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Stacked image of the SWEMN20210423_040329 Lyrid fireball as recorded at 4h03m29.0 ± 0.1s UTC on 2021 April 23 from Calar Alto. (Credit J.M. Madiedo).

- Meteor work in Spain
- Geminids 2020
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New June Aquilid Complex meteor shower: June theta² Sagittariids (JTT#1129)

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A new meteor shower from an eccentric sunskirting-comet orbit was detected by CAMS networks on June 9 to 14, 2021. Similar activity occurred last year but was not seen in prior years from 2010 to 2019. The geocentric radiant is located at R.A. = 304.4 deg, Decl. = -32.9 deg (equinox J2000.0), part of the JAQ#299 June Aquilid Complex. This new shower has been added to the IAU MDC working list of meteor showers as the June theta² Sagittariids (JTT#1129).

1 Introduction

The southern-hemisphere networks of the CAMS video-based meteoroid orbit survey detected what appears to be a newly registered meteor shower from an eccentric sunskirting-comet orbit. During this time of year, the June Aquilid Complex (#295, JAQ) is active with a number of showers below the ecliptic plane leading up to the Southern June Aquilids (NZC#165) (Jenniskens, 2006).

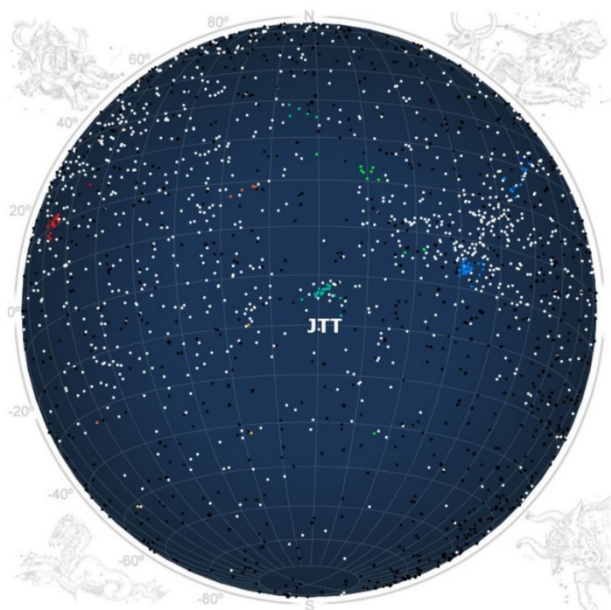


Figure 1 – The June theta² Sagittariids (JTT#1129), marked as the green cluster just below the ecliptic plane in the radiant-data visualization posted at CAMS website¹ for the dates 2021 June 10–13.

2 The observational results

The shower was detected in observations of the CAMS Namibia low-light video camera network (*T. Hanke, E. Fahl, R. van Wyk*), with additional detections by CAMS Australia (*M. Towner, L. Toms, C. Redford*), CAMS Chile (*S. Heathcote, E. Jehin, T. Abbott*), CAMS South Africa (*T.*

Cooper, P. Mey), and CAMS New Zealand (*J. Baggaley, I. Crumpton, N. Frost, C. Duncan*).

Table 1 – Median orbital elements for the June theta² Sagittariids (JTT#1129) (equinox J2000.0) obtained from CAMS data for 2021.

	2021
λ_o (°)	352.26 ± 0.05
α_g (°)	304.4
δ_g (°)	-32.9
v_g km/s	36.9
a a.u.	1.05 ± 0.19
q a.u.	0.070 ± 0.008
e	0.932 ± 0.015
ω (°)	158.2 ± 0.8
Ω (°)	260.5 ± 1.1
i (°)	49.6 ± 5.9
N	52

The shower was active between 2021 June 9 22^h to June 14 01^h UTC, corresponding to solar longitude 79.0° – 83.0° (equinox J2000.0). The shower is visible as a green cluster just below the ecliptic plane in the radiant maps of June 10 to June 14, 2021, at the data visualization website¹. Median orbital elements from 52 triangulated orbits are listed in Table 1. The radiant is significantly dispersed in longitude, in a direction similar to the overall dispersion of the underlying shower #165, but narrow in latitude. This shower is now called the June theta² Sagittariids and was added to the IAU Working List of Meteor Showers as number 1129 (Jenniskens, 2021).

Similar activity was detected last year, from 2020 June 6 to 14, with a broad maximum on June 10 at solar longitude 79.7° (see CAMS website¹ for those dates) but not in prior years from 2011 to 2019. It is possible that poor coverage in the southern hemisphere prior to 2020 contributed to that.

¹ <http://cams.seti.org/FDL/>

3 Discussion

From our lookup table, the CAMS data visualization mis-identified the shower as the radar-detected shower #765, the alpha Sagittariids (Pokorny et al., 2017). That shower, however, has a lower median speed and is very dispersed. The CMOR radar identified the activity as shower #165 at their website². Instead, this shower has a compact radiant off-center from that of the diffuse shower 165 and is only active for a few days.

The Northern June Aquilids have been linked to SOHO comet C/2009 U10 (Holman and Jenniskens, 2012). It is possible that the new shower is due to another comet fragment from a family of such fragments that resulted from the breakup of a common parent body some time ago and that have now dispersed by rotation of the nodal line.

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² <https://fireballs.ndc.nasa.gov/cmor-radiants/earth.html>

The Geminids in 2020

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An analysis of visual observations of the Geminids in 2020 is presented. The maximum activity was expected to take place above Europe. Indeed, there was a peak in activity around solar longitude 262.14 degrees, but with a ZHR of 90 ± 4 it was remarkably low.

1 Introduction

The 2020 Geminid observational campaign was long awaited. Not only was the maximum was predicted for Europe, but 2020 also fell nicely in the comparison series 1996–2004 and 2012. Unfortunately, the Corona pandemic also severely hit Europe, making all kinds of large-scale movements almost impossible. Borders were closed, planes grounded and so the options to move to clear weather slowly but surely dried up. For the author and a number of Dutch observers, this meant waiting to see whether it would become clear in the Netherlands or not. Unfortunately, as so often in December, the weather did not cooperate. Almost nothing has been seen from the Benelux around the Geminid maximum. But the weather conditions were also poor in the rest of Europe, here and there people could benefit from small-scale clear sky periods. The observers in Israel were better off in that regard and were able to observe extensively on the nights of December 12–13 and December 13–14. There hasn't been much observed on the American continent either. So, there was not much hope for a good analysis. Fortunately, it turned out that the latter was not so bad and that nice results were still achieved.

2 The observers and analysis

On the IMO website, 7445 Geminids were reported by 50 observers. The author of this article received another observation with 169 Geminids. See *Table 1* with all the observers who observed the Geminids in 2020.

All data was pre-checked on the following points:

- The limiting magnitude was rounded off at least at 5.9;
- The radiant height was at least 25 degrees or higher;
- Hourly counts were used for this analysis. These were added together when shorter counting periods were reported. Short isolated periods were not used;
- A known C_p was used or calculated for all observers from whom data was used;
- Extreme outliers are always removed, but this did not appear to be necessary in this analysis.

3 Population index r

The Geminids are known to have a strong variation in the size of the meteoroids during their activity period. Especially shortly after the maximum, this manifests itself through the appearance of bigger meteoroids, causing more brighter meteors. We can depict this phenomenon with the population index r . This number says something about the average brightness of the meteor shower. A low population index r means relatively many bright meteors, a high population index r means a lot of weak meteors.

To determine the population index r you must have enough meteors available per time unit. For the nights before December 12, it is therefore only possible to determine a population index r per night. For 12–13 December periods of a few hours could be used and around the maximum there was enough data for every hour.

To calculate the population index r , the observation data must meet two criteria:

- The limiting magnitude may not be less than 5.9;
- The difference between the limiting magnitude and mean magnitude of the meteors should not exceed 4 magnitudes.

For the calculation of the population index r , 3961 Geminids could be used (Steyaert, 1981). *Table 2* and *Figures 1 and 2* show the results of the population index r calculations (only for $r [-2;+5]$ and $r [-1;+5]$).

If we look at *Figures 1 and 2* in detail, we see that during the night 12–13 the population index r varies mostly between 2.0 and 2.5. During the maximum night over Europe, a steady decrease is visible after 2020 December 14, 00^h00^m UT ($\lambda_{\odot} = 262.15^{\circ}$). Based on this, you would expect a maximum before this time.

The Geminids are also known for short-lived periods with many fireballs. This can be quite spectacular for an observer. For example, in 2007 the author and some observers saw 22 Geminid fireballs with magnitudes between -3 to -8 within hours (Miskotte et al., 2010; 2011; Vandeputte, 2008)!

Table 1 – List of observers who observed the Geminids in 2020.

Observer	Sessions	T _{eff.}	GEM	Observer	Sessions	T _{eff.}	GEM
Adams Mark	2	09 ^h 29 ^m	171	Melandri Fabrizio	1	02 ^h 30 ^m	192
Amorim Alexandre	1	00 ^h 57 ^m	2	Merlin Frederic	1	04 ^h 25 ^m	113
Bao Wenjie	1	01 ^h 30 ^m	27	Nilforoushan M.	1	01 ^h 40 ^m	43
Ben Craig	1	03 ^h 06 ^m	73	Pineau François	1	01 ^h 00 ^m	24
Benítez S. Orlando	1	02 ^h 19 ^m	109	Plum Jonas	1	00 ^h 40 ^m	7
Brown Steve	2	04 ^h 30 ^m	110	Prokofyev Sasha	1	00 ^h 15 ^m	1
Correa da Silva Riziele	1	03 ^h 07 ^m	2	Ratz Ella	2	10 ^h 38 ^m	451
Deconinck Michel	2	02 ^h 00 ^m	85	Rendtel Ina	7	17 ^h 51 ^m	240
Dubishkin Dmitry	1	00 ^h 45 ^m	6	Rendtel Jurgen	9	20 ^h 24 ^m	239
Edin Howard	4	04 ^h 08 ^m	214	Romanov Filipp	10	05 ^h 20 ^m	178
Eini Shlomi	2	08 ^h 30 ^m	476	Ross Terrence	8	12 ^h 09 ^m	502
Gavriljuk Dmitry	1	01 ^h 00 ^m	7	Sergey Ivan	2	04 ^h 52 ^m	2
Gerber Christoph	1	00 ^h 28 ^m	22	Shi Wei	1	03 ^h 15 ^m	227
Godley William	1	01 ^h 00 ^m	27	Sperberg Ulrich	1	02 ^h 00 ^m	0
Growe Matthias	1	01 ^h 04 ^m	0	Sun Fengwu	3	03 ^h 28 ^m	245
Hergenrother Carl	1	00 ^h 57 ^m	48	Taibi Richard	2	02 ^h 10 ^m	14
Hickel Gabriel	1	01 ^h 28 ^m	34	Tchenak Tamara	2	14 ^h 41 ^m	753
Hughes Glenn	1	00 ^h 45 ^m	0	Uchiyama Shigeo	2	02 ^h 42 ^m	74
Jiménez López Gerardo	2	02 ^h 50 ^m	33	Vandenbruaene H.	1	01 ^h 04 ^m	32
Jones Paul	1	02 ^h 00 ^m	169	Weiland Thomas	4	09 ^h 17 ^m	359
Jung Hansub	1	02 ^h 10 ^m	29	Westfried Ariel	3	08 ^h 32 ^m	528
Katz Omri	2	08 ^h 42 ^m	426	Wächter Frank	2	01 ^h 15 ^m	108
Kostenko Roman	8	03 ^h 20 ^m	161	Wächter Sabine	2	01 ^h 39 ^m	73
Levin Anna	2	16 ^h 21 ^m	792	Xiaofan Wei	1	02 ^h 06 ^m	165
Marsh Adam	2	06 ^h 54 ^m	14	Zeinodini Mostafa	1	00 ^h 19 ^m	7
Marsh Jemma	2	02 ^h 00 ^m	0				

Table 2 – Population index r Geminids 2020.

Date	λ_{\odot} (°)	$r[-1;+5]$	\pm	$r[-2;+5]$	\pm
7–12–2020 19 ^h 00 ^m	255.819	3.00	~	3.00	~
12–12–2020 05 ^h 55 ^m	260.383	2.18	0.4	~	~
12–12–2020 21 ^h 40 ^m	261.048	2.38	0.33	~	~
13–12–2020 00 ^h 20 ^m	261.161	2.11	0.21	2.27	0.21
13–12–2020 05 ^h 34 ^m	261.383	2.35	0.22	~	~
13–12–2020 06 ^h 36 ^m	261.427	2.53	0.15	2.64	0.15
13–12–2020 19 ^h 00 ^m	261.953	2.40	0.12	2.24	0.12
13–12–2020 20 ^h 02 ^m	261.997	2.02	0.14	2.05	0.14
13–12–2020 22 ^h 07 ^m	262.088	1.88	0.08	1.97	0.08
13–12–2020 23 ^h 02 ^m	262.124	2.10	0.08	2.07	0.07
14–12–2020 00 ^h 06 ^m	262.169	2.16	0.08	2.25	0.08
14–12–2020 01 ^h 30 ^m	262.228	1.90	0.07	2.01	0.06
14–12–2020 03 ^h 19 ^m	262.297	1.60	0.09	1.73	0.08
14–12–2020 06 ^h 57 ^m	262.459	1.74	0.15	1.96	0.15
14–12–2020 21 ^h 10 ^m	263.062	2.17	0.48	~	~
15–12–2020 00 ^h 10 ^m	263.189	2.20	0.4	~	~
15–12–2020 05 ^h 05 ^m	263.398	2.55	0.69	2.30	0.69

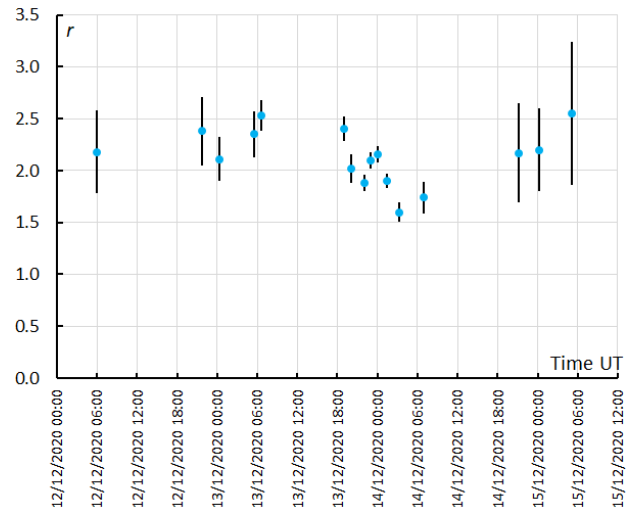
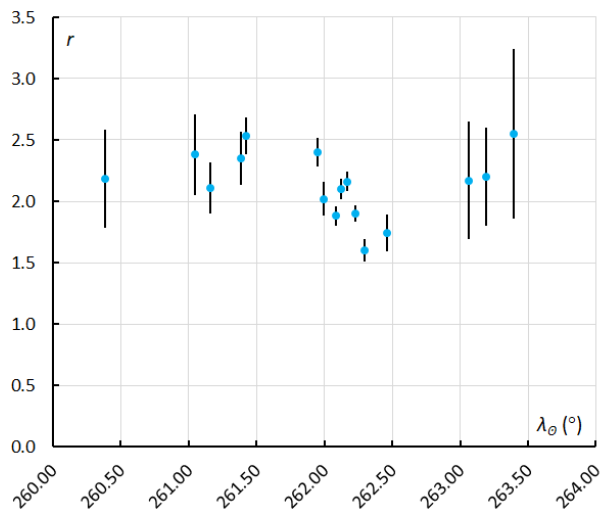


Figure 1 (left) and Figure 2 (right) – Population index r for the Geminids 2020 $[-1:+5]$ against solar longitude λ_{\odot} ($^{\circ}$) (left) and against GMT 12 December 2020 00^h00^m UT to 15 December 2020 12^h00^m UT (right).



Figure 3 – Composition with 7 Geminids, captured at a location near Evora, Portugal, during the night 2007 December 14–15. Photo and composition made by the author.

Table 3 – Overview of observations of many Geminid fireballs in a short time.

Observers	Date	Period UT	Start λ_{\odot} ($^{\circ}$)	End λ_{\odot} ($^{\circ}$)	Mean λ_{\odot} ($^{\circ}$)	Location
Johannink, Miskotte, Vandeputte, Vanderkerken	15 Dec.2007	00 ^h 45 ^m –04 ^h 15 ^m	262.539	262.687	262.613	Portugal
Weiland, Bettonvil	13–14 Dec. 2012	19 ^h 25 ^m –00 ^h 10 ^m	262.025	262.227	262.126	Oman
Martin	15 Dec.2015	05 ^h 00 ^m –08 ^h 30 ^m	262.668	262.817	262.743	US
Ross, Craig	14 Dec. 2020	06 ^h 11 ^m –10 ^h 22 ^m	262.419	262.603	262.511	US

Remarkable in this respect are the 2020 observations of Terrence Ross and Ben Craig from Texas and California respectively. Terrence Ross saw 7 Geminids of -3 ($2\times$), -4 ($2\times$), -5 and -6 ($2\times$) on 2020 December 14, between $7^{\text{h}}25^{\text{m}}$ UT and $8^{\text{h}}30^{\text{m}}$ UT³. The time he observed before this period (December 14, 2020 between $05^{\text{h}}28^{\text{m}}$ and $06^{\text{h}}30^{\text{m}}$ UT) there were no bright Geminids at all⁴. This observation reminded the author on the 2007 observations from Portugal. Observer Ben Craig saw 14 bright Geminids (-5 , -4 and 12×-3) between $6^{\text{h}}11^{\text{m}}$ and $10^{\text{h}}22^{\text{m}}$ UT on 2020 December 14⁵. Similar stories are known: in 2012 Felix Bettonvil and Thomas Weiland saw quite a few fireballs from Oman in a short time (Weiland and Bettonvil, 2015). Pierre Martin also witnessed several fireballs in a short time in 2015 (Martin, 2018)⁶. Table 3 provides an overview of these observations.



Figure 4 – Spectacular composition made by Pierre Martin from Texas, US in the night 14–15 December 2015. Canon EOS 6D, Sigma ART 24-35mm F2, (stopped at $f/2.2$), focal length: 24mm, 25 sec exposures $\times 61$, ISO 1600. More beautiful photos can be seen online⁷.

