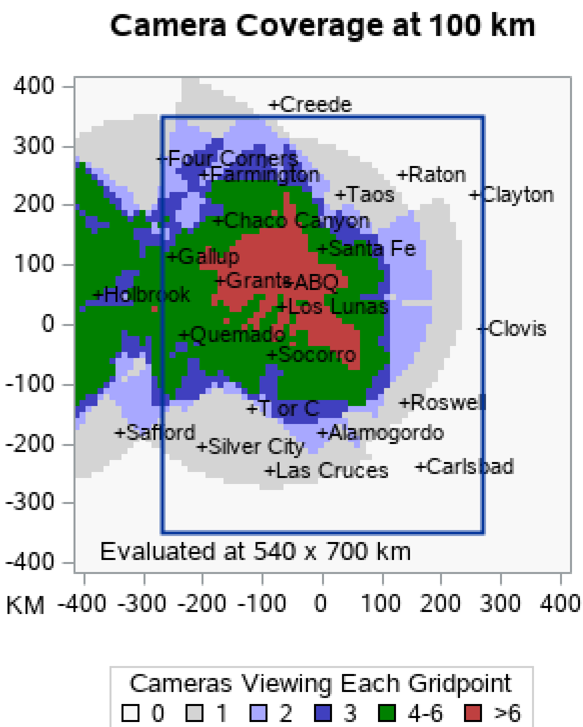

Figure 6 – Coverage at 100 km by the NMMA and the Lowell network before optimization.

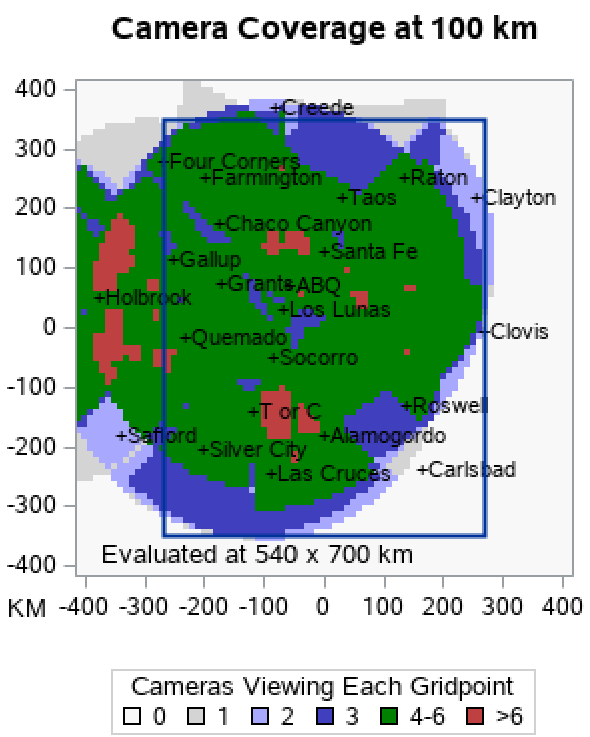

Figure 7 – Coverage at 100 km by the NMMA and the Lowell network after optimization.

Table 3 – Figures of merit for region of optimization.

Figure of Merit	Pre-Optimization	Post-Optimization
Objective Value	7406	18433
Balancing Index	0.35	0.78
Q_c Score	11.9	25.6

4 Conclusion

The TIS approach of modeling the field of view of the cameras as a sector with a fixed range is conceptually simple, easy to implement, still useful for orienting cameras within a network, but not ideal. A different approach is needed to more accurately capture the complex shape and asymmetry of the actual field of view of the cameras. This could even be expanded to include the effects of atmospheric extinction and sensitivity loss. We are investigating an alternative approach that determines, for every possible camera orientation, which grid points are covered by the irregular polygon that represents the field of view.

The goal of the Global Meteor Network is: "No Meteor Unobserved". One key to achieving that goal is optimal orientation of the cameras within the regional networks that comprise GMN. This work presents a methodology to optimize the orientation of multiple cameras so as to maximize the likelihood of simultaneous detection of meteors.

Acknowledgment

We thank the NMMA camera owner/operators without whom this work would not be possible: *Peter Eschman* (Coordinator), *John Briggs*, *Ollie Eisman*, *Jim Fordice*, *Bob Greschke*, *Larry Groom*, *Tim Havens*, *Bob Hufnagel*, *Ron James Jr.*, *Steve Kaufman*, *Jean-Baptiste Kikwaya*, *Bob Massey*, *Alex McConahay*, *Robert McCoy*, *Dave Robinson*, *Jim Seargeant*, *Eric Toops*, *Bill Wallace* and *Steve Welch*.

We thank *Denis Vida* for his insights leading to the development of the Q_c Score as a figure of merit.

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July 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of July 2021 is presented. July 2021 allowed to obtain meteor orbits during 28 nights resulting in 7125 multiple station meteors, with a total number of 2525 orbits for July 2021. A maximum of 81 cameras was operational at 27 camera stations during this month.

1 Introduction

Although a summer month, the weather in July is often unfavorable for astronomy in the BeNeLux area. The short nights with only about 6 hours of observing time are easily ruined by bad weather. The overall meteor activity increases significantly during this month with some well-established showers late July while Perseid activity becomes clearly visible. So far, July 2018, 2019 and 2020 were all excellent months of July for our CAMS network, would July 2021 become another successful month of July?

2 July 2021 statistics

CAMS BeNeLux collected 7125 multi-station meteors, good for 2525 orbits (against 12834 multi-station meteors and 3823 orbits in July 2020). This is much less than previous 3 years and the poorest result for July since 2016.

July 2018 and 2019 had more than half of all July nights with almost completely clear nights for the network, July 2020 had about half of its nights with unfavorable weather and July 2021 got only few complete clear nights. Three nights ended without any single orbit, just like previous year, 11 nights had more than 100 orbits (14 in 2020 and 17 in 2019), only 2 nights had more than 200 orbits (6 in 2020, 9 in 2019). July 29–30 was the most successful night with 285 orbits, much less than the record July night of 30–31 July 2020 with 542 orbits or July 29–30 in 2019 with 504 orbits. The statistics of July 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, 247 July nights allowed to obtain orbits with a grand total of 20988 orbits collected during this month in all these years.

The BeNeLux CAMS network had its last major expansion in the summer of 2017 and since then every now and then some new cameras were added. No new cameras were added in July 2021, but as many 25 cameras at several CAMS stations in the Netherlands and Germany were not available for various reasons in July 2021. It remains a challenge to keep all the hardware operational and people motivated. In a video camera network, the success of each participant depends on the availability and goodwill of all others involved in order to obtain multi-station events. When a number of camera locations have no cameras running, this reduces the number of paired meteors. Since AutoCAMS got applied at most camera stations, the practice of running cameras only occasionally on nights with clear sky got limited to four of the CAMS stations.

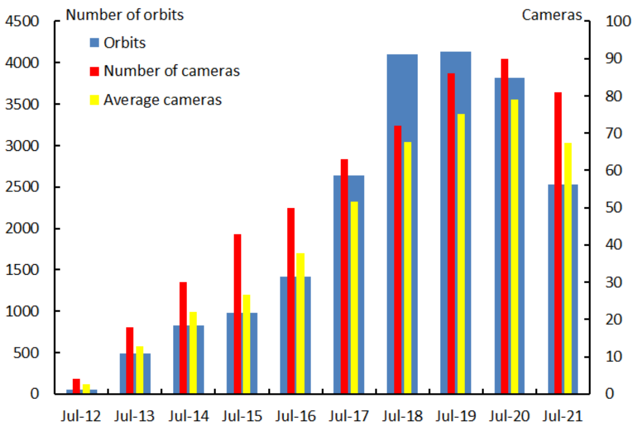

Figure 1 – Comparing July 2021 to previous months of July in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras capturing in a single night and the yellow bar the average number of cameras capturing per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	7	49	4	4	–	2.6
2013	22	484	10	18	–	12.9
2014	19	830	14	30	–	22.0
2015	28	976	15	43	–	26.7
2016	28	1420	18	50	10	37.9
2017	27	2644	20	63	30	51.6
2018	30	4098	19	72	59	67.7
2019	30	4139	21	86	63	75.2
2020	28	3823	24	90	59	79.1
2021	28	2525	27	81	55	67.3
Total	247	20988				

3 Conclusion

A combination of unfavorable weather circumstances with less operational cameras available explains why this month was the least successful month of July since 2016. Considering the poor weather and the availability of less cameras, the total of 2525 orbits is still a very good result in these circumstances.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[27]. The CAMS BeNeLux team was operated by the following volunteers during July 2021:

Hans Betlem (Woold, 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 and 327), *Giuseppe Canonaco* (Genk, RMS 3815), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806 and 3888), *Tammo Jan Dijkema* (Eelderwolde, Netherlands, RMS 3198, Dwingeloo, Netherlands, RMS 3199), *Jean-Paul Dumoulin, Dominique Guiot and Christian Walin* (Grapfontaine, Belgium, CAMS 814 and 815, RMS 3814), *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 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 3001, 3002, 3003, 3004, 3005, 3006, 3007, 3008, 3009 and 3010), *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), *Tim Polfliet* (Gent, Belgium, CAMS 396), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *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 348).

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

August 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of August 2021 is presented. The CAMS BeNeLux network experienced favorable weather circumstances during the rich Perseid nights. Especially August 13–14 produced remarkable many paired meteors. As many as 24179 multiple station meteors were recorded. A total of 7382 orbits were collected during this month with a maximum of 89 operational cameras available at 27 camera stations.

1 Introduction

The Perseid month of August remains the favorite observing month for many amateurs. Moon wise, the circumstances were favorable in 2021 and the only uncertain factor remained the weather. The corona pandemic kept most amateur astronomers at home so that most camera owners remained available for meteor work at home. During most past years, August was the best month of the year in terms of number of orbits. What would August 2021 bring?

2 August 2021 statistics

CAMS BeNeLux collected 24179 multi-station meteors (28479 in 2020 and 33231 in 2019), good for 7382 orbits (8756 in 2020 and 9921 in 2019). The total for 2021 is less than the two previous years but still much better than August 2018 when 'only' 5403 orbits were recorded.

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. Still, this isn't a record harvest in orbits in a single night for CAMS BeNeLux. The absolute record remains for August 12–13 in 2017 when 1555 orbits were collected in a single night. December 12–13, 2018 had 1396 orbits and the 2018 Draconid outburst October 08–09 had 1391 orbits. If we ever get a clear Geminid maximum with our current number of cameras, these record numbers will be history.

16 August nights had more than 100 orbits (25 in 2020), 5 nights had more than 500 orbits (also 5 in 2020). Two nights remained without any orbits (none in 2020). The weather was definitely less favorable than in 2020 or 2019 as less meteors were caught in 2021 with about the same number of cameras available.

The statistics of August 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, 278 August nights allowed to obtain orbits with a grand total of 52552 orbits collected during this month for all these years together.

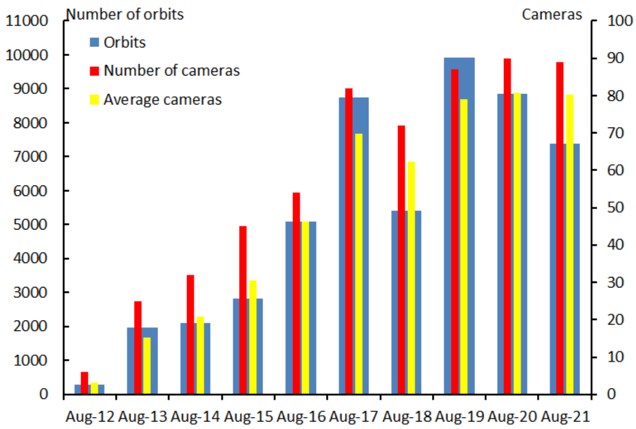

Figure 1 – Comparing August 2021 to previous months of August in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras capturing in a single night and the yellow bar the average number of cameras capturing per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Camas	Mean Cams
2012	21	283	5	6	–	3.2
2013	27	1960	13	25	–	15.3
2014	28	2102	14	32	–	20.8
2015	25	2821	15	45	–	30.4
2016	30	5102	20	54	15	46.2
2017	28	8738	21	82	45	69.9
2018	30	5403	19	72	56	62.4
2019	29	9921	23	87	65	79.0
2020	31	8756	24	90	59	80.7
2021	29	7382	27	89	65	80.2
Total	278	52552				

Most camera operators use AutoCams, only some CAMS stations in the Netherlands and Germany do not yet use AutoCAMS. Remote control allows to operate the cameras and to report data from any holiday resort during the summer holidays without causing any delays. For this purpose, the RMS cameras are most valuable as these systems are fully automated and can be easily remotely accessed by using AnyDesk.

Three new cameras were installed during August 2021. CAMS 3817 at OCA, Grapfontaine, an RMS camera (BE0005) with a 6 mm lens (FoV 54° × 30°) pointed low in western direction. CAMS 3818 and 3819 (BE0007 and BE0008) were installed at Cosmodrome in Genk, both RMS cameras with 6 mm lenses. BE0003 (CAMS 3815) was moved from Genk to Zillebeke where it started to register meteors in September.

It is worthwhile to look at the number of orbits collected with these RMS cameras, compared to the Watecs in the CAMS BeNeLux network. The 20 best scoring cameras during August 2021 are listed in *Table 2*. The efficiency of the RMS cameras compared to the best performing Watecs is obvious.

Table 2 – Comparing RMS cameras among the twenty cameras of the CAMS BeNeLux network with the best score in terms of orbits during August 2021.

Camera	Total orbits	Total nights
003814 (RMS, Grapfontaine, BE)	**975**	**31**
003816 (RMS, Lesve, BE)	**932**	**31**
000378 (RMS, Kattendijke, NL)	**571**	**31**
003800 (RMS, Langenfeld, DE)	**570**	**31**
003801 (RMS, Holdorf, DE)	**529**	**31**
000806 (Watec, Zoersel, BE)	437	31
003817 (RMS, Grapfontaine, BE)	**434**	**19**
003830 (RMS Mechelen, BE)	**430**	**31**
003004 (Watec, Gronau, DE)	427	18
003815 (RMS Genk, BE)	**404**	**13**
003891 (Watec, Mechelen, BE)	397	31
000394 (Watec, Dourbes, BE)	392	31
000805 (Watec, Zoersel, BE)	379	31
003833 (Watec, Mechelen, BE)	376	30
003003 (Watec, Gronau, DE)	373	18
003834 (Watec, Mechelen, BE)	368	30
003832 (Watec, Mechelen, BE)	365	30
000816 (Watec, Humain, BE)	365	31
003005 (Watec, Gronau, DE)	363	18
003035 (Watec, Oostkapelle, NL)	357	25

3 Conclusion

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.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[28]. The CAMS BeNeLux team is operated by the following volunteers:

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

September 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of September 2021 is presented. September 2021 counted many clear nights. 24894 multiple station meteors were recorded. A record number of 7457 orbits were collected during this month with a maximum of 93 cameras available at 27 locations.

1 Introduction

Previous years the month of September brought favorable weather circumstances combined with a rich meteor activity, although no major showers are active this time of the year. Nights are getting longer, about two hours more nighttime between begin of September and the end of the month. What did September 2021 bring us?

2 September 2021 statistics

CAMS BeNeLux collected 24894 multi-station meteors (12997 in September 2020, 14826 in 2019), good for 7457 orbits (6132 in 2020, 4609 in 2019). 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 (20 in 2020, 15 in 2019). 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 (4 in 2020, 1 in 2021). The statistics of September 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, 265 September nights allowed to obtain orbits with a grand total of 37602 orbits collected during September during all these years together.

The weather was very favorable in September 2021, with almost twice as many multi-station meteors than in 2020. The larger number of cameras that were operational also provided better coverage compared to previous years with favorable weather. The northern part of the CAMS BeNeLux network still suffered less good coverage as some of the CAMS stations were temporarily inactive or unable to contribute for various reasons.

The volume of atmosphere monitored by the CAMS BeNeLux cameras is huge. If all or most cameras are kept operational, most of the meteors registered will help to obtain an orbit. It is important to keep as many cameras operational as possible. This remains a challenge as technical failures cannot be ruled out. Some extra camera stations would be very welcome to reinforce the northern and entire western part of the network. The new RMS cameras are most suitable for this task as these systems are fully automatic.

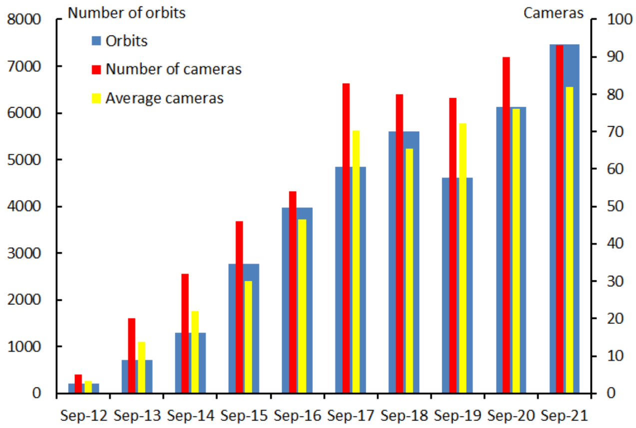

Figure 1 – Comparing September 2021 to previous months of September in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bar the average number of cameras running per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	18	209	5	5	–	3.4
2013	19	712	9	20	–	13.7
2014	27	1293	14	32	–	22.0
2015	29	2763	15	46	–	30.0
2016	30	3982	19	54	32	46.5
2017	29	4839	22	83	47	70.2
2018	28	5606	20	80	57	65.4
2019	29	4609	20	79	64	72.3
2020	26	6132	24	90	52	76.2
2021	30	7457	27	93	64	82.0
Total	265	37602				

Two RMS cameras were added at Zillebeke near Ypres, CAMS 3853 (BE0003 which was previously installed at Cosmodrome in Genk) and CAMS 3851 (BE0009 home built by Steve Rau). These new cameras will improve the coverage above Belgium and Zeeland. With a total of 93 cameras, never before more cameras were available during September.

The effectiveness of the RMS cameras is obvious when we compare the number of orbits obtained by individual cameras. An RMS camera with a 6 mm lens has the same resolution of 2.5 arcminutes per pixel for its FoV of 54° × 30° compared to a Watec in PAL format with FoV of 30° × 22°. The RMS will capture more meteors because of its larger FoV. Moreover, the astrometric calibration of the RMS software is superior to that of the CAMS software for its Watecs.

Table 2 – Comparing RMS cameras among the twenty cameras of the CAMS BeNeLux network with the best score in terms of orbits during September 2021.

Camera	Total orbits	Total nights
003817 (RMS, Grapfontaine, BE)	**1063**	**30**
003814 (RMS, Grapfontaine, BE)	**1045**	**30**
003816 (RMS, Lesve, BE)	**668**	**30**
000378 (RMS, Kattendijke, NL)	**530**	**30**
003830 (RMS Mechelen, BE)	**527**	**30**
003800 (RMS, Langenfeld, DE)	**504**	**30**
000816 (Watec, Humain, BE)	493	30
003819 (RMS Genk, BE)	**493**	**30**
003801 (RMS, Holdorf, DE)	**471**	**30**
003900 (Watec, Nancy, FR)	469	30
000380 (Watec, Wilderen, BE)	454	30
003891 (Watec, Mechelen, BE)	447	30
000394 (Watec, Dourbes, BE)	445	30
003831 (RMS Mechelen, BE)	**433**	**30**
003818 (RMS Genk, BE)	**425**	**30**
000814 (Watec, Grapfontaine, BE)	421	30
003833 (Watec, Mechelen, BE)	404	28
003836 (Watec, Mechelen, BE)	386	28
000393 (Watec, Uccle, BE)	381	30
003890 (Watec, Mechelen, BE)	378	30

3 Conclusion

September 2021 confirmed the reputation of this month with a very rich background meteor activity and favorable weather. It will be hard to improve the record number of orbits in the future.

Acknowledgment

Many thanks to all participants in the CAMS BeNeLux network for their dedicated efforts. The data on which this report is based has been taken from the CAMS website[29]. The CAMS BeNeLux team was operated by the following volunteers during September 2021:

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

Aurigids (AUR#00206) 2021 using worldwide radio meteor observations

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In the evening of August 31, 2021, an unusual activity has been observed by worldwide radio meteor observations. It seems that this was caused by the Aurigid 2021 outburst which had been predicted by several researchers. The outburst occurred at $\lambda_\odot = 158.39°$ (August 31, 21^h UT). The Activity Level Index (AL) was $AL = 1.1 \pm 0.3$. This corresponds to a $ZHR_r = 55 \pm 19$. In a more detailed activity profile using every 10-minute counts, the Aurigid peak was estimated to occur at $\lambda_\odot = 158.402°$ (August 31, 21^{h}45^m UT) with a $ZHR_r = 85 \pm 27$. This unusual activity was of a very short duration for about one hour. Besides, a lot of Long Echoes were observed during the period of $\lambda_\odot = 158.38° – 158.41°$ (August 31, 21^{h}10^m–22^{h}00^m UT).

1 Introduction

With Radio Meteor Observations it is possible to observe meteor activity continuously even during bad weather or daytime. Besides, the radiant elevation problem is solved by organizing a worldwide project. One of worldwide projects is the *International Project for Radio Meteor Observations* (IPRMO)[30]. IPRMO uses the Activity Level Index for analyzing the meteor shower activity (Ogawa et al., 2001).

The Aurigids (AUR#00206) have produced outbursts in 1935, 1986, 1994, 2007 and 2019. On September 1, 2007, the outburst peak occurred at $\lambda_\odot = 158.556°$ with a ZHR = 132 ± 26 (Rendtel, 2007). The Aurigids 2019 displayed a peak $ZHR = 65 \pm 12$ at $\lambda_\odot = 157.918°$ (Rendtel et al., 2020). Radio Meteor Observations sometimes caught weak activity during the interval $\lambda_\odot = 158°–159°$[31]. The traditional peak occurred around September 1 ($\lambda_\odot = 158.6°$). Since the Aurigid meteor shower has a very fast geocentric velocity of 66 km/s, we should keep the height ceiling effect in mind in the case of radio meteor observation.

Sato M., Lyytinen E. and Vaubaillon J. published the prediction of an extra peak expected in 2021 around $\lambda_\odot = 158.3°–158.4°$ (August 31, 21^h–22^h UT) (Rendtel, 2020). The best location with best conditions was located in Asia. Many Japanese radio observers prepared for this possibility. Since it was daytime around the predicted peak time (September 1, 6^{h}00^m–7^{h}00^m Local Time), radio meteor observations were the best method for this observation.

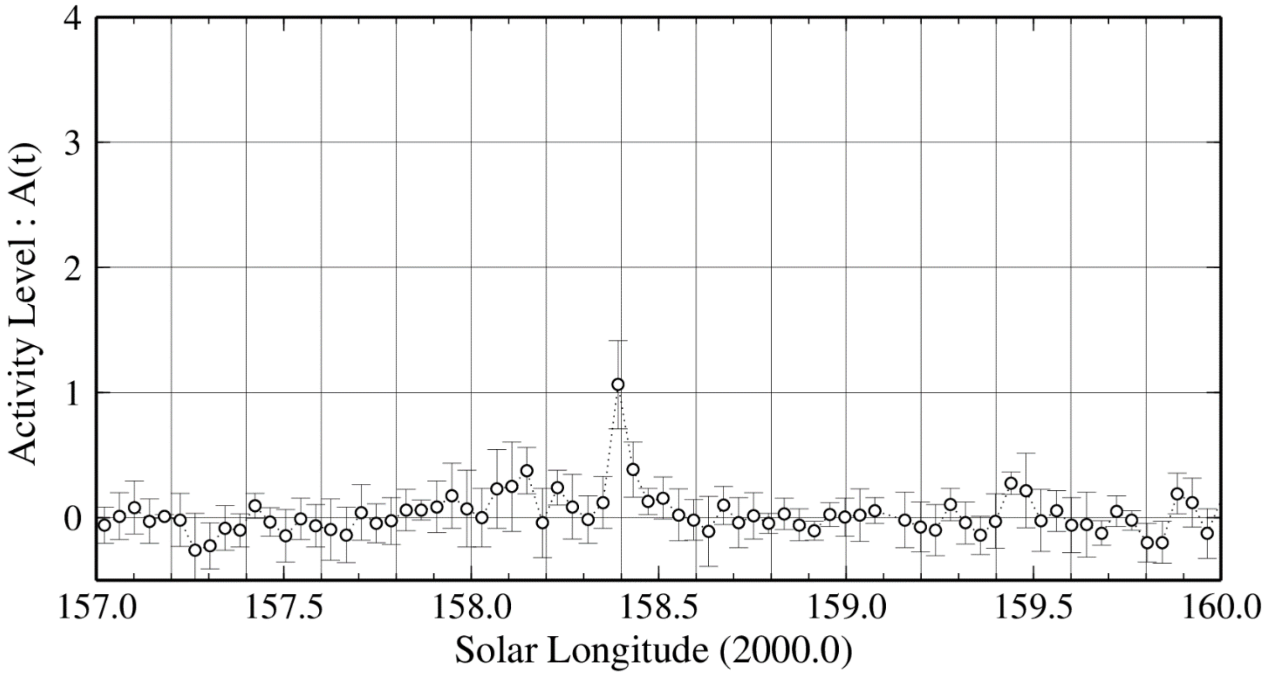

Figure 1 – The Activity Level Index for the Aurigids 2021.

[30] https://www.iprmo.org

[31] http://www5f.biglobe.ne.jp/~hro/Flash/index-e.htm

2 Method

This research adopted two methods for estimating the Aurigid meteor shower activity. One is the *Activity Level Index* which is being used by IPRMO (Ogawa et al., 2001). This index has been used in many studies of meteor showers (Ogawa and Steyaert, 2017). The structure of the meteor activity profile was estimated by using the Lorentz profile (Jenniskens et al., 2000).

Another method is the estimated ZHR_r (Sugimoto, 2017). This index is obtained by using the *Activity Level Index* and a factor named S_{bas} which translates to ZHR_r. This method is very useful in order to compare the radio data with visual observations.

3 Results

3.1 Activity Level Index

Figure 1 shows the result for the Aurigids in 2021 based on the calculation of the *Activity Level Index* using 39 observing entries from 13 countries. There was no unusual activity until $\lambda_{\odot} = 158.35°$ (August 31, 20^{h} UT). The unusual activity started suddenly. The peak occurred at $\lambda_{\odot} = 158.39°$ (August 31, 21^{h} UT) with an *Activity Level Index* = 1.1±0.3. The high activity level lasted less than one hour. The activity level went back to the normal level at $\lambda_{\odot} = 158.5°$ (September 1, 0^{h} UT).

3.2 Estimated *ZHR_r*

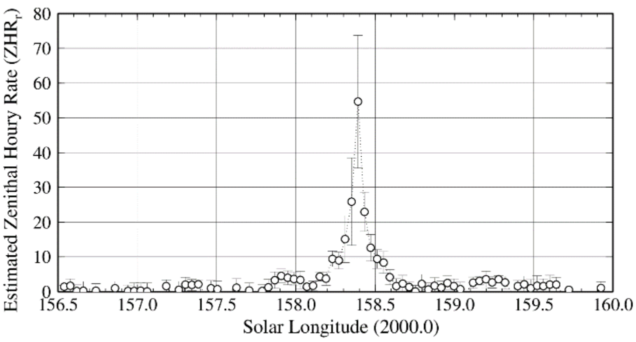

Figure 2 – The estimated ZHR_r of the Aurigids 2021.

Table 1 – The *Activity Level Index* (*AL*) and the estimated ZHR_r of the Aurigids 2021.

Time (UT)	$\lambda_{\odot}$	Activity Level		ZHR_r	
		N	*AL*	*N*	ZHR_r
Aug 31, 17^{h}	158.230°	8	0.2 ± 0.1	6	9 ± 2
Aug 31, 18^{h}	158.271°	11	0.0 ± 0.3	6	9 ± 2
Aug 31, 19^{h}	158.311°	9	–0.0 ± 0.2	6	15 ± 7
Aug 31, 20^{h}	158.351°	9	0.1 ± 0.2	4	26 ± 13
Aug 31, 21^{h}	158.391°	6	1.1 ± 0.3	12	55 ± 19
Aug 31, 22^{h}	158.432°	7	0.4 ± 0.2	6	23 ± 6
Aug 31, 23^{h}	158.472°	7	0.1 ± 0.1	4	13 ± 4
Sep 1, 00^{h}	158.512°	15	0.2 ± 0.2	7	9 ± 3
Sep 1, 01^{h}	158.553°	13	0.0 ± 0.2	10	8 ± 3

Figure 2 shows the result for the Aurigids in 2021 according to the calculation of the ZHR_r-values based on 39 observing reports from 12 countries. The activity began at $\lambda_{\odot} = 158.31°$ (August 31, 19^{h} UT). From $\lambda_{\odot} = 158.35°$ (August 31, 20^{h} UT), the activity increased rapidly. The peak was over at $\lambda_{\odot} = 158.39°$ (August 31, 21^{h} UT).

Figure 3 shows a more detail Aurigids activity using Japanese radio observers every 10-minutes counts. The high activity was seen only about 30 minutes during for the period of $\lambda_{\odot} = 158.388°–158.402°$ (August 31, 20^{h}20^{m} – 20^{h}50^{m} UT) with over $ZHR_r = 60$. The peak was over at $\lambda_{\odot} = 158.402°$ (August 31, 21^{h}45^{m} UT). The ascending branch was wider than the descending branch. The full width of half maximum (FWHM) = –0.025° / +0.020° (about –40 minutes /+30 minutes) was determined by using the Lorentz activity profile.

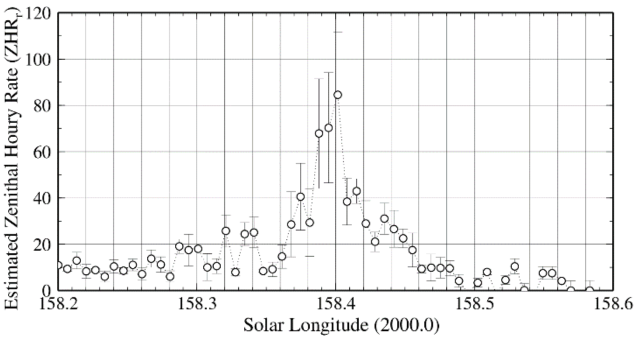

Figure 3 – A more detailed ZHR_r profile for the Aurigids using the Japanese radio meteor observers.

3.3 Long duration echoes

Strong overdense meteor echoes called "long echoes" have been often observed. A long echo of more than 60 seconds is recorded every now and then. Although there are a lot of long echoes observed during the activity period of major meteor showers, there are only few long echoes at the end of August and begin of September during ordinary years.

Figure 4 shows a comparison of the number of long echoes for some days in 2021 compared to past years as recorded by Japanese observing stations. Each echo lasting more than 20 seconds or longer is defined as a long echo. The number of long echoes in 2021 was six times higher than in previous year.

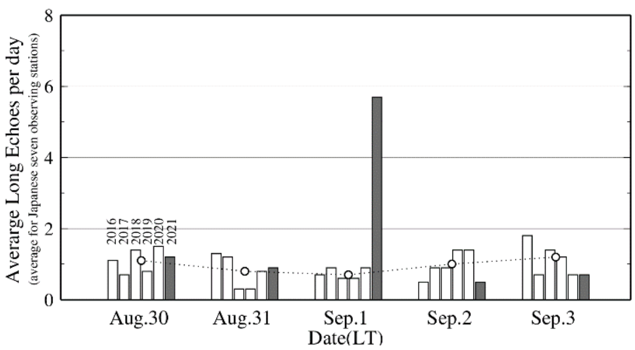

Figure 4 – A comparison of the number of long echoes for some days in 2021 compared to past years as recorded by Japanese observing stations. (Circles represent the average for the period of 2016–2020).

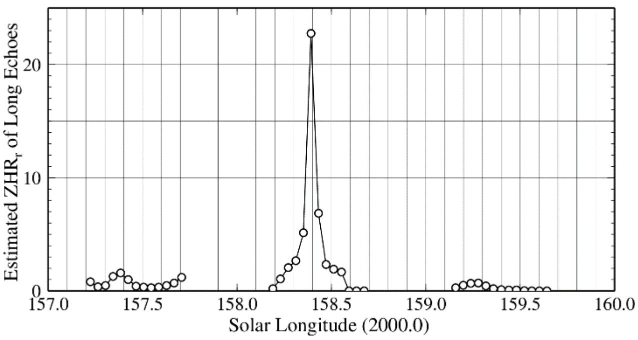

Figure 5 – The estimated ZHR_r for the long duration echoes.

Moreover, most of the long echoes have been observed during the period of Aug. 31, $18^h – 23^h$ UT. *Figure 5* shows the estimated ZHR_r for the long echoes around the time of the peak activity. A lot of long echoes were seen during the period of $\lambda_O = 158.30° – 158.45°$ (August 31, 19^h – 22^h UT). On the other hand, however, there was no unusual activity before or after this period.

Figure 6 shows some images of a number of observed long echoes including some obtained the days before and after the peak at the Shibukawa observing stations using 89.4MHz (by Masaki Kano, Japan). The days before and after the peak, there were few long echoes. On the other hand, there were a lot of long echoes on August 31.

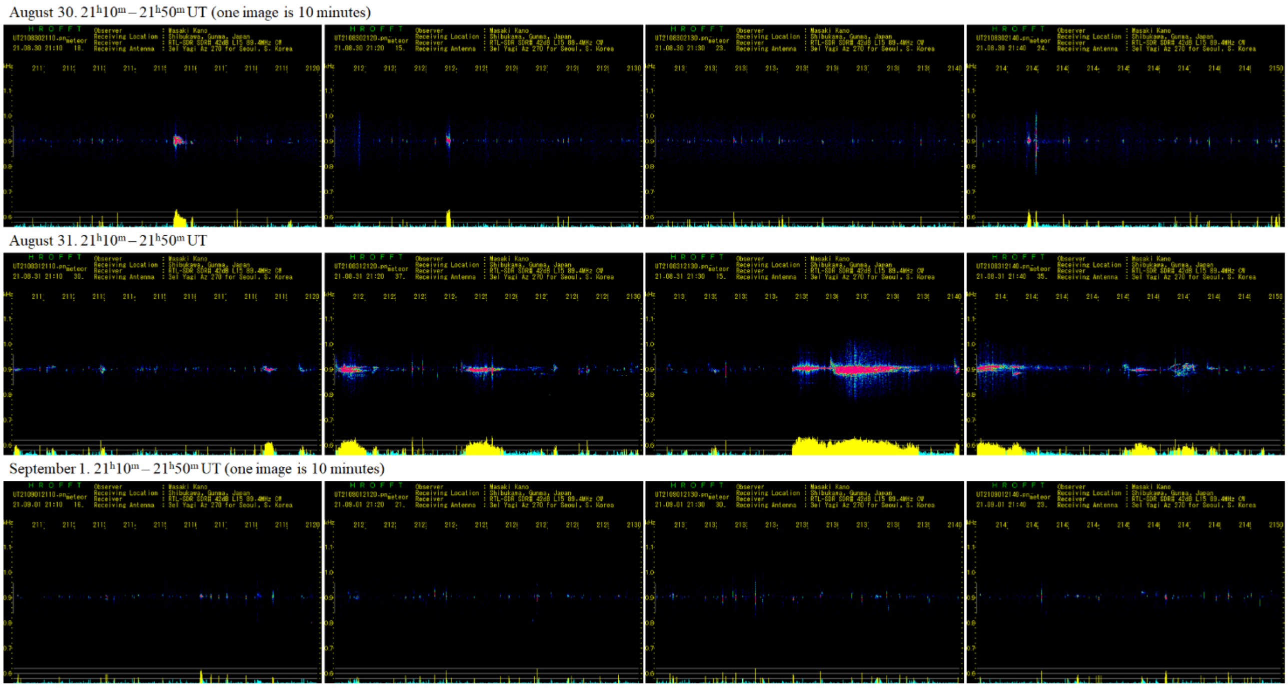

Figure 6 – Several long duration echoes recorded during the period of 21^h10^m–21^h50^m (UT) at the Shibukawa observing stations (by Masaki Kano, Japan) using 89.4MHz. (up: August 30, middle: August 31, bottom: September 1).

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Arids 2021 using worldwide radio meteor observations

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The Arids outburst released by the 2014 dust trail from comet 15P/Finlay has been observed on October 7 using worldwide radio meteor observations. The observing conditions were difficult for many radio meteor observers, being located at the Northern hemisphere. This time, the outburst was mainly caught at Mexican observing stations. The outburst occurred at October 7, 0^h – 1^h UT ($\lambda_\odot$ = 193.67–193.71°) with an Activity Level Index = 1.7 ± 0.1 and an estimated ZHR_r = 80 ± 10.

1 Introduction

An encounter with meteoroids of comet 15P/Finlay, named Arids, had been predicted for 2021 by several researchers (Rendtel, 2020; Vaubaillon, 2020). The first outburst was already detected on September 27–30 (Jenniskens, 2021). After that, another encounter caused by the 2014 dust trail was expected on October 7. It was calculated for the period of October 7, 00^h30^m–01^h30^m (UT) (Ye et al., 2021).

Radio meteor observations make it possible to observe meteor activity continuously even if bad weather interferes or during daytime. Besides, the problem with the radiant elevation is solved by organizing radio observing as a worldwide project. One of the worldwide projects is the *International Project for Radio Meteor Observations* (IPRMO)[33]. IPRMO uses the Activity Level index for analyzing the meteor shower activity (Ogawa et al., 2001). The first outburst of the Arids was not detected by the worldwide radio meteor observations because the radiant elevation was too low to be observed at almost all observing stations.

2 Method

2.1 Activity Level Index and Estimated *ZHR$_r$*

This research adopted two methods to estimate the Arids meteor shower activity. One is the Activity Level Index which is used by IPRMO (Ogawa et al., 2001). The second is the estimated ZHR_r (Sugimoto, 2017). This index is estimated by using the Activity Level index and a factor named S_{bas} which translates the activity to the ZHR_r. This method is very useful to compare radio observations with visual observations.

2.2 Considering the zenith attraction

Since the geocentric velocity of the Arids is very slow with 11 km/s, the zenith attraction needs to be taken into consideration (Richardson, 1999). This analysis has taken this factor into account.

3 Results

3.1 Activity Level Index

Figure 1 shows the result for the Arids 2021 based on the calculation of the Activity Level Index using 30 observing stations in 11 countries. Almost all of the observing stations had difficulties to observe this shower because of the low radiant elevation even with the zenith attraction taken into account). Some unusual activity has been recorded around October 7, 0^h–1^h ($\lambda_\odot$ = 193.67°–193.71°). The maximum occurred at October 7, 0^h UT ($\lambda_\odot$ = 193.67°) with an Activity Level Index = 1.7 ± 0.1. This outburst was mainly observed by Mexican observing stations.

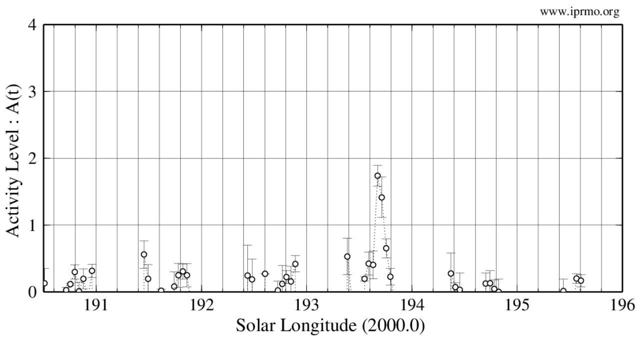

Figure 1 – Activity Level Index of Arids 2021.

3.2 Estimated *ZHR$_r$*

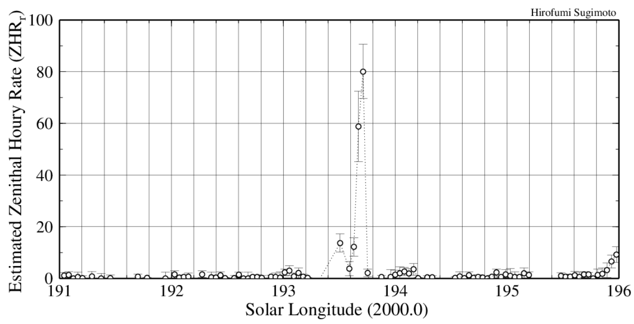

Figure 2 – Estimated ZHR_r of Arids 2021.

[33] https://www.iprmo.org

Figure 2 shows the result for the Arids in 2021 based on the calculation of the ZHR_r. A strong activity was recorded at October 7, 1^h UT ($\lambda_{\odot}$ = 193.71°) with ZHR_r = 80 ± 10.

Although the time of the maximum is different between the Activity Level Index and the estimated ZHR_r, it seems that this depends on the rather few observations (only a couple of observing stations in Mexico).

Table 1 – Activity Level Index (AL) and estimated ZHR_r of Arids 2021.

Time (UT)	$\lambda_{\odot}$ (°)	Activity Level		ZHR_r	
		N	AL	N	ZHR_r
Oct 6, 20^h	193.507	1	–	2	14 ± 3
Oct 6, 21^h	193.548	2	0.2 ± 0.0	0	-
Oct 6, 22^h	193.589	3	0.4 ± 0.2	3	4 ± 3
Oct 6, 23^h	193.630	3	0.4 ± 0.2	3	12 ± 4
Oct 7, 00^h	193.672	2	1.7 ± 0.1	2	59 ± 14
Oct 7, 01^h	193.713	3	1.4 ± 0.3	2	80 ± 10
Oct 7, 02^h	193.754	9	0.6 ± 0.1	1	2 ± 4
Oct 7, 03^h	193.795	4	0.2 ± 0.1	1	(–7 ± 3)
Oct 7, 04^h	193.836	6	–0.1 ± 0.2	1	(–6 ± 2)

Acknowledgment

The worldwide data were provided by the Radio Meteor Observation Bulletin (RMOB)[34]. Although most observing stations suffered bad conditions such as a low radiant elevation, many observes provided data. We thank the following observers for their contribution:

Chris Steyaert (Belgium), *Felix Verbelen* (Belgium), *Johan Coussens* (Belgium), *Jean Marie F5CMQ* (France), *WHS Essen* (Germany), *Balogh Laszlo* (Hungary), *Istvan Tepliczky* (Hungary), *GAML Osservatorio Astronomico Gorga* (Italy), *Mario Bombardini* (Italy), *Oss Monte San Lorenzo DLF* (Italy), *Hirofumi Sugimoto* (Japan), *Hironobu Shida* (Japan), *Hiroshi Ogawa* (Japan), *Kenji Fujito* (Japan), *Masaki Kano* (Japan), *Masaki Tsuboi* (Japan), *Nobuo Katsura* (Japan), *Tomohiro Nakamura* (Japan), *Juan Zapata* (Mexico), *Rainer Ehlert* (Mexico), *Salvador Aguirre* (Mexico), *Rafael Martinez* (Puerto Rico), *Karlovsky Hlohovec Observatory* (Slovakia), *Jochen Richert* (Switzerland), *Philip Norton* (United Kingdom), *Philip Rourke* (United Kingdom), *Simon Holbeche* (United Kingdom), *Eric Smestad_KC0RDD* (United States of America), *Richard Schreiber* (United States of America).

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Ye Q.-Z., Vaubaillon J., Sato M., Maslov M. (2021). "Dust ejecta from comet 15P/Finlay". *Astronomers Telegram*, 2 Oct. 2021.

[34] https://www.rmob.org

Radio observations in July 2021

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This article presents the results of radio observations made in July 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

There are no main showers in July, so the activity of meteors is more or less uniform. Three waves of activity can be seen on the graph. The first is until July 10–11, the second from July 12–24, and the third from July 25-31. The peak in the third wave may be the combined activity of SDA (#0005), CAP (#0001), GDR (#0184) (Rendtel, 2020).

Figure 1 shows the hourly rates of radio meteors in July 2021 at 88.6 MHz. *Figure 2* shows the corresponding heat map.

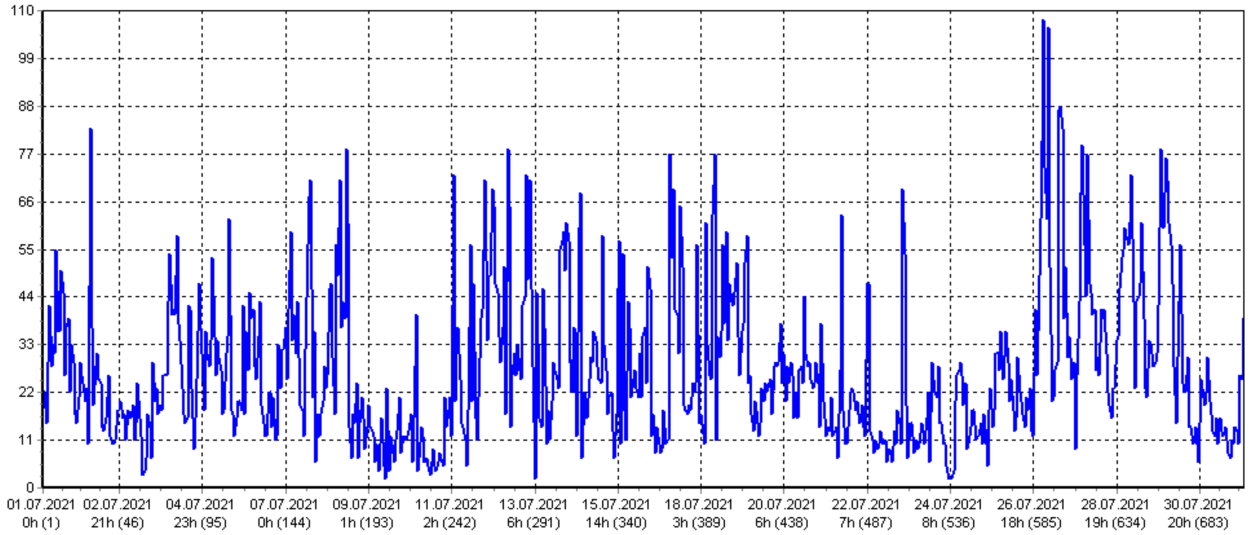

Figure 1 – Radio meteor echo counts at 88.6 MHz for July 2021.

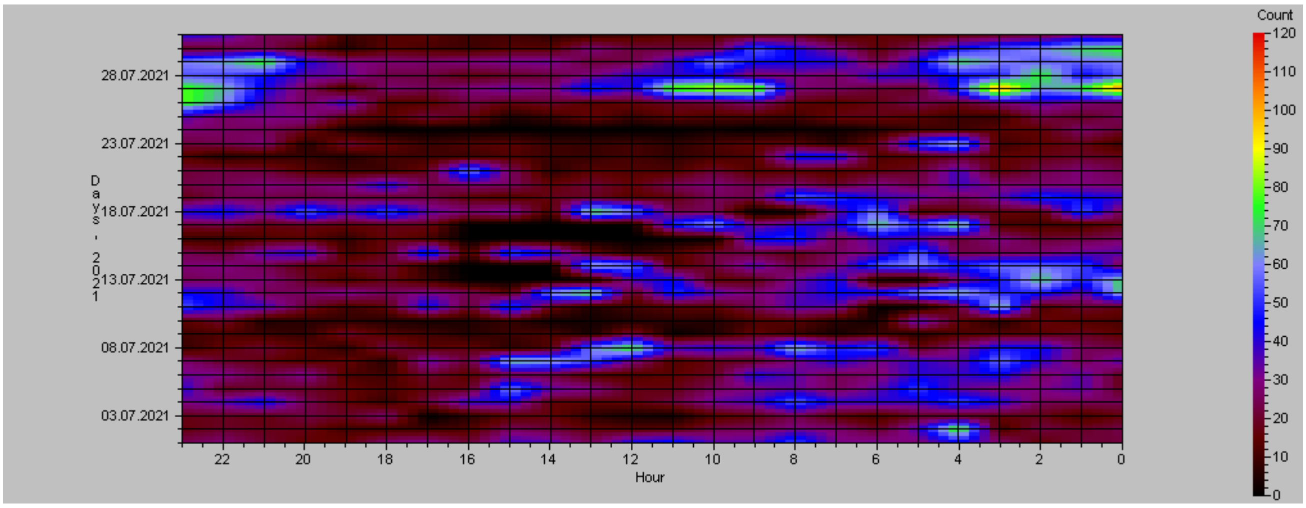

Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for July 2021.

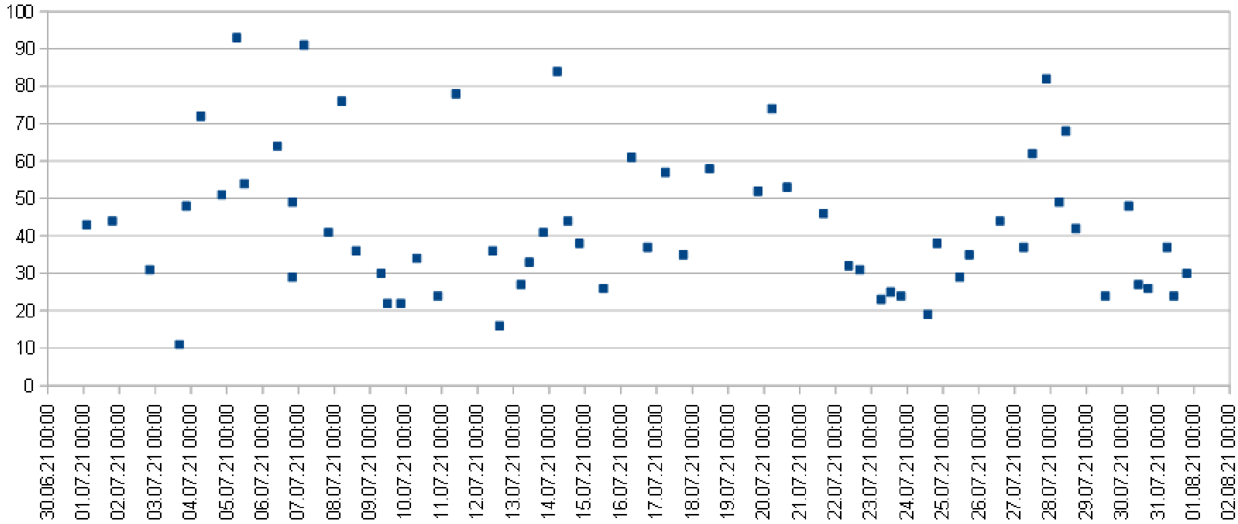

Figure 3 – The result with the calculated hourly numbers of echoes of meteors by listening to the radio signals for July 2021.

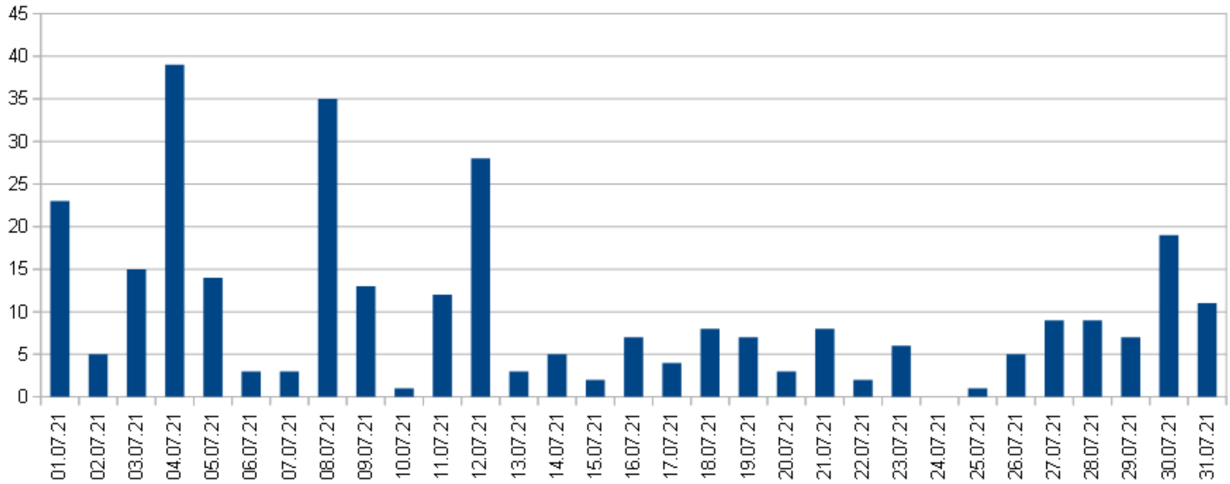

Figure 4 – Daily activity of radio fireballs in July 2021.

3 Listening to radio echoes on 88.6 MHz

Listening to the radio signals 1 to 3 times a day for one hour was done in order to control the level of the hourly rates, as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 63 hours.

The radio listening method shows three waves of meteor signal activity during the month. The first wave until July 11, the second from July 12 to 24, and the third from July 25 to 31. The peak on the third wave may be the combined activity of SDA (#0005), CAP (#0001), GDR (#0184).

4 Fireballs

In order to quickly search for signals of the radio fireballs, the program SpectrumLab was running in parallel to the Metan program. Screenshots were saved every 10 minutes. The search for fireball events was performed visually by viewing many thousands of screenshots obtained over a month. Then, we selected fireball events from the log files of the Metan program. For fireball activity statistics, I have selected signals from the log files with a peak power greater than 10000 as fireballs and with a signal duration greater than 10 seconds. *Figure 4* shows the daily activity of the fireball radio signals. *Figure 5* displays one of the fireball radio echoes.

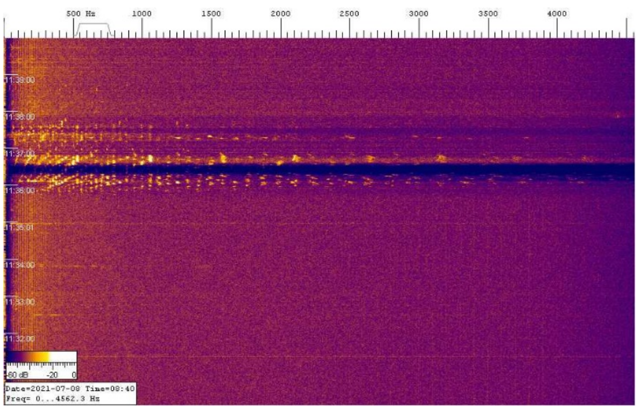

Figure 5 - Radio fireball recorded by SpectrumLab on July 08 at 08^h37^m UT.

There is no known source of increased fireball activity in the first half of the month.

5 CAMS Data

Figure 6 shows the total daily activity of meteors from the CAMS video network data (Jenniskens et al., 2011). There is a noticeable correlation between the activity level of sporadic meteors and the activity level of shower meteors. At the end of the month, the total activity of shower meteors exceeded the activity of the sporadic background.

On July 9, the Northern June Aquilids NZC (#0164) and Southern June Aquilids SZC (#0165) complex had a cumulative maximum of activity. The July 18 activity peak is a result of the combined activity of the most active minor showers xi2 Capricornids XCS (#0623), kappa Perseids KAP (#0547), and several others. The sharp increase in meteor shower activity at the end of the month is primarily due to SDA (#0005), CAP (#0001), and PER (#0007).