It is striking that the fireball observations from 2007, 2017

and 2020 partly overlap in solar longitude. The 2012 observation is an outlier that fell much earlier in solar longitude. It also seems that this phenomenon did not occur every year. The author will investigate this in a larger study of the Geminids in a future publication.

4 Zenital Hourly Rate (ZHR)

The ZHR could also be determined with the calculated population index r . In total, of the 7445 Geminids reported to IMO, 4808 were used for the ZHR analysis. The results of the calculations are shown in Table 4 and Figure 5.

If we look closely at Figure 5, we see ZHR values between 30 and 60 for December 12–13, something you would expect at this time. There is an isolated ZHR point near solar longitude 161.5° (ZHR 119 ± 15).

During the maximum night (13–14 December 2020) we see indeed a peak around solar longitude 262.14° in Europe. However, this is a very low peak with a ZHR of 90 ± 4 followed by a declining ZHR. The question is whether this is the real peak or rather a sub-peak. However, the decreasing population index r (more brighter Geminids) after 2020 December 14, after $00^{\text{h}}00^{\text{m}}$ UT seems to confirm that this was the main peak. If this is really the case, the maximum ZHR value found is very low. The problem in this story is the higher ZHR values that are found at the end of the night and above the USA. Unfortunately, this data from only a few observers is based on relatively low Geminid numbers. It is also quite a late time for a major peak, but it has sometimes happened before in previous years.

The 1996–2004–2012–2020 series

Every eight years we can observe at almost the same solar longitude and almost the same phases of the moon. In the article about 30 years of Geminid observations (Miskotte et al., 2010; 2011) we looked at whether we could find something of a trend in activity over a period of 30 years. It was concluded that the maximum Geminid ZHR increased from 1983 to 1996/2004 (from 80–100 to 120–140) and then remained stable or decreased slightly to 100–120. There are good data sets from 1996, 2004 and 2012, so we can (cautiously) compare the data from 2020 with these years. The ZHR graphs from previous years have been determined in an exactly identical manner. Hourly counts were used, and an assumed r value was used with the population index $r = 2.2$ to solar longitude 262.2° , after that $r = 2.00$. The 2020 data was also calculated in this way. The ZHR values found hardly deviate from the curve with the r values calculated in this article. Figures 6, 7, 8 and 9 are results from these comparisons.

³ https://www.imo.net/members/imo_vmdb/view?session_id=81849

⁴ https://www.imo.net/members/imo_vmdb/view?session_id=81848

⁵ https://www.imo.net/members/imo_vmdb/view?session_id=81831

⁶ https://www.imo.net/members/imo_vmdb/view?session_id=76023

⁷ <https://pmartin.smugmug.com/Astronomy/2015121317-Astronomy-Trip-to-T>

Table 4 – ZHR of the Geminids in December 2020.

Day	UT	λ_{θ} (°)	periods	GEM	ZHR	\pm
7	19.50	255.875	1	2	5.1	3.6
10	7.25	258.404	2	8	6.5	2.3
12	5.93	260.381	3	59	27.7	3.6
12	21.49	261.041	6	131	31.6	2.8
13	1.17	261.197	3	142	51.6	4.3
13	5.26	261.37	3	145	51.6	4.3
13	6.34	261.416	6	224	60.2	4.0
13	8.64	261.514	3	218	114.2	7.7
13	19.29	261.965	6	220	72.3	4.9
13	20.47	262.015	6	357	76.7	4.1
13	21.53	262.06	10	595	79.4	3.3
13	22.66	262.108	5	372	85.8	4.4
13	23.42	262.14	6	527	89.6	3.9
14	0.30	262.177	6	489	75.7	3.4
14	1.36	262.222	6	445	80.3	3.8
14	2.30	262.262	4	273	75.6	4.6
14	4.43	262.352	2	113	95.3	9.0
14	5.78	262.41	2	61	118.9	15.2
14	7.49	262.482	4	281	91.5	5.5
14	20.17	263.020	1	9	18.1	6.0
14	21.17	263.062	1	9	14.4	4.8
14	22.17	263.104	1	9	12.2	4.1
14	23.17	263.147	1	10	12.2	3.8
15	0.17	263.189	1	21	24.9	5.4
15	1.17	263.232	1	8	9.6	3.4
15	5.09	263.398	2	15	12.9	3.3
16	20.72	265.079	2	10	5.6	1.76
17	4.45	265.406	5	16	4.3	1.07
18	0.42	266.254	3	8	3.1	1.09
18	22.44	267.188	2	8	2.1	0.74
19	1.71	267.326	6	15	2.9	0.75
19	21.24	268.155	4	8	2.8	0.98

It is very well visible in *Figure 6* that the activity and curves are comparable to each other. However, the graph of 2004 seems to have shifted slightly earlier in solar longitude compared to 1996. Both curves are of good quality based on 7531 Geminids from 1996 and 8340 Geminids from 2004.

Some details require attention in *Figure 7*. In the period before the maximum (12–13 December), activity appears to be considerably higher in 2012 compared to 1996 and 2004, while the activity appears to be somewhat lower around the maximum. In 2012 there seems to be a dip in the activity profile that was also seen in 1996 (but not seen in 2004) around solar longitude 261.8°. The 2012 curve is also of a very reliable quality, based on 6650 Geminids.

In *Figure 8* it really looks like, with the exception of a few points, that the ZHR was visible lower in 2020. It seems a trend that confirms that we have had the most beautiful Geminid years in the past (1996–2004). The 2020 curve is based on 4733 Geminids.

Figure 9 shows another comparison between 1996 and 2020, because this is the longest period (24 years). This clearly reflects the problem of a comparison between the 1996 and 2020 activity profiles. Part of the night 13–14 December 2020 observed from Europe has too few points to be compared with 1996. This is partly because we do not look exactly at the same solar longitude every eight years. And if we then look at the ZHR points of 1996 and 2004 at solar longitude 262.2°, then there is indeed some similarity between the two years, also in terms of activity. More research with overlapping years from other series will certainly follow in a future article.

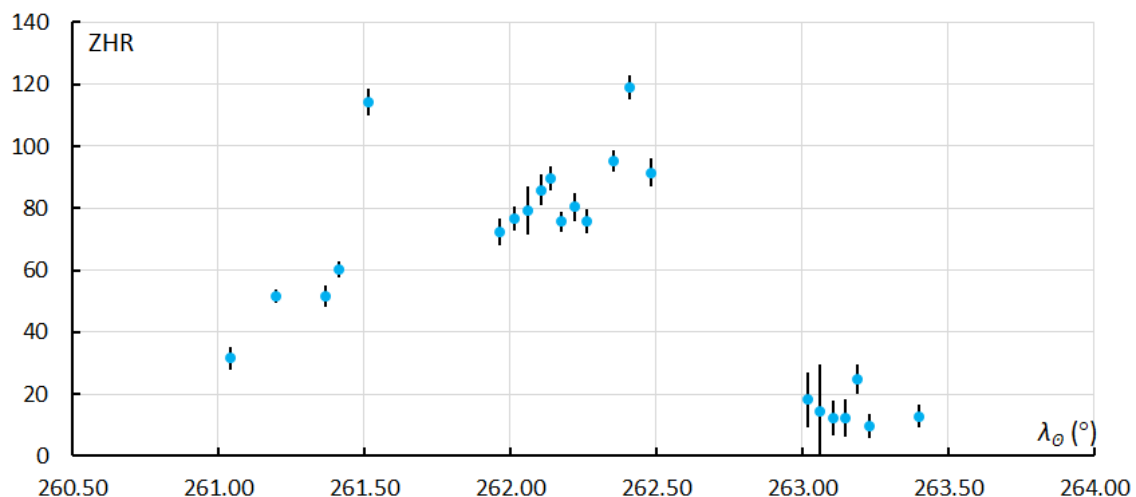


Figure 5 – The ZHR of the Geminids in 2020 (variable population index r , $\gamma = 1,0$). As usual, only Europe is well represented in the observational data.

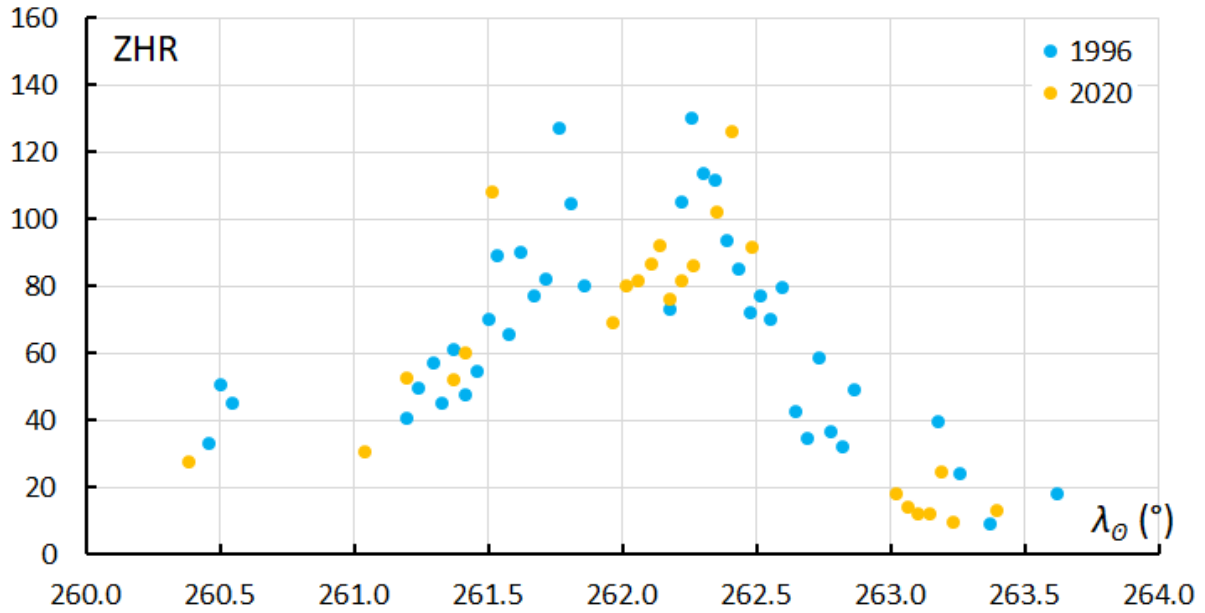


Figure 6 – Comparison of the Geminids in 1996 and 2004.

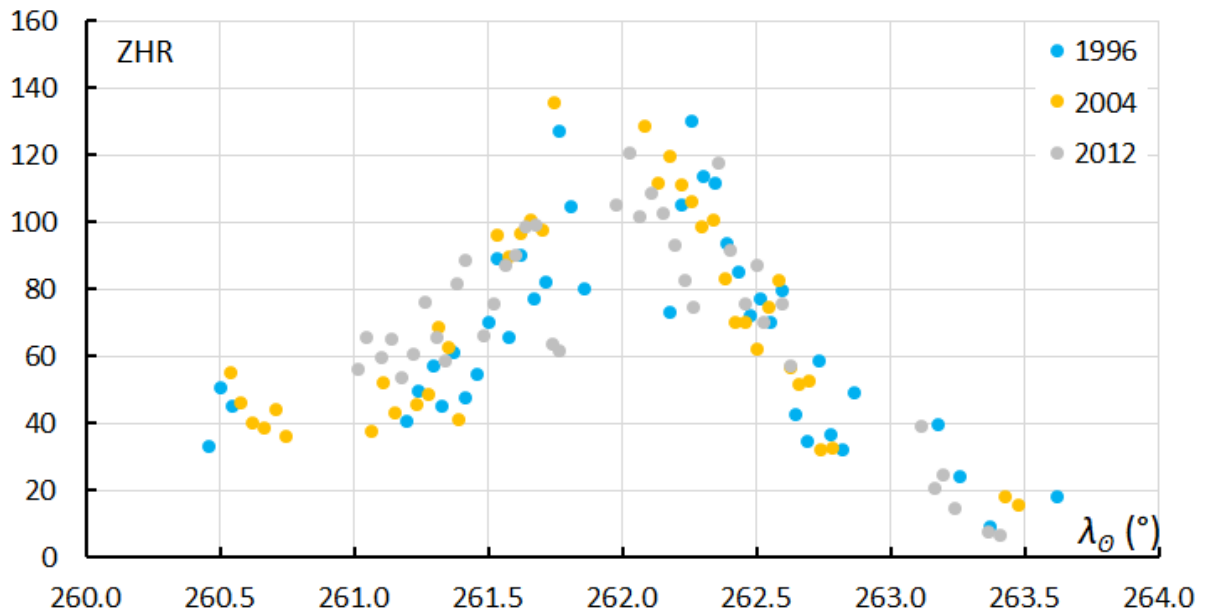


Figure 7 – Comparison of the Geminids in 1996,2004 and 2012.

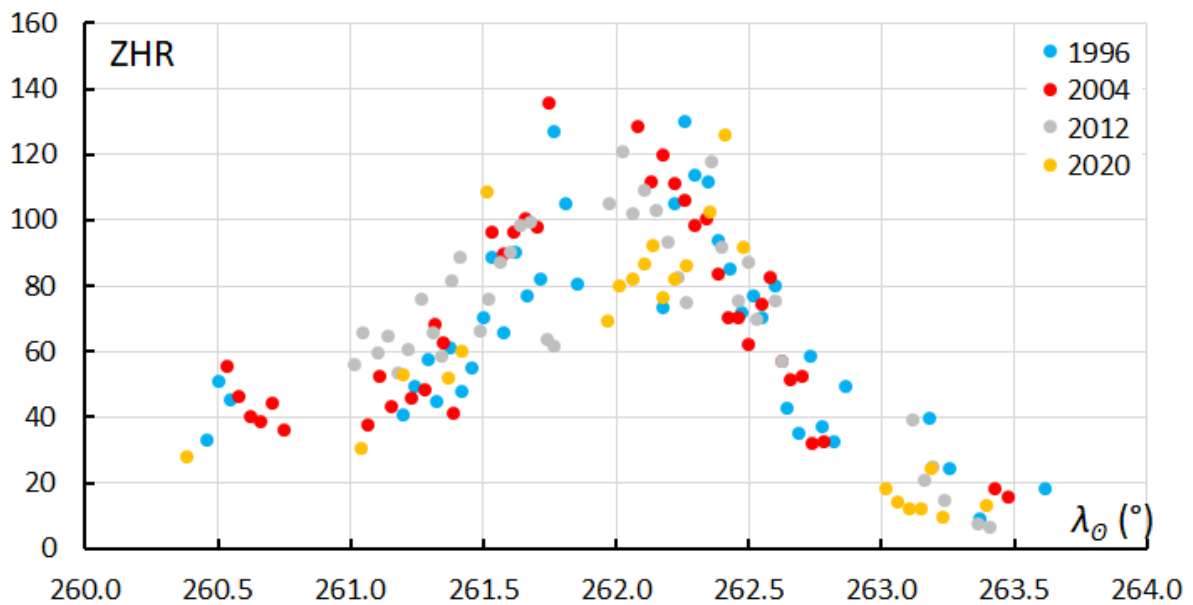


Figure 8 – Comparison of the Geminids in 1996, 2004, 2012 and 2020.

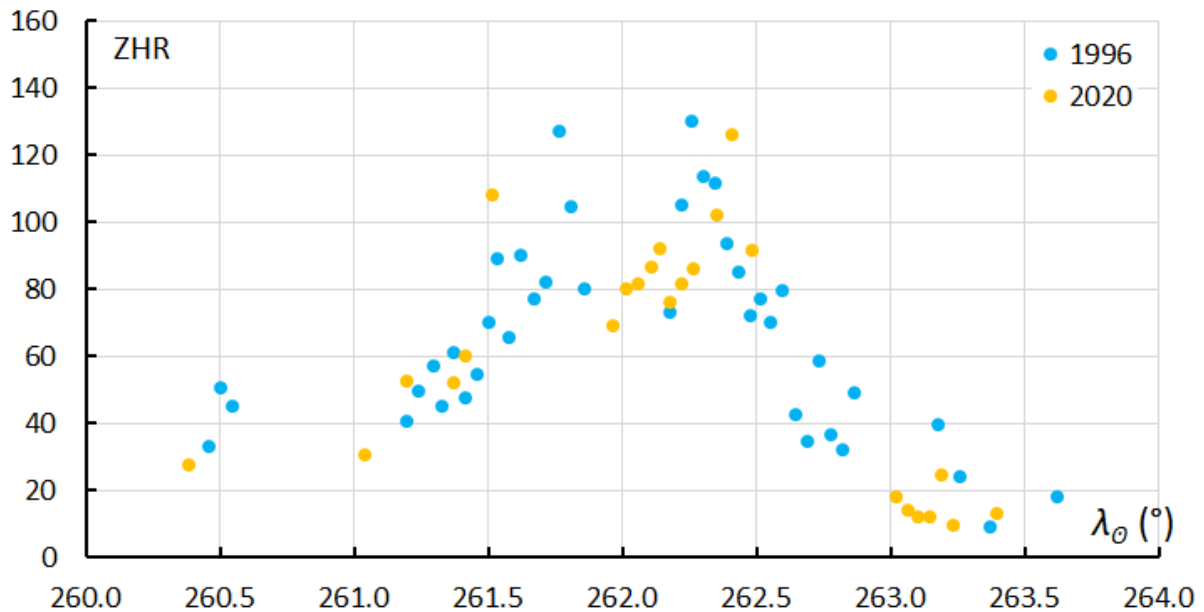


Figure 9 – Comparison of the Geminids in 1996 and 2020 (24 years).

5 Conclusion and recommendations

The Geminids could hardly be observed from the BeNeLux, and it was also only moderately well observed in Europe. Nevertheless, a good result could ultimately be achieved. The expected maximum above Europe was weak. However, it is still not 100% certain that the best Geminids years are behind us. At best, there are some indications that this may be the case. It is clear, however, that the Geminid activity does not increase further compared to 1996–2004. This is in contrast to what is written in the article by Galina Ryabova and Jürgen Rendtel (Ryabova and Rendtel, 2018). The author hopes that good Geminid analyzes can be performed even more often in the future.

For the observers, it is highly recommended to observe in dark locations. The darker the starry sky, the (much) more you see! Observers are also advised to make a minimum of 10–15 hours observations in August so that C_p values can be calculated using hourly counts of the sporadic meteors. With these recommendations, both observations and analyzes will become much more reliable!