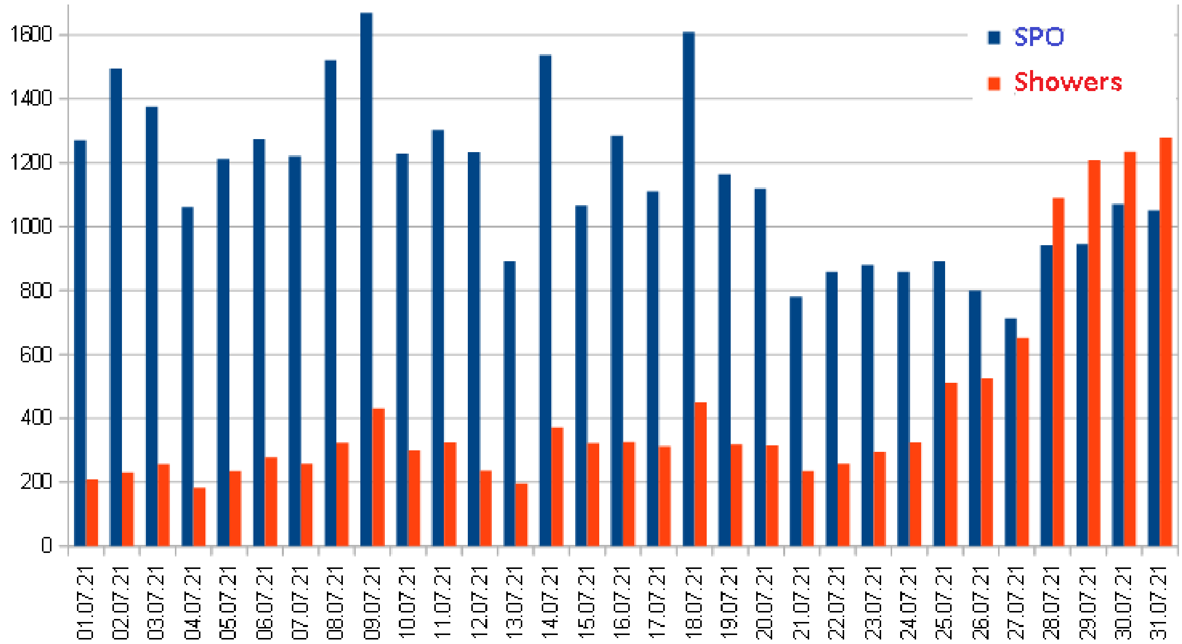

Figure 6 – Daily activity meteors of video networks CAMS in July 2021.

6 Conclusion

There is a satisfactory correlation between the methods of automatic signal detection and the method of listening to the radio echoes by manual counting of the number of meteor signals. The counting method and the automatic detection method show a three-wave profile of activity during the month of July. Such activity fluctuations are poorly visible in the CAMS data, which may indicate that this monthly activity fluctuations are caused by smaller meteoroids, hence fainter meteors. The level of shower activity according to CAMS data increases by about 2 times by the end of the month, while the level of activity in the radio band does not increase that much. The poor correlation between video-network data and radio-observations is related to the detection of meteoroids of different masses. Most likely a huge abundance of small particles during the radio observations does not allow to detect the activity profile for larger meteoroids which are registered by video networks as these are predominated by the majority of smaller dust.

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 August 2021

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This article presents the results of radio observations made in August 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

High activity of the Perseids (#0007) was recorded from August 11 to 14. Increased activity of meteor signals around August 17 may be associated with the activity of the meteoroid stream KCG (#0012).

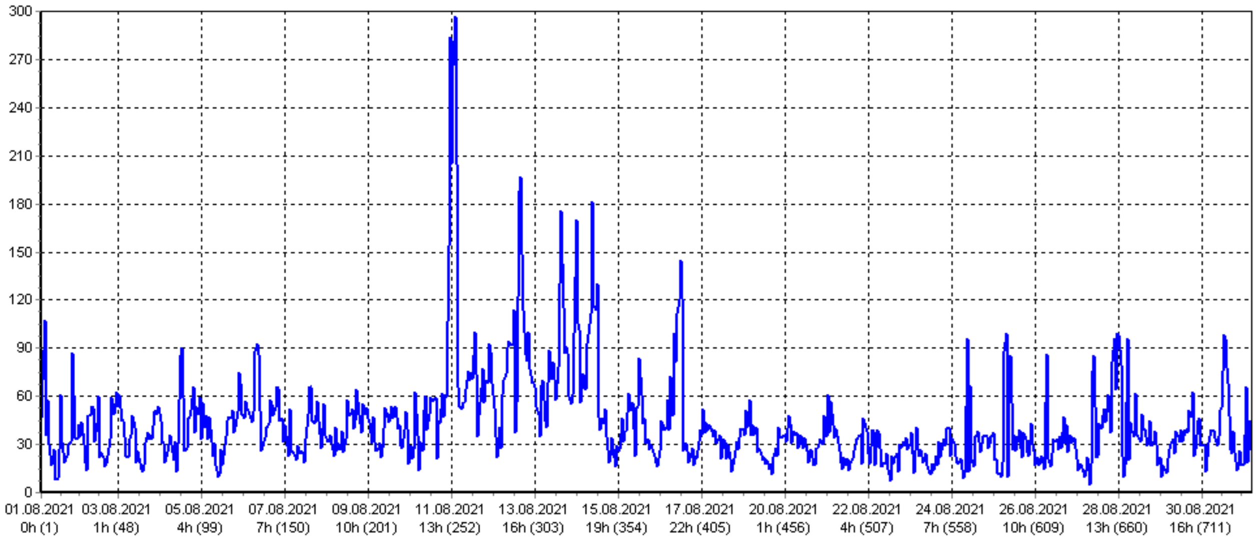

Figure 1 – Radio meteor echo counts at 88.6 MHz for August 2021.

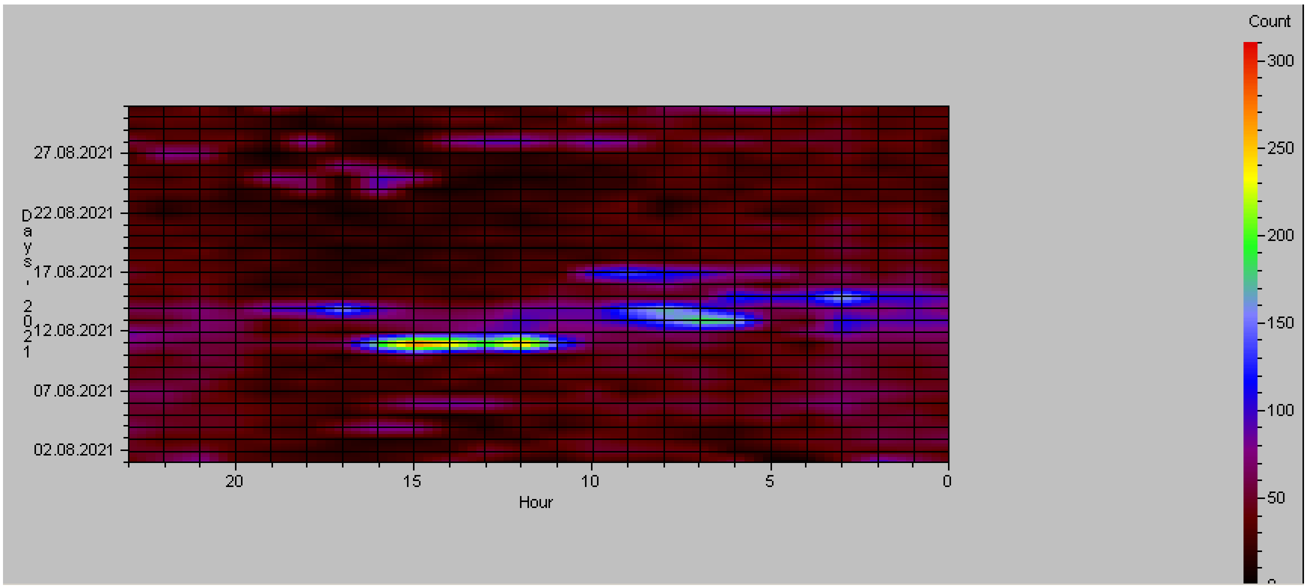

Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for August 2021.

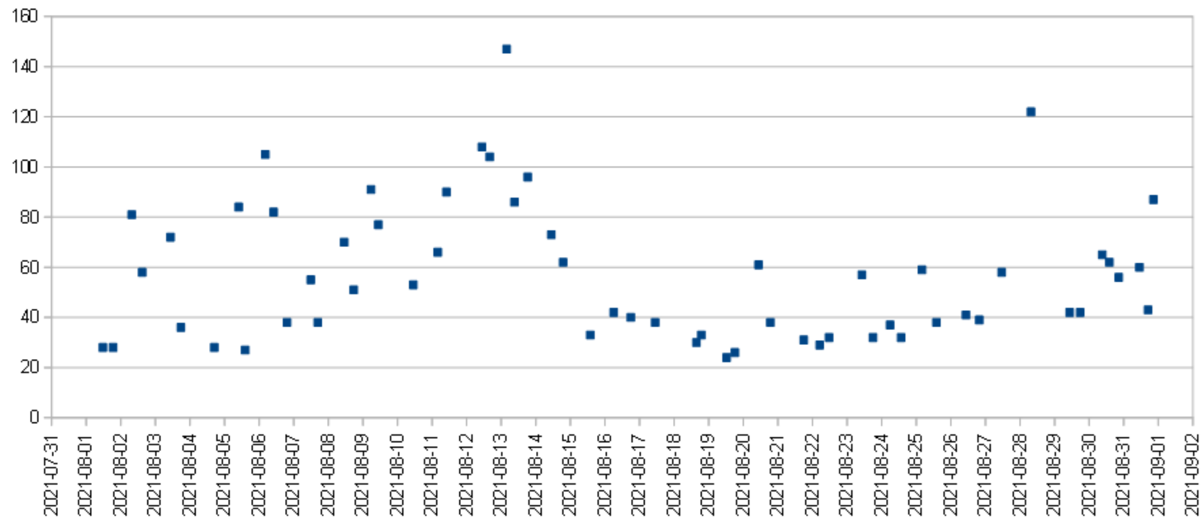

Figure 3 – The result with the calculated hourly numbers of echoes of meteors by listening to the radio signals for August 2021.

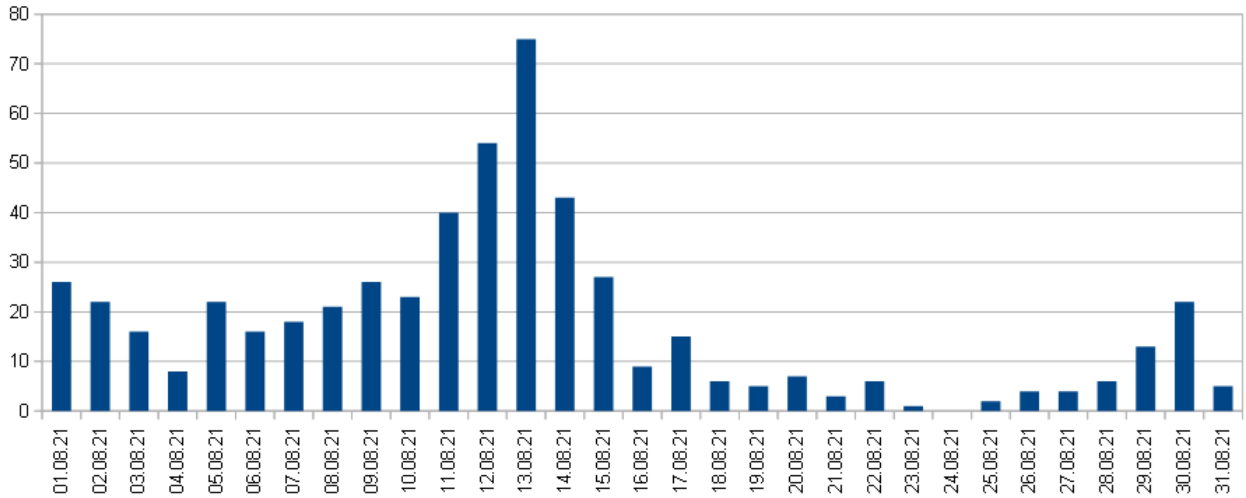

Figure 4 – Daily activity of radio fireballs in August 2021.

According to IMO visual data, high Perseid activity lasted from August 13 to 15[35], see also Miskotte et al. (2021), which correlates satisfactorily with radio observation data. The origin of the short burst of activity on August 11 from 11^{h} to 15^{h} UT, is unclear. Perhaps this event is related to a short flaring up of the Perseids. Increased shower activity was recorded between 16^{h}–19^{h} UT on August 14 and 01^{h}–06^{h} UT on August 15.

Figure 1 shows the hourly rates of radio meteors in August 2021 at 88.6 MHz. *Figure 2* shows the corresponding heat map.

3 Listening to radio echoes on 88.6 MHz

Listening to the radio signals 1 to 3 times a day for one hour was done in order to control the level of the hourly rates, as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 59 hours.

The radio listening method shows a peak of Perseid activity on the night of August 13 to 14, with activity of about 150 meteor signals per hour. The origin of the high signal activity on August 28 is unknown (some increase in meteor activity on August 28 is also apparent from automatic observations). It is possible there has been an overlap of several small meteor showers. The peak around August 31 is probably due to the activity of the Aurigids (#0206).

4 Fireballs

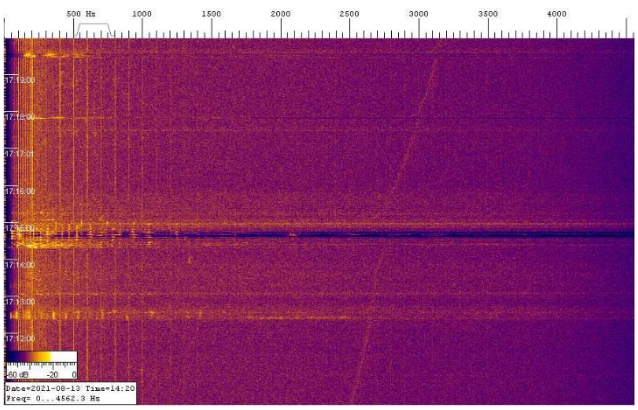

Figure 5 - Radio fireball recorded by SpectrumLab on August 13 at 14^{h}15^{m} UT.

[35] https://www.imo.net/members/imo_live_shower?shower=PER&year=2021

In order to quickly search for signals of the radio fireballs, the program SpectrumLab was running in parallel to the Metan program. Screenshots were saved every 10 minutes. The search for fireball events was performed visually by viewing many thousands of screenshots obtained over a month. Then, we selected fireball events from the log files of the Metan program. For fireball activity statistics, I have selected signals from the log files with a peak power greater than 10000 as fireballs and with a signal duration greater than 10 seconds. *Figure 4* shows the daily activity of the fireball radio signals. *Figure 5* displays one of the fireball radio echoes.

From the fireball activity profile, we can conclude that the peak activity of the bolides occurred on August 13, about 75 bolides were recorded that day. The peak of fireballs activity on August 17 is probably due to the KCG (#012), the peak on August 30 may be due to the AUR (#0206), when large particles cross Earth's orbit one day earlier than the main mass of meteoroids with a peak activity on August 31 according to the IMO table (Rendtel, 2020).

5 Preliminary CAMS Data

Figure 6 shows the total daily activity of meteors from the CAMS video network data (Jenniskens et al., 2011). There is a noticeable correlation between the activity level of sporadic meteors and the activity level of shower meteors.

From August 1 to 11, the abundance of shower meteors was comparable to, or slightly above, the level of sporadic meteor activity. On August 12 and 13, the Perseids made the level of shower meteors nearly 2–3 times larger than the sporadic background. Between August 16 and 31, the shower meteors were 2–5 times less active than the sporadic background.

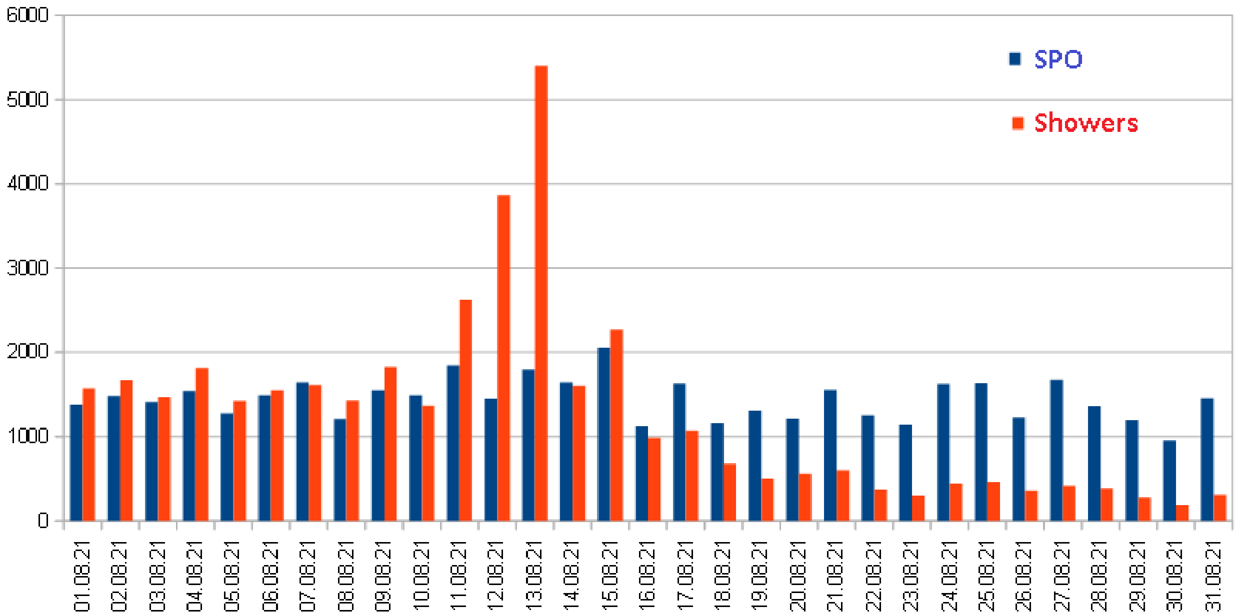

Figure 6 – Daily activity meteors of video networks CAMS in August 2021, data as available on September 12.

6 Conclusion

There is a satisfactory correlation between the methods of automatic signal detection and the method of listening to the radio echoes by manual counting of the number of meteor signals. The radio data correlates satisfactorily with the CAMS video network data. The advantage of the radio listening method is the efficiency in terms of "scanning" the level of signal activity, i.e., the observer knows in real time what is happening at the sky in the radio band. The profile of the fireball activity satisfactorily correlates with the activity profile of the shower meteors from preliminary the CAMS 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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2 Automatic observations

September is a fairly calm month in terms of meteor activity. The increased signal level activity up to 35–42 per hour with an average background level of 12–18 per hour probably belongs to AUR (# 0206) during the intervals 00^h–01^h UT and 05^h–07^h UT on 1 September 2021. My results agree well with the theoretical predictions in the article of Miskotte (2021).

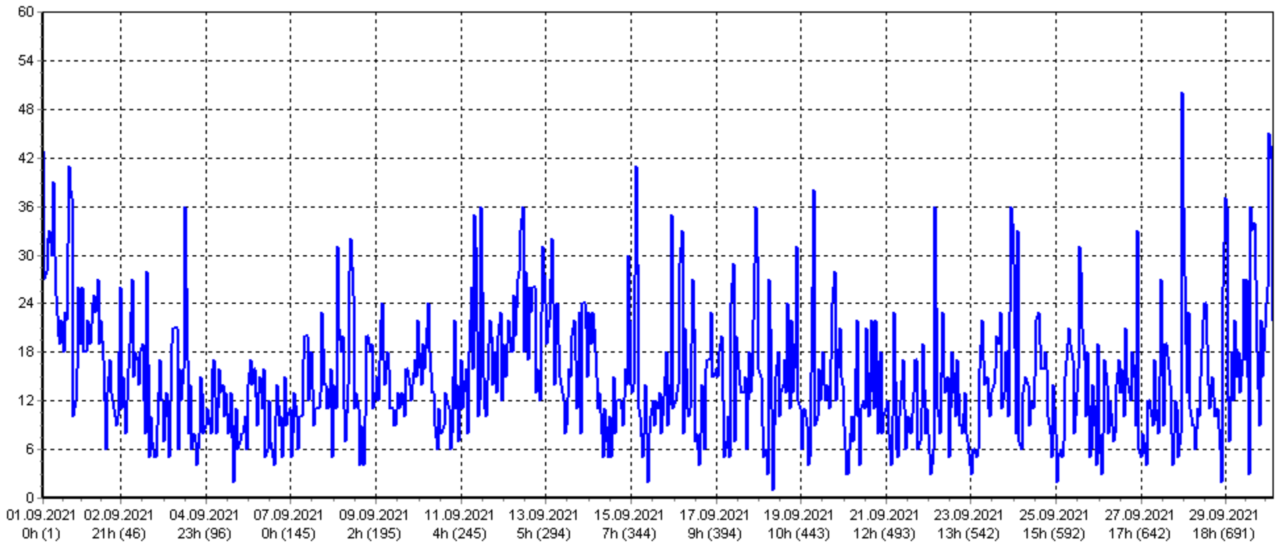

Figure 1 – Radio meteor echo counts at 88.6 MHz for September 2021.

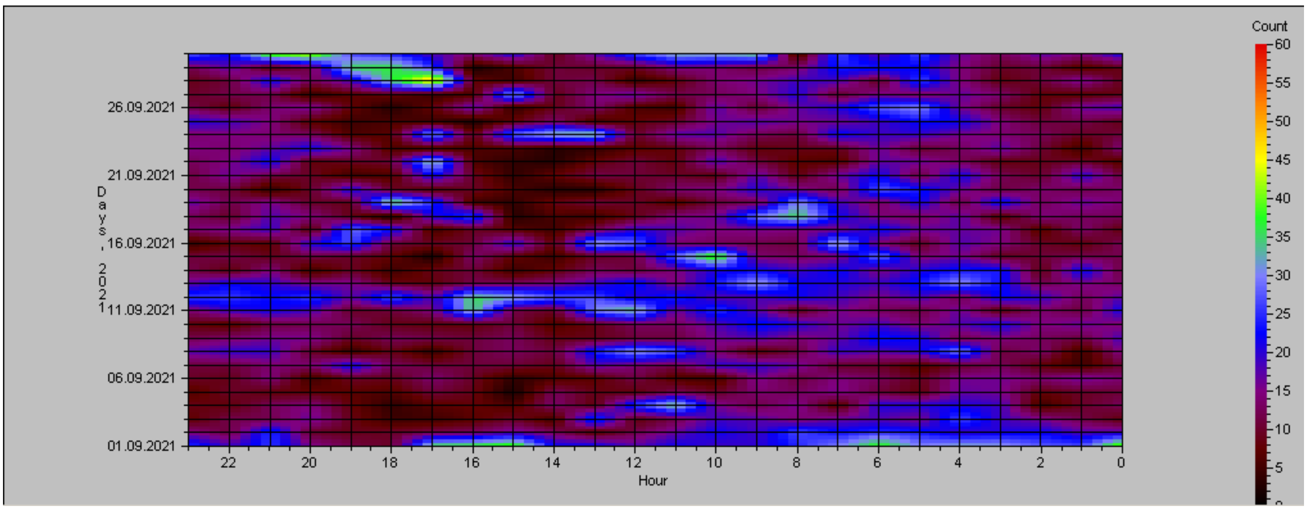

Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for September 2021.

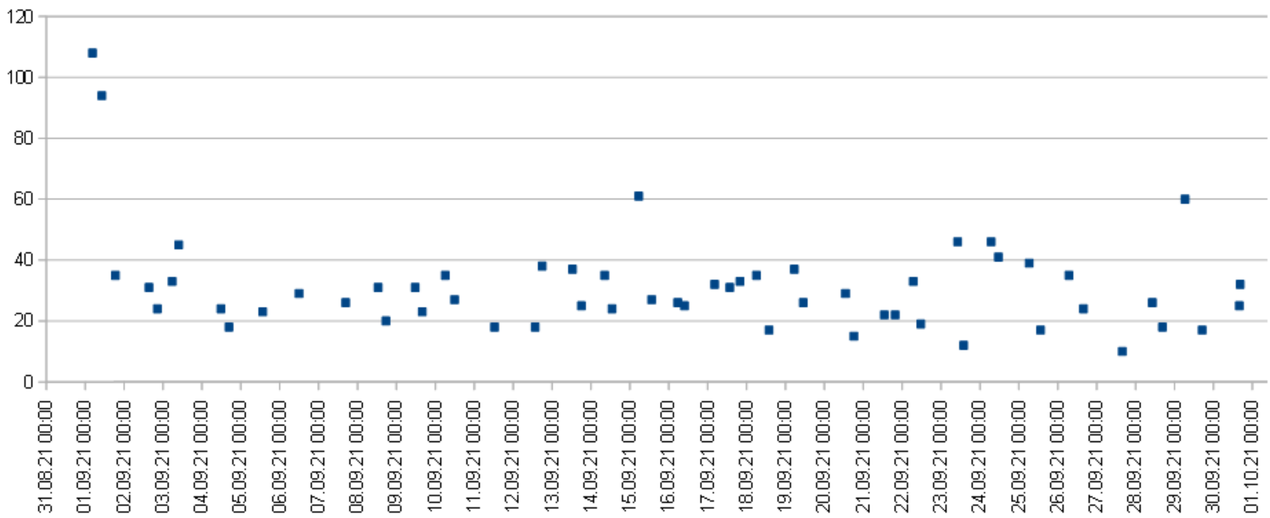

Figure 3 – The result with the calculated hourly numbers of echoes of meteors by listening to the radio signals for September 2021.

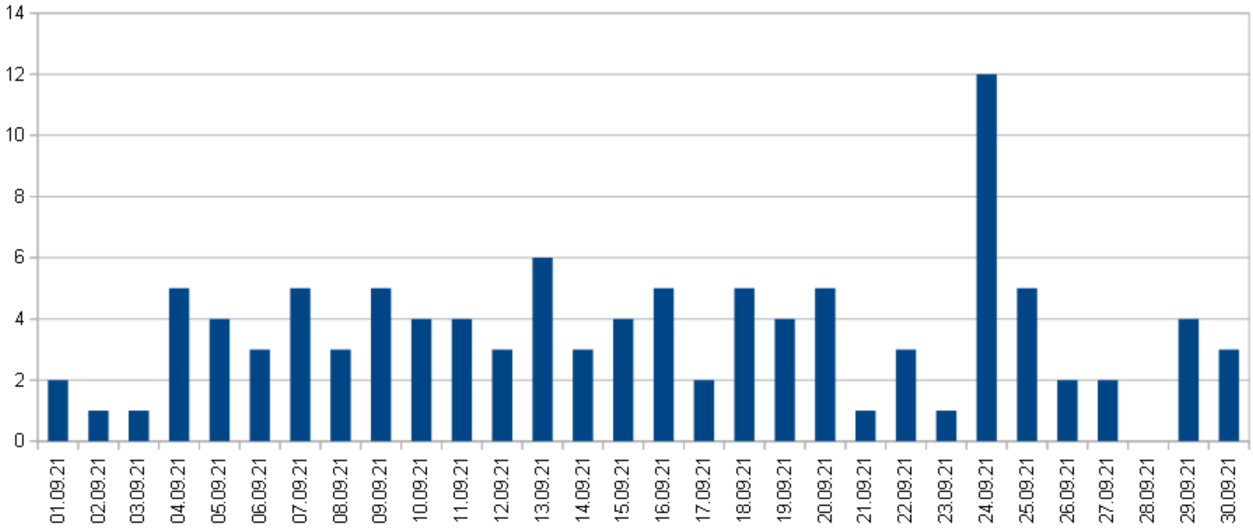

Figure 4 – Daily activity of radio fireballs in September 2021.

On September 9 and 27, the maxima of two minor showers, SPE (# 0208) and DSX (# 0221), were expected according to the IMO Meteor Shower Calendar. No peak activity of these showers could be recorded on the predicted dates. On September 12 and 13, a slight increase in the level of activity of meteor signals has been observed. The identification of this increase in activity will be discussed below.

Figure 1 shows the hourly rates of radio meteors in September 2021 at 88.6 MHz. *Figure 2* shows the corresponding heat map.

3 Listening to radio echoes on 88.6 MHz

Listening to the radio signals 1 to 3 times a day for one hour was done in order to control the level of the hourly rates, as well as to distinguish between periods of tropospheric passage and other natural radio interference. The total effective listening time was 57 hours.

The method of listening to the radio broadcast showed an increased level of activity of meteor signals with 94–108 on September 1 at 04^h–11^h UT compared to an average background level of about 25–35 signals per hour. Undoubtedly, this increase in activity is associated with the outburst of the minor shower AUR (# 0206).

4 Fireballs

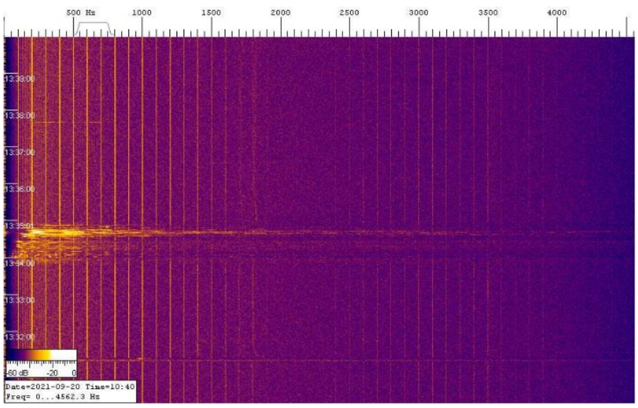

Figure 5 - Radio fireball recorded by SpectrumLab September 20 at 10^h35^m UT.

In order to quickly search for signals of the radio fireballs, the program SpectrumLab was running in parallel to the Metan program. Screenshots were saved every 10 minutes. The search for fireball events was performed visually by viewing many thousands of screenshots obtained over a month. Then, we selected fireball events from the log files of the Metan program. For fireball activity statistics, I have selected signals from the log files with a peak power greater than 10000 as fireballs and with a signal duration greater than 10 seconds. *Figure 4* shows the daily activity of the fireball radio signals. *Figure 5* displays one of the fireball radio echoes.

The month is quite calm in terms of fireball activity with an average level of 2–3 fireballs per day. The reason for the increase in fireball activity on September 24 is not known.

5 Preliminary CAMS Data

Figure 6 shows the total daily activity of meteors from the CAMS video network data (Jenniskens et al., 2011). There is a noticeable correlation between the activity level of sporadic meteors and the activity level of shower meteors. The preliminary CAMS data has been used like it was available on October 22. The background activity of the sporadic background is sinusoidal with a peak around September 6–8 at about 2400 meteors and a minimum around September 26–27 at 800–900 meteors per day. The level of the shower activity also correlates with the level of sporadic activity, reaching a peak around September 8 and a minimum around September 26.

Figure 7 shows the total number of meteor showers detected by the CAMS video networks in September 2021.

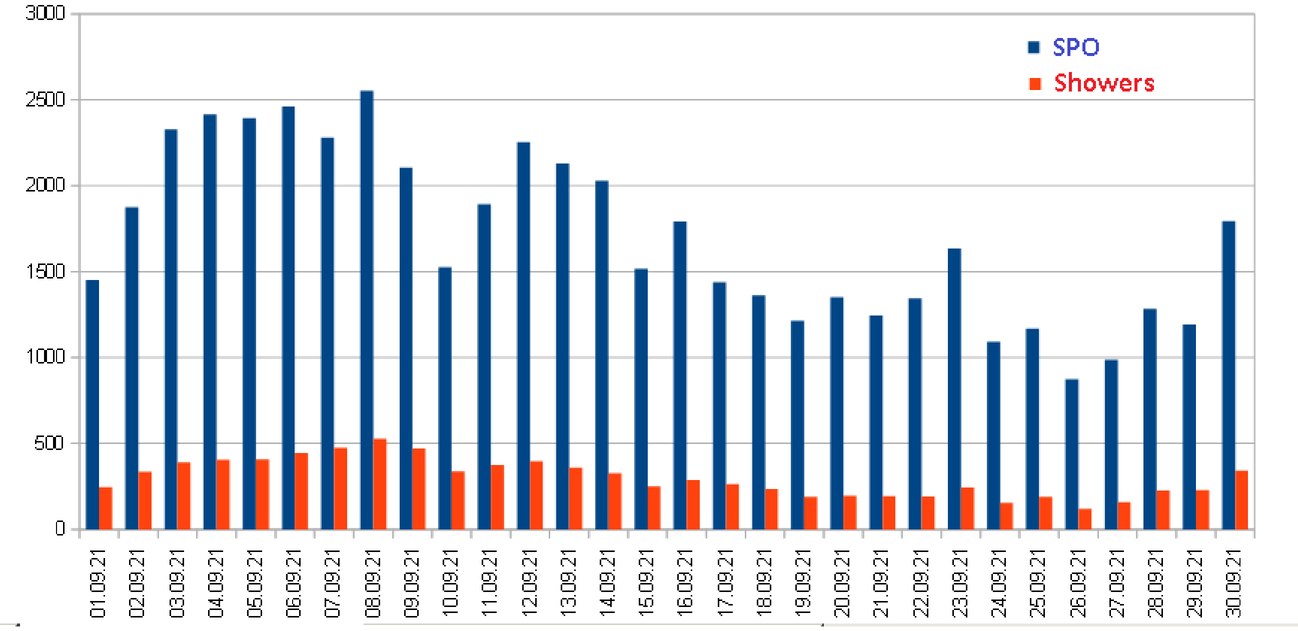

Figure 6 – Daily activity meteors of video networks CAMS in September 2021.

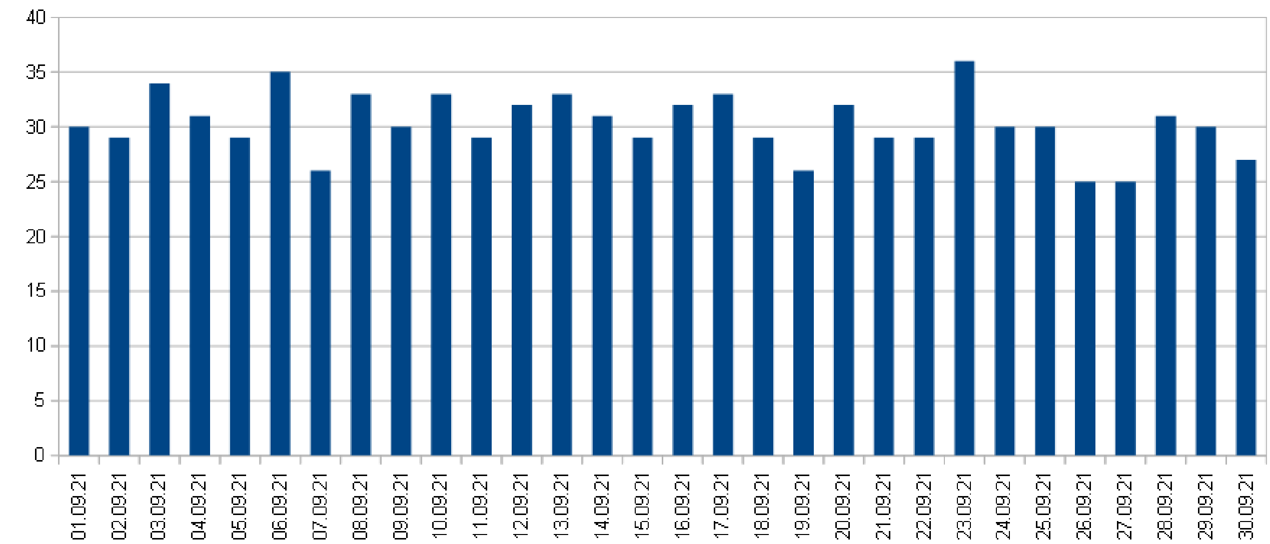

Figure 7 – Total number of meteor showers detected by the CAMS video networks in September 2021.

The activity peak on September 8 is associated with the maximum activity of the minor shower SPE (# 0208). The weak activity peak on September 23 can be explained by the activity of the meteor showers NUE (# 0337) and STA (#0002), combined with an increase in the number of detected showers. So, on September 23, CAMS detected 36 showers, a day earlier, 30 showers, a day later, 29 showers. On September 12 and 13, a small peak in the activity of shower meteors as well as in the level of sporadic meteors can be seen, which is also recorded by my radio meteor system. This was caused by the activity produced by some minor showers, NTA (#0017), NUE (#0337), SLY (#0081), as well as an increase in the number of detected showers. The rise in activity on September 30 is mainly associated with an increase in the activity of the Taurid meteor showers STA, NTA, and also some other minor showers.

6 Conclusion

By the method of automatic signal detection and by the method of listening to the radio broadcast, on the night of August 31 to September 1, an increased activity of the minor shower (AUR) has been recorded. Both methods make it possible to detect the total activity of meteor showers and sporadic meteors, regardless of weather conditions. The data from the CAMS video networks make it possible to determine which stream (s) are responsible for the increased activity. The September data show a not very good correlation between radio and video observations. This may be because the CAMS data is affected by the weather, i.e. series of cloudy nights which makes it impossible to estimate the real meteor activity level.

Acknowledgment

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Radio meteors August 2021

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An overview of the radio observations during August 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 August 2021.

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

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

As usual, observations were sometimes complicated by unwanted interference, unidentified noise, and on 7 days, moderate to strong lightning activity. On three of these days (August 7, 9 and 21), the discharges occurred in the immediate vicinity of the beacon, giving rise to series of short pulses that are difficult to distinguish from meteor reflections. In addition, a lot of solar eruptions were recorded during the last 6 days of the month, but these did not pose a problem in counting the meteors. To minimize the effects of these disturbances, the automatic counts were corrected manually.

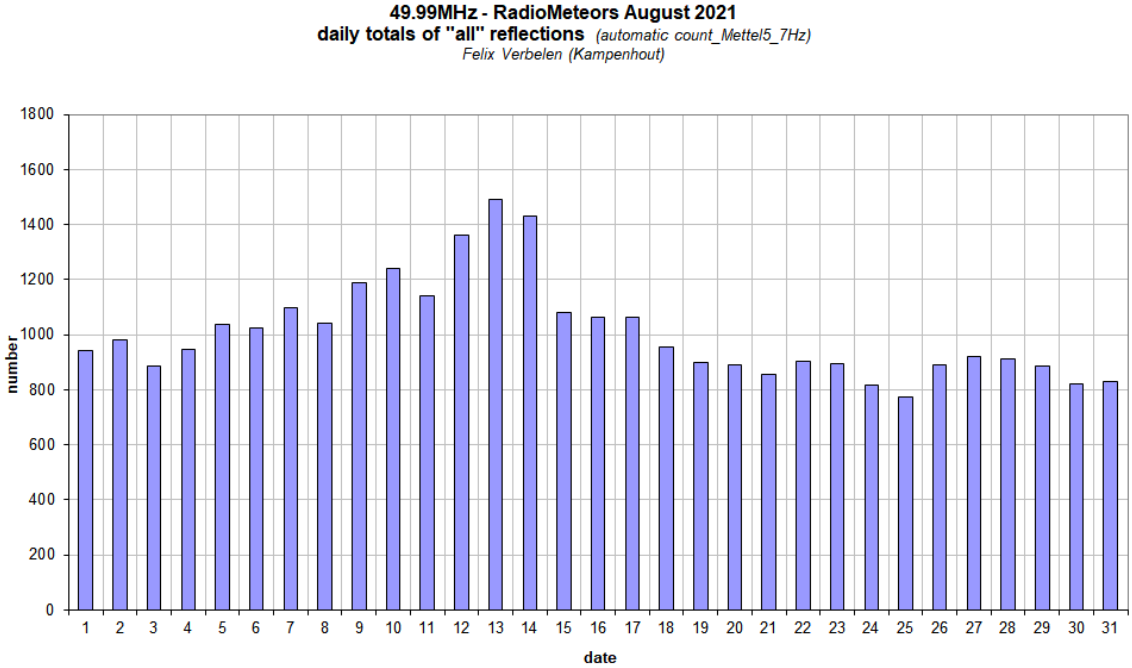
The eye-catchers of the month were, of course, the Perseids, with many long-lasting reflections, as every year.

After a start-up period with increased activity in the first part of the month, the expected maximum came in the night of 12–13 August. The surprise, however, came on August 14th, with a massive eruption that exceeded the forecasted maximum, peaking here between 08^h00^m and 09^h00^m UT. Some screenshots of this eruption have been included in this report (*Figures* 5 to 14). If desired, the counts per 5 minutes are also available for August 14, 2021.

After the shower maximum, meteor activity declined very rapidly and remained quite low during the second half of the month, with however several long and strong reflections.

Over the entire month, 77 reflections longer than 1 minute were recorded here. A selection of others striking or strong reflections is also added in this report (*Figures* 14 to 30).

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



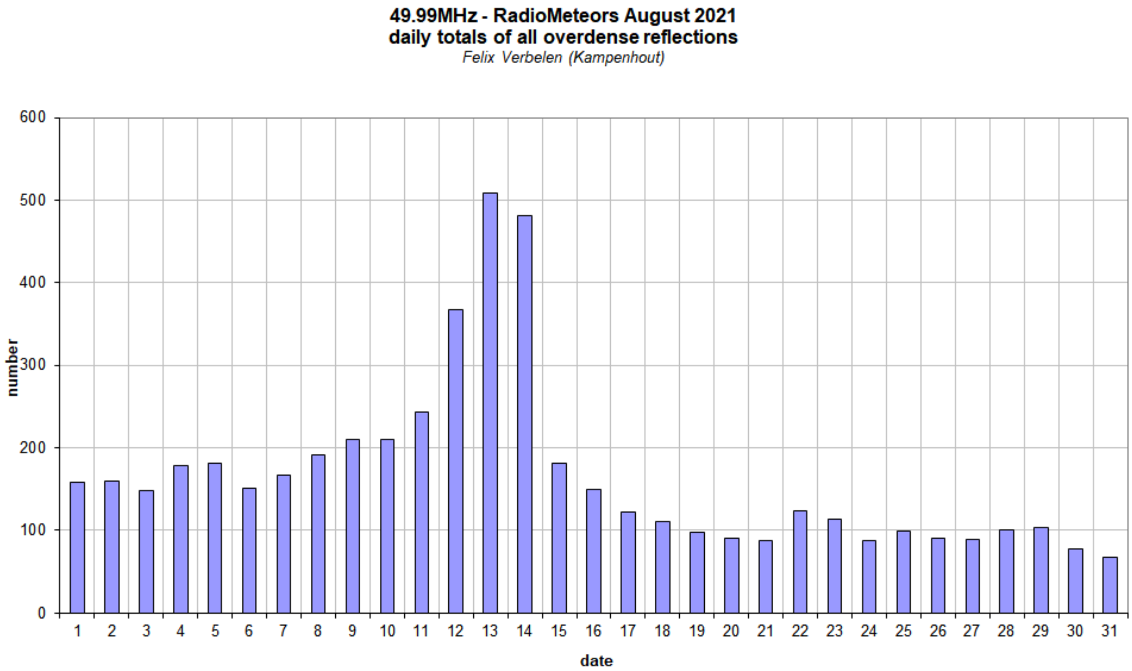
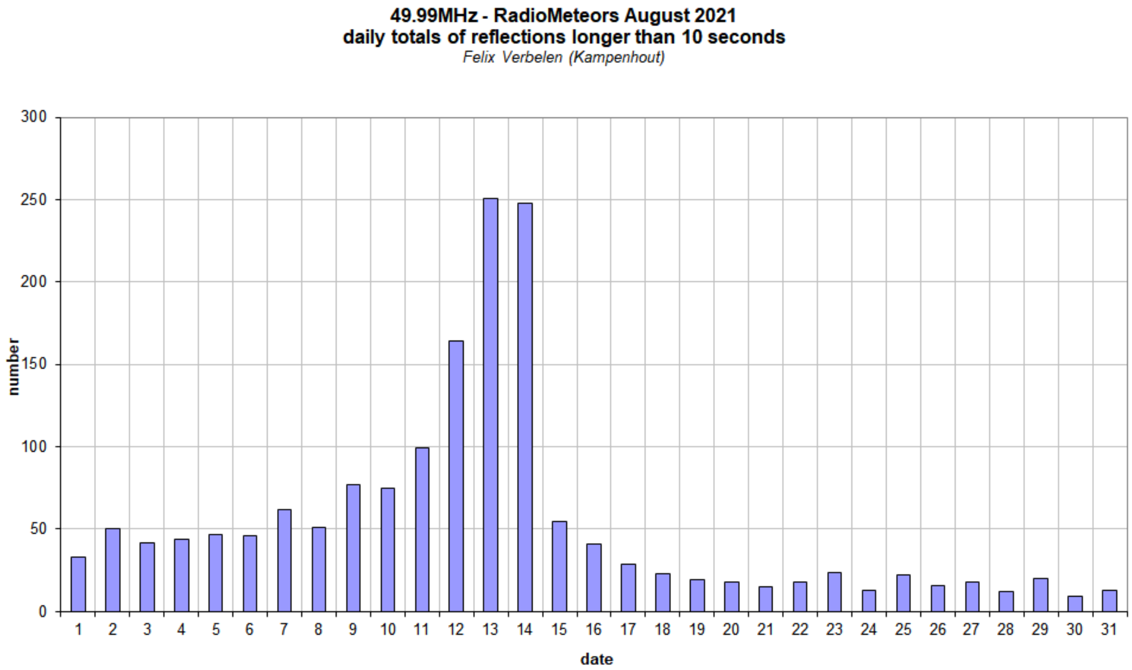


Figure 1 – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2021.



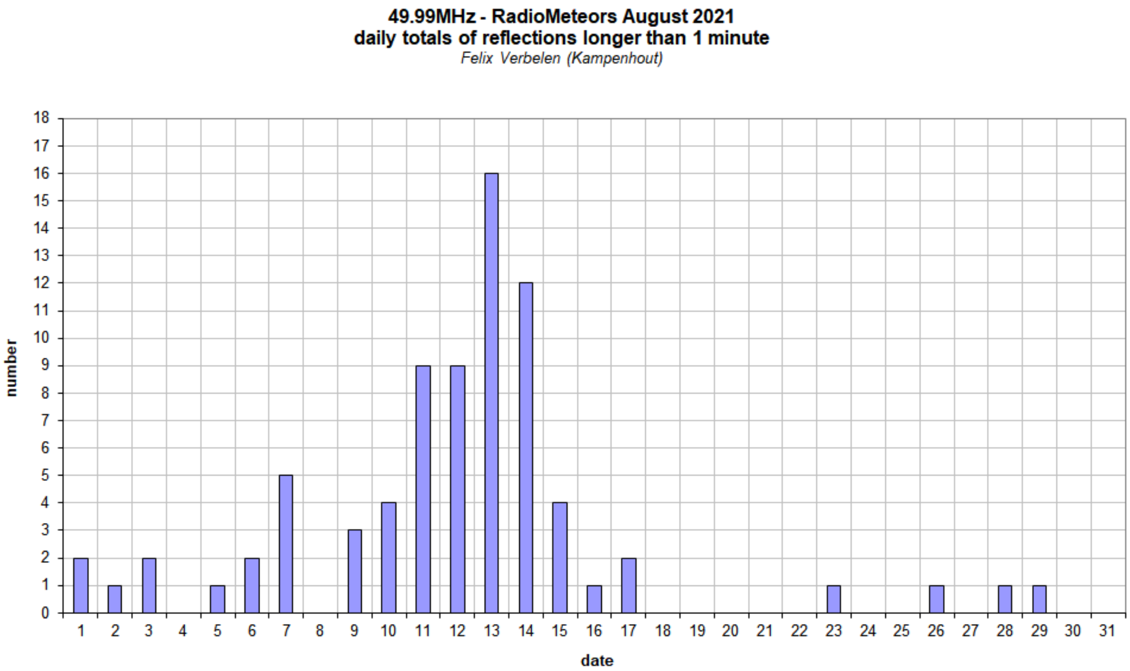
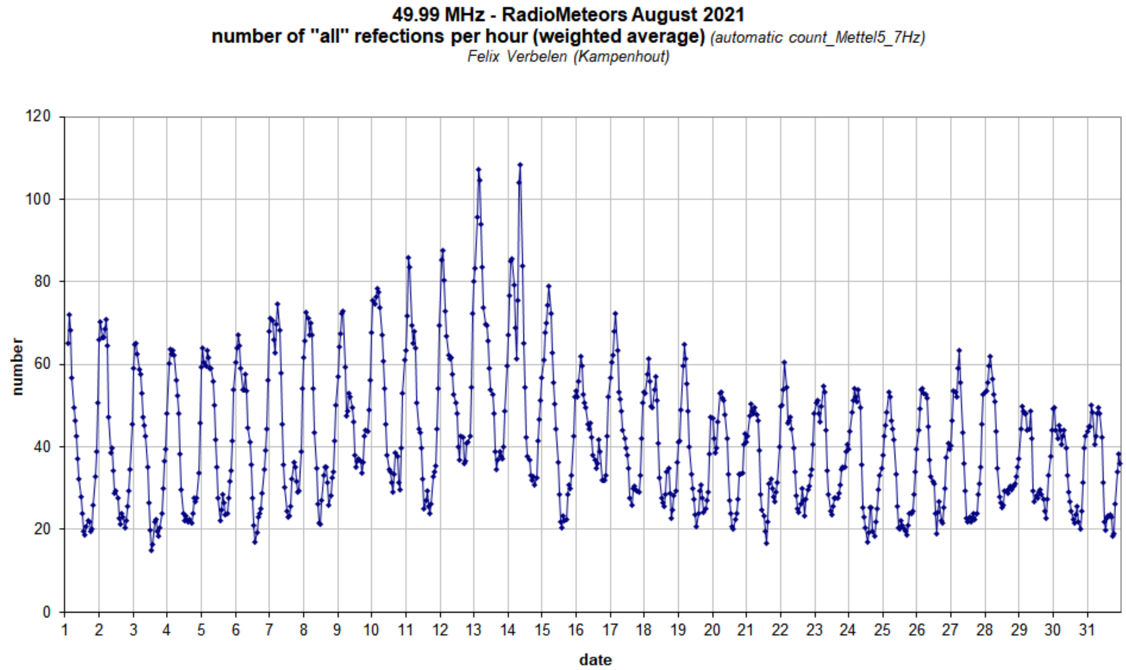


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2021.



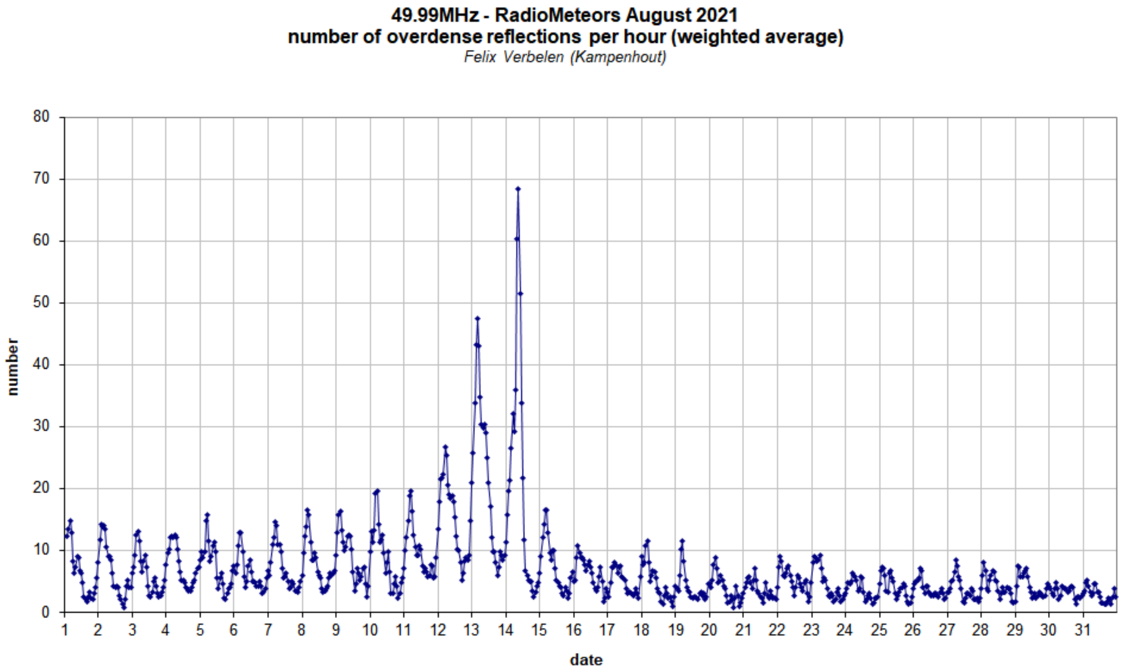
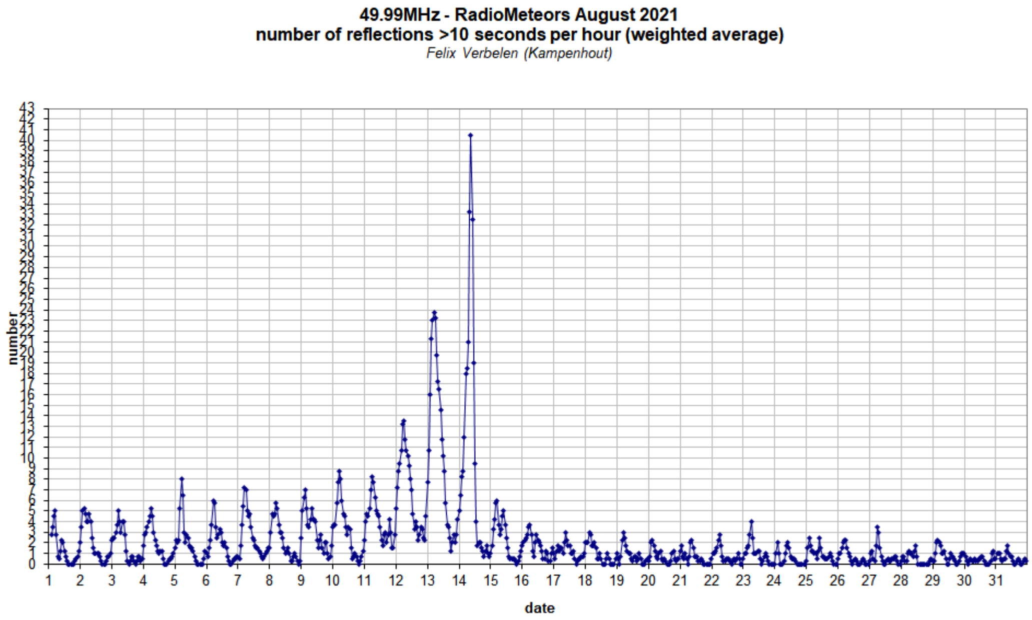


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2021.