Acknowledgment

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25 years of the Spanish Meteor Network (SPMN) and the 2020 Ursid Meteor Activity

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We present a short update about the Spanish Fireball and Meteorite Recovery Network (in brief known as SPMN) after 25 years of continuous monitoring of the sky over Spain and bordering countries. A recent progress has been done in the development of a unique software called 3D-FireToc, which allows the detection and fully automatic reduction of photographic and video digital recordings. To exemplify the network coverage and the application of the code for a fireball analysis, we describe the 2020 Ursid meteor shower study and the event SPMN221220C.

1 The Spanish Meteor Network (SPMN)

The Spanish Meteor Network (SPMN) arose in 1996 in the framework of the first doctoral thesis focused on the study of the meteoric phenomenon, which was defended in 2002 (Trigo-Rodríguez, 2002). From the beginning, links were established between the professional and amateur astronomer community, establishing the foundations of the

first active nodes (Trigo-Rodríguez et al., 2004; 2006a). Especially between 2003 and 2005 there was an intense period of collaboration between the nodes, with the fall on January 4, 2004 of the Villalbeto de la Peña chondrite in Palencia. The scientific results were the first recovery and characterization of a meteorite in 57 years (Llorca et al., 2005) and the ninth orbit of a meteorite in the world (Trigo-Rodríguez et al., 2006b).

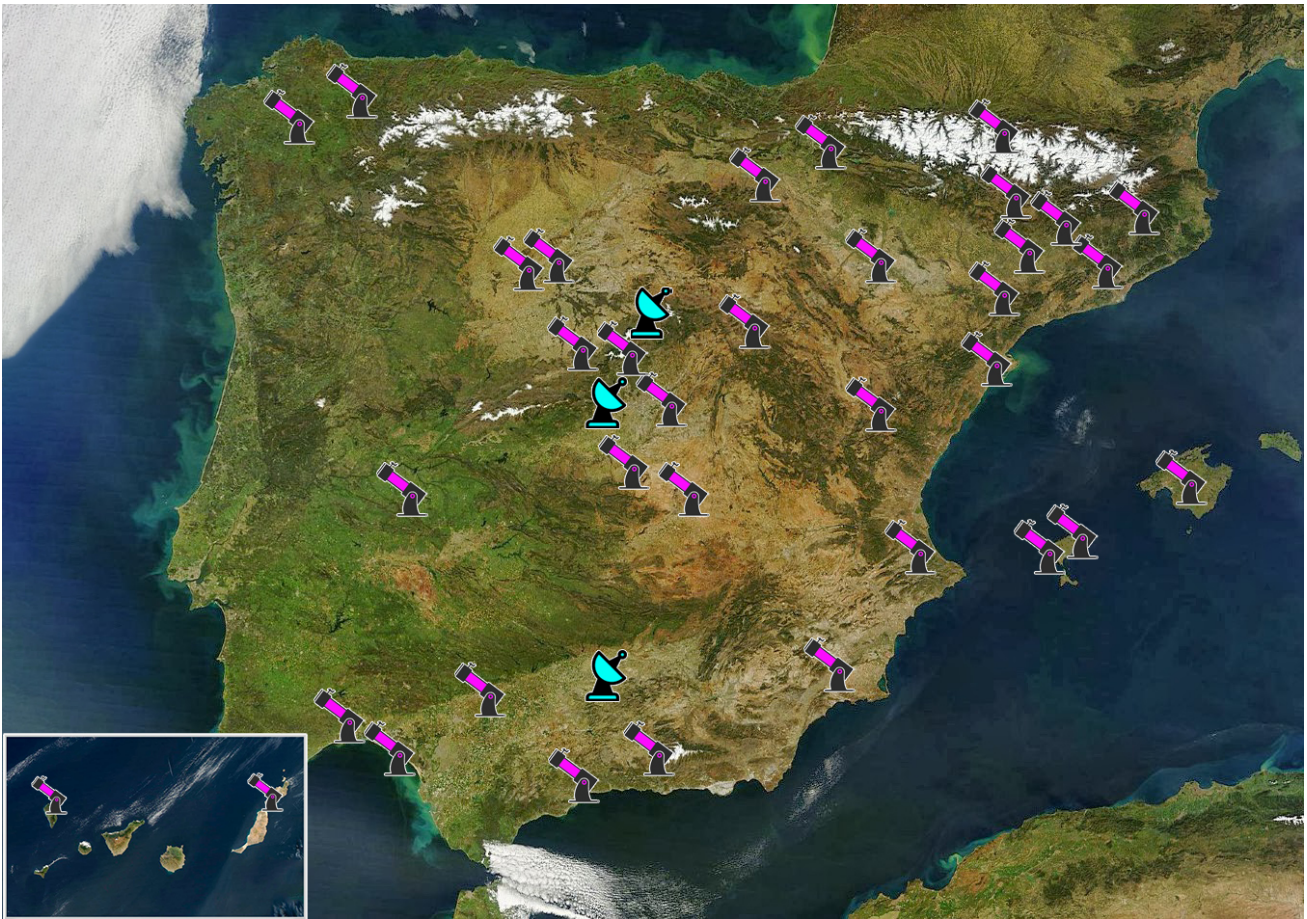


Figure 1 – SPMN camera and forward-scatter stations.

At that time, the pioneering techniques applied by the members of the SPMN, and international collaborations led to the detection of large fireballs that allowed us to discover that near-Earth asteroids could also be meteorite producers (Trigo-Rodríguez et al., 2007). Just in that year (2007), the international congress Meteoroids 2007 was organized in Barcelona, where the members of the SPMN presented to the scientific community not only their first recovered meteorite (the chondrite L6 Villalbeto de la Peña) but also two other relevant achievements:

- i) the development of all-sky cameras and their application to the study of meteors and bolides (Trigo-Rodríguez et al., 2008), and
- ii) the pioneering application of video-detection systems to the calculation of meteoroid orbits (Madiedo and Trigo-Rodríguez, 2008). In 2008, the fall of the second meteorite recovered in 2007 occurred: the eucrite Puerto Lápice. The study of this meteorite, from asteroid 4 Vesta, further encouraged scientific collaboration.

In the last decade, high impact results have been obtained, for example, forty refereed research articles, mostly in the first quartile and five published books. In addition, the various groups involved in the SPMN have been funded with research projects on a regular basis, expanding the detection systems and nodes. During this time, coordination of the enormous volume of data generated has been established through a mailing list sponsored by Red Iris and

a database at ICE (CSIC/IEEC). In fact, three PhD theses directly related to SPMN research have been defended at this center since 2006, which, at the same time, have allowed the development of new techniques for the quantification of impact hazard by meteoroids and small asteroids (Moreno-Ibáñez et al., 2018; 2020).

The SPMN has currently 30 stations equipped with wide-angle video recorders and fisheye CCD cameras, as well as two forward-scatter systems (see Figure 1).

Now we are also organizing a very close cooperation with the French network FRIPON. Our astrometric method can be complementary and valuable to have the chance to increase the recovery of meteorites in Europe.

2 New 3D-FireTOC detection software

In recent years, new challenges have arisen associated with the exponential increase in the volume of data, the existence of heterogeneous systems and, finally, their astrometric reduction, which until recently was practically manual. This entailed a high number of manual tasks making the process slow and tedious. With the advance in the development of artificial vision and databases, the opportunity has opened up to automate the entire process: from the detection, recording and cataloguing of events to the precise extraction of the meteoroid trajectory. In this regard, in the framework of a final master thesis (Peña-Asensio, 2020), we started in 2019 the development of a Python-based software package

called 3D-FireTOC (3D Fireball Trajectory and Orbit Calculator), a code capable of automating the detection and analysis of fireballs while producing a realistic 3D representation (Peña-Asensio et al., 2021a).

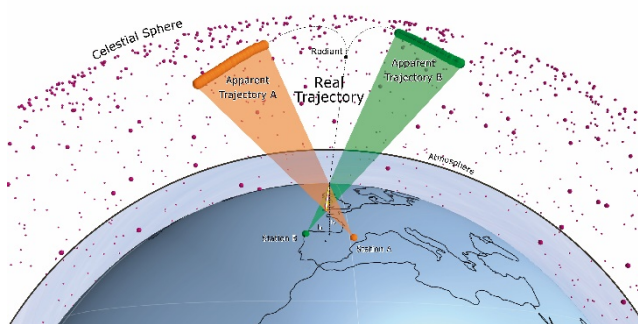


Figure 2 – Illustration of the Method of Planes for computing the real trajectory and radiant position of the meteoroid.

The process begins by capturing a video of a meteoric event. For this purpose, we have implemented and extended the open-source CV2 OpenCV library (Bradski and Kaehler, 2000). The first step is to detect the movement of the fireball throughout the recording. This is achieved by evaluating the variation of the pixels with respect to a reference frame.

When entering the atmosphere at hypervelocity, meteoroids undergo an intense ablation process producing strong flares. These luminous bursts can saturate the pixels and reflect flares, making detection difficult and even generating false positives. Therefore, three methods have been developed to avoid these possible errors:

- 1) a system of discrimination based on the area size detected,
- 2) a real-time prediction of the next bolide position to narrow down the search area, and
- 3) a post-processing to discard inconsistent points with a more or less straight and continuous trajectory.

The second step consists of performing astrometry of the recorded stars. The frames where the fireball does not appear are chosen in order to correctly measure the position and luminosity of the stars. The chosen frames are stacked and processed to reduce noise and highlight the reference stars. Using a stellar catalog, each of the identified stars is compared. Having the position in the image of each star and its position in the sky, it is possible by iterative methods to

adjust a transformation matrix that converts pixels into real coordinates considering also the distortion produced by the lens. In this way, an apparent trajectory on the sky as seen from that location is obtained for each observation point.

Since these apparent trajectories are projections on the celestial sphere of the path travelled by the meteoroid in the atmosphere, it is necessary to combine two or more observations to triangulate the real position of the fireball. This is achieved using the plane intersection method developed by (Ceplecha, 1987), depicted in Figure 2. For each observation point, a mean plane containing the station and the apparent trajectory is generated, minimizing the error. As a result of the intersection of each of the generated planes, a straight line is obtained, through which the trajectory of the fireball must have passed. This is possible because the atmospheric flight of a meteoroid defines practically a perfect straight line due to its hypervelocity. One of the most complex parts of fireball analysis is to develop a mathematical model that adequately describes the flight in the atmosphere. One can describe this motion as a time-dependent third-order dynamical system, including air resistance and lift. This allows characterizing the atmospheric flight and estimating the initial and final mass, facilitating the classification of events according to their meteorite-producing capacity based on a method developed by (Gritsevich, 2009).

Finally, to calculate the orbital parameters of the heliocentric orbit of origin, it is first necessary to compute the radiant, that is, the position in the sky from which the fireball appears to come. This is achieved by propagating backward the atmospheric trajectory until it collides with the celestial sphere, or equivalently, by intersecting the great circles containing the apparent trajectories. It is also necessary to take into account the rotational motion of the Earth and the gravitational attraction on the meteoroid (Andreev, 1990). Once these considerations have been made, the orbit in the solar system of its parent body is obtained (Dubiago, 1961).

The automation of the bolide detection and analysis process facilitate dealing with the increasing massive data, which was beginning to saturate storage capacity. With the implementation of this new software, the SPMN gains in capacity to rapidly generate new knowledge about the hazards associated with large meteoroids and their dynamic



Figure 3 – SPMN221220C recorded from Estepa, Sevilla (left) and from La Aparecida, Alacant (center) and La Murta, Murcia (right).

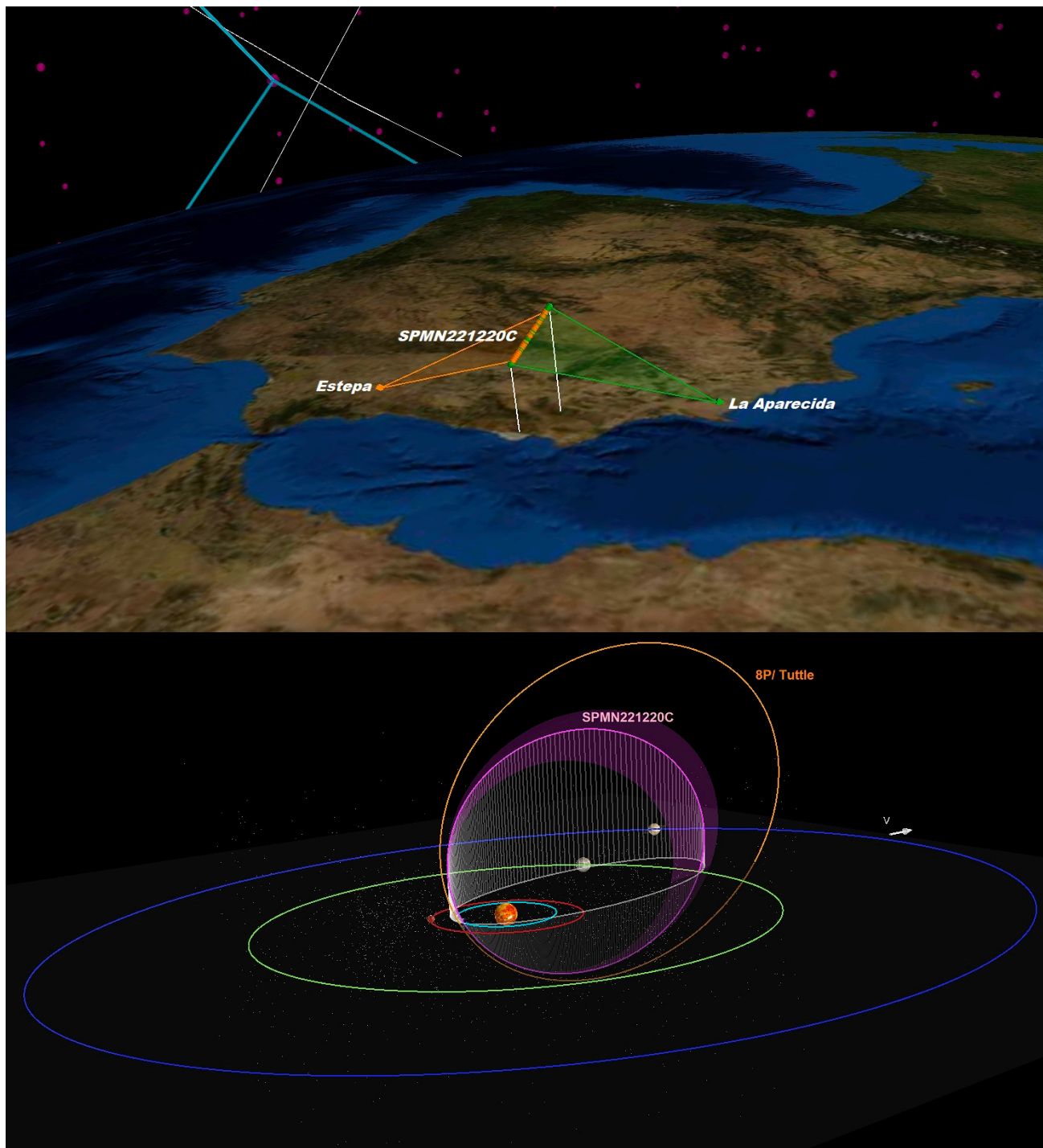


Figure 4 – Top: SPMN221220C atmospheric reconstruction with Estepa (orange) and La Aparecida (green) stations. Bottom: The computed heliocentric orbit of SPMN221220C and 8P/Tuttle.

association with comets, asteroids or even planetary bodies. In addition, this automation will allow the immediate preparation of fresh meteorite search campaigns.

3 Last study case: SPMN221220C

As a practical application of the 3D-FireTOC software, we report the very bright fireball SPMN221220C, which reached a magnitude of -9 ± 1 . This event occurred on 2020 December 22nd (Peña-Asensio et al., 2021b) and was recorded by 3 SPMN stations, see Table 1 for the geographic coordinates and Figure 3 for the meteor trails.

The starting altitude was 111.8 ± 0.1 km and the observed velocity at its atmospheric inlet was 34.3 ± 0.1 km/s. The bolide suffered a disruption followed by a bright flare at 73.4 ± 0.1 km, having a velocity of 29.3 ± 0.1 km/s. A 3D representation of the atmospheric flight and the heliocentric orbit is depicted in Figure 4 in real scale.

Table 1 – Stations recording the event SPMN221220C.

Station	Longitude	Latitude	Alt.
Estepa	4°52'36" W	37°17'29" N	537 m
La Aparecida	1°00'14" W	38°04'54" N	35 m
La Murta	1°40'32" W	38°05'48" N	469 m

The aerodynamic strength results in 4.35 ± 0.10 kPa. Both the velocity, radiant and calculated orbital parameters point out to a clear association with the Ursids, and the parent comet 8P/Tuttle (*Figure 4*), as compared with the annual component given by (Jenniskens, 2006). The radiant, velocities and orbital parameters for PMN221220C:

- $\alpha_o = 213.8 \pm 0.8^\circ$
- $\delta_o = 74.2 \pm 0.3^\circ$
- $v_\infty = 34.29 \pm 0.12$ km/s
- $\alpha_g = 219.6 \pm 1.3^\circ$
- $\delta_g = 74.5 \pm 0.6^\circ$
- $v_g = 65.6 \pm 0.6$ km/s
- $\alpha_h = 18.0 \pm 0.6^\circ$
- $\delta_h = 51.2 \pm 0.5^\circ$
- $v_h = 39.6 \pm 0.3$ km/s
- $a = 3.8 \pm 0.4$ AU
- $e = 0.749 \pm 0.027$
- $q = 0.9424 \pm 0.0028$ AU
- $\omega = 205.6 \pm 0.9^\circ$
- $\Omega = 270.425 \pm 0.006^\circ$
- $i = 52.5 \pm 0.5^\circ$

Figure 5 shows the velocity curve superimposed with the photometric counts from the 3 stations. As expected, an abrupt drop in velocity is observed at the moment of maximum luminosity, i.e., when the blast that causes the catastrophic disruption of the meteoroid occurs.