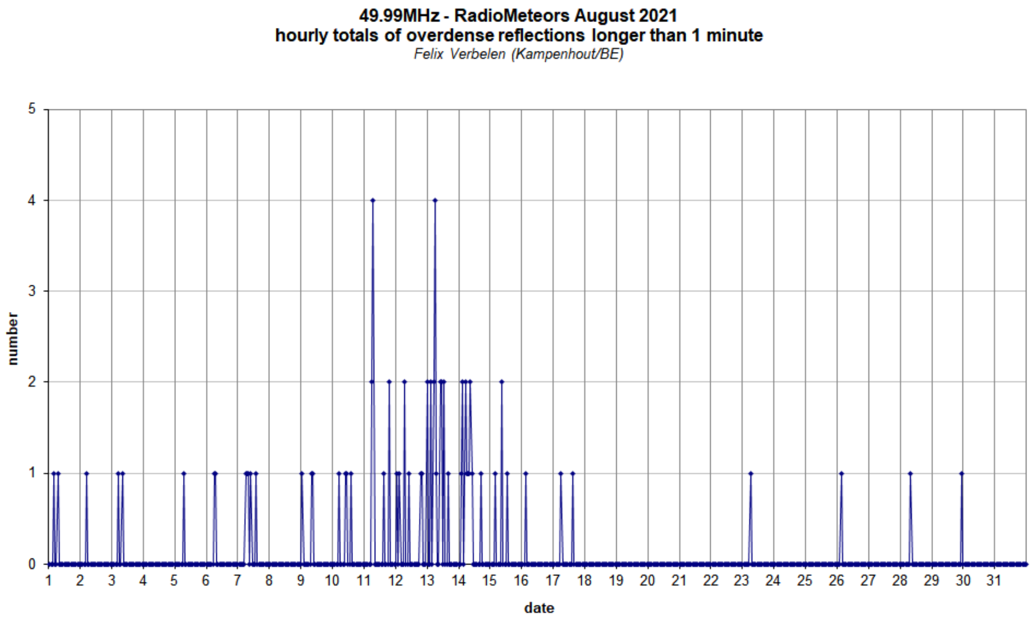


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during August 2021.

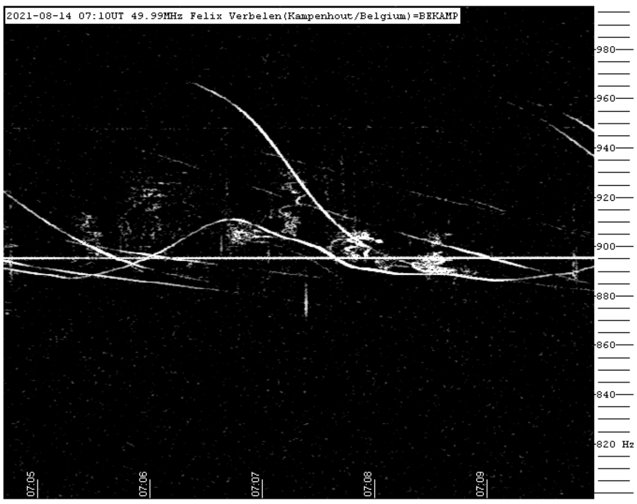


Figure 5 – Meteor reflection 14 August 2021, 07^h10^m UT.

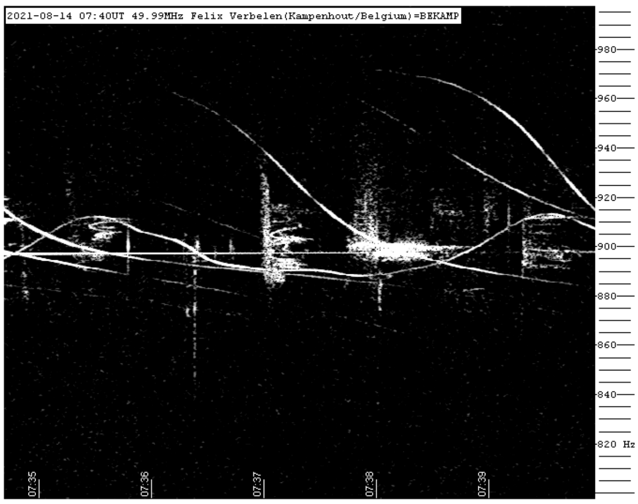


Figure 6 – Meteor reflection 14 August 2021, 07^h40^m UT.

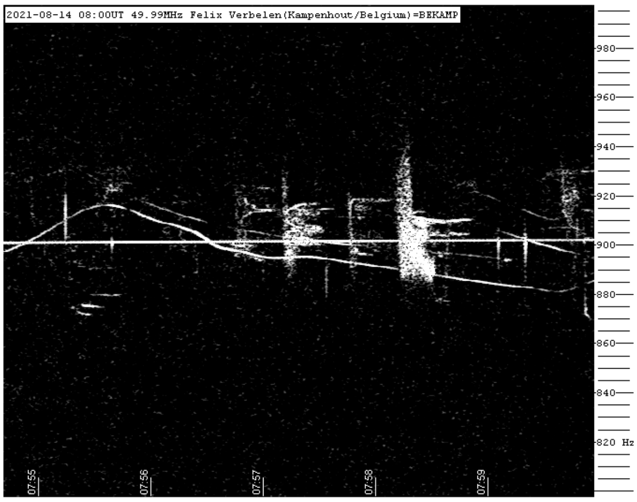


Figure 7 – Meteor reflection 14 August 2021, 08^{h}00^m UT.

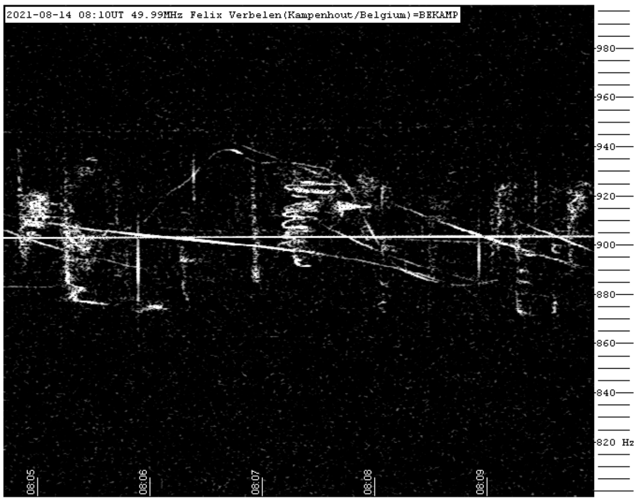


Figure 8 – Meteor reflection 14 August 2021, 08^{h}10^m UT.

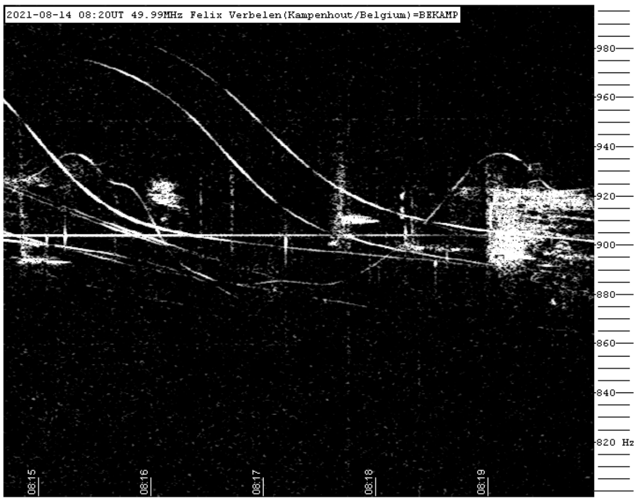


Figure 9 – Meteor reflection 14 August 2021, 08^{h}20^m UT.

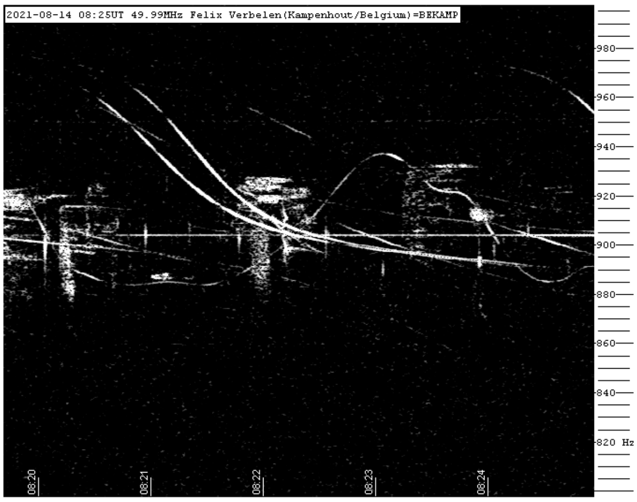


Figure 10 – Meteor reflection 14 August 2021, 08^{h}25^m UT.

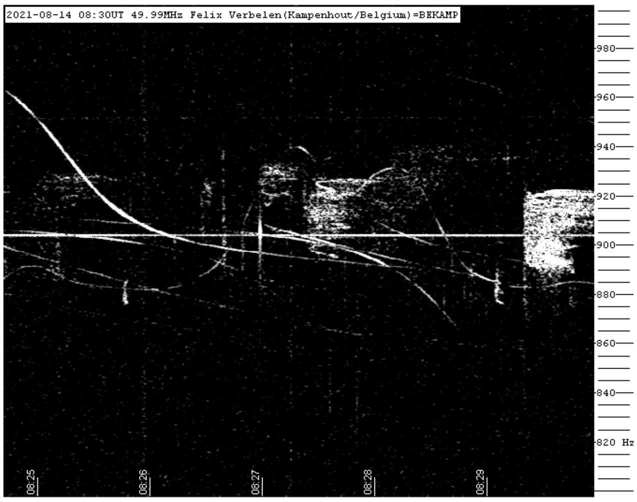


Figure 11 – Meteor reflection 14 August 2021, 08^{h}30^m UT.

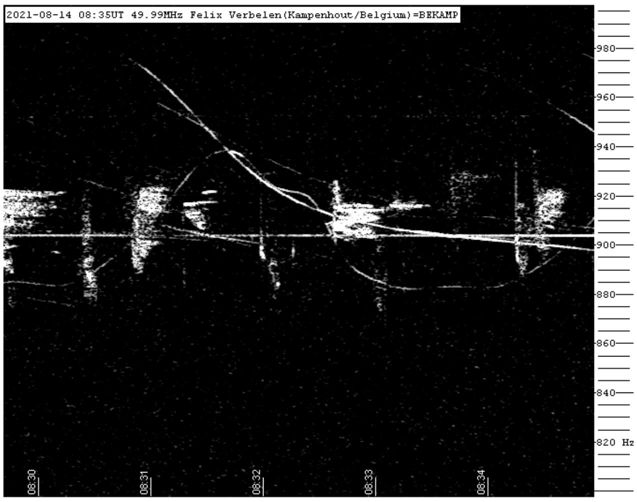


Figure 12 – Meteor reflection 14 August 2021, 08^{h}35^m UT.

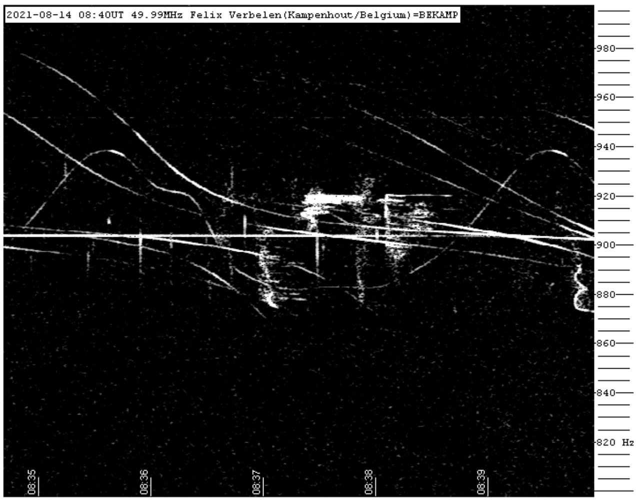


Figure 13 – Meteor reflection 14 August 2021, 08^{h}40^m UT.

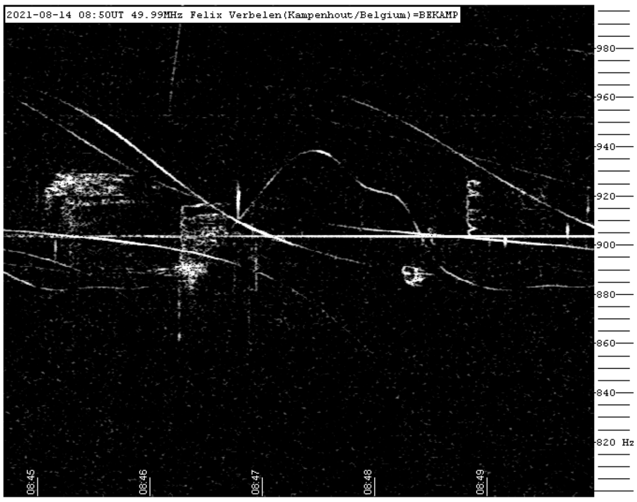


Figure 14 – Meteor reflection 14 August 2021, 08^{h}50^m UT.

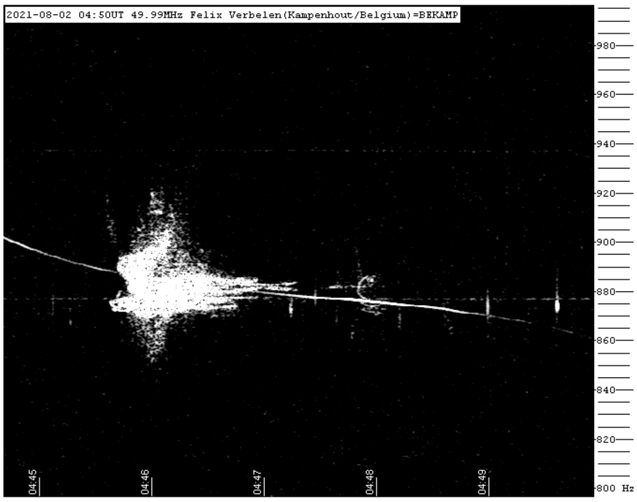


Figure 15 – Meteor reflection 02 August 2021, 04^{h}50^m UT.

Figure 16 – Meteor reflection 06 August 2021, 06^{h}40^m UT.

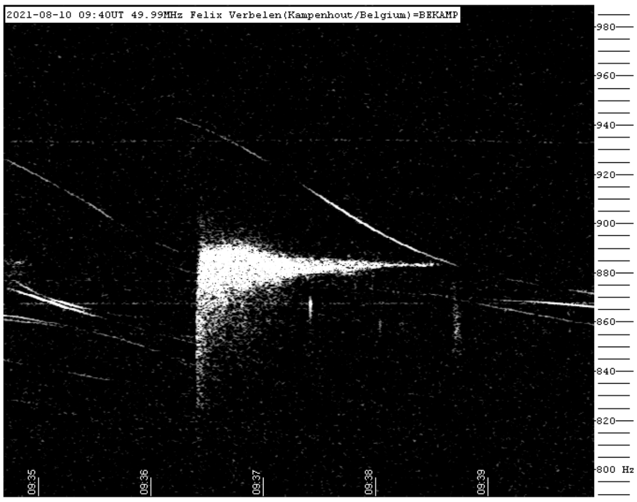


Figure 17 – Meteor reflection 10 August 2021, 09^{h}40^m UT.

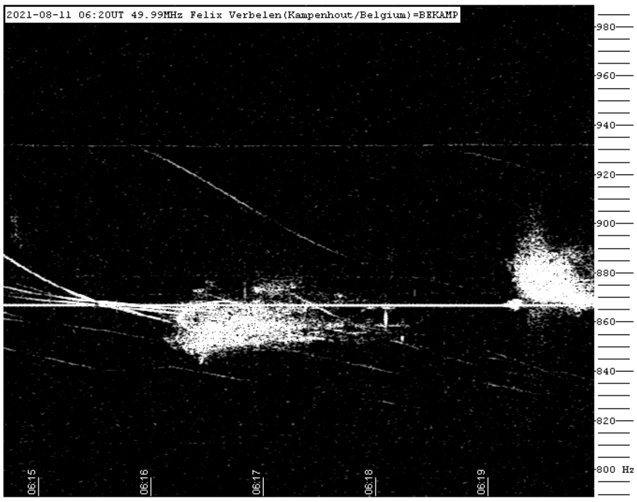


Figure 18 – Meteor reflection 11 August 2021, 06^{h}20^m UT.

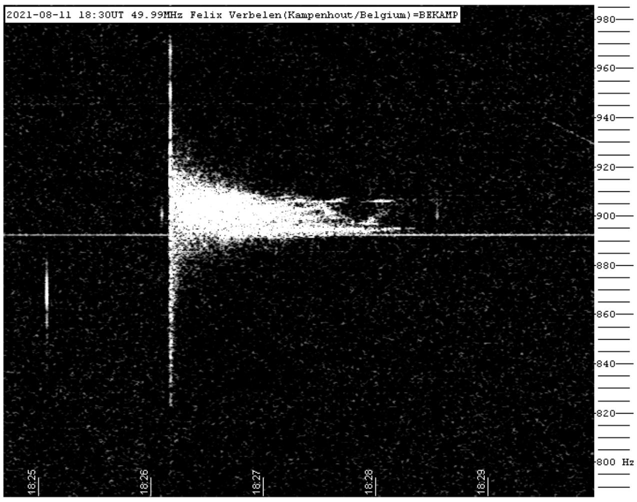


Figure 19 – Meteor reflection 11 August 2021, 18^h30^m UT.

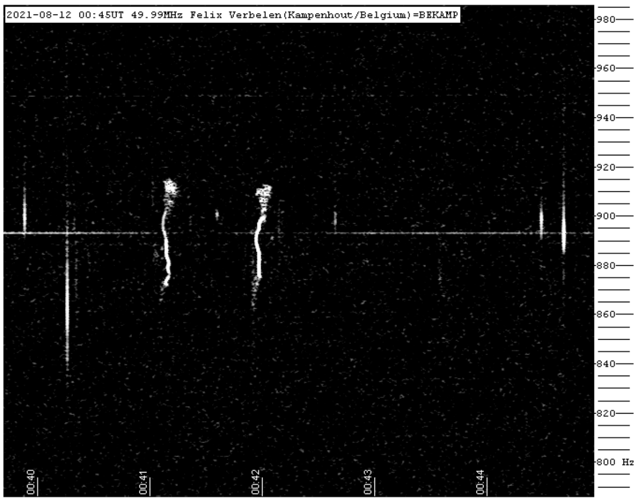


Figure 20 – Meteor reflection 12 August 2021, 00^h45^m UT.

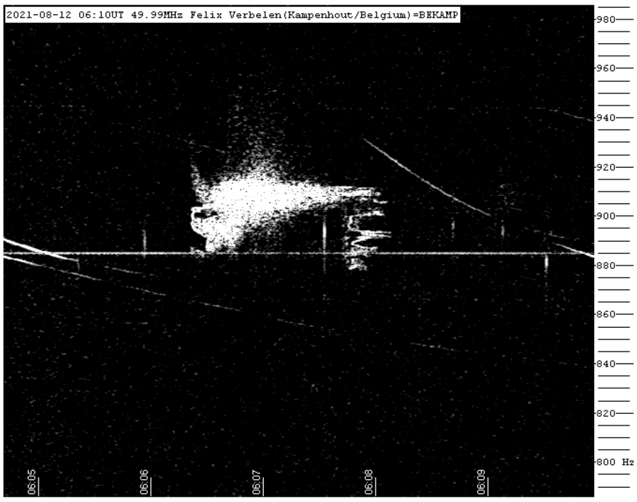


Figure 21 – Meteor reflection 12 August 2021, 06^h10^m UT.

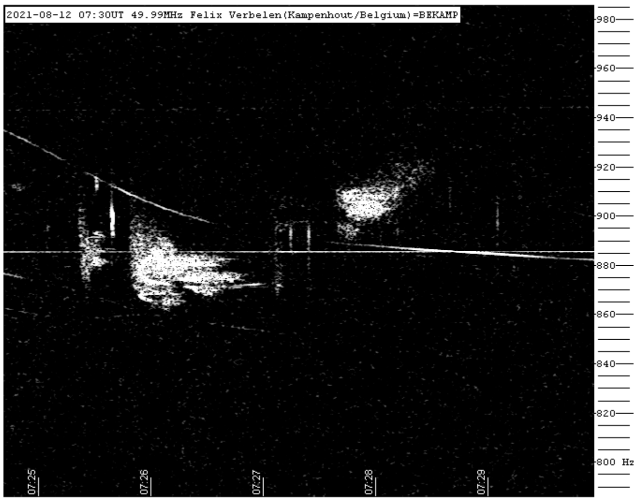


Figure 22 – Meteor reflection 12 August 2021, 07^h30^m UT.

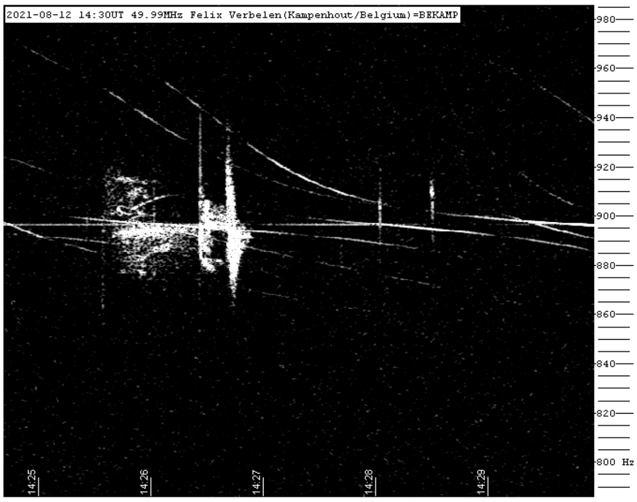


Figure 23 – Meteor reflection 12 August 2021, 14^h30^m UT.

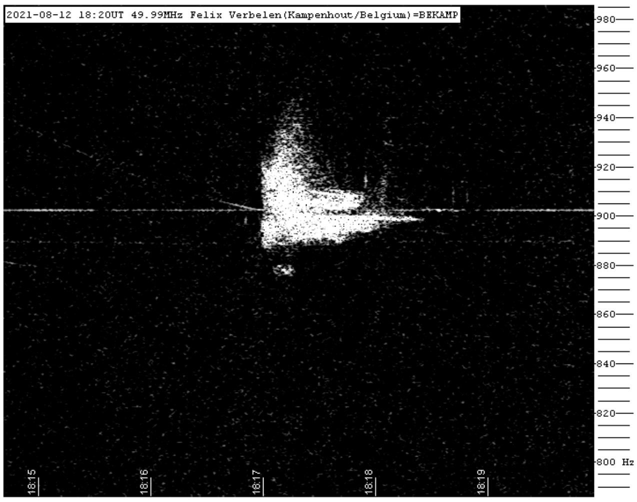


Figure 24 – Meteor reflection 12 August 2021, 18^h20^m UT.

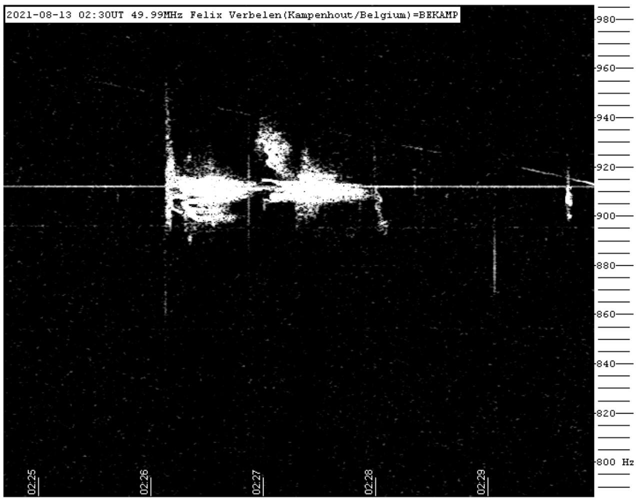


Figure 25 – Meteor reflection 13 August 2021, 02ʰ30ᵐ UT.

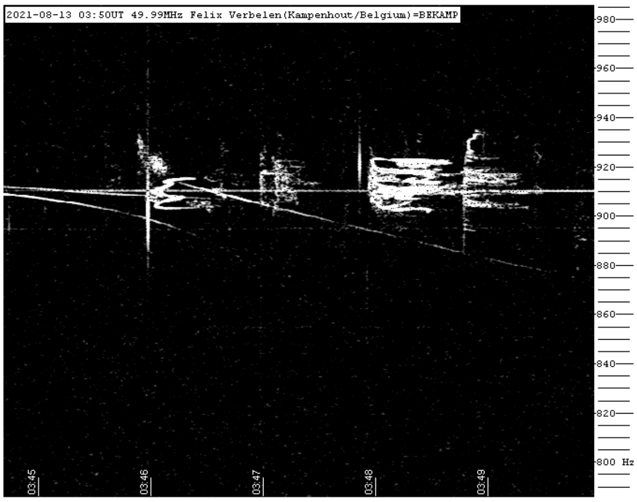


Figure 26 – Meteor reflection 13 August 2021, 03ʰ50ᵐ UT.

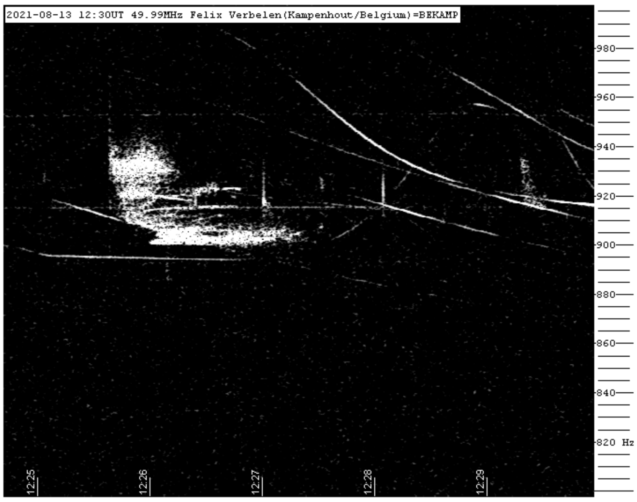


Figure 27 – Meteor reflection 13 August 2021, 12ʰ30ᵐ UT.

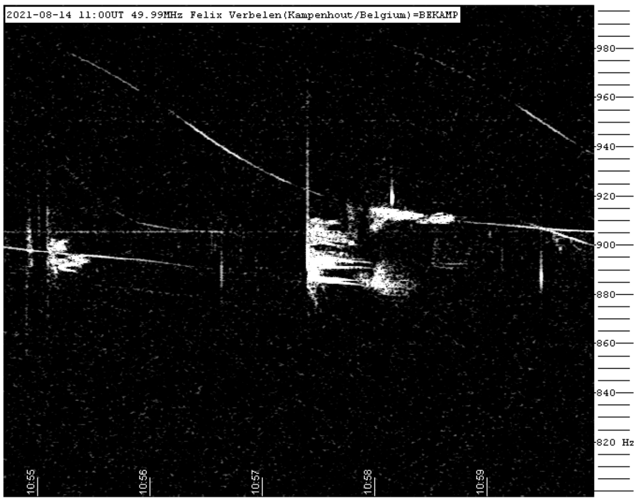


Figure 28 – Meteor reflection 14 August 2021, 11ʰ00ᵐ UT.

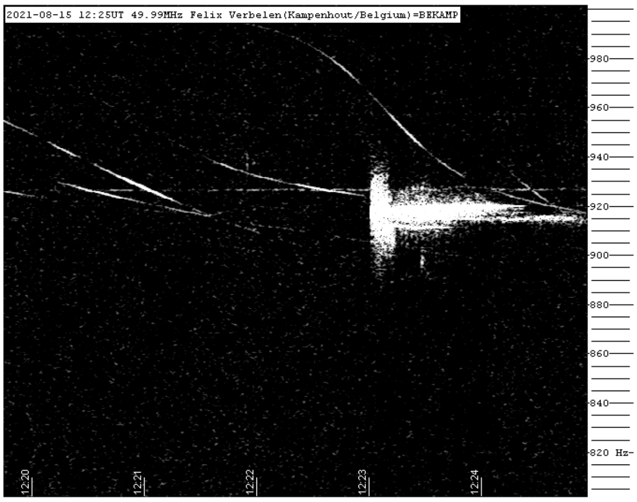


Figure 29 – Meteor reflection 15 August 2021, 12ʰ25ᵐ UT.

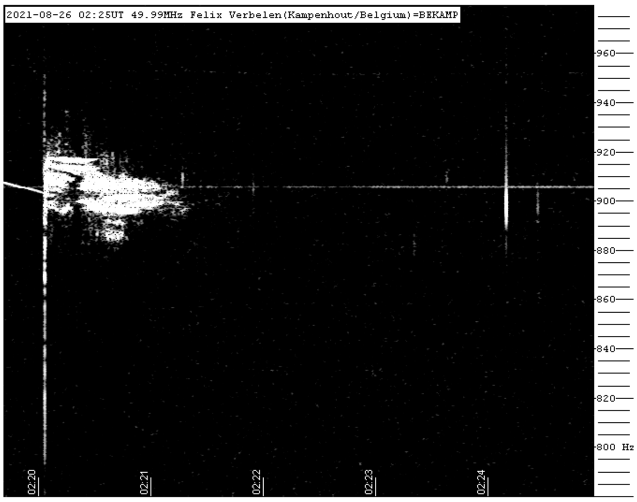


Figure 30 – Meteor reflection 26 August 2021, 02ʰ25ᵐ UT.

Radio meteors September 2021

Felix Verbelen

Vereniging voor Sterrenkunde & Volkssterrenwacht MIRA, Grimbergen, Belgium

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An overview of the radio observations during September 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 September 2021.

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

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

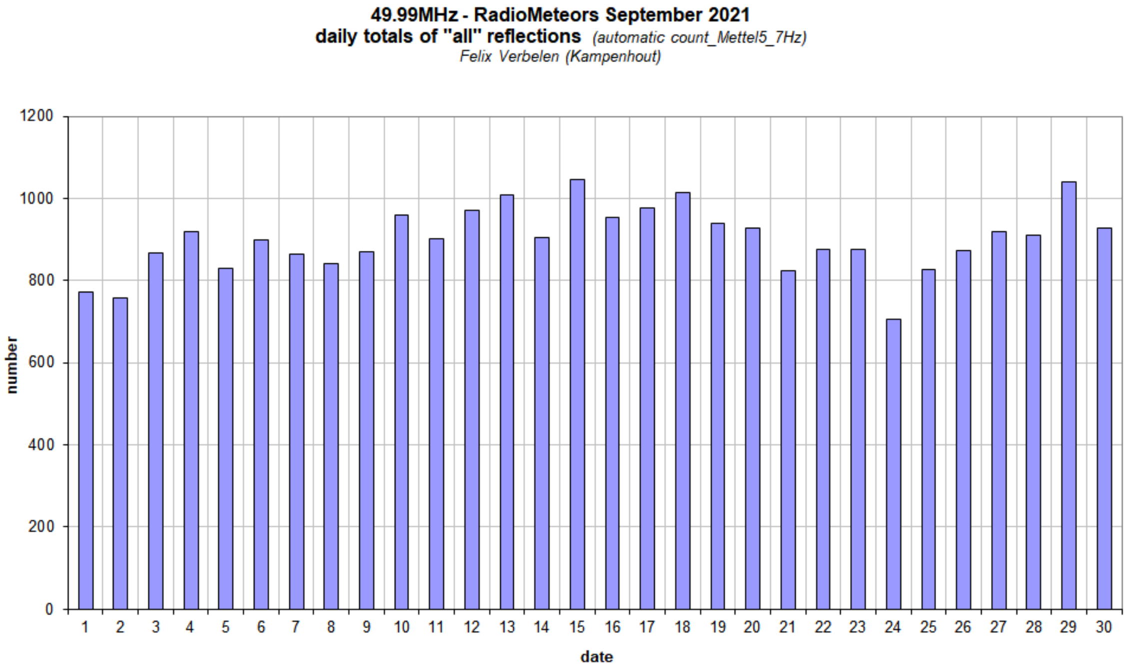
Local interference and unidentified noise remained moderate during most of the month. On 4 days lightning activity was observed.

During this month no real eye-catching shower was active, but the activity remained quite interesting, showing both a number of minor showers and a fair number of long reflections.

Determining the radiant of minor showers on the basis of forward scatter isn't strait forwards but nonetheless usually possible if several parameters are taken into account. Some of these are the time of greatest activity, the type of reflection (underdense vs. long lasting overdense), the approximate velocity derived from measurable head echoes and others. In the absence of suitable software, careful examination of all of these can be very time consuming and a challenge, but at the same time quite rewarding!

This month 13 reflections longer than 1 minute were observed here. A selection of others striking or strong reflections is also added in this report (*Figures* 5 to 13).

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



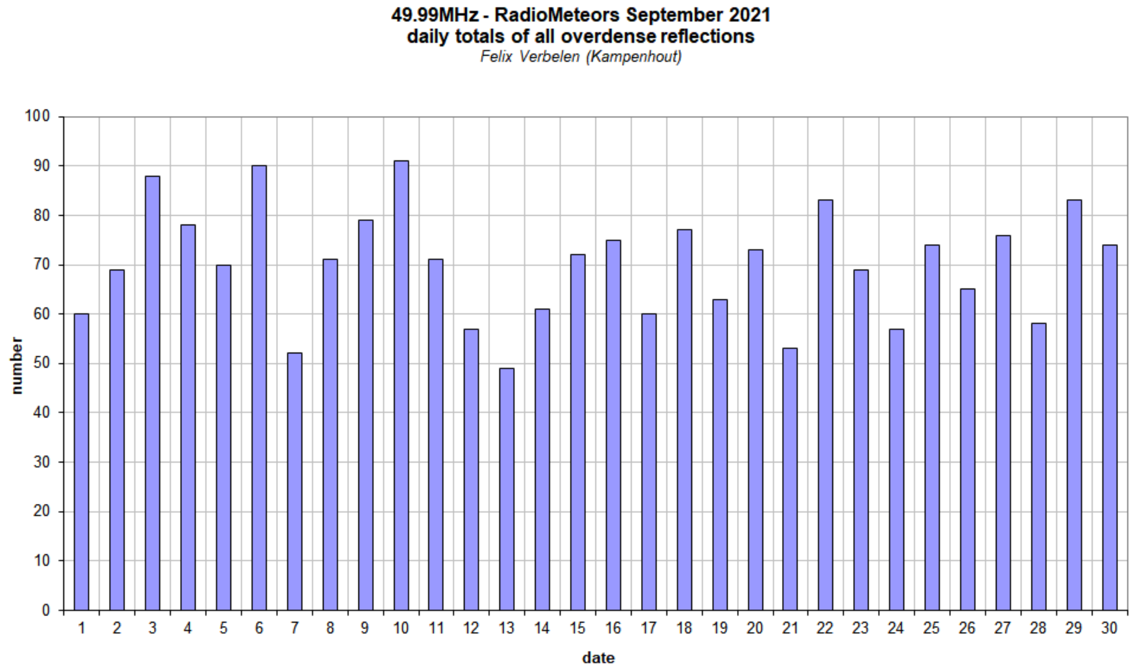
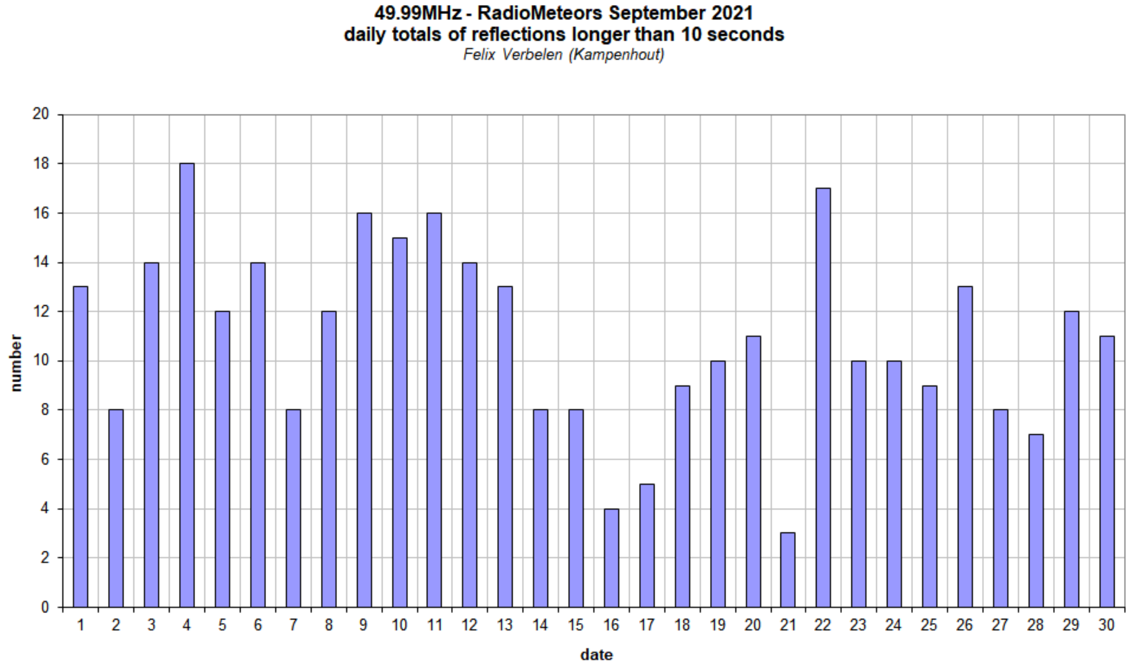


Figure 1 – The daily totals of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2021.



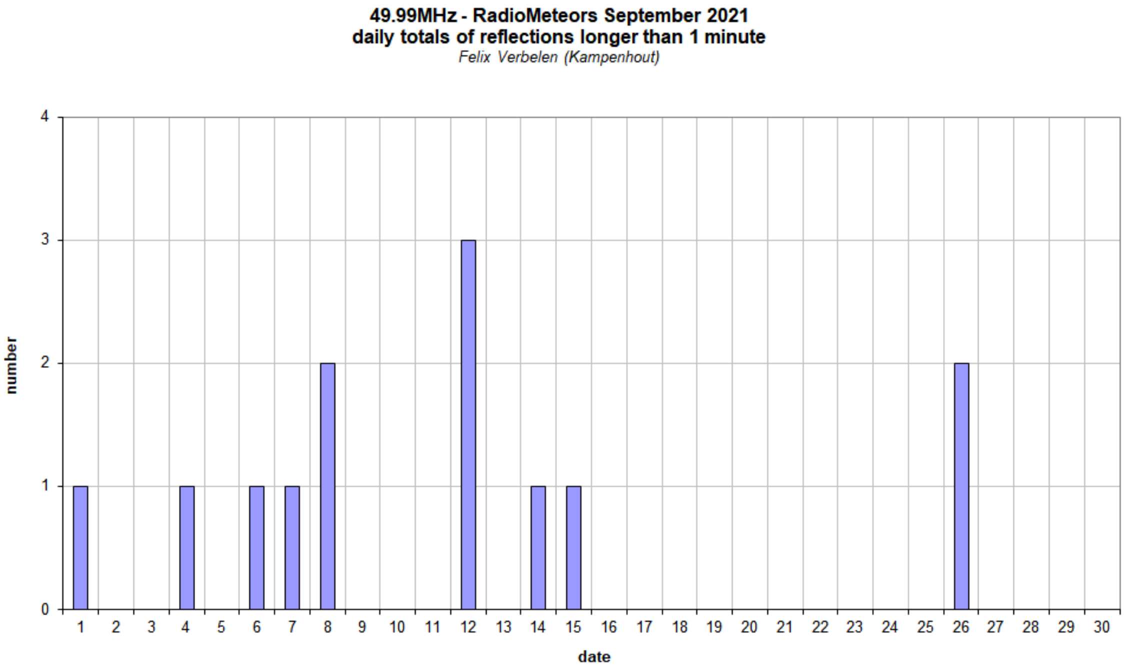
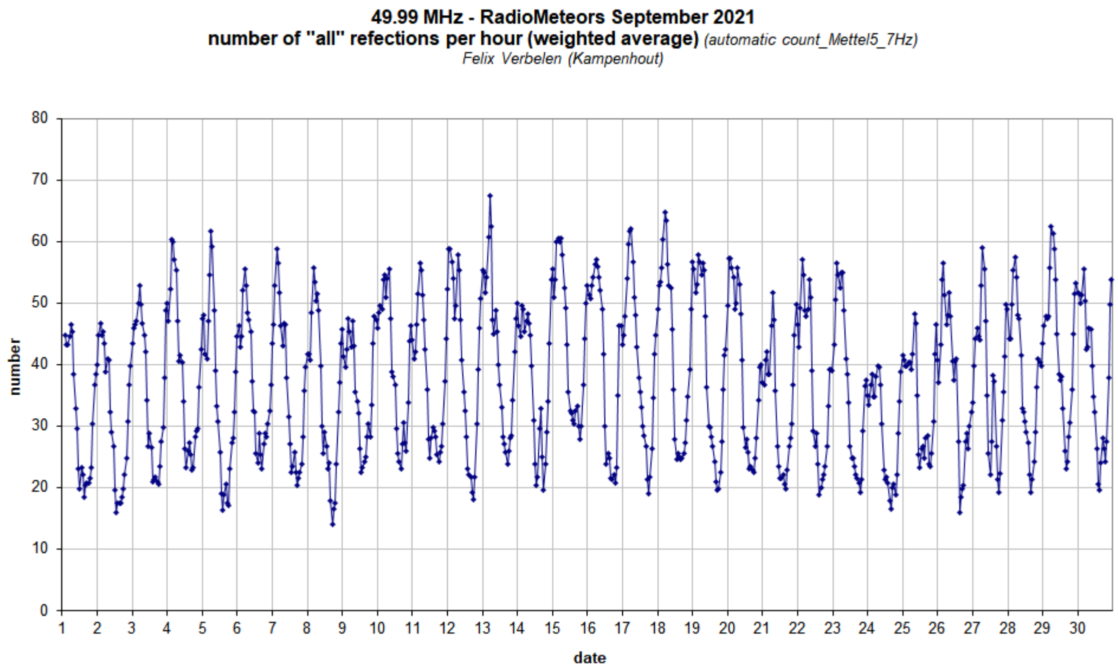


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2021.



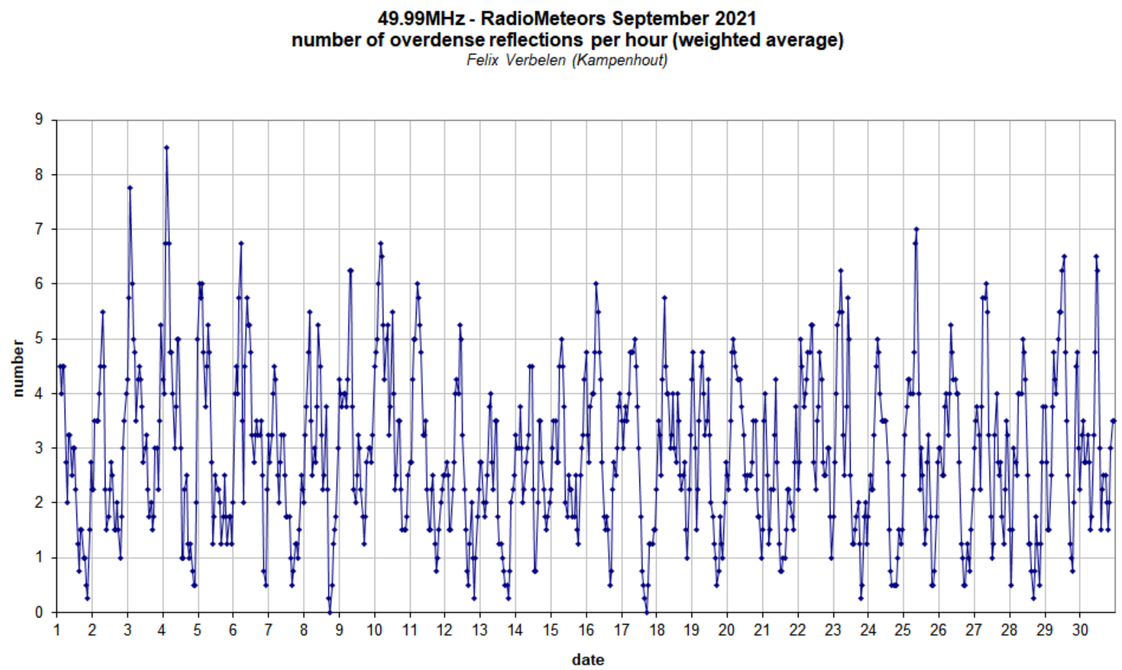


Figure 3 – The hourly numbers of "all" reflections counted automatically, and of manually counted "overdense" reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2021.

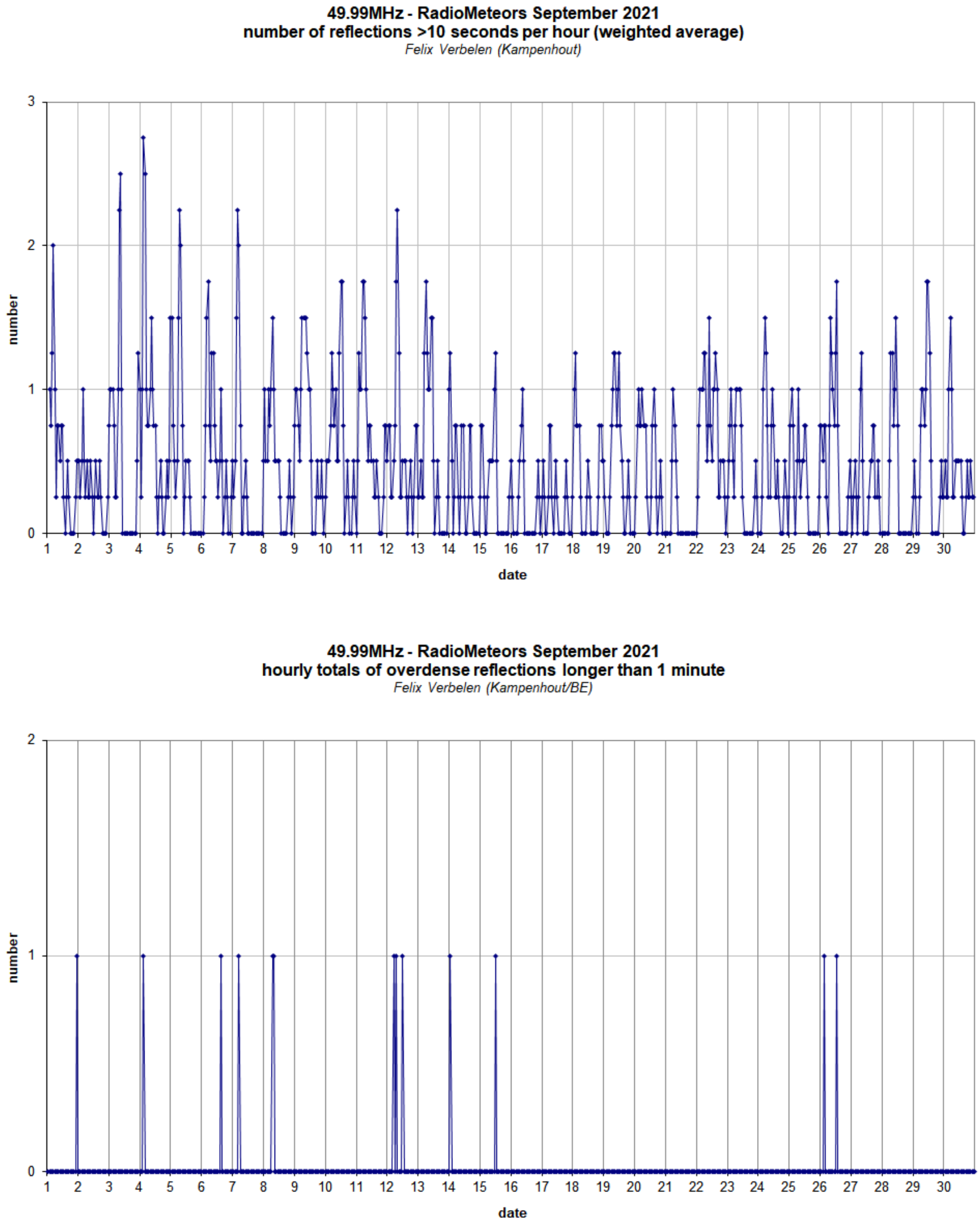


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during September 2021.

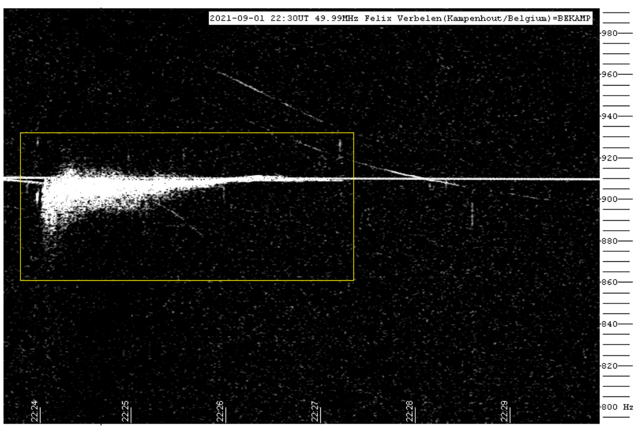


Figure 5 – Meteor reflection 1 September 2021, 22^h30^m UT.

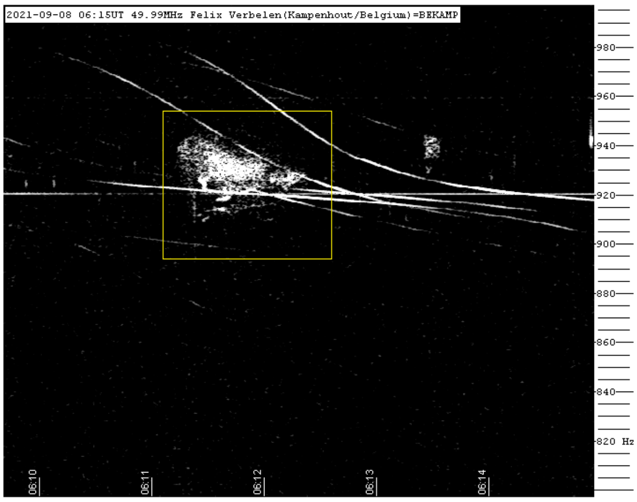


Figure 6 – Meteor reflection 8 September 2021, 06^{h}15^m UT.

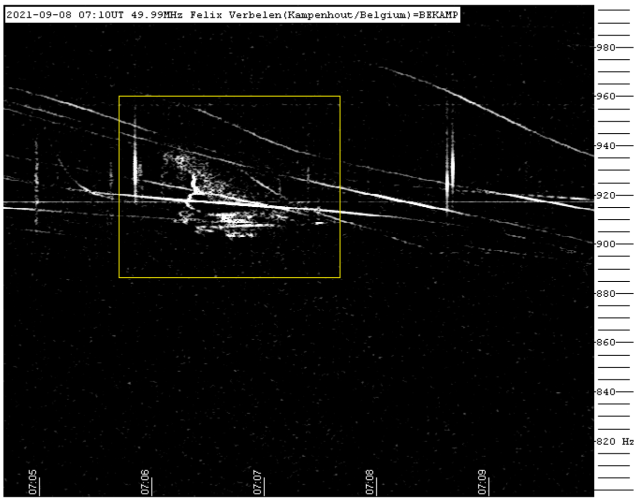


Figure 7 – Meteor reflection 8 September 2021, 07^{h}10^m UT.

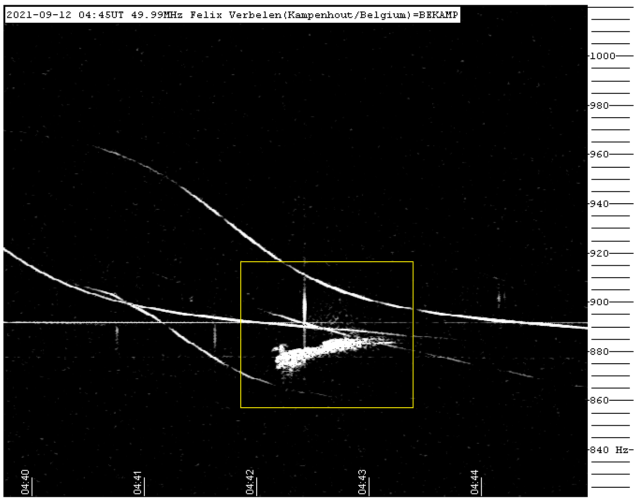


Figure 8 – Meteor reflection 12 September 2021, 04^{h}45^m UT.

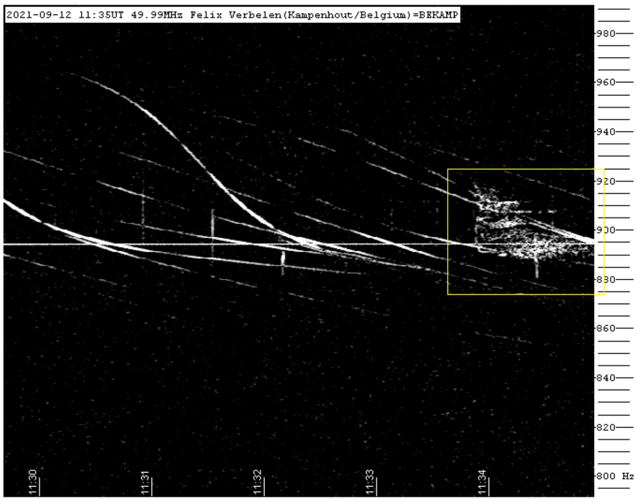


Figure 9 – Meteor reflection 12 September 2021, 11^{h}35^m UT.

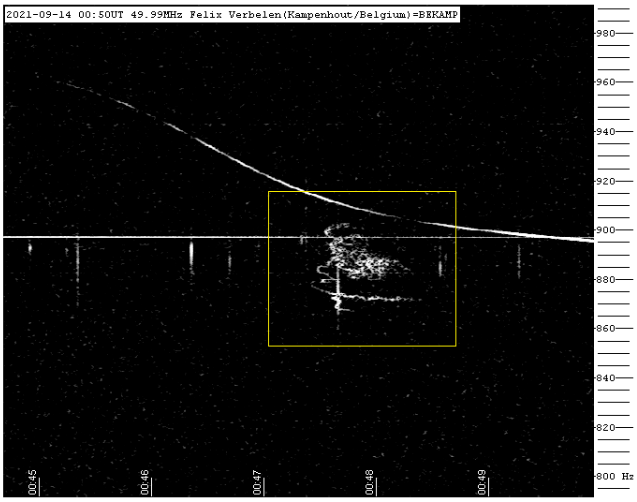


Figure 10 – Meteor reflection 14 September 2021, 0^{h}50^m UT.