In addition, we also recorded the meteor activity from Fuenlabrada and Jaén forward-scatter stations. *Figure 6* shows the data compared with 2019 Ursids activity from the same stations. The 2020 Ursids did not produce an outburst as predicted by Jenniskens (2006), but still provided a nice display. From the data collected (*Figure 6*), an average flux of 20 echoes per hour was estimated, exhibiting a particular peak on the 21st and 22nd of overdenses echoes. The 2020 Ursid activity was even smaller than that of 2019, without any evidence of outburst.

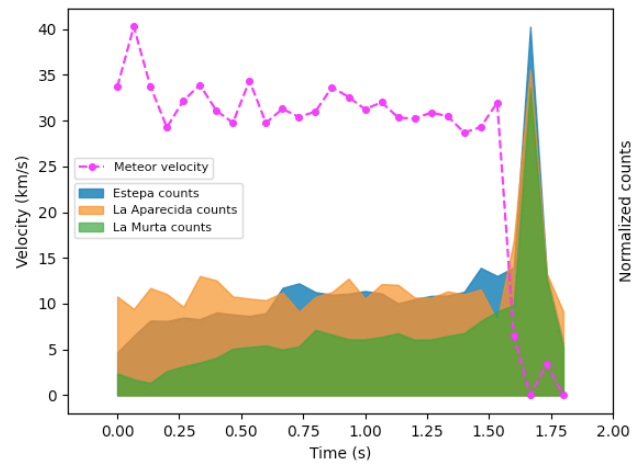


Figure 5 – SPMN221220C observed velocity curve crossed with the normalized photometric counts.

4 Conclusion

After the long road travelled together, both professionals and amateurs involved in the Spanish Meteor Network (SPMN), we have the challenge to continue collaborating to promote the study of interplanetary matter and meteoritics. Among our future objectives, we can identify the following ones:

- Automated bolide trajectory and orbit reconstruction, controlling the maintenance of a database of meteoroid orbits that will allow automated searches with their parent bodies.
- As the main scientific objective of our network, to use that database to identify possible meteorite falls. To join efforts in the recovery and characterization of meteorites.
- To deepen in those techniques that allow us to understand in-depth the nature and magnitude of the danger of impact by small asteroids.

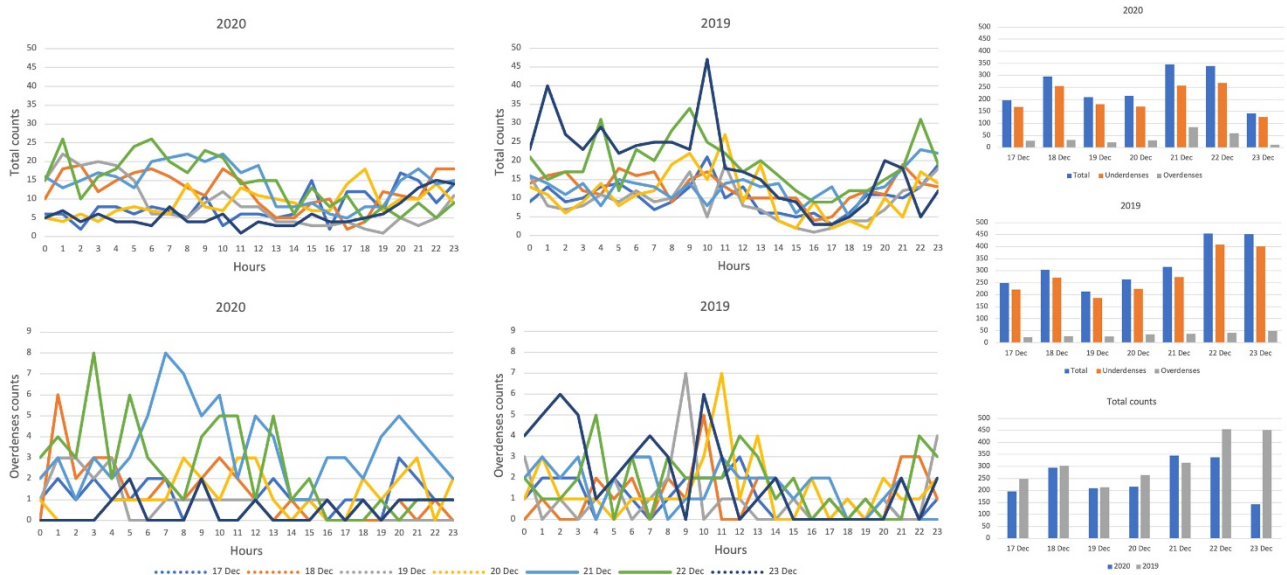


Figure 6 – Forward-scatter comparison of 2020 and 2019 Ursids activity by days and hours.

As an example of all the work developed and the latest advances implemented in the SPMN detection network, we analyzed the SPMN221220C event and the 2020 Ursids activity. The 2020 Ursids have not produced a meteor outburst but were composed of large meteoroids producing a nice fireball display. The maximum occurred at solar longitude 270.315° (J2000.0) with a meteoroid flux estimated from three video stations in the visual range up to magnitude +4 was 20 meteoroids/1000 km²·h.

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The Southwestern Europe Meteor Network: recent advances and analysis of bright fireballs recorded along April 2021

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We present here some recent improvements performed in the framework of the Southwestern Europe Meteor Network (SWEMN) and the SMART project. In particular, we focus on the development of the first digital database dedicated to meteor events recorded over Spain and neighboring areas. This includes, among other information, the circumstances of each event, orbital data, emission spectrum, lightcurve, and meteoroid physical properties. We also discuss in this work the main fireballs recorded by our network along April 2021.

1 Introduction

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

To improve our knowledge about the Earth-Moon meteoric environment, SMART works in close connection with another project conducted by IAA-CSIC: the MIDAS survey (Moon Impacts Detection and Analysis System). MIDAS uses the Moon as a laboratory that provides information about meteoroids hitting the lunar ground (Ortiz et al., 2015; Madiedo et al., 2018; Madiedo et al., 2019a). A strong synergy has been proved to exist between this survey and the SMART project (Madiedo et al. 2015a,b; Madiedo et al. 2019b).

This work focuses on two new steps taken in the framework of SWEMN. The first of these is our openness to the amateur astronomy community. The second step involves the development of the first comprehensive digital database containing information about bolides and meteors recorded over the Iberian Peninsula, and the software tools necessary to exploit this new resource. In addition, as in previous reports (see for instance Madiedo et al., 2021), we also discuss here the most remarkable bolides recorded during April 2021 by our systems.

2 Pro-Am collaboration

The SMART survey was started as a professional project in 2006 (Madiedo, 2014; Madiedo, 2017). Since then, the results obtained in the framework of this project and the most remarkable fireballs recorded by our meteor stations have been widely disseminated among the public, mainly through social networks, media and conferences. In particular, YouTube, Facebook and Tweeter have played a key role in our outreach activities. These have contributed to increase the interest of the public in Spain for meteor science. And, consequently, the number of amateur astronomers that expressed their interest in establishing



Figure 1 – Fixed meteor stations based on CCD and/or CMOS devices operating in the framework of the Southwestern Europe Meteor Network.

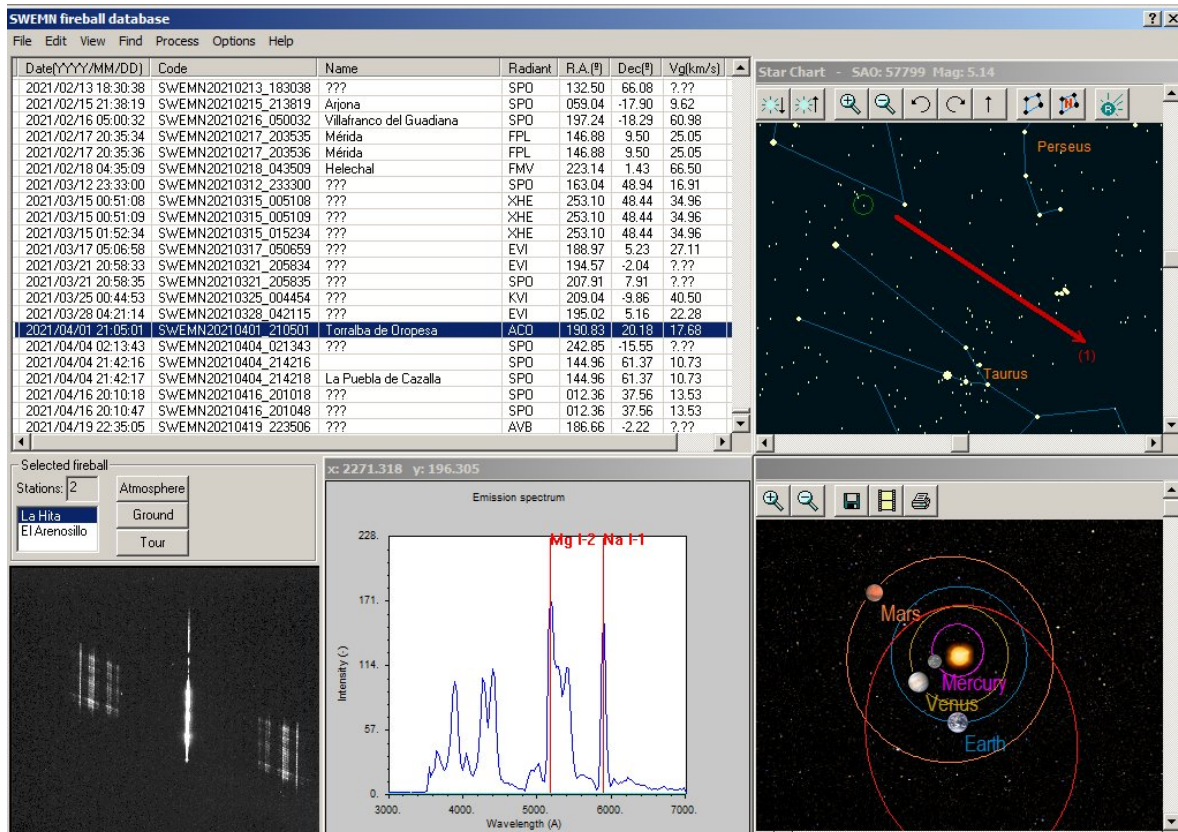


Figure 2 – Screenshot of the software interface employed by the SWEMN digital database. In this example, the interface displays the orbit viewer, the spectrum viewer, the fireball viewer and the star chart viewer.

some kind of collaboration with SMART also increased. For this reason, we decided in 2021 to convert SMART into a Pro-Am project. As a result, the number of meteor-observing stations working in the framework of the SWEMN has also increased. *Figure 1* shows an updated map of the fixed stations in this network based on CCD and/or CMOS cameras. In addition to these, there are 3 mobile video stations, and also three forward-scatter stations. One of these stations for radio meteors is mobile, and the other two operate at fixed position at La Hita and Sevilla, respectively. The video station at Coruña and Tudela are currently being setup. The systems at Coruña will begin to collect data on June 30, in commemoration of the International Asteroid Day.

3 The SWEMN digital database

One important step taken in the framework of SWEMN has been the development of a digital and interactive database containing meteors recorded and analyzed by the SMART project since this survey was started in 2006. This includes a new dedicated software to handle and exploit the contents of this database. Before these tools were available, we employed a Microsoft Excel file as a simple database to store information about meteors recorded by our cameras. Thus, every meteor spotted by SMART was assigned a unique code after its recording date and time. And then a new record was appended to that Excel file, which included that unique code and very basic data about said meteor (typically, its radiant position, radiant name, and peak magnitude). But this system was not comfortable, since in order to recover additional information for a given meteor (e.g., its emission spectrum or its lightcurve, or even the method(s) employed to perform the calculations), the operator had to locate those data manually in the specific storage device where the all of the files recorded and calculated for that particular event were stored. This manual process was very slow, and did not allow to perform automatic or efficient comparisons between the different events included in the Excel file.

The new database is the first digital database ever developed for meteors recorded over the Iberian Peninsula and neighboring areas, and it stores very comprehensive information about these events. Thus, among other data, for each meteor it contains the images taken from different observing stations, the calculated atmospheric trajectory (including geographical coordinates, velocity, and deceleration along the meteor path), the radiant coordinates, the orbital parameters of the meteoroid, the meteor lightcurve, its flickering frequency, the emission spectrum, and the main physical properties of the meteoroid (bulk density, diameter, initial and terminal mass, and strength).

Each event is also identified in the SWEMN database by means of its unique code. And, in addition to the above-mentioned results obtained from the analysis of each meteor, this database also stores the x, y coordinates for the meteor and reference stars on each image recorded for the event, information about the method(s) and software package(s) employed to obtain the different parameters

calculated for the meteor, the name of the operator(s) involved in the recording and analysis of the event, and even the reports (if any) provided by causal eyewitness.

Figure 3 – Screenshot of the software interface that allows to define manually a new entry in the database, or modify the information related to a previously stored entry.

Software interface

The SWEMN database is stored in a binary file which is handled by a software tool developed to access, edit or enter information about meteor events. *Figure 2* shows a typical screenshot of the software interface of the digital database. This software is written in C++ and runs under MS-Windows. This interface is customizable and displays a list containing the meteor events included in the database. It provides an orbit viewer and an emission spectrum viewer. It can also display different plots, as for instance the lightcurve of the event and curves showing the evolution with time and/or height of different meteor parameters (velocity, deceleration, position, etc.) An interactive star chart displays the apparent position of the selected meteor from the different meteor-observing stations that spotted the event. This interface is connected with Google Earth, which allows viewing meteor trajectories by employing this popular software tool.

New meteor events can be added to the database either manually or automatically. *Figure 3* shows a screenshot of the software interface that allows to define manually a new entry in the database, or modify the information related to a previously stored entry. The automatic option scans disk drives or folders specified by the user and locates output files produced by our meteor analysis software packages. These files contain the results from the calculations related to a specific meteor (e.g., spectrum, lightcurve, orbital data, atmospheric path, etc.). If the software finds in those files a meteor that was not previously stored in the database, then it includes it automatically. After this automatic process takes place, new meteors appended to the database have to be validated to ensure that the corresponding information is reliable. Currently, the SWEMN database contains around 4000 validated events, most of which are fireballs with peak luminosity above mag. -7 . This figure is expected to

increase very rapidly as soon as the validation process advances and fainter events are also included.

Searching the database

Figure 4 shows a screenshot of the software module employed to browse information in the database. Once the user specifies the selected options, the software retrieves a list of meteor events fulfilling the search criteria. That list is displayed by a software interface identical to the one shown in Figure 2. In this way, the user can easily access any data or information stored in the database for a particular event contained in that list.

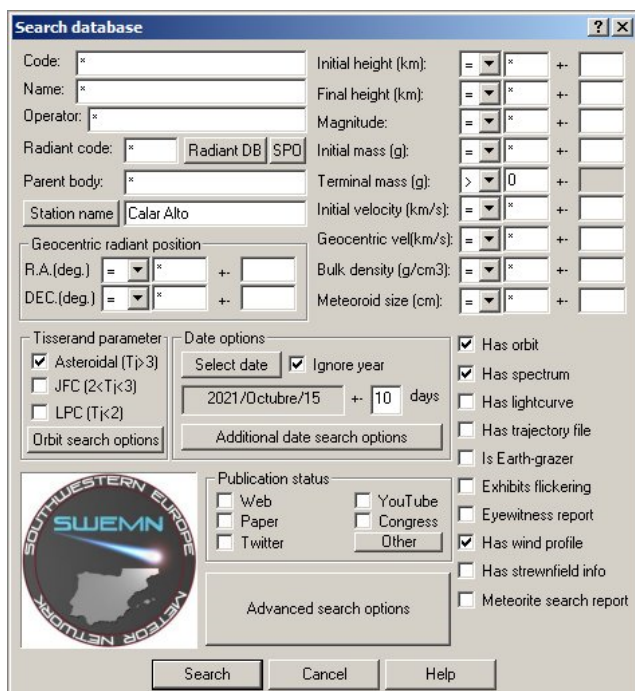


Figure 4 – Screenshot of the software interface employed to search information in the SWEMN database.

Contribution to Meteor Science

It is possible to find likely links between events included in the SWEMN database by means of the above-described software. This can be done either manually or automatically. Thus, every time a new event is appended, the software tries to find any connection with other meteors in the database. This can be very useful for different purposes. For instance, this can be employed to identify new meteor showers, or to provide valuable information about poorly-known meteoroid streams, fireball streams. Other interesting applications are related to the identification of fireball streams, especially those that could be associated with meteorite-producing events or with bright lunar impact flashes.

4 Instrumentation and methods

Below we present the main bolides recorded by our meteor-observing stations along April 2021. These bright meteors 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, 2015a).

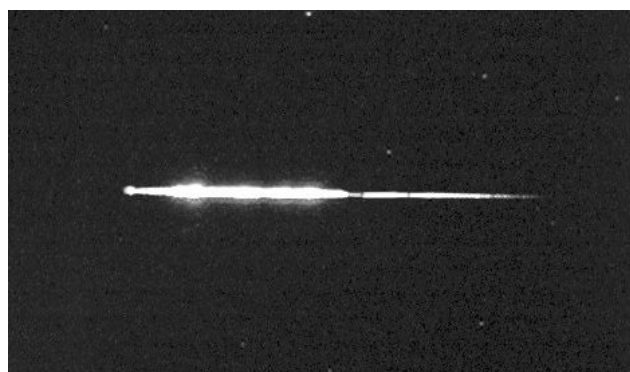


Figure 5 – Stacked image of SWEMN20210401_210501 “Torralba de Oropesa” fireball as recorded from the SWEMN meteor-observing station at La Hita Astronomical Observatory.

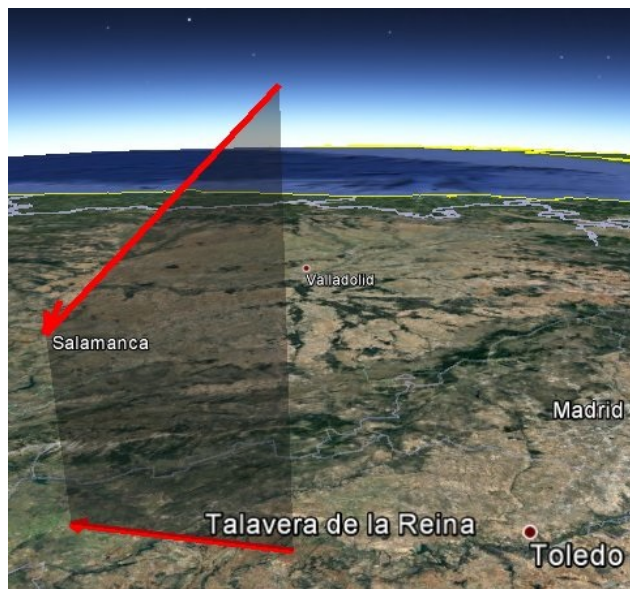


Figure 6 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210401_210501 fireball.

5 The 2021 April 1 meteor event

On April 1, our systems recorded the first bright meteor of that month. The event was spotted at $21^{\text{h}}05^{\text{m}}01.7 \pm 0.1^{\text{s}}$ UTC from the SWEMN stations operating at La Hita, La Sagra, Madrid, Sevilla, Calar Alto, and El Arenosillo. It had a peak absolute magnitude of -11 ± 1 (Figure 5). This event was included in our meteor database with the code

SWEMN20210401_210501. A video showing images of the fireball and its trajectory was uploaded to YouTube ⁸.

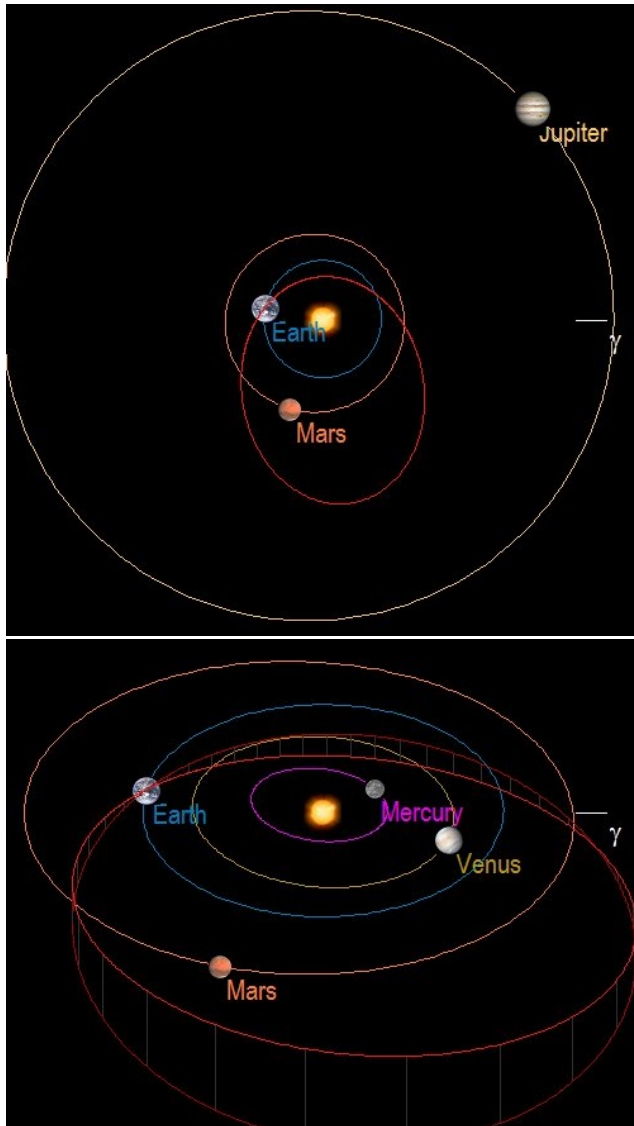


Figure 7 – Up: orbit (red line) of the parent meteoroid of the SWEMN20210401_210501 fireball, and projection of this orbit (dark red line) on the ecliptic plane; Down: close-up view of the orbit.

Table 1 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210401_210501 “Torralba de Oropesa” fireball.

a (AU)	1.98 ± 0.07	ω (°)	249.6 ± 0.2
e	0.62 ± 0.01	Ω (°)	12.06187 ± 10^{-5}
q (AU)	0.749 ± 0.002	i (°)	11.5 ± 0.2

Atmospheric trajectory, radiant and orbit

By combining the recordings from the different stations that observed this fireball, we concluded that this bright meteor overflowed the province of Toledo. Besides, we obtained a pre-atmospheric velocity for the progenitor meteoroid of $v_{\infty} = 21.1 \pm 0.3$ km/s, with the position of the apparent radiant at the equatorial coordinates $\alpha = 190.82^{\circ}$, $\delta = +20.18^{\circ}$. The analysis of the atmospheric path also revealed that the meteor began at a height $H_b = 92.0 \pm 0.5$

km, and ended at an altitude $H_e = 43.3 \pm 0.4$ km. The zenith angle of this trajectory was of about 45 degrees. Since the terminal point of the bolide was almost over the vertical of the town of Torralba de Oropesa, we named the fireball after this location. The atmospheric path of the meteor and its projection on the ground are shown in Figure 6.

The geocentric velocity of the meteoroid was $v_g = 17.6 \pm 0.3$ km/s. Its orbital parameters before its encounter with our planet are shown in Table 1, and this orbit is drawn in Figure 7. The information found in the IAU meteor database indicates that the fireball was an April α -Comae Berenicids (ACO#0272). This poorly-known meteoroid stream produces every year a display of meteors peaking around April 7 (Porubcan and Gavajdova, 1994). According to the calculated value of the Tisserand parameter with respect to Jupiter ($T_J = 3.57$), the meteoroid followed an asteroidal orbit before impacting the Earth’s atmosphere. This agrees with the proposed asteroidal origin for this stream.

Emission spectrum

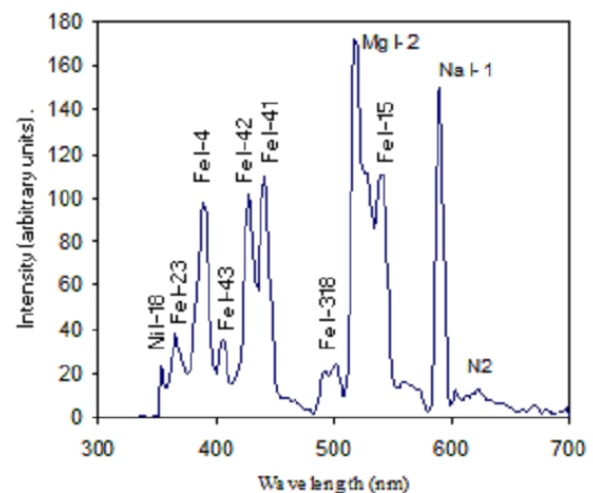


Figure 8 – Calibrated emission spectrum of the SWEMN20210401_210501 “Torralba de Oropesa” fireball.

The emission spectrum of the SWEMN20210401_210501 fireball was recorded by our spectrographs from the astronomical observatories of Calar Alto, La Hita, La Sagra, and El Arenosillo. As in previous works, this spectrum was analyzed with the ChiMet software, which calibrates the signal in wavelength and then corrects it by taking into account the spectral sensitivity of the device (Madiedo et al., 2014; Madiedo, 2015b; Passas et al., 2016). The resulting calibrated spectrum is shown in Figure 8, where the most remarkable emission lines have been highlighted. The majority of these correspond to neutral iron, as usual in meteor spectra (Borovička, 1993; Madiedo, 2014; Espartero and Madiedo, 2016). Thus, we have identified the emissions from Fe I-23, Fe I-4, Fe I-43, Fe I-42, Fe I-41, Fe I-318, and Fe I-15. Nevertheless, the most important emissions are those of the Na I-1 doublet (588.9 nm) and the Mg I-2 triplet (516.7 nm). The Ni I-18 line was also

⁸ <https://youtu.be/daEYX6agr-k>

detected, and the contribution from atmospheric N₂ is present in the red part of the spectrum.

6 The 2021 April 4 fireball

This bolide was recorded from the SWEMN meteor-observing stations operating at La Sagra, La Hita, Madrid, Sevilla, and El Arenosillo. The fireball can be viewed on this YouTube video⁹, and had a peak absolute magnitude of -9 ± 1 (Figure 9). It appeared at $21^{\text{h}}42^{\text{m}}18.4 \pm 0.1^{\text{s}}$ UTC, and so it was included in our database under the code SWEMN20210404_214218.

Atmospheric path, radiant and orbit

This fireball overflew the provinces of Sevilla and Cadiz (west of Andalusia). The meteoroid hit the atmosphere with an initial velocity $v_{\infty} = 15.4 \pm 0.3$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 144.9^{\circ}$, $\delta = +61.4^{\circ}$. The bolide began at an altitude $H_b = 81.0 \pm 0.5$ km, near from the vertical of the town of La Puebla de Cazalla (province of Sevilla). In our meteor database we named the event after this location. The terminal point of its trajectory was reached at a height $H_e = 29.8 \pm 0.5$ km over the northeast of the province of Cadiz. The calculated atmospheric path and its projection on the ground are shown in Figure 10.



Figure 9 – Stacked image of the SWEMN20210404_214218 “La Puebla de Cazalla” fireball as recorded from the SWEMN meteor-observing station located at El Arenosillo.

Table 2 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210404_214218 fireball.

a (AU)	2.7 ± 0.2	ω (°)	183.0 ± 0.2
e	0.63 ± 0.03	Ω (°)	15.04381 ± 10^{-5}
q (AU)	0.9997 ± 0.0001	i (°)	11.5 ± 0.3

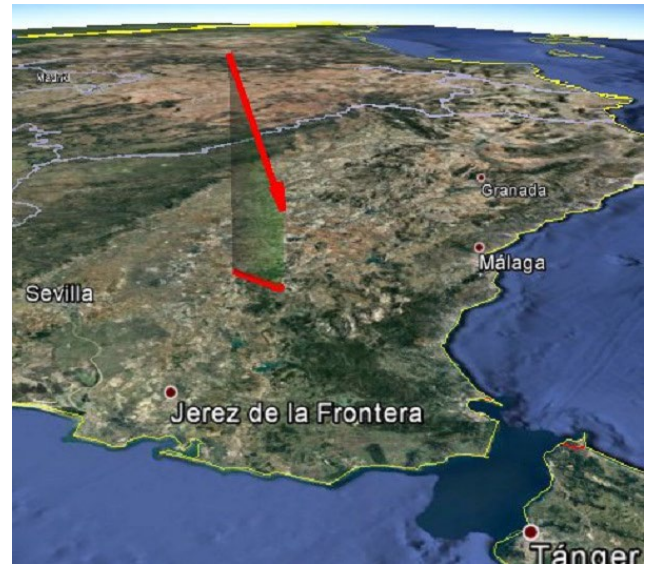


Figure 10 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210404_214218 fireball.

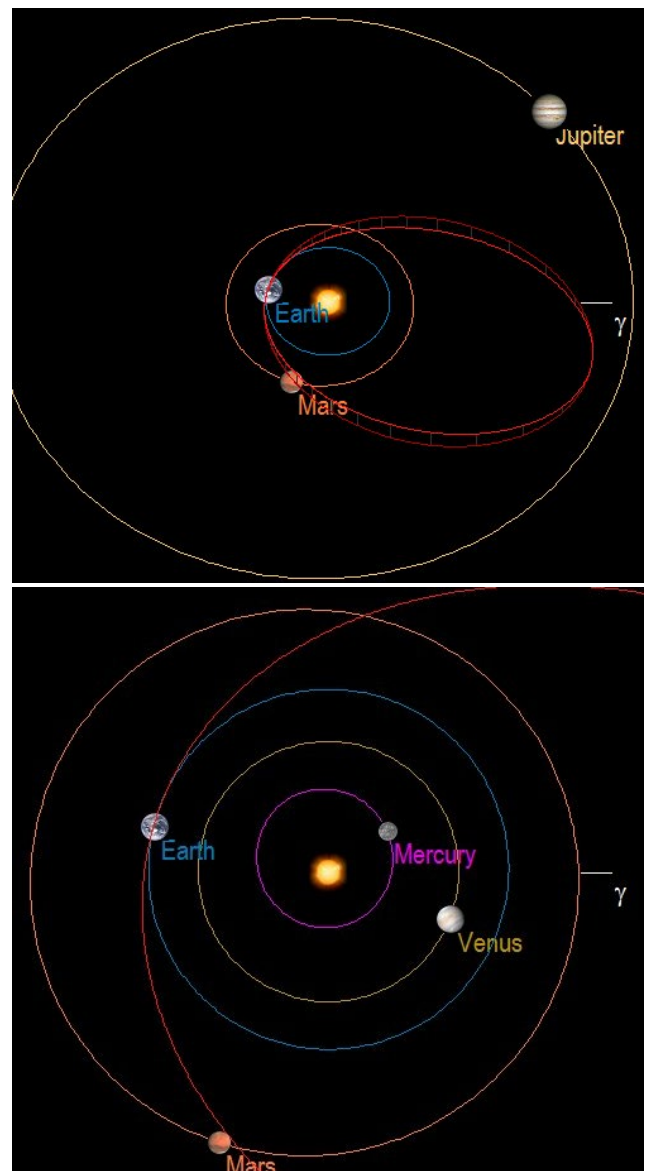


Figure 11 – Up: orbit (red line) of the parent meteoroid of the SWEMN20210404_214218 fireball, and projection of this orbit (dark red line) on the ecliptic plane; Down: close-up view of the orbit.

⁹ <https://youtu.be/XpYAGNiRkEQ>

The calculation of the orbital elements of the progenitor meteoroid yields the results listed in *Table 2*, and the corresponding heliocentric orbit is shown in *Figure 11*. The value derived for the geocentric velocity is $v_g = 10.7 \pm 0.4$ km/s. The value of the Tisserand parameter with respect to Jupiter ($T_J = 3.0$) shows that the orbit followed by this meteoroid would lie in the limit between an asteroidal orbit and a Jupiter Family Comet (JFC) orbit. Radiant and orbital data do not match any of the meteoroid streams listed in the IAU meteor database. So, we concluded that this event was produced by the sporadic background.

7 The 2021 April 16 fireball

At $20^{\text{h}}10^{\text{m}}14.8 \pm 0.1^{\text{s}}$ UTC on April 16, we recorded a slow bolide with a peak absolute magnitude of -8 ± 1 . This was an Earth-grazing fireball that was spotted from the meteor-observing stations located at La Hita, Sevilla, El Arenosillo, La Sagra, and Madrid (*Figure 12*). It could be also seen by many casual eyewitnesses, and most of them reported that the bolide exhibited a reddish color. A video showing this event was uploaded to YouTube¹⁰. It was included in the SWEMN meteor database with the code SWEMN20210416_201014.

Atmospheric path, radiant and orbit

The luminous phase of this event began over the northwest of Spain and ended over the southeast of this country. The projection on the ground of the atmospheric trajectory of the fireball is shown in *Figure 13*. From the preliminary analysis of this trajectory, we obtained that the apparent radiant was located at the equatorial coordinates $\alpha = 12.3^\circ$, $\delta = +37.5^\circ$. The meteoroid hit the atmosphere over the province of Lugo (Galicia), with an initial velocity $v_\infty = 16.1 \pm 0.2$ km/s. The initial and terminal points of this path were located at an altitude $H_b = 86.9 \pm 0.5$ km and $H_e = 89.3 \pm 0.5$ km, respectively. At this final stage the fireball was located over the Mediterranean Sea, next to the coast of Almería (Andalusia).



Figure 12 – Stacked image of the SWEMN20210416_201014 fireball as recorded from La Hita Observatory.



Figure 13 – Projection on the ground of the trajectory of the SWEMN20210416_201014 Earth-grazing fireball.

The heliocentric orbit of the meteoroid before its encounter with our planet is drawn in *Figure 14*, and the value of the corresponding orbital parameters are listed in *Table 3*. For the geocentric velocity we have obtained the value $v_g = 11.9 \pm 0.2$ km/s. and the Tisserand parameter with respect to Jupiter yields $T_J = 6.19$. According to this, the meteoroid followed an asteroidal orbit before entering the atmosphere. As in the previous case, and according to the information found in the IAU meteor database, we associated this event with the sporadic background.

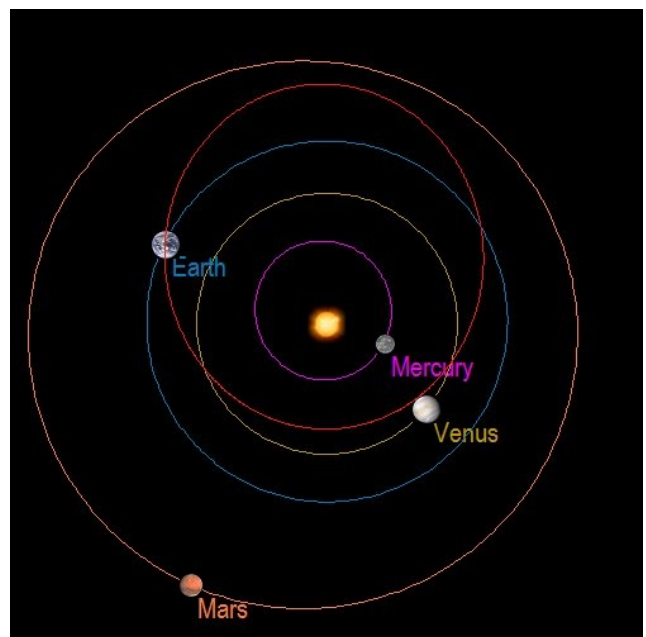


Figure 14 – Projection on the ecliptic plane of the orbit (red line) of the parent meteoroid of the SWEMN20210416_201014 fireball before the encounter of this particle with our planet.

It is interesting that the meteoroid exhibited a non-zero terminal mass. So, the surviving fragment left the atmosphere following a modified orbit. A paper describing

¹⁰ <https://youtu.be/lofMkg8a7wQ>

in detail the circumstances of this case is currently in preparation.

Table 3 – Orbital parameters (J2000) of the progenitor meteoroid of the SWEMN20210416_201014 fireball before the encounter of this particle with our planet.

a (AU)	0.96 ± 0.01	ω (°)	61.2 ± 1.0
e	0.393 ± 0.005	Ω (°)	26.75338 ± 10^{-5}
q (AU)	0.5836 ± 0.0002	i (°)	7.6 ± 0.3



Figure 15 – Stacked image of the SWEMN20210423_040329 fireball as recorded from Calar Alto.