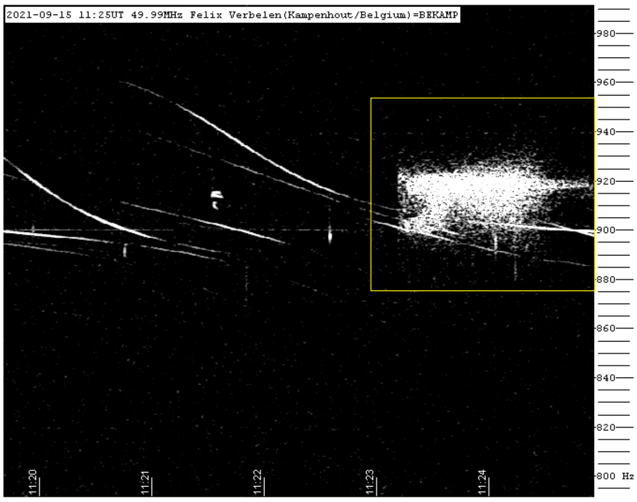


Figure 11 – Meteor reflection 15 September 2021, 11^{h}25^m UT.

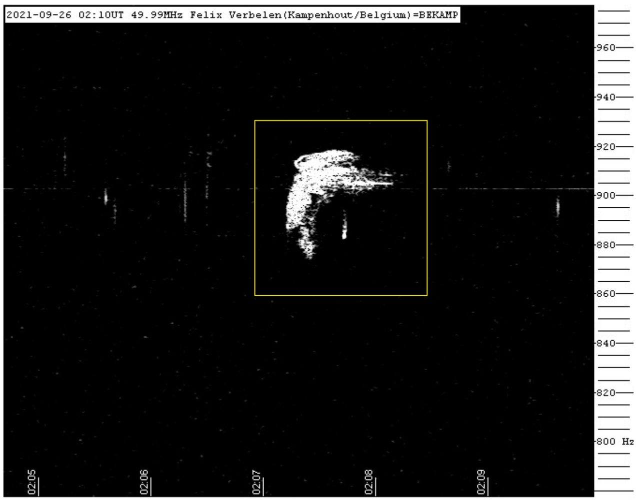


Figure 12 – Meteor reflection 26 September 2021, 2^h10^m UT.

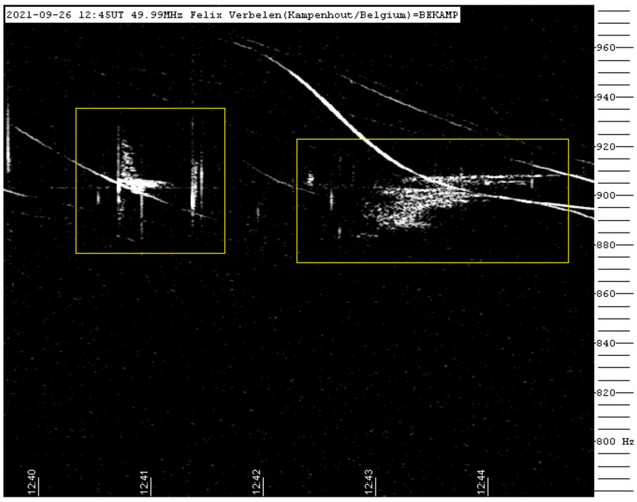


Figure 13 – Meteor reflection 26 September 2021, 12^h45^m UT.

Winter observations 2020–2021

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An overview is given of the visual meteor observations by the author in December 2020 and January 2021, covering the Geminids and Quadrantid activity.

1 December 14–15, 2020

The viewing conditions for the Geminids in 2020 were excellent, so local amateur astronomer/photographer Raymond Dubois and I intended to view them at a local dark site. Unfortunately, the peak night (December 13–14) was completely overcast and had almost no hopes of clearing. We both made a last-ditch attempt by meeting at a site about an hour's drive east of Ottawa, in the hopes that we might get a hole. Unfortunately, it was solid clouds for a couple of hours, until we eventually gave up and returned home.

The following night was more promising with an early evening clearing trend to the south-west of Ottawa. After analyzing the weather, Raymond and I decided to go to the North Frontenac Dark Sky Preserve Site (NFDSP) near Plevna. I was the first one to arrive early in the evening, and Raymond arrived shortly after with his new truck. It was not too cold at –13° C, but the gusts produced a –20° C windchill so we bundled up well. Raymond and I setup our chairs behind the newly installed fencing (provided a nice wind blocking) while our cameras were out on the concrete pad. The fence also helps to block lights from other cars arriving at the parking lot area. I opted to keep it simple with my cameras by skipping the tracking and running them on fixed tripods, aimed at the same parts of the sky all night long. Some residual clouds were present early in the evening, around 9 pm local time, otherwise the sky transparency was average quality and the winter Milky Way was beautiful.

Figure 1 – Composite image consisting of all the meteors captured during the night with a Canon 6D and a Rokinon 14mm f/2.8 lens. ISO 6400. 25 sec individual exposures. 1306 images were taken between 01^h11^m UT and 10^h45^mUT on December 15 2021, of which 21 frames were found with meteors, that were added into this image. Two of the meteors may be Monocerorids and one may be a Sigma Hydrid. By Pierre Martin.

Figure 2 – Composite image consisting of all the meteors captured during the night with a Canon 5D and a Rokinon 24mm f/2.0 lens. ISO 3200. 20 sec individual exposures. 1306 images were taken between 01^h24^m UT and 07^h56^m UT on December 15 2021, of which 7 frames were found with meteors, that were added into this image. By Pierre Martin.

I signed on for a formal meteor watch just before 03^h UT Dec 15, and I observed for nearly 5 hours, until just after 07^h UT Dec 15 when the sky clouded over. I saw 72 meteors (35 Geminids, 7 Monocerotids, 6 December Leonis Minorids, 5 anthelions, 4 Comae Berenicids, 3 sigma Hydrids, one December Alpha Draconid and 11 sporadics). Geminids visual rates were below ten per hour but produced some fairly bright meteors up to mag –3. The most impressive meteor was a –4 blue-green Comae Berenicid that shot in Ursa Major and flared twice, leaving a ten seconds persistent train! The sky cleared up again before dawn, and I decided to do a bit of photography in other parts of the sky before going to sleep.

Observation December 14–15 2020, 02^h50^m–07^h15^m UT (21^h50^m–02^h15^m EST). Location: North Frontenac Dark Sky Preserve Site, Ontario, Canada. (Long: –76°56’23” West; Lat: 44°55’04” North)[36].

Observed showers:

- Southern chi Orionids (ORS) – 05^h52^m (088°) +18°
- Anthelion (ANT) – 06^h16^m (094°) +23°
- December Monocerotids (MON) – 06^h49^m (102°) +08°
- Geminids (GEM) – 07^h30^m (112°) +33°
- sigma Hydrids (HYD) – 08^h36^m (129°) +02°
- December Leonis Minorids (DLM) – 10^h20^m (155°) +34°
- Comae Berenicids (COM) – 11^h24^m (171°) +20°
- December chi Virginids (XVI) – 12^h40^m (190°) –10°
- December Sigma Virginids (DSV) – 13^h16^m (199°) +07°
- December Alpha Draconids (DAD) – 13^h46^m (206°) +56°

02^h50^m–03^h50^m UT (21^h50^m–22^h50^m EST); 3/5 trans; F 1.00; LM 6.65; facing SE50 deg; t_{eff} 1.00 hr.

- GEM: seven: –1; +2(2); +3(2); +5(2)
- MON: one: +4
- Sporadics: two: +3(2)
- Total meteors: Ten

03^h50^m–04^h50^m UT (22^h50^m–23^h50^m EST); 3/5 trans; F 1.00; LM 6.70; facing SE50 deg; t_{eff} 1.00 hr.

- GEM: nine: 0; +1; +2(4); +3; +4; +5
- ANT: two: +2; +4
- MON: one: +1
- HYD: one: +4
- DLM: one: +3
- Sporadics: four: +3; +4(2); +5
- Total meteors: Eighteen

[36] https://www.imo.net/members/imo_vmdb/view?session_id=82752

04^h50^m–05^h50^m UT (23^h50^m–00^h50^m EST); 3/5 trans; F 1.00; LM 6.70; facing SE50 deg; t_{eff} 1.00 hr.

- GEM: nine: –3; +1; +2(2); +3; +4(4)
- ANT: three: +1; +3; +5
- MON: one: +3
- HYD: one: +4
- Sporadics: two: +3; +4
- Total meteors: Sixteen

05^h50^m–06^h50^m UT (00^h50^m–01^h50^m EST); 3/5 trans; F 1.00; LM 6.70; facing SE50 deg; t_{eff} 1.00 hr.

- GEM: seven: +1; +2(4); +4; +5
- COM: four: –4; +2; +3; +5
- MON: three: +2(2); +4
- DLM: three: +1; +4(2)
- HYD: one: +4
- Sporadics: two: 0; +4
- Total meteors: Twenty

06^h50^m–07^h15^m UT (01^h50^m–02^h15^m EST); 3/5 trans; F 1.00; LM 6.70; facing SE50 deg; t_{eff} 0.42 hr.

- GEM: three: +3; +4; +5
- DLM: two: +3; +4
- MON: one: +3
- DAD: one: +3
- Sporadics: one: +3
- Total meteors: Eight

Total meteors during this session: 72

A link to the time lapse of a Geminid fireball persistent train created with Canon 5D and Rokinon 24mm f/2.0 lens, ISO 3200. 20 sec exposures (real time span is 10 minutes from 02^h46^m UT to 02^h56^m UT on December 15 2021)[37].

Figure 3 – The Geminid 2021 observing sites.

Figure 4 – The Geminid 2021 observing sites.

Figure 5 – The Geminid 2021 observing sites.

Figure 6 – Zodiacal Light with Canon 6D and Rokinon 14mm f/2.8 lens, ISO 6400. 25 sec exposure. By Pierre Martin.

2 2020 Ursids report

There was a possibility that the 2020 Ursids might produce a series of predicted outbursts during the night of December 21–22.

The weather appeared hopelessly cloudy within driving distance, but I decided to venture out anyway with the 2 hours drive to the North Frontenac Dark Sky Preserve Site late at night, in a last-ditch attempt to catch a possible clear

[37] https://pmartin.smugmug.com/Astronomy/20201215-Geminids-at-North-Frontenac-Dark-Sky-Preserve/i-4TVj6MM/A

break. It was a long shot. I arrived at the site near 1^h30^m am EST (local time), and the sky was about 95% cloudy (not much to be seen at all). I went ahead and setup my cameras, as the satellite image showed a small hole approaching in the west. It was very mild at 0° C, and calm. Unlike the Geminids session, I opted to setup at the south end of the parking lot to gain a better view of the northern sky. In fact, all of the horizons were great from that spot, except for a low tree line in the west.

Just before 2^h am, the sky showed a gradual sign of clearing trend to the west – I could see a few more stars. By 2^h10^m am, I could see the Big Dipper, and stars down to mag +3 in the south-west. Ursa Minor became visible. It took until 2^h50^m am for the sky to clear up just enough (20% clouds) to attempt signing-on for a meteor watch. The sky transparency was poor with a limiting magnitude of only 5.6. I was only able to observe for 25 minutes before it clouded over again. During that time, I saw two meteors (a December Leonis Minorid and a sporadic). I was viewing far past the predicted timing of possible Ursids outbursts, and as such, none were seen.

The 2020 Ursids did in fact produce above average around 5^h UT (midnight EST) as reported by the CAMS network in the US. No sensational outburst, but a significant number of Ursid orbits (Roggemans, 2021).

December 21–22, 2020, 07^h50^m–08^h15^m UT (02^h50^m–03^h15^m EST). Location: North Frontenac Dark Sky Preserve Site, Ontario, Canada. (Long: –76°56'23" West; Lat: 44°55'04" North)[38].

Observed showers:

- Anthelion (ANT) – 06^h44^m (101°) +23°
- December Monocerotids (MON) – 07^h10^m (108°) +07°
- alpha Hydrids (AHY) – 07^h50^m (117°) –06°
- Geminids (GEM) – 08^h02^m (121°) +31°
- sigma Hydrids (HYD) – 09^h03^m (136°) –00°
- December Leonis Minorids (DLM) – 10^h49^m (162°) +30°
- Comae Berenicids (COM) – 12^h01^m (180°) +15°
- December chi Virginids (XVI) – 13^h02^m (195°) –13°
- December sigma Virginids (DSV) – 13^h46^m (206°) +05°
- Ursids (URS) – 14^h22^m (215°) +76°

07^h50^m–08^h15^m UT (02^h50^m–03^h15^m EST); 1/5 trans; F 1.25; LM 5.60; facing NW80°; t_{eff} 0.42 hr.

- DLM: one: +2
- Sporadics: one: +4
- Total meteors: Two

3 Quick report on the 2021 Quadrantids

I did not have any luck with the weather for the 2021 Quadrantids peak, however the sky partly cleared briefly at the end of the night at my east-end Ottawa home. In a period of ten minutes between 10^h35^m–10^h45^m UT (05^h35^m–05^h45^m EST), viewing from my deck (facing the south-east sky), with a 75% waning gibbous moon, 50% clouds, and a limiting magnitude of only about +4.5, I saw 14 Quadrantids!! The brightest ones were mag 0. These rates (better than one per minute) were impressive in the poor sky conditions. The Quadrantids had a strong double-peak structure as reported by radio observations (Ogawa and Sugimoto, 2021).

References

Ogawa H. and Sugimoto H. (2021). "Quadrantids 2021 with Worldwide Radio Meteor Observations". *eMetN*, **6**, 271–273.

Roggemans P. (2021). "Global Meteor Network and the 2020 Ursid return". *eMetN*, **6**, 15–18.

[38] https://www.imo.net/members/imo_vmdb/view?session_id=82755

July-August-September 2021 observations

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An overview is given of the visual meteor observations by the author during the months July, August and September 2021. An unexpected outburst of the Perseids during the night August 13–14 was the absolute highlight of this campaign.

1 July 30–31, 2021

After several months of being away from observing and having rather poor luck with weather for the late 2020 meteor showers maximums, it was good to finally be out again this summer. The period from late July and into August has long been among my favorite times of the year for observing. It's hard to beat the mild nights, the drop in mosquitoes and the increasing meteor activity. The hot humid days, as well as the smoke in the atmosphere made observing more difficult, but things improved during the second half of the summer. Hard to believe that my first active meteor watch took until more than halfway through the year to happen!

So, on the evening of July 30, I drove to Bootland Farm. It is still a nice dark sky site on a private property south-west of Arnprior. The property owner maintains the usual large rectangular grassy area. The site is still available for local amateur astronomers between the months of Spring and Fall. I have been using this site since 2004. On good nights there, the Milky Way can look quite impressive. I enjoy the quietness and seclusion there, with a low tree line/decent horizon.

On this particular night, the sky was okay but clearly affected by forest fire smoke in the atmosphere. The LP glows from Arnprior and Ottawa were more significant than usual, and some patchy cirrus clouds were present.

I meteor observed for two hours from 11^h pm until 1^h am EDT (local time), with a LM initially at 6.35 but gradually declining to 6.01 due to the Quarter Moon rising at midnight. During that time, I saw 20 meteors (6 Perseids, 3 anthelions, 2 alpha Capricornids, one July gamma Draconid, one Southern delta Aquariid and 7 sporadics).

The two alpha Capricornids were fireballs of mag –3 and –4. The first one was seen at 11^h14^m pm EDT very low in the east and well into the tree line. It had a vivid blue-green color and fragmented! It most likely would have appeared much brighter had it been overhead. The second alpha Cap fireball was seen just a few minutes before the end of the session. It was blue-white and produced a terminal flash in the circle of Pisces. Quite rewarding!

July 30–31, 2021, 03^h00^m–05^h00^m UT (23^h00^m–01^h00^m EDT). Location: Bootland Farm, Ontario, Canada. (Long: –76°29' West; Lat: 45°23' North)[39].

Observed showers:

- kappa Cygnids (KCG) – 18^h38^m (280°) +43°
- July gamma Draconids (GDR) – 18^h38^m (280°) +51°
- alpha Capricornids (CAP) – 20^h28^m (307°) –09°
- Anthelion (ANT) – 21^h24^m (321) –16°
- Northern delta Aquariids (NDA) – 22^h30^m (337°) –03°
- Southern delta Aquariids (SDA) – 22^h45^m (341°) –16°
- Piscids Austrinids (PAU) – 23^h14^m (349°) –22°
- July Pegasids (JPE) – 00^h21^m (005°) +17°
- Perseids (PER) – 02^h12^m (033°) +55°
- eta Eridanids (ERI) – 02^h27^m (037°) –15°

03^h00^m–04^h00^m UT (23^h00^m–00^h00^m EDT); 2/5 trans; F 1.00; LM 6.35; facing S50 deg; t_{eff} 1.00 hr.

- PER: four: +1; +2; +3(2)
- GDR: one: +1
- CAP: one: –3
- ANT: one: +5
- SDA: one: +5
- Sporadics: five: +1; +4; +5(3)
- Total meteors: Thirteen

04^h00^m–05^h00^m UT (00^h00^m–01^h00^m EDT); 2/5 trans; F 1.00; LM 6.01; facing S50 deg; t_{eff} 1.00 hr.

- PER: two: +1; +4
- ANT: two: +1; +4
- CAP: one: –4
- Sporadics: two: +2; +5
- Total meteors: Seven

Total meteors for this session: 20

[39] https://www.imo.net/members/imo_vmdb/view?session_id=82761

2 August 2–3, 2021

A few nights later, I returned to Bootland Farm for a two hour meteor watch (from about midnight to 2^h am EDT local time). The sky conditions were much better than the previous session, with 3/5 transparency, and a quite nice summer Milky Way! The limiting magnitude was 6.48 in the first hour but dropped to 6.31 when the crescent moon rose after 1^h am. There was a nice light breeze, no bugs and no dew – a really pleasant night to be out! Shortly after I arrived at the site, and while setting up, I saw a probable alpha Capricornid that crawled in Aquarius.

I saw 30 meteors (8 Southern delta Aquariids, 7 Perseids, 4 kappa Cygnids, 3 alpha Capricornids, one anthelion and 7 sporadics). The swift Perseids coming in from the north-east would contrast nicely the slower Aquariids and Capricornids coming from the south. And the Kappa Cygnids were active. The brightest meteor was a –3 alpha Capricornid seen at 1^h46^m am that was yellow and travelled 20 degrees before fragmenting in Perseus. Nice!

August 2–3, 2021, 04^h10^m–06^h12^m UT (00^h10^m–02^h12^m EDT). Location: Bootland Farm, Ontario, Canada. (Long: –76°29' West; Lat: 45°23' North)[40].

Observed showers:

- kappa Cygnids (KCG) – 18^h38^m (280°) +43°
- alpha Capricornids (CAP) – 20^h28^m (307°) –09°
- Anthelion (ANT) – 21^h24^m (321°) –16°
- Northern delta Aquariids (NDA) – 22^h30^m (337°) –03°
- Southern delta Aquariids (SDA) – 22^h45^m (341°) –16°
- Piscids Austrinids (PAU) – 23^h14^m (349°) –22°
- July Pegasids (JPE) – 00^h21^m (005°) +17°
- Perseids (PER) – 02^h12^m (033°) +55°
- eta Eridanids (ERI) – 02^h27^m (037°) –15°

04^h10^m–05^h10^m UT (00^h10^m–01^h10^m EDT); 4/5 trans; F 1.00; LM 6.48; facing S50 deg; t_{eff} 1.00 hr.

- SDA: six: +2; +3(2); +4(2); +5
- PER: five: –1; +1; +2; +5(2)
- KCG: one: +4
- CAP: one: +5
- Sporadics: four: 0(2); +4; +5
- Total meteors: Seventeen

05^h10^m–06^h12^m UT (01^h10^m–02^h12^m EDT); 4/5 trans; F 1.00; LM 6.31; facing S50 deg; t_{eff} 1.03 hr.

- KCG: three: +3(2); +4
- PER: two: 0; +3
- CAP: two: –3; +3
- SDA: two: +3(2)
- ANT: one: +5
- Sporadics: three: +4(2); +5
- Total meteors: Thirteen

Total meteors for this session: 30

3 August 11–12, 2021

I went to the Moosecreek site (dark sky site located about 60 km east of Ottawa, Ontario) on the evening of August 11 for a short meteor session, one night before the predicted peak. It was a very warm 26°C, muggy and hazy night. No need for any sleeping bag or blanket; it was actually uncomfortably warm. The breeze kept the mosquitoes away. I expected to last only about an hour before clouds would move in. As it turned out, I was about to observe for three hours starting just before 11^h pm and going until about 2^h am EDT local time. The sky quality was very poor, with muted constellations near the horizons and many bright stars that were barely visible. The sky was only observable overhead but occasionally affected by a few passing clouds. Distant lightning would flash to the east.

I was still able to count 46 meteors (32 Perseids, 4 Kappa Cygnids, one alpha Capricornid, one anthelion, one Northern delta Aquariid, one Southern delta Aquariid and 6 sporadics). Perseids hourly rates were low at 5, 9 and 18, but that was expected with the poor sky conditions and the relatively low radiant. Some nice, long Perseids were seen, and the brighter ones made some pretty neat halos in the hazy sky. The best meteor was a +1 sporadic earth grazer at 10^h58^m pm that shot 60 degrees heading to the west, with a one second train! Another highlight was a –1 yellow sporadic at 1^h38^m am that moved slowly, starting near Ursa Minor and ending in Cepheus. I packed it in just as the sky was clouding over for good.

August 11–12, 2021, 02^h43^m–05^h55^m UT (22^h43^m–01^h55^m EDT). Location: Moosecreek, Ontario, Canada. (Long: –75°02'57" West; Lat: 45°15'13" North)[41].

Observed showers:

- August xi Draconids (AXD) – 18^h30^m (278°) +46°
- kappa Cygnids (KCG) – 18^h52^m (283°) +46°
- alpha Capricornids (CAP) – 20^h42^m (311°) –07°
- Anthelion (ANT) – 21^h52^m (328°) –13°
- Northern delta Aquariids (NDA) – 22^h52^m (343°) –00°
- Southern delta Aquariids (SDA) – 23^h02^m (346°) –15°
- Piscids Austrinids (PAU) – 23^h36^m (354°) –20°
- Perseids (PER) – 02^h50^m (042°) +57°
- eta Eridanids (ERI) – 02^h51^m (043°) –12°

02^h43^m–03^h47^m UT (22^h43^m–23^h47^m EDT); 1/5 trans; F 1.20; LM 5.44; facing NE70 deg; t_{eff} 1.00 hr.

- PER: five: –2; –1; +2; +3(2)
- KCG: two: +2; +3
- CAP: one: +4
- NDA: one: +5

[40] https://www.imo.net/members/imo_vmdb/view?session_id=82762

[41] https://www.imo.net/members/imo_vmdb/view?session_id=82765

- Sporadics: three: +1; +3; +4
- Total meteors: Twelve

03^h47^m–04^h51^m UT (23^h47^m–00^h51^m EDT); 1/5 trans; F 1.25; LM 5.45; facing SE70 deg; t_{eff} 1.00 hr.

- PER: nine: +1(3); +2; +4(3); +5(2)
- KCG: two: 0; +3
- SDA: one: +2
- Total meteors: Twelve

04^h51^m–05^h55^m UT (00^h51^m–01^h55^m EDT); 1/5 trans; F 1.06; LM 5.45; facing SE70 deg; t_{eff} 1.06 hr.

- PER: eighteen: –4; –2; –1(2); 0; +1; +2(2); +3(5); +4(4); +5
- ANT: one: +3
- Sporadics: three: –1; +2; +4
- Total meteors: Twenty-two

Total meteors for this session: 46

4 August 12–13, 2021

For the predicted peak night, local amateur astronomer and photographer Raymond Dubois was interested in joining me at a dark sky site. We discussed our options and the weather forecasts ahead of time, and we considered a few different possibilities. Some early evening cirrus and late-night patchy clouds were possible, but the forecast was generally pretty good. It was warm but less humid and muggy than the previous night. By early afternoon on August 12, it seemed that the area surrounding Renfrew (west of Ottawa) would be decent! So, we decided to head to our friend Shane Finnigan's property (near Renfrew) and setup there for the night. Chris Thuemen joined in as well for some observing with his telescope.

I arrived after suppertime, and setup out on the property next to the pumpkin vines. I had a really great view of the sky facing east with the Madawaska Optical Observatory (MOO) in front of me. Not too buggy, and pleasant out there with a temperature of about 20°C. While Shane gave Chris a tour of the observatory, Raymond and I setup our tracking mounts, cameras and other paraphernalia. Overhead, the sky was very clear – better than I expected! I even casually saw a few long and colorful Perseids shooting up into the twilight sky.

With my three cameras running exposures automatically, I signed on at 02^h35^m UT (10^h35^m pm EDT) and observed until 08^h30^m UT (04^h30^m am EDT) for a total of 3.88 hours effective time. The LM started off at 6.25 and gradually improved to 6.40 as the night went on. The session was interrupted by a few breaks either to check or adjust my cameras, or to wait out passing cloud cover. From about 2^h am to 3^h am local time, the sky was overcast due to a patch of cirrocumulus moving through quickly. Waiting it out

Figure 1 – Composite image of 77 Perseids and 4 Kappa Cygnids captured between 01^h57^m UT (09^h57^m pm EDT) and 08^h34^m UT (04^h34^m am EDT) on August 12–13 2021 with the Madawaska Optical Observatory (MOO) in foreground. Note the highly foreshortened Perseids near the radiant. It was produced with a Canon 6D at ISO 3200, 35 sec exposures, and a Rokinon 14mm f/2.8 lens. Tracking was provided by a Vixen GPDX mount. 725 continuous exposures were made of which 81 meteors were found and digitally combined into this image. Sporadics and other minor shower meteors are not included. Photographed near Renfrew, Ontario by Pierre Martin.

Figure 2 – Composite image of 25 Perseids captured between 01^h55^m UT (09^h55^m pm EDT) and 08^h34^m UT (04^h34^m am EDT) on August 12–13, 2021. It was produced with a Canon 5D at ISO 1600, 25 sec exposures, and a Rokinon 24mm f/2.0 lens. Tracking was provided by a Vixen GPDX mount. 725 continuous exposures were made of which 25 meteors were found and digitally combined into this image. Sporadics and other minor shower meteors are not included. Photographed near Renfrew, Ontario by Pierre Martin.

Figure 3 – Composite image of 37 Perseids and 3 Kappa Cygnids captured between 02^h03^m UT (10^h03^m pm EDT) and 05^h32^m UT (01^h32^m am EDT) on August 12–13 2021. It was produced with a Nikon D750 at ISO 6400, 15 sec exposures, and a Laowa 12mm f/2.8 lens. Setup was unguided. 613 continuous exposures were made of which 40 meteors were found and digitally combined into this image. Photographed near Renfrew, Ontario by Pierre Martin.

Figure 4 – Composite image of 60 Perseids and 3 Kappa Cygnids captured between 05^h32^m UT (01^h32^m am EDT) and 08^h42^m UT (04^h42^m am EDT) on the night of August 12–13 2021. It was produced with a Nikon D750 at ISO 6400, 15 sec exposures, and a Laowa 12mm f/2.8 lens. Setup was unguided. 669 continuous exposures were made of which 63 meteors were found, and digitally combined into this image. The gegenshein is faintly visible left of centre along the ecliptic. Photographed near Renfrew, Ontario by Pierre Martin.

paid off. The hour that followed was clear with a high radiant, quite productive in meteor activity. It then clouded over again just as the night was ending.