8 The 2021 April 23 fireball

This bolide was recorded at $4^{\text{h}}03^{\text{m}}29.0 \pm 0.1^{\text{s}}$ UTC on 2021 April 23 from the SWEMN meteor-observing stations located at La Hita, La Sagra, Calar Alto, Sevilla, and Sierra Nevada. It reached a peak absolute magnitude of -9 ± 1 (Figure 15). A video about this fireball was uploaded to YouTube¹¹. The meteor was included in the SWEMN meteor database with the code SWEMN20210423_040329.

Atmospheric path, radiant and orbit

According to our calculations, the meteoroid entered the atmosphere with an initial velocity $v_{\infty} = 47.6 \pm 0.4$ km/s, and the apparent radiant of the meteor was located at the equatorial coordinates $\alpha = 274.9^{\circ}$, $\delta = +34.0^{\circ}$. The event overflowed the Mediterranean Sea. It began at an altitude $H_b = 114.2 \pm 0.5$ km, and ended at a height $H_e = 59.7 \pm 0.5$ km over the sea. This atmospheric trajectory and its projection on the ground are shown in Figure 16.

Table 4 – Orbital data (J2000) of the progenitor meteoroid of the SWEMN20210423_040329 fireball.

a (AU)	11.2 ± 3.7	ω (°)	211.6 ± 0.4
e	0.91 ± 0.02	Ω (°)	32.94233 ± 10^{-5}
q (AU)	0.9338 ± 0.0009	i (°)	79.3 ± 0.3

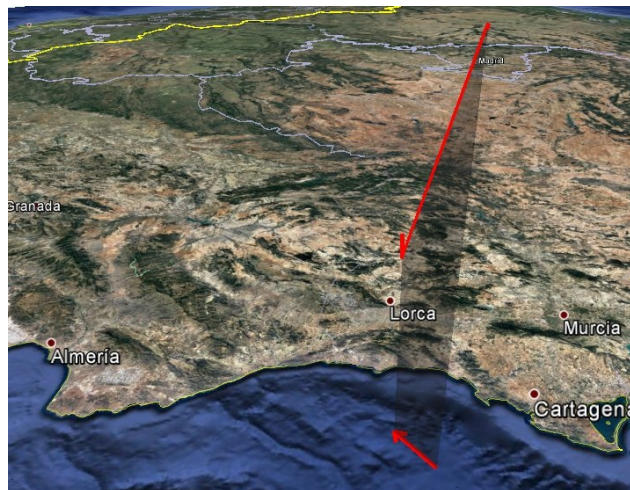


Figure 16 – Atmospheric path and projection on the ground of the trajectory of the SWEMN20210423_040329 fireball.

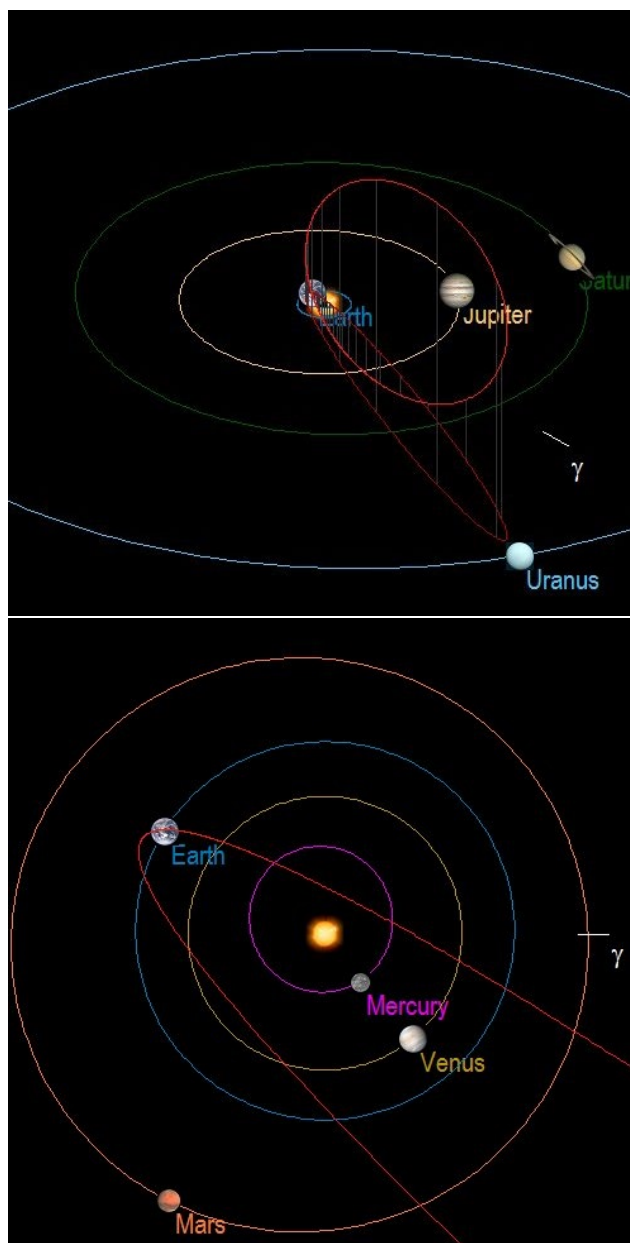


Figure 17 – Up: orbit (red line) of the parent meteoroid of the SWEMN20210423_040329 fireball, and its projection (dark red line) on the ecliptic plane; Down: close-up view of the orbit.

¹¹ <https://youtu.be/wGkKYSHoHXY>

Table 4 contains the orbital elements calculated for the parent meteoroid. This orbit is plotted in Figure 17. The calculated value of the geocentric velocity of this particle is $v_g = 46.2 \pm 0.4$ km/s. The Tisserand parameter with respect to Jupiter yields $T_J = 0.6$, which shows that this meteoroid followed a cometary orbit before entering our atmosphere. In fact, according to the information found in the IAU meteor database, these results show that the fireball was an April Lyrid (LYR#0006). This major meteor shower, which is produced by meteoroids from Comet C/1861 G1 (Thatcher), reaches its activity peak around April 22 (Jenniskens et al., 2016). So, this event was recorded a few hours after said peak.

Emission spectrum

Our spectrographs located at the astronomical observatories of Sierra Nevada and Calar Alto recorded the emission spectrum of this Lyrid fireball. Figure 18 shows the calibrated signal, together with the most important emissions. As can be noticed, the most important emission line is that from Fe I-4. Additional contributions from neutral iron have been also found, and the most significant ones are those from Fe I-23, Fe I-21, Fe I-43, Fe I-41, Fe I-318, and Fe I-15. The lines produced by Mg I-2 and Na I-1 are also present.

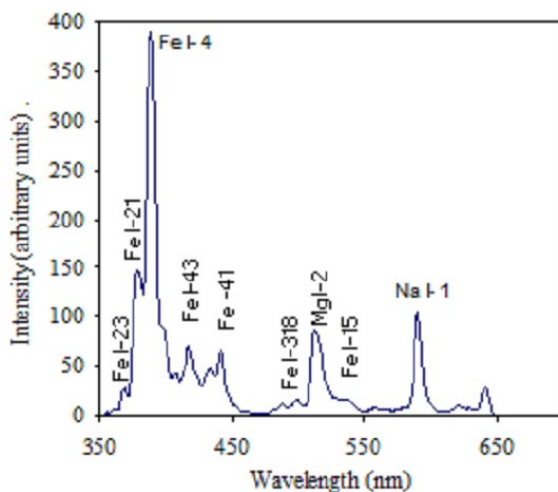


Figure 18 – Calibrated emission spectrum of the SWEMN20210423_040329 fireball.

9 Conclusion

We have focused here two new steps taken in the framework of SWEMN. The first of these is our openness to the amateur astronomy community. The second involves the development of the first digital database containing information about bolides and meteors recorded over the Iberian Peninsula and neighboring areas, and the software tools necessary to handle this new resource. We have described the main characteristics of this new tool and its likely contribution to, for instance, the identification of new meteor showers and fireball streams.

We have also presented the most remarkable fireballs recorded in April 2021 by the Southwestern Europe Meteor Network. The absolute magnitude of these events during

their peak luminosity ranged from -8 to -11 . The first of these is the “Torralba de Oropesa” mag. -11 bolide, which was recorded on April 1 and overflow the province of Toledo. This fireball was associated with the April α -Comae Berenicids (ACO#0272), a poorly-known meteoroid stream that peaks around April 7. Our results are consistent with the proposed asteroidal origin for this stream. In the spectrum obtained for this event the most important lines are those of Na I-1 (588.9 nm) and Mg I-2 (516.7 nm). The signal also exhibits the emission from several neutral iron multiplets (Fe I-23, Fe I-4, Fe I-43, Fe I-42, Fe I-41, Fe I-318, and Fe I-15) and the Ni I-18 line.

The “La Puebla de Cazalla” event, spotted on April 4, overflow the provinces of Sevilla and Cádiz (Andalusia) and reached a peak absolute magnitude of -9 . The parent meteoroid followed a JFC orbit and was associated with the sporadic background.

An Earth-grazing fireball with a peak absolute magnitude of -8 was observed on April 16. It overflow Spain from northwest to southeast, and ended over the Mediterranean Sea. The meteoroid, which followed an asteroidal orbit before its encounter with our planet, was also associated with the sporadic background and exhibited a non-zero terminal mass. So, it left the atmosphere with a modified orbit.

And finally, we spotted a mag. -9 Lyrid that overflow the Mediterranean Sea on April 23, some hours after the peak of this major shower. The most remarkable contributions in its emission spectrum are those produced by Fe I-4, Fe I-21, Mg I-2, and Na I-1. An in-deep analysis of this spectrum will provide key information about the composition of Lyrid meteoroids.

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A summary of the activity of the CAMS BeNeLux network during the month February 2021 is presented. This month displayed a normal weather pattern for this time of the year without being exceptional bad or poor. In total 6922 multiple station meteors were recorded, good for in total 2131 orbits. The number of available cameras increased from 84 in 2020 to 91 in 2021.

1 Introduction

The months of February in 2018 and in 2019 were exceptional favorable months for CAMS but last year weather remained extremely poor during this month. After an exceptional poor January 2021, we all looked forward to see some improvement during February 2021.

2 February 2021 statistics

The month started with the same poor weather pattern as we had in January. An improvement occurred on 10 February with a series of mostly clear nights followed by variable weather with partial clear nights. Eight nights had over 100 orbits (3 nights in 2020). February 2019 had eight nights with more than 200 orbits, 2018 even had eleven nights with over 200 orbits, 2021 had just 3 nights with more than 200 orbits.

CAMS BeNeLux managed to collect 6922 multi-station meteors (against 3517 in 2020 and 10570 in 2019) with a maximum of 91 cameras capturing at 26 participating stations. Only 3 nights remained without any single orbit obtained (compared to 5 nights without orbits in 2020). This was good for 2131 orbits (against 1215 in 2020 and 3485 in 2019). With the 2021 results the total number of orbits for February obtained by CAMS BeNeLux is 14191 orbits collected in 190 successful February nights. The statistics for February 2021 are compared in *Table 1* with all previous February months since the start of the CAMS BeNeLux network. Some better weather than last year combined with more operational cameras at more participating stations resulted in a higher number of orbits.

On average 78.6 of the available 91 cameras were capturing each night (73.1 of 84 in 2020). In the first years, before AutoCams was available in the BeNeLux, many cameras remained switched off when the weather did not look good in the evening. This way the chances to obtain double station meteors for the cameras that remained active were rather small. Luckily, many camera stations function 7 on 7 now. AutoCAMS kept a minimum of 60 cameras active on all nights, even on completely overcast nights (compared to 62 in 2020). On as many as 24 nights orbits have been collected just like during previous year. *Figure 1* shows the camera capacity got restored compared to 2018 and the network got back at its strength of February 2018.

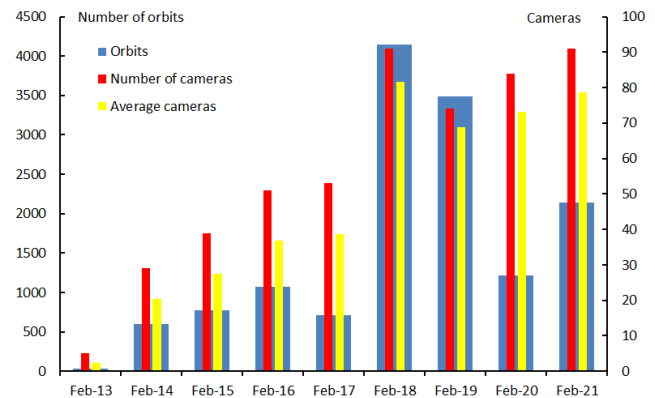


Figure 1 – Comparing February 2021 to previous months of February in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bars the average number of cameras running per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2013	9	38	6	5		2.3
2014	21	601	12	29		20.3
2015	21	777	14	39		27.4
2016	24	1075	17	51	13	36.9
2017	16	717	18	53	20	38.6
2018	26	4147	22	91	48	81.7
2019	24	3485	18	74	50	68.8
2020	24	1215	22	84	62	73.1
2021	25	2136	26	91	60	78.6
Total	190	14191				

3 Conclusion

February 2021 was an average month with typical weather for this time of the year with no exceptional good or bad weather circumstances. The total number of orbits puts this month as the 3rd best month of February for the CAMS BeNeLux network.

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 website¹². The data from all stations were collected and the trajectories and orbits calculated by Carl Johannink. The CAMS BeNeLux team is operated by the following volunteers:

Hans Betlem (Woold, Netherlands, CAMS 3071, 3702 and 3073), *Felix Bettonvil* (Utrecht, Netherlands, CAMS 376 and 377), *Jean-Marie Biets* (Wilderen, Belgium, CAMS 379, 380, 381 and 382), *Martin Breukers* (Hengelo, Netherlands, CAMS 320, 321, 322, 323, 324, 325, 326 and 327), *Guiseppe Canonaco* (Genk, RMS 3815), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806), *Tammo Jan Dijkema* (Dwingeloo, Netherlands, RMS 3198, 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 810, 811, 812 and 813), *Robert Haas / Edwin van Dijk* (Burlage, Germany, CAMS 801, 802, 821 and 822), *Kees Habraken* (Kattendijke, Netherlands, RMS 378), *Klaas Jobse* (Oostkapelle, Netherlands, CAMS 3030, 3031, 3032, 3033, 3034, 3035, 3036 and 3037), *Carl Johannink* (Gronau, Germany, CAMS 311, 314, 317, 318, 3000, 3001, 3002, 3003, 3004 and 3005), *Hervé Lamy* (Dourbes, Belgium, CAMS 394 and 395), *Hervé Lamy* (Humain Belgium, CAMS 816), *Hervé Lamy* (Ukkel, Belgium, CAMS 393), *Koen Miskotte* (Ermelo, Netherlands, CAMS 351, 352, 353 and 354), *Tim Polfliet* (Gent, Belgium, CAMS 396), *Steve Rau* (Zillebeke, Belgium, CAMS 3850 and 3852), *Paul and Adriana Roggemans* (Mechelen, Belgium, CAMS 3832, 3833, 3834, 3835, 3836 and 3837, RMS 3830 and 3831), *Hans Schremmer* (Niederkruechten, Germany, CAMS 803) and *Erwin van Ballegoij* (Heesch, Netherlands, CAMS 347 and 348).

¹² <http://cams.seti.org/FDL/index-BeNeLux.html>

March 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of March 2021 is presented. 6397 multi-station meteors were reported, good for 1998 orbits, collected with a maximum of 91 operational cameras at 27 different CAMS stations. March 2021 was the second-best month of March in 10 years of the CAMS BeNeLux network.

1 Introduction

March is a rather difficult month for astronomy in the BeNeLux area. It is no surprise that March remains about the poorest month of the year for the network. Without any relevant activity from any of the major or minor meteor showers, hourly rates remain low. March 2021 marked the 9th anniversary of the CAMS BeNeLux network as the first stations of the network collected the first orbits in the night of 14–15 March 2012. What would March 2021 bring for the network?

2 March 2021 statistics

The weather continued the same pattern we got end of February, the first week of March 2021 had some clear nights and longer periods with clear sky. The next ten nights were dominated by cloudy skies. The last period of March had variable circumstances with each night some clear skies, sometimes with almost complete clear nights. Only three nights in March 2021 remained without any single orbit (4 in March 2020). The best night was 5–6 March when 222 orbits were collected.

In total 6397 multi-station meteors were reported by all stations (10301 in March 2020), good for 1998 orbits (3026 in March 2020), the second-best result for the month of March, a significant better result than in 2019 and 2018. At best 91 cameras were active in March 2021 (93 previous year and 78 in 2019), a slight decrease in the number of operational cameras in spite of few new cameras added during the last year. The minimum of 59 operational cameras capturing each night was less than last year (66). Also, the average of operational cameras per night with 78.9 was a bit less than last year (81.7).

Figure 1 and Table 1 allow to compare the statistics for this month for all previous years. In 10 years, 217 nights in March allowed to collect orbits, good for 11330 orbits in total. Apart from few technical issues, motivation remains an important factor to keep camera operators continue their efforts after many years. A typical requirement for a successful video network is that there are enough stations and cameras available 7/7. This is one of the reasons why RMS cameras score very well.

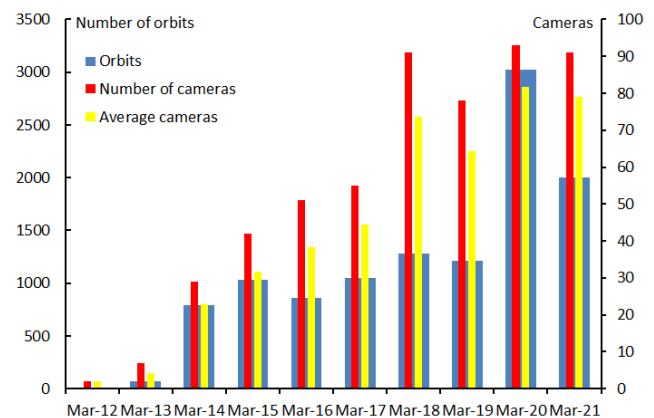


Figure 1 – Comparing March 2021 to previous months of March in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bars the average number of cameras running per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	2	12	2	2		2.0
2013	10	69	6	7		4.2
2014	24	793	12	29		22.8
2015	23	1033	14	42		31.7
2016	23	856	16	51	12	38.2
2017	26	1048	19	55	20	44.4
2018	25	1280	22	91	53	73.5
2019	29	1217	20	78	54	64.4
2020	27	3026	25	93	66	81.7
2021	28	1998	27	91	59	78.9
Total	217	11330				

As many as 27 different camera stations contributed to the network, a new record. The network could welcome *Ludger Boergerding* as new participant with his RMS DE000B, alias CAMS 003801 at Holdorf, Germany. Contributing CAMS data since 15–16 March, this new camera helped to determine 56 orbits in its first successful nights.

3 Conclusion

March 2021 became a favorable month of March for the network with a nice number of orbits as result, the second-best result for this month in 10 years.

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 website¹³. The data reduction and orbit calculation for all stations is coordinated by *Carl Johannink*. The CAMS BeNeLux team is operated by the following volunteers:

Hans Betlem (Woold, Netherlands, CAMS 3071, 3702 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), *Guiseppe Canonaco* (Genk, RMS 3815), *Pierre de Ponthiere* (Lesve, Belgium, RMS 3816), *Bart Dessoy* (Zoersel, Belgium, CAMS 397, 398, 804, 805, 806), *Tammo Jan Dijkema* (Dwingeloo, Netherlands, RMS 3199), *Jean-Paul Dumoulin*, *Dominique Guiot* and

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¹³ <http://cams.seti.org/FDL/index-BeNeLux.html>

April 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of April 2021 is presented. 3061 orbits were collected during 28 nights with a maximum of 91 operational cameras at 27 different CAMS stations. Favorable weather circumstances during the Lyrid activity allowed to monitor the April Lyrid activity for a fourth year in a row.

1 Introduction

April is often a better month for astronomical observations after a general unfavorable first three months of the year. April also brings the Lyrids, a major annual shower with modest activity apart from some outbursts. CAMS BeNeLux got exceptional favorable observing conditions during the Lyrids 2018, 2019 and 2020, three years on a row. It seemed a bit unlikely to be lucky another year. What would April 2021 bring us?

2 April 2021 statistics

The month started with one clear night followed by 9 mostly cloudy nights. Luckily the weather improved and remained stable until almost the end of the month. As many as 16 nights had more than 100 orbits (same as in 2020, 8 in 2019), 2 nights counted more than 200 orbits (4 in 2020 and 3 in 2019) and the best night was April 22–23 with 339 orbits, still much less than the record night April 21–22 in 2020 with as many as 460 orbits in a single night. Only two nights, April 09–10–11 remained without any orbit. For the fourth year in a row, the CAMS BeNeLux network enjoyed clear sky during much of the Lyrid activity. It would definitely be worthwhile to analyze the data collected about this shower by the network.

CAMS BeNeLux captured 10247 multi-station events (14924 in 2020, 7894 in 2019). April 2021 ended with a very nice result for this month with 3061 orbits in total (compare with 4128 orbits in 2020 and 2534 in 2019). This is the second-best score ever for the month of April in terms of orbits. The maximum of 91 cameras available was slightly less than previous year (94 in 2020 and 84 cameras in 2019). Unfortunately, many cameras remained switched off during a number of nights, reducing the 7 on 7 coverage to 59 cameras (against 76 cameras in 2020 and 44 in April 2019). This is also visible in the average number of operational cameras which dropped from 89.4 operational cameras in 2020 to 81.1 in 2021 (against 67.7 in April 2019). The awareness that meteor camera networks require 7 on 7 coverage is present, but technical issues and private circumstances sometimes prevent volunteers to keep their cameras running all nights.

In total CAMS BeNeLux collected 15646 orbits during 238 April nights accumulated during the past 10 years. The statistics for April 2021 are compared in *Table 1* with all previous months of April since the start of the CAMS BeNeLux network. *Figure 1* shows the changes in number of orbits and operational cameras compared to previous years.

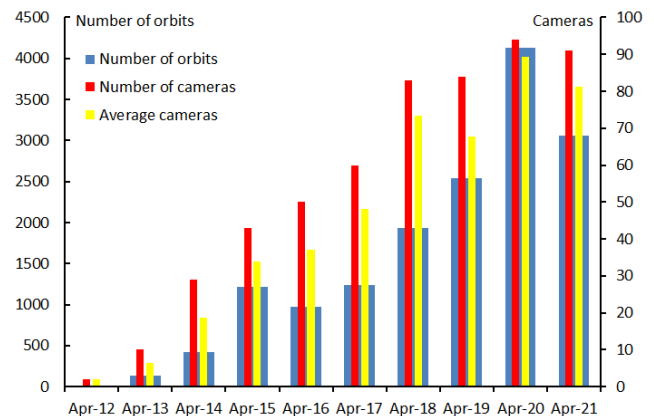


Figure 1 – Comparing April 2021 to previous months of April in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bars the average number of cameras running per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	6	11	4	2		2.0
2013	19	140	9	10		6.5
2014	19	421	12	29		18.8
2015	27	1212	15	43		33.9
2016	26	971	17	50	15	37.0
2017	28	1235	20	60	32	48.2
2018	27	1929	21	83	59	73.3
2019	29	2534	20	84	44	67.7
2020	29	4128	25	94	76	89.4
2021	28	3061	27	91	59	81.1
Total	238	15646				

3 Conclusion

2021 brought another month of April with in general favorable weather for the CAMS BeNeLux network. Just like in 2018, 2019 and 2020 clear nights during much of the Lyrid activity period resulted in large numbers of Lyrid orbits.

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 website¹⁴. The data reduction and orbit calculation for all stations is coordinated by *Carl Johannink*. The CAMS BeNeLux team is operated by the following volunteers:

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¹⁴ <http://cams.seti.org/FDL/index-BeNeLux.html>

May 2021 report CAMS BeNeLux

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A summary of the activity of the CAMS BeNeLux network during the month of May 2021 is presented. 4759 multi-station meteors were collected which resulted in 1503 orbits during 28 nights with a maximum of 82 operational cameras available at 26 different CAMS stations.

1 Introduction

The first weeks of May offer nice levels of meteor activity with the eta Aquariids in the early morning hours. The last couple of weeks get shorter nights while the meteor activity decreases to the lowest level of the year. With short nights, low activity and often poor weather this time of the year it remains a challenge to collect orbits. May 2020 was exceptionally favorable, but what would 2021 bring?

2 May 2021 statistics

May 2021 was an exceptional cold and rainy month with a lot of cloudy sky and therefore rather unfavorable weather for meteor work. Only 6 nights resulted in 100 or more orbits (against 18 in 2020 and 7 in 2019). Only three nights remained without any orbits (2 nights in 2020 and 2019). The best night of all was the last night of the month, May 31–June 1 with 151 orbits. During most nights multiple station events were recorded during clear spells at least where the cameras were kept capturing all nights.

In total 4759 multi-station meteors were recorded (against 11584 in May 2020 and 5886 in 2019), good for 1503 orbits (against 3226 in 2020 and 1825 in May 2019). This is the poorest result for this month since 2016 when the network had significant less operational cameras available.

The statistics for May 2021 are compared in *Table 1* with all previous months of May since the start of the CAMS BeNeLux network. The maximum number of operational cameras dropped to 82 against 93 one year ago and 84 in 2018 and 2019. The number of cameras that remained operational all nights with AutoCAMS decreased to 51 against 70 in 2020 and 53 in May 2019. The average number of operational cameras dropped significantly at 69.2 from 90.5 during May last year. Since the start of CAMS BeNeLux 232 nights in May allowed to collect as many as 12406 orbits during this month.

Figure 1 shows the drop in camera capacity and number of orbits compared to previous few years. Apart from the less favorable weather, the modest harvest in orbits can be explained by the fact that 11 cameras couldn't be used this month for various reasons while at some stations cameras weren't operated during several nights. The lack of camera capacity affected especially the northern part of the network where the coverage was rather poor during many nights.

The network could welcome Reinhard Kühn with CAMS 3802, an RMS camera installed at Flatzby in northern Germany close to the border with Denmark and pointed towards the North-Eastern part of the CAMS BeNeLux network.

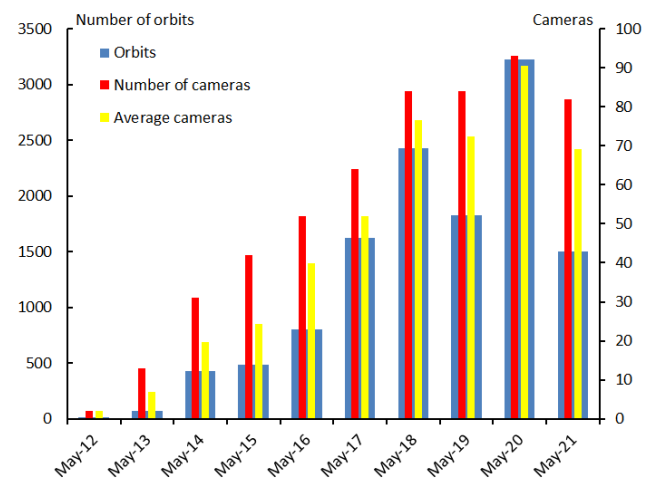


Figure 1 – Comparing May 2021 to previous months of May in the CAMS BeNeLux history. The blue bars represent the number of orbits, the red bars the maximum number of cameras running in a single night and the yellow bars the average number of cameras running per night.

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

Year	Nights	Orbits	Stations	Max. Cams	Min. Cams	Mean Cams
2012	5	13	4	2		2
2013	13	69	9	13		6.8
2014	22	430	13	31		19.7
2015	25	484	15	42		24.2
2016	26	803	17	52	16	39.9
2017	24	1627	19	64	22	52.0
2018	31	2426	21	84	64	76.6
2019	29	1825	20	84	53	72.4
2020	29	3226	24	93	70	90.5
2021	28	1503	26	82	51	69.2
Total	232	12406				

3 Conclusion

May 2021 was the poorest month of May since 2016. Although the weather wasn't exceptionally unfavorable with 28 nights that allowed to collect at least some meteors. A significant decrease in available cameras compared to previous year reduced the chances to record multi-station meteors. This combined with much less favorable weather resulted in less than half the number of orbits for May 2021 compared to 2020.

Acknowledgment

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¹⁵ <http://cams.seti.org/FDL/index-BeNeLux.html>

The making of AutoCAMS

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AutoCAMS is a term loosely used to describe the autonomous workflow processing of a CAMS station. CAMS has evolved from some simple batch scripts to help automate the daily processing of video files throughout the night to nearly full autonomous operation for months at a time.

The purpose of the NASA/SETI CAMS project¹⁶ is to confirm the known meteor showers and discover new ones. The project has proven to be accomplishing its original goals as well as revealing more information about the complex dust distribution in our solar system.

This purpose of this paper is to provide a history of AutoCAMS from the prospective of its original creator. AutoCAMS was originally a checklist style menu-based set of batch scripts or subroutines, run in a windows command shell console window, that would be performed in the order they needed to be performed (in computing, we call this a “workflow”). While the term AutoCAMS still refers to the workflow, it also refers to the subroutines and programs written to create an almost completely autonomous research project.

1 Introduction

AutoCAMS was originally a checklist style menu-based set of scripts or subroutines run in a windows command shell console window that could be performed in the order they needed to be performed (in computing, we call this a “workflow”). It was originally called CamsMenu.bat in 2011 (*Figure 1*). The menu included the ability to execute each

of the steps that needed to be performed from manually restarting capture to post-capture processing, to sending the results to the NASA server. The menu included the ability to execute each of the steps that needed to be performed. There is a main menu and a Utility menu. Eventually, it was renamed to AutoCAMS in 2011 when it was apparent that it was evolving into automating CAMS processing.

```

Administrator: [CamsMenu.bat] "D:\cams2_queue\RunFolder\CamsMenu.bat" - indent_call.bat
1. Choose target location      d:\cams2_board0\CAMS
2. Enter Camera                000525      Camera list:
3. Enter Capture Session      2020_03_22      Time: 23_19_08
3s. Choose capture session from SubmissionFiles
4. Choose CapturedFiles       [Files=14]     "d:\cams2_board0\CAMS\CapturedFiles\2020_0
5. Choose ArchivedFiles       [F/Det=0/]     "d:\cams2_board0\CAMS\ArchivedFiles\2020_0
                               23_19_08 [detect=]
Calibration Options for :
7a. Cal Update                based on: "d:\cams2_board0\CAMS\ArchivedFiles\2020\es\2020
9. Apply Cal to Archived      Latest Cal:    [9...]
9b. Test Apply                Detect Cal:    [GetApplyCalStatus.bat]
10. FTP_Confirmation          [Count: ]     ""
11. Edit comments.txt file
Submission dir functions:     ["" ]
13. Package Working dirs into SubmissionFiles dirs [13...] [submitted] [submitted...]
14. Choose Submission dir
15. Move SubmissionFiles dirs to working dirs [15...] [157b...]
16. Zip Submitted dir         [16...] [16a getzip]
17. Upload Zip via FTP [Submit] [17...]
. Enter choice:

```

Figure 1 – Original Cams Menu.

¹⁶ <http://cams.seti.org>

Circa 2006–2010, Peter Jenniskens (*Figure 2*), world-renowned meteor scientist, and member of the Fremont Peak Observatory Association, near Salinas, California, used to bring college students and interns up to the Observatory to teach them how to perform meteor shower observations and recording. He'd bring a group of people with lawn chairs and hot drinks and they'd set up and manually record meteors on the sky maps. He was teaching them an astronomy skill of observing meteor showers. Very often, Peter would also point his DSLR at the sky and record the showers with photographic evidence. At the time, I was a board member at the observatory and Peter and I had some discussions about his work. Sometimes, he would invite me to participate in broader campaigns in order to use the camera images from different locations so that he could triangulate the trajectories of the meteors. I was able to help with triangulation with my own photographic images from my house in Pleasanton, CA.



Figure 2 – Peter Jenniskens, leading scientist of the CAMS project.

It was probably 2007 when one night in the dark, Peter and I were discussing how he'd ideally like to be able to perform multi-site video triangulation using highly-sensitive and expensive WATEC 902 H2 Ultimate security cameras. It was during that discussion that I mentioned to him that it might be possible to configure a computer to have multi-port video cards and record video from multiple cameras per computer to a hard drive. I told him how I had a Windows Media Server computer with a capture card that had two video ports for recording two simultaneous NTSC TV channels at the same time to a hard drive, but that I had also heard about cards with four ports. About a year or so went by when Peter told me about his new research project, which he called CAMS (acronym for Cameras for All-sky Meteor Surveillance). Of course, they needed sites for triangulation and Fremont Peak could be the first. Peter and I were able to convince the FPOA board in 2008–2009 that it would be good for FPOA to have a real NASA/SETI research project associated with the FPOA (*Figure 3*).



Figure 3 – FPOA “Challenger” 1-meter f/3.58 telescope has been in operation since 1986.

During that time span, in 2008, Pete Gural, under contract from NASA for Peter Jenniskens wrote some C++ programs that perform capture, calibration, meteor detection, and so on, to run on BCSI Linux servers that had 4 port capture cards.

In 2010, we had attached the first 20 camera CAMS box to the East side of the FPOA observatory building and 20 coax cables were very tightly squeezed through a 4-inch conduit to the 5 Linux servers inside the observing room (*Figure 4*). No internet connection was provided. The servers were configured under contract from BCSI out of Colorado. The software for capture, calibration, and post-capture detection was written by Pete Gural. First light for FPOA was August, 2010 (*Figure 5*).

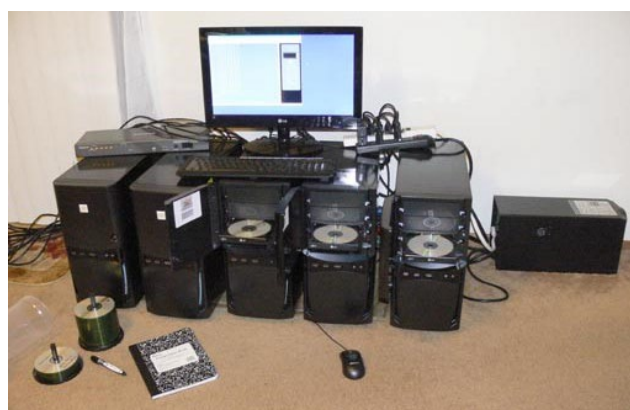


Figure 4 – 5 Linux based BCSI servers and equipment for a single CAMS station.

In 2011, Pete ported those Linux programs to Windows and made them available to Windows computer users in the form of what was called “single-CAMS”. AutoCAMS became a set of scripts that, among other things, called Pete's programs in the correct order and with command-line parameters that reflected the selected capture session. In essence, AutoCAMS was a wrapper around the programs developed by Pete Gural. In addition, AutoCAMS included

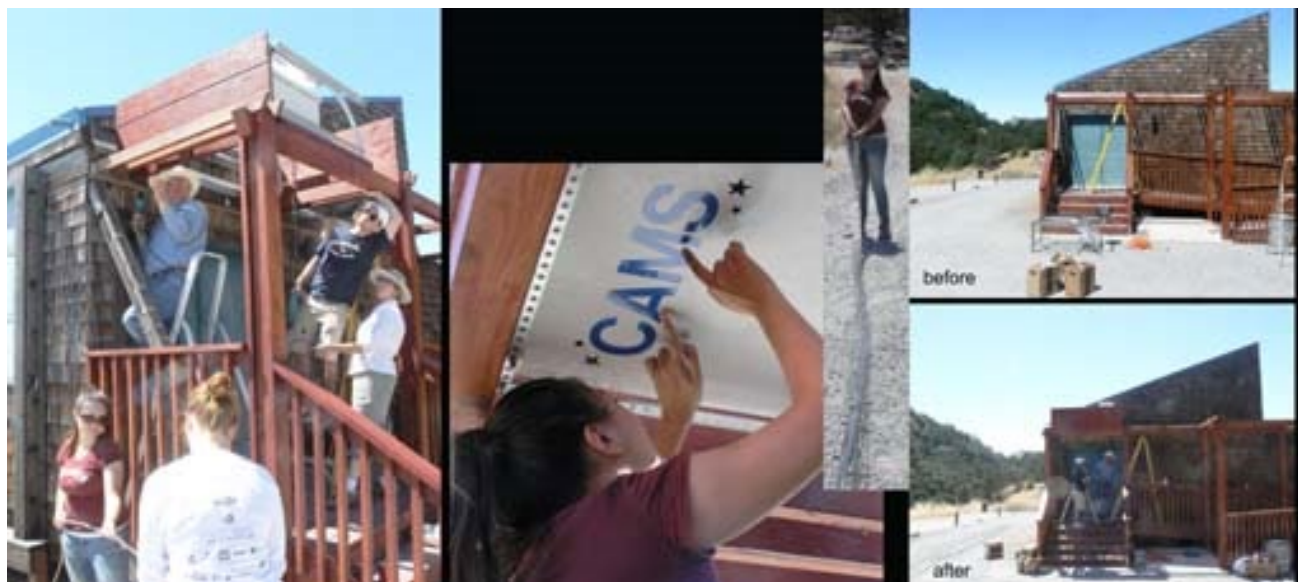


Figure 5 – July 2010, Work party for installing the first CAMS station at Fremont Peak, California.