I saw a total of 195 meteors (150 Perseids, 9 kappa Cygnids, 7 Southern delta Aquariids, 3 Northern delta Aquariids, one alpha Capricornid and 25 sporadics). The Perseids had decent rates that reached 50/hr late at night. I was quite pleased with the Kappa Cygnids I was seeing – this minor shower has been quite active this year, but it has not been a "fireball year" for them. The Southern delta Aquariids continued to be mildly active.

There were several very nice meteors and highlights! The brightest Perseid came at 10^h49^m pm EDT… It was a 40 degrees long –4 fireball that shot towards Capricornus just as another fainter +3 Perseid went by! One of my favorite moments was at 12^h19^m am EDT with two bright Perseids almost back-to-back high up in the sky… a 30 degrees long –1 from Pegasus to Aquarius, followed just a couple seconds later by a stunning 40 degrees long –3 beauty with a 15 seconds persistent train! We all shouted loudly in our excitement! The late mag 0 blue-green alpha Capricornid that appeared at 3^h19^m am EDT was a very pretty meteor tracing a long 30 degrees path between Andromeda and Aries. Last but not least, at 4^h06^m am EDT, a foreshortened –3 bluish Perseid flared near the radiant and it left a 3 seconds train.

My three cameras caught a total of 279 meteors. Quite a productive night, even despite the cloudy spells! A collection of my four Perseids composite images taken on that night below on my Smugmug photo gallery is shown in *Figures 1, 2, 3 and 4*. Several Kappa Cygnids were also captured.

These images can also be viewed here in higher resolution[42].

The company of Raymond, Chris and Shane was fun! In between meteors, I enjoyed listening to Raymond talking about his recent northern June annular solar eclipse road trip. At the end of the night, I had a nice, long snooze in the car. I enjoyed this night very much! Shane is fortunate in having access to these dark skies just steps away from his home.

August 12–13, 2021, 02^h35^m–08^h30^m UT (22^h35^m–04^h30^m EDT). Location: Renfrew, Ontario, Canada (45°25'48" N 76°38'24" W)[43].

Observed showers:

- August xi Draconids (AXD) – 18^h24^m (276°) +55°
- zeta Draconids (AUD) – 19^h06^m (287°) +59°
- kappa Cygnids (KCG) – 19^h08^m (287°) +52°
- alpha Capricornids (CAP) – 21^h10^m (317°) –05°
- Anthelion (ANT) – 22^h20^m (335°) –10°
- Northern delta Aquariids (NDA) – 23^h14^m (349°) +02°
- Southern delta Aquariids (SDA) – 23^h24^m (351°) –14°
- Perseids (PER) – 03^h30^m (053°) +59°
- eta Eridanids (ERI) – 03^h15^m (049°) –10°

02^h35^m–03^h35^m UT (22^h35^m–23^h35^m EDT); 3/5 trans; F 1.00; LM 6.25; facing SE55 deg; t_{eff} 1.00 hr.

- PER: thirty-three: –4; –1(2); 0; +1(6); +2(3); +3(5); +4(4); +5(11)
- NDA: one: +1
- Sporadics: six: +3(3); +4; +5(2)
- Total meteors: Forty

04^h00^m–05^h22^m UT (00^h00^m–01^h22^m EDT); 3/5 trans; F 1.00; LM 6.35; facing SE55 deg; t_{eff} 1.00 hr.

- PER: thirty-nine: –3; –1; 0(4); +1(11); +2(6); +3(5); +4(5); +5(6)
- KCG: four: +1; +2; +4(2)
- NDA: one: +3
- SDA: one: +4
- Sporadics: seven: +1; +2; +3; +4(2); +5(2)
- Total meteors: Fifty-two

05^h22^m–06^h03^m UT (01^h22^m–02^h03^m EDT); 3/5 trans; F 1.00; LM 6.35; facing SE55 deg; t_{eff} 0.50 hr.

- PER: thirteen: +1(5); +2; +3(4); +4(3)
- KCG: two: 0; +4
- SDA: two: +3; +5
- Sporadics: two: +1; +4
- Total meteors: Nineteen

07^h07^m–08^h07^m UT (03^h07^m–04^h07^m EDT); 3/5 trans; F 1.02; LM 6.40; facing SE55 deg; t_{eff} 1.00 hr.

- PER: fifty: –3; –1; 0(3); +1(7); +2(7); +3(9); +4(14); +5(8)
- SDA: four: +3(2); +4(2)
- KCG: three: +1; +3; +5
- CAP: one: 0
- Sporadics: nine: +3(4); +4(4); +5
- Total meteors: Sixty-seven

08^h07^m–08^h30^m UT (04^h07^m–04^h30^m EDT); 2/5 trans; F 1.04; LM 6.40; facing SE55 deg; t_{eff} 0.38 hr.

- PER: fifteen: 0; +1; +2(3); +3; +4(4); +5(5)
- NDA: one: +3
- Sporadics: one: +1
- Total meteors: Seventeen

Total meteors for this session: 195

[42] https://pmartin.smugmug.com/Astronomy/20211308-Perseids-at-Renfrew-Ontario/

[43] https://www.imo.net/members/imo_vmdb/view?session_id=82773

5 August 13–14, 2021 – A Perseid outburst

Here's my report on an extraordinary and surprising 2021 Perseid meteor outburst.

This was a session that nearly didn't happen. On the afternoon of August 13, I looked at what the weather forecasts had in store for the coming night. It was pretty questionable. It was becoming cloudy, and a series of thundershowers were in the forecast for the evening hours. On the other hand, the weather forecasts showed a cold front approaching the region overnight. It appeared that locations roughly 80–100 km northwest of Ottawa would start clearing just after 1^h am local time. I was exhausted from the previous nights up watching and photographing the Perseids, so I was thinking that I would skip this night to get some much-needed sleep. I went to bed early, but I woke up just before 11^h pm. I rechecked the weather just out of curiosity, and I found that the satellite image was matching the model forecasts quite well. The nap made me feel more rested and I decided to go for it! The car was still mostly packed from the previous night so I was able to get ready quickly. I took off to Westmeath Lookout, a two-hour drive! This was as far as I was willing to go, as it was already late. I left my east-end Ottawa home at 11^h30^m pm and drove through terrible weather conditions. More than once, I went through a heavy downpour (at times with poor visibility as one wall of heavy rain hit after another). Along the way, I contemplated turning around and returning home as the weather seemed to be getting worse. But I pressed on, and made it to Westmeath Lookout, arriving there at 1^h30^m am EDT. In a sharp contrast, the weather was so much nicer out there! It was dry, the wind was picking up significantly and the sky was clearing just as expected! Yeah!!! The air felt wonderfully dry and a mild 15° C, which was great compared to the hot, muggy days we had throughout the summer. As the last few clouds receded to the east, I spent a few minutes just looking up and admiring the sky before setting up. I was awed by the clarity. The Milky Way was thick and showed a wealth of details against a sea of faint stars! A few Perseids and sporadics flashed by! WOW!! What a great view! So, I grabbed my chair, a blanket, my observing accessories bag, a small table, the coffee and snacks, and I made my way up the hill to setup. The camera bag stayed in the car for now.

Westmeath Lookout is a beautiful and tranquil public sightseeing area, located within the Whitewater Region (a township on the Ottawa River in Renfrew County, eastern Ontario). It is popular for taking in panoramic views of the Ottawa Valley scenery from an elevated point, or for seeing sunsets or sunrises. There is a paved parking lot at the base of the hill, and a gazebo at the top. It is a fairly steep climb uphill by foot (better suited for light setups), but well worth it. The site has dark mag 6.7 skies overhead, and 360 degrees views of the horizons!

With the clouds completely gone, the transparency was excellent. It was the best I had seen this year and I was excited! I setup my chair facing east, with the wind on my back. I signed on at 05^h50^m UT (01^h50^m am EDT local time). Right away, I was seeing very good meteor activity, with Perseids coming in with one or two per minute. Then it was followed by a few minutes of absence. The lulls were however few and far in between before more meteors would appear. I presumed that the excellent sky transparency helped with the visibility of the meteors, but I was suspicious that something unusual might be happening. Then, in just 7 minutes between 06^h26^m UT (02^h26^m am EDT) to 06^h33^m UT (02^h33^m am EDT), I saw 18 meteors (with as many as 14 Perseids)! This was a far stronger rate than what I would expect to see a full day after the annual maximum. One of the Perseids was a –3 that flared with an 8 seconds train! I was now convinced that an outburst was in progress! I took a pause from visual observing, quickly went back down the hill to my car to grab my camera bag, and a small tripod, and back uphill I went. Meteors flashed left and right on the periphery of my vision, and a sense of excitement and adrenaline kicked in! I quickly setup my camera (a Canon 6D with a 14mm f/2.8 lens) towards the north where the sky was darkest. I didn't have my dew heaters and batteries, so instead, I improvised by putting a couple of hand warmers in a sock and wrapping it around the lens to keep dew from forming on the optics. I set the interval-meter to run continuous 20 seconds exposures for the rest of the night.

I settled back on my chair at 06^h55^m UT (02^h55^m am EDT) to resume visual observing. The meteor action continued – in fact, it got better and better! After 07^h UT (3^h am EDT), the Perseids were going crazy!!! Multiple meteors per minute was becoming common! Perseids went left and right, up and down all over the sky! Just before 03^h30^m am EDT, I muttered in my tape recorder… "What the heck is going on? Ohhh and there goes another one!!!". I started counting the seconds in between meteors, and I would typically get to 15 or 30 seconds before I would see another. In some instances, two or three meteors would flash one after another, all within a second! The outburst peaked at about 08^h15^m UT (04^h15^m am EDT). My highest 10-minute count was 42 Perseids with a radiant elevation of 61 degrees! Then, the outburst started declining just as morning twilight grew stronger past 08^h30^m UT (4^h30^m am EDT).

The Perseids brightness was on the average/faint side, and no major fireballs occurred. A small proportion of Perseids stood out. At 06^h26^m UT (02^h26^m am EDT), a –3 Perseid flared and left an 8 seconds train. At 07^h27^m UT (3^h27^m am EDT), a similar –3 Perseid produced a terminal flash and left a 3 seconds train.

In three hours of observing 05^h50^m UT (01^h50^m am EDT) to 09^h08^m UT (05^h08^m am EDT), I saw 394 meteors (340 Perseids, 9 kappa Cygnids, 7 Northern delta Aquariids, 2 anthelions, 2 eta Eridanids, one alpha Capricornid, one August xi Draconid and 32 sporadics). My visual hourly rates for the Perseids were 64, 162 and 114! These rates make the 2021 Perseids the most active Perseid meteor shower that I've seen in my 33 years of observing!

Figure 5 – Composite image of 282 Perseids captured between 06^{h}50^m UT (2^{h}50^m am EDT) and 09^{h}00^m UT (5^{h}00^m am EDT) on the night of August 13–14, 2021. Canon 6D at ISO 6400, 20 sec exposures, Rokinon 14mm f/2.8 lens. Setup was mounted on tripod unguided. 364 continuous exposures were made of which 282 meteors were found, and digitally combined into this image (a few additional Perseids were found but are not included here due to sky rotation). Sporadics and other minor shower meteors are not included. Photographed near Westmeath, Ontario by Pierre Martin. A high resolution version of the composite image on my photo gallery site[44].

[44] https://pmartin.smugmug.com/Astronomy/20211408-Perseids-at-Westmeath-Lookout-Ontario/

Figure 6 – A single 20 seconds exposure with 4 Perseids taken at 07^h17^m UT (3^h17^m am EDT) on August 13–14, 2021. Canon 6D at ISO 6400, Rokinon 14mm f/2.8 lens. Photographed near Westmeath, Ontario by Pierre Martin.

Sporadics were quite active with hourly rates of 14, 12 and 6. Talk about a stunning night, it was something really special! My only wish is that more people would have seen this display.

I observed as long as I could before the morning twilight was too strong, ending just after 5^h am local time. I was still full of energy, and I was eager to find out if anyone else had seen the outburst within the meteor community. I sent a message to Koen Miskotte, long time amateur astronomer specialized in meteors from the Dutch Meteor Society, alerting him on what I had just seen and asking if he was aware? Koen responded a short time later that he hadn't yet seen other reports. He looked at the preliminary worldwide radiodata[45] and then he wrote back to me with… "WOW radio data got crazy!". It confirmed a strong, sharp outburst near solar longitude 141.47° above North American longitudes. Koen was interested in calculating a preliminary visual ZHR using my counts, producing a preliminary summary article, and sharing visual data with Peter Jenniskens (SETI Institute and NASA Ames Research Center). So as soon as I arrived home, I got busy listening to my voice recordings, noting all the times and numbers of meteors seen. I then shared my 5-minute interval counts with Koen (included further below). That same day, Koen posted a "first results" summary on the MeteorNews website, and shortly after that, P. Jenniskens also wrote a summary. The ZHR as calculated by Koen was 245 ± 37 and there may have been two peaks. By averaging the values, the ZHR calculates at 210 ± 20. These rates are 4 to

[45] http://www5f.biglobe.ne.jp/~hro/Flash/2021/PER/index-e.htm

5 times higher than what you would expect at that time. Six observers saw the outburst, but unfortunately, three of them had poor observing conditions, or saw only part of the outburst. I was one of the few meteor observers in North America privileged with excellent sky conditions at the ideal time. (Jenniskens and Miskotte, 2021).

On the following day, P. Jenniskens, posted a ‘Central Bureau for Astronomical Telegram’ (CBET) to the broader astronomical community (Jenniskens, 2021). More recently, a detailed collaborative article was published: “The Big surprise: a late Perseid outburst”, by Koen Miskotte (Dutch Meteor Society), Hirofumi Sugimoto (The Nippon Meteor Society) and Pierre Martin (Ottawa, Canada) (Miskotte et al., 2021).

The 364 exposures produced by my camera helped determine the photographic ZHR. I supplied Koen a list with the number of Perseids per image with a time indication. To determine the photographic ZHR, the 20-second counts were summed to 15-minute counts. Determining this requires constant weather conditions and a fixed camera that must be pointed exactly at the same point during the entire period (unguided) and settings may not be adjusted. The purpose of this ZHR determination was not so much to determine the ZHR but more to see when the maximum photographically took place. The photographic maximum occurred at at λ_{O} = 141.470° very close to the time of the visual and radio maxima.

My images were also the basis of the composite that I created by co-adding all 282 captured into one image. It is not often that I submit my images to APOD (NASA Astronomy Photo of the Day) but a few people suggested that I should submit this one. On September 23, I received an email from Jerry T. Bonnell (UMCP) (one of the two authors and editors for APOD) letting me know that my image would run as APOD[46] for the following day!

It was a night that I won’t soon forget! It was followed by a collaboration between the amateur and professional astronomical community, coordinating in a way to quickly disseminate data results of this unusual outburst. It is not yet clear what mechanism is behind this outburst (as well as the less dramatic ones seen in recent years, shortly after the traditional maximum). Perhaps further research by meteor dynamicists and future observations will provide answers. It goes to show that even the more well-known meteor showers such as the Perseids can provide nice surprises. In this case, the effort and sleep deprivation were very much worth it!

Observation August 13–14 2021, 05^h50^m–09^h08^m UT (01^h50^m–05^h08^m EDT local time). Location: Westmeath Lookout (Beachburg), Ontario, Canada(45°47’34”, –76°51’32”). Observer: Pierre Martin[47].

Observed showers:

- August xi Draconids (AXD) – 18^h24^m (276°) +55°
- zeta Draconids (AUD) – 19^h06^m (287°) +59°
- kappa Cygnids (KCG) – 19^h08^m (287°) +52°
- alpha Capricornids (CAP) – 21^h10^m (317°) –05°
- Anthelion (ANT) – 22^h20^m (335°) –10°
- Northern delta Aquariids (NDA) – 23^h14^m (349°) +02°
- Southern delta Aquariids (SDA) – 23^h24^m (351°) –14°
- Perseids (PER) – 03^h30^m (053°) +59°
- eta Eridanids (ERI) – 03^h15^m (049°) –10°

Standard one-hour visual periods (times in UT):

05^h50^m–07^h08^m UT (01^h50^m–03^h08^m EDT); 5/5 trans; F 1.00; LM 6.65; facing E55 deg; t_{eff} 1.00 hr.

- PER: sixty-four: –3; –2; –1; 0(6); +1(7); +2(15); +3(7); +4(10); +5(15); +6(1)
- KCG: four: 0; +3(2); +4
- ANT: two: +3; +4
- NDA: two: +4; +5
- CAP: one: +1
- ERI: one: +4
- AUD: one: +4
- Sporadics: fourteen: +1(2); +2; +3; +4(5); +5(5)
- Total meteors: Eighty-nine

07^h08^m–08^h08^m UT (03^h08^m–04^h08^m EDT); 5/5 trans; F 1.00; LM 6.65; facing E55 deg; t_{eff} 1.00 hr.

- PER: one-hundred-sixty-two: –3; –1(3); 0(9); +1(19); +2(37); +3(33); +4(32); +5(28)
- KCG: two: –1; +6
- NDA: two: +3; +4
- Sporadics: twelve: +1(2); +2; +3; +4(4); +5(3); +6
- Total meteors: One-hundred-seventy-eight

08^h08^m–09^h08^m UT (04^h08^m–05^h08^m EDT); 4/5 trans; F 1.00; LM 5.81; facing E65 deg; t_{eff} 1.00 hr.

- PER: one-hundred-forteen: –1(2); 0(4); +1(20); +2(23); +3(23); +4(27); +5(14); +6(1)
- KCG: three: +4(2); +5
- NDA: three: +1; +3; +5
- ERI: one: +1
- Sporadics: six: +1; +3(2); +4(2); +5
- Total meteors: One-hundred-twenty-seven

Short visual periods (times in UT):

- 0550–0555 (0.0833 t_{eff}, LM=6.65); 6 PER, 1SPO
- 0555–0600 (0.0833 t_{eff}, LM=6.65); 3 PER, 2 KCG, 1 ERI, 1 SPO
- 0600–0605 (0.0833 t_{eff}, LM=6.65); 3 PER, 1 NDA
- 0605–0610 (0.0833 t_{eff}, LM=6.65); 1 ANT, 2 SPO
- 0610–0615 (0.0833 t_{eff}, LM=6.65); 6 PER, 1 KCG, 3 SPO

[46] https://apod.nasa.gov/apod/ap210924.html

[47] https://www.imo.net/members/imo_vmdb/view?session_id=82735

- 0615–0620 (0.0833 t_{eff}, LM=6.65); 4 PER, 1 KCG, 1 SPO
- 0620–0625 (0.0833 t_{eff}, LM=6.65); 3 PER, 1 ANT, 1 AUD, 1 SPO
- 0625–0630 (0.0833 t_{eff}, LM=6.65); 6 PER, 1 CAP, 2 SPO
- 0630–0635 (0.0833 t_{ef}f, LM=6.65); 9 PER, 1 SPO
- 0635–0637 (0.0333 t_{eff}, LM=6.65); 2 PER, 1 NDA
- 0655–0700 (0.0833 t_{eff}, LM=6.65); 12 PER
- 0700–0705 (0.0833 t_{eff}, LM=6.65); 4 PER, 2 SPO
- 0705–0710 (0.0833 t_{eff}, LM=6.65); 11 PER, 1 SPO
- 0710–0715 (0.0833 t_{eff}, LM=6.65); 9 PER
- 0715–0720 (0.0833 t_{eff}, LM=6.65); 13 PER, 1 NDA, 1 KCG, 3 SPO
- 0720–0725 (0.0833 t_{eff}, LM=6.65); 15 PER, 3 SPO
- 0725–0730 (0.0833 t_{eff}, LM=6.65); 15 PER, 1 SPO
- 0730–0735 (0.0833 t_{eff}, LM=6.65); 11 PER
- 0735–0740 (0.0833 t_{eff}, LM=6.65); 9 PER, 1 SPO
- 0740–0745 (0.0833 t_{eff}, LM=6.65); 8 PER, 1 NDA, 1 SPO
- 0745–0750 (0.0833 t_{eff}, LM=6.65); 21 PER, 1 SPO
- 0750–0755 (0.0833 t_{eff}, LM=6.65); 16 PER, 1 KCG
- 0755–0800 (0.0833 t_{eff}, LM=6.65); 13 PER
- 0800–0805 (0.0833 t_{eff}, LM=6.65); 14 PER
- 0805–0810 (0.0833 t_{eff}, LM=6.65); 19 PER, 2 KCG, 2 SPO
- 0810–0815 (0.0833 t_{eff}, LM=6.65); 22 PER, 1 NDA
- 0815–0820 (0.0833 t_{eff}, LM=6.65); 9 PER, 1 KCG
- 0820–0825 (0.0833 t_{eff}, LM=6.55); 17 PER, 1 NDA
- 0825–0830 (0.0833 t_{eff}, LM=6.52); 16 PER, 1 ERI, 3 SPO
- 0830–0835 (0.0833 t_{eff}, LM=6.49); 9 PER, 1 NDA
- 0835–0840 (0.0833 t_{eff}, LM=6.45); 10 PER
- 0840–0845 (0.0833 t_{eff}, LM=6.25); 6 PER
- 0845–0850 (0.0833 t_{eff}, LM=5.90); 6 PER, 1 SPO
- 0850–0855 (0.0833 t_{eff}, LM=5.40); 3 PER
- 0855–0900 (0.0833 t_{eff}, LM=5.20); 6 PER, 1 SPO
- 0900–0908 (0.1333 t_{eff}, LM=3.80); 4 PER, 1 SPO

Break: 0637–0655 (18 minutes)

Total meteors for this session: 394

6 August 15–16, 2021

On the morning of August 16, I went to the Bootland Farm site (about 70km west of Ottawa) for a three hour meteor session. The sky was clear with average quality transparency (about 2.5/5). It was slightly hazy, possibly from some forest fire smoke in the atmosphere. It was a cool 12C, very dewy, but a decent night to be out. This was my final outing during the Perseids activity period.

Between 1:02am and 4:11am local time, I saw 68 meteors (30 Perseids, 9 kappa Cygnids, 6 Northern delta Aquariids, 2 anthelions, 2 Southern delta Aquariids and 19 sporadics. The Perseids were back to their normal activity, as they wound down, with hourly rates of 5, 11 and 14. The best meteor was a blue-green -1 Perseid with a three seconds train at 2:28am EDT.

This has been a good year for the Kappa Cygnids. They have been pretty active with a handful of meteors per hour, over several nights, typically with the best rates earlier while the radiant is still very high. I did not see any fireballs from them this year. During August 2007, they produced many large fireballs (aka flashbulb shower) that delighted observers! During other years, very few Kappa Cygnids are seen. Recent analysis appears to support a suggested 7-year periodicity in activity.

August 15–16, 2021, 05^h02^m–08^h11^m UT (01^h02^m–04^h11^m EDT). Location: Bootland Farm, Ontario, Canada. (Long: –76°29' West; Lat: 45°23′ North)[48].

Observed showers:

- August xi Draconids (AXD) – 18^h24^m (276°) +55°
- zeta Draconids (AUD) – 19^h06^m (287°) +59°
- kappa Cygnids (KCG) – 19^h08^m (287°) +52°
- Anthelion (ANT) – 22^h20^m (335°) –10°
- Northern delta Aquariids (NDA) – 23^h14^m (349°) +02°
- Southern delta Aquariids (SDA) – 23^h24^m (351°) –14°
- Perseids (PER) – 03^h30^m (053°) +59°
- eta Eridanids (ERI) – 03^h15^m (049°) –10°

05^h02^m–06^h02^m UT (01^h02^m–02^h02^m EDT); 2/5 trans; F 1.00; LM 6.38; facing SSE55 deg; t_{eff} 1.00 hr.

- PER: five: 0; +3; +4(2); +5
- KCG: five: +2; +3; +4(3)
- NDA: five: +1; +2; +4; +5(2)
- ANT: one: +3
- Sporadics: six: +3; +5(5)
- Total meteors: Twenty-two

06^h02^m–07^h02^m UT (02^h02^m–03^h02^m EDT); 3/5 trans; F 1.00; LM 6.40; facing SSE55 deg; t_{eff} 1.00 hr.

- PER: eleven: –1; +2(3); +3(2); +4(2); +5(3)
- KCG: three: +1; +2(2)
- ANT: one: +3
- SDA: one: +5
- Sporadics: five: +1; +3; +4; +5(2)
- Total meteors: Twenty-one

07^h02^m–08^h11^m UT (03^h02^m–04^h11^m EDT); 3/5 trans; F 1.00; LM 6.40; facing SSE55 deg; t_{eff} 1.15 hr.

- PER: fourteen: 0; +1(2); +2(4); +3(2); +4(3); +5(2)
- KCG: one: +1
- NDA: one: +4
- SDA: one: +5
- Sporadics: eight: +2; +3; +4; +5(5)

[48] https://www.imo.net/members/imo_vmdb/view?session_id=82777

- Total meteors: Twenty-five

Total meteors for this session: 68

7 September 8–9, 2021

I ventured out to the west of Ottawa on the morning of September 9, to observe near the peak of the minor September epsilon Perseids shower. On arrival, I was disappointed to find a completely overcast sky. Luckily, it cleared up after several minutes and I was able to get in a couple of hours of observing until dawn. The transparency was a solid 4/5 quality. It was very humid with some minor ground fog, but it didn't seem to affect the sky too much. Owls and coyotes were heard in the distance most of the time.

Between 2^h45^m am and 4^h47^m am EDT local time, I saw 22 meteors (including 6 September epsilon Perseids, 3 nu Eridanids, one September Lyncid and 12 sporadics). The September epsilon Perseids had rapid, short paths and seemed to radiate from a point located a few degrees further to the south than the published position.

The highlight of the night was at 07^h47^m UT (3^h47^m am EDT) with an exceptionally SLOW moving and vividly blue +1 sporadic! It was shaped like a tear drop and it crawled for several seconds below Gemini, persisting for a few more seconds, before fading away. It was about the speed of a fast-moving satellite! A beautiful meteor!

September 8–9, 2021, 06^h45^m–08^h47^m UT (02^h45^m–04^h47^m EDT). Location: Bootland Farm, Ontario, Canada. (Long: –76°29' West; Lat: 45°23' North)[49].

Observed showers:

- zeta Draconids (AUD) – 15^h36^m (234°) +56°
- Anthelion (ANT) – 23^h40^m (355°) –02°
- August beta Piscids (NDA) – 00^h18^m (005°) +10°
- September epsilon Perseids (SPE) – 02^h52^m (064°) +39°
- nu Eridanids (NUE) – 04^h16^m (043°) –01°
- eta Eridanids (ERI) – 04^h25^m (066°) –05°
- September Lyncids (SLY) – 06^h36^m (099°) +55°

06^h45^m–07^h45^m UT (02^h45^m–03^h45^m EDT); 4/5 trans; F 1.00; LM 6.48; facing SSE50 deg; t_{eff} 1.00 hr.

- SPE: three: +2; +4(2)
- NUE: two: +3; +4
- Sporadics: six: +2(2); +3; +4(2); +5
- Total meteors: Eleven

07^h45^m–08^h47^m UT (03^h45^m–04^h47^m EDT); 4/5 trans; F 1.00; LM 6.45; facing SSE50 deg; t_{eff} 1.00 hr.

- SPE: three: +2; +4(2)
- NUE: one: +5
- SLY: one: +4
- Sporadics: six: +1; +4; +5(3); +6
- Total meteors: Eleven

Total meteors for this session: 22

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[49] https://www.imo.net/members/imo_vmdb/view?session_id=83181

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