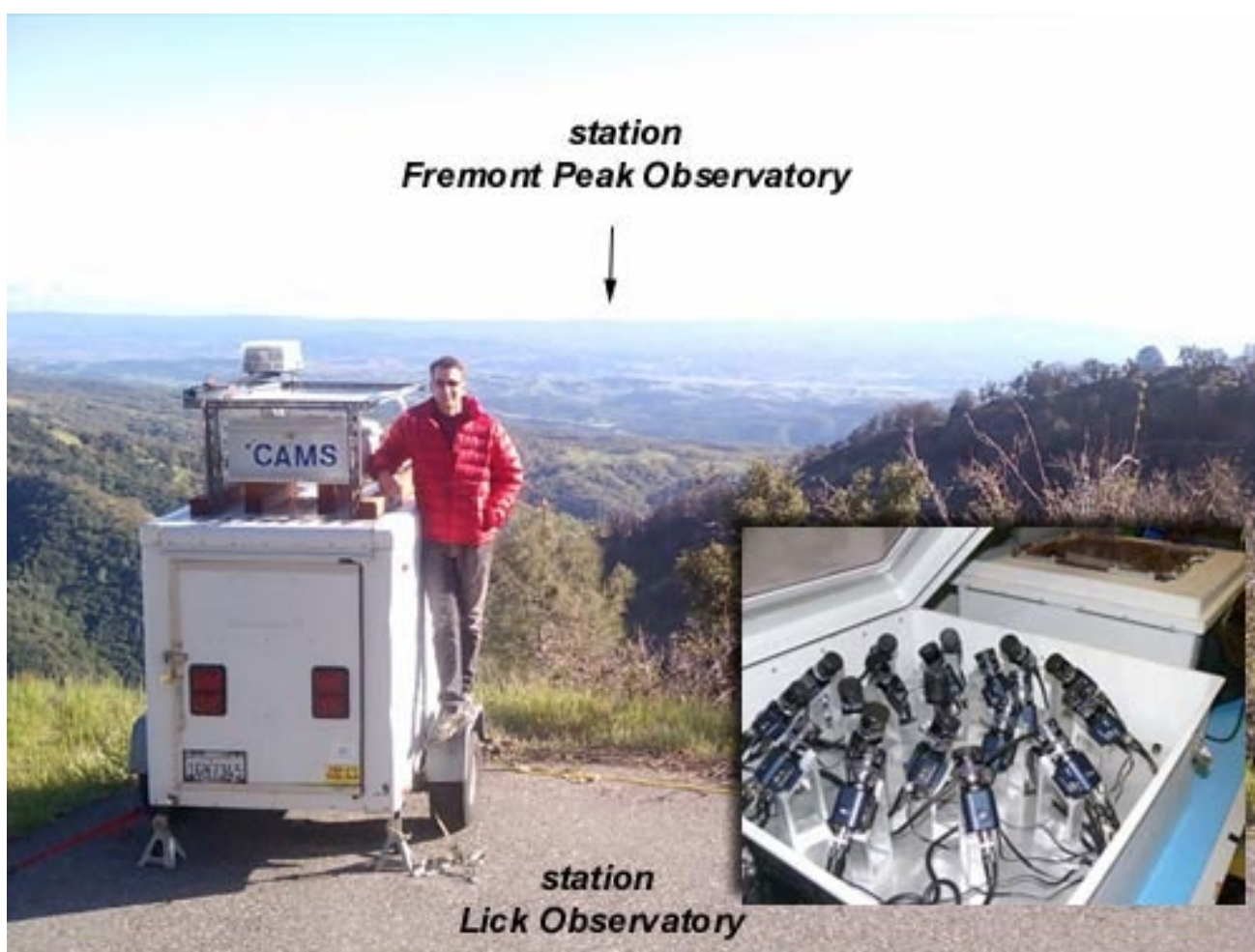


Figure 6 – Lick Observatory CAMS station (seen with Jim Albers) is about 70 miles from Fremont Peak, California.

several additional utilities and reporting facilities as it related to managing a CAMS site.

Fremont Peak’s overlapping stations were Lick Observatory site and Sunnyvale, CA (Figure 6).

Late autumn 2017, Peter J eventually replaced the 5-BCSI Linux-based servers per site at Fremont Peak, Lick, and Sunnyvale with the single windows-based computer. Where there were 5 BCSI servers for 20 cameras before, we now

have 1 computer with three 8-camera Sensoray boards with 20 cameras. And we put the current AutoCAMS system that we designed for the Single-CAMS sites.

2 Single-CAMS principles

With all the things that could go wrong with an amateur operated single-CAMS station, it was apparent from the

start that these three principles of single-CAMS should be adopted:

- Capture is the first priority. No matter what, capture.
- Don't send bad data to NASA.
- Avoid causing requests to resend data.

Capturing is indeed the single-most important function. If you capture but don't do the other stuff right away, you can always do it later. But if you don't capture, then you'll never be able to re-create what you've missed... the data is lost forever. If you are triangulating with another site, then if you don't capture, it makes the work that the other site is doing useless. There have been numerous times when it was raining or cloudy in the evening (but captured anyway), to find out that it cleared up not too much later and the station was able to contribute valuable data that night. In some cases, a fireball would be captured through a hole in the clouds. Originally, I had my camera set up on a tripod under my back patio. Eventually, I purchased a set of security camera enclosures so that I'd have more flexibility as to the pointing. Enabling the camera only when you believe that it is good enough clear sky works against this first principle and the data proves that point. Automation is the way to achieve the goals of this principle.

3 Evolution

I believe it was in June 25, 2011, I met Pete Gural (*Figure 7*) and Peter Jenniskens at the Fremont Peak observatory. They told me that Pete had just released his Windows version of

the Single-CAMS software that was used on the Linux based systems. Peter Jenniskens knew that I had a Webcam already, and that getting started would not be any great expense for me as a kind of test site. Also, Peter knew that I lived within the range of being able to overlap with the CAMS California network.



Figure 7 – Pete Gural.

```

[AutoCams.bat] "D:\cams2_queue\RunFolder\AutoCams.bat" - indent_call.bat
D:\cams2_queue\RunFolder\AutoCams.bat - CAMS MENU Vers 3.001

1. Choose target location      D:\cams2_queue
2. Enter Camera                Camera list:
3. Enter Capture Session      Time:
3s. Choose capture session from SubmissionFiles
3r. Migrate vers 2 cal files to vers 1 [redo]
3u. Migrate vers 1 cal files to vers 2 [undo]
4. Choose CapturedFiles       [Files=199] ""
5. Choose ArchivedFiles       [F/Det=214/] ""
   [detect=]
6. Check Skipped Frames and dropped frames [/v] [/ok]
Calibration Options for :
7a. [Obsolete] Cal Update      based on: ""
7b. Auto Calibration Update    based on: "" [7b...] [7-9]
7c. Auto Cal with prompts      based on: ""
7d. Manual Calibration         based on: whatever file you choose
7e. Meteor Cal Nudge
7f. ListCalFilesForDate
7g. Convert all CAL files from 2x to 1x
7h. Convert all the CAL files from 1x to 2x

9. Apply Cal to Archived      Latest Cal: [9...]
9b. Test Apply                 Detect Cal: [getApplyCalStatus.bat]

10. FTP_Confirmation          [Count: ] ""

11. Edit comments.txt file
12. Apply Cal to Confirmed     Confirmed Cal: [12b get status]

Submission dir functions: ["" ]
13. Package Working dirs into SubmissionFiles dirs [13...] [submitted] [submitted...]
14. Choose Submission dir
15. Move SubmissionFiles dirs to working dirs [15...] [157b...]
16. Zip Submitted dir         [16...] [16a getzip]
17. Upload Zip via FTP [Submit] [17...]

A. Autonomous mode          FA. Fix Detect Paths Archived [FixDetectPaths.bat]
R. Reset                    FC. Fix Detect Paths Confirmed [FixDetectPaths.bat]
S. Sort Detect               ClearError. Clear recent error message
U. Utility Menu             ZipLogs. Zip the logs files "D:\cams2_queue\logs\AutoCams_full.log"
Q. Quit
Test1. Test One Camera      Test2. Test Two Cameras

Last error msg:

```

Figure 8 – Screenshot of AutoCAMS.bat checklist menu. Notice how steps 1-17 are in the order they should be performed. Detection is actually #45 on the utility menu, since at that time we were using real-time detection.


```

AutoCams.bat "D:\cams2_queue\RunFolder\AutoCams.bat" -indent_call.bat

CAMS MENU Vers 3.001

31. Command Prompt [ D:\cams2_queue\RunFolder> ]
32. Check for bad FF*.bin files [CheckBinFileSize.bat]
33. Delete bad FF*.bin files [CheckBinFileSize.cleanup.bat]
34. Check free disk space [CheckFreeSpace.bat ~0,2]
35. List all drives [ListDrives.bat]
36. Validate Calibration files for "" [ValidateCal.bat]
36b. Get Pointing for Date [GetPointingForDate.bat "" ]
36c. Get ALL Pointing for Camera [Get_ALL_PointingForCamera.bat ]
36d. Get Pointing for Detect [GetPointingForDetect "" ]
37. Meteor Count Working dirs [MeteorCount.presubmission.bat ]
38. Meteor Count Submitted dirs [MeteorCount.submitted.bat ]
39. Display CapturedFiles info [GetFFDirectoryListing.bat]
40. Display 3 days' CapturedFiles [GetCaptured.bat]
41. Display 3 days' ArchivedFiles [GetArchived.bat]
42. CheckTwilight for "Captured Date" [CheckTwilight.bat]
43. Launch Capture Script [LaunchCapture.bat] [43p Capture8_postprocess]
44. Multi-tasked Meteor Scan [MakeCaseListing.bat] [44...]
44b. Merge Multi-tasked Meteor Scan Files [MergeCaseFiles.bat]
45. Single-threaded Meteor Scan [FTP_Reprocess.exe]
45b. Post MultiScan Processing [PostMultiScanCalibration.bat]

47. Calculate Day Of Week for ""
48. Save Configuration ["D:\cams2_queue\RunFolder\AutoCams.bat.ini"]
49. Night Mode [toggle on]
50. List sessions that need processing [Working CapturedFiles dir]
51. List Unzipped Nights [Not zipped]
52. List Untransmitted Zips [Not transmitted]
53. Make Movie from ConfirmedFiles [MovieFromDetect.bat]
54. coincidence [Coincidence.bat "" ]

55. Single Camera Live Viewer 59. Adjust FF timestamp (extreme caution)
56. Single FF movie 60. Cal Summary
57. Camera Movies [deprecated] 61. Pre-DVD Archive
58. Mosaic 62. Split dual capture

70. Thumbnails 72. Single File Viewer (first file)
71. Spectral Prescreen 73. Single File Viewer (Choose starting file)

80. Migrate from Cams 2.x [redo]
81. Migrate back to Cams 2.x [undo]

M. Main Menu
Q. Quit

Last error msg:

```

Figure 9 – Screenshot of AutoCAMS utility menu.

Brentwood, CA: August 10, 2011, was first light for the first Single-CAMS. Starting capture manually, and performing all the post-capture processing the next morning was obviously time-consuming and onerous to do manually. The first piece of automating CAMS was done the first or second night – creating a scheduled task in Windows to launch a script that launches the capture program. That way, I wouldn't miss any part of the night due to forgetting to start capture or just not being home in time to start it. So, for me, CAMS has been automated from the beginning. AutoCAMS evolved from that point.

Pete modified his programs so that it would take command line arguments from scripts in order to parameterize the startup. I also helped Pete design some multi-threaded programming so that he could do capture and meteor scanning at the same time, which Pete has implemented brilliantly in his capture programs and other programs he has developed since then. (However, in the evolution of AutoCAMS, we later disabled the real-time meteor detection (with INI file settings) because it is not resilient to power outages and other interruptions and we had to figure out a way, outside of capture, to handle power interruptions). Also, Pete Gural improved the speed of detection by about 70×, which made it feasible to do post-capture detection in a reasonable amount of time.

AutoCAMS was originally called “CAMS Menu”. That's because it was a menu that executed necessary CAMS functions by entering the checklist item number (*Figures 8 and 9*). A few months later, it was renamed to AutoCAMS. AutoCAMS started as a simple set of Windows batch scripts and Windows scheduled tasks. When batch language was too slow, a batch script would create a VBScript, which

was called and executed. There are only about 8 of those VB scripts. I wanted AutoCAMS to be “open-source”. The reason that batch script language was chosen was so that anyone, in any time zone or location in the world, at any time of the day or night, could modify them if there was a problem. I could have written AutoCAMS in C, C++, Java, or VB, since I have decades of experience in those languages, but I chose Windows Batch language because nothing would need to be installed on people's computers and there shouldn't be versioning or DLL or runtime library version issues. With the other languages, not everyone would be able to program, compile, and link without having to deal with licensing issues, training, and such. From 2011 – 2017, the scripts evolved into over 100+ batch scripts that would call each other to get the job done. By 2021, there are over 300 script files with over 90000 lines of code. Over time, some of the scripts have become obsolete and no longer used. Some effort should eventually be put into removing all that are no longer useful. One of the first scripts was LaunchCapture.bat, which was called by a scheduled task.

Then Jim Wray (*Figure 10*) joined the CAMS project and first light for his site was December 13, 2011, starting with a single old Wattec camera, just in time to capture the annual Geminids meteor shower, and he has been providing data since then. Jim is the author of the 1967 book "The computation of orbits of doubly photographed meteors", which he wrote when he was director of the Institute of Meteoritics at the University of New Mexico in Albuquerque. Jim's site was over 100 miles from my house (until I recently moved to Texas), and it triangulated well with me, Lick Observatory, and eventually Sunnyvale. With

Jim's station being the first remote station, AutoCAMS had to evolve to be more user-friendly and reliable.



Figure 10 – Jim Wray.

2012 saw CAMS sites installed in the BeNeLux sites (that's Belgium, Netherlands, and Luxembourg) started with 4 cameras. By February 8, 2014, there were 30 BeNeLux cameras operational.

October 28, 2013, AutoCAMS was configured and tested in Sunnyvale for the professional New Zealand arrays before shipping them out. This was the first time that the single-CAMS software and AutoCAMS was used on one of the professional CAMS stations. The boxes arrived in New Zealand December 12, 2013, one damaged during transport. These stations were the last to use the expensive 16-port \$1500 Sensoray board. The 8-port boards are only about \$220 each.

In 2014, Jim Wray came up with the idea that we should be able to prove that cheap 1/3-inch cameras could now be sensitive enough to be used for CAMS data collection. So, Jim purchased 2 eight-port Sensoray boards (about \$220 each) and 18 of those cameras (average about \$45 each), not all the same model and brand, and I purchased a 4 port Sensoray grabber and a few different models of Chinese based 1/3" cameras and he and I tested the efficacy of using those cameras with CAMS so that people would be able to set up sites with more cameras for less money than using the Watecs. The Watec cameras cost about \$400–\$500 plus the \$120 lens, depending on where you buy them from, availability, tariffs, etc. A typical 16-camera site would commonly top \$10000 using the Watec cameras. Some of these 1/3" based cameras purchased from Ali-Express were as low as \$25 each. Pete Gural modified his FTP_CaptureAndDetect program and produced FTP_Capture8AndDetect.exe and FTP_Capture4AndDetect.exe so that we could run our tests. Jim ran two Sensoray boards at the same time for several months and we got good results. A paper was published at the 2014 conference in Giron,

France (Samuels et al., 2015), that shows how we can attain almost equal sensitivity to the Watec cameras (+5.9 meteor limiting magnitude) when the Watecs are using f/1.2 lenses and the 1/3" cameras are using f/0.8 lenses. Jim had f/0.75, and f/0.9 lenses and I had originally f/1.2 lenses and eventually switched to f/1.0 lenses. However, f/0.8 lenses are not readily available in the 1/3" format, so we typically settle for f/1.0 lenses. Jim and I also calculated the spatial resolution for an average Watec camera with a 12mm lens pointing at roughly 45 degrees elevation. We came up with about 100–110 meters per pixel at the 90 km layer at that distance. Therefore, we aimed to achieve that same spatial resolution with the 1/3" cameras. Doing the math, we decided to use 12mm lenses when pointing at 26 degrees, 8mm lenses when pointing 45 degrees, and 6mm lenses when pointing above 74 degrees (Figure 11).

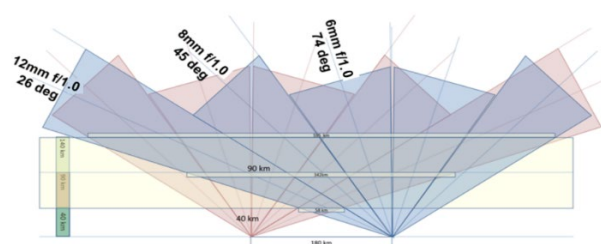


Figure 11 – This shows how to tune the focal length to match the elevation angle. On the right, we show how two 16 camera stations, when designed for each other, can achieve full-sky coverage.

That strategy achieves full-sky coverage from 13 degrees elevation to 90 degrees.

Jim's 16-camera station was the first array with 2 Sensoray boards with 16 cheap 1/3-inch cameras in 2014. His site contributes almost as many meteors as any other around the world. Which proves its sensitivity.

San Mateo College became the third single-CAMS station December 23, 2011.



Figure 12 – Steve Rau.

Steve Rau (*Figure 12*), in BeNeLux, had been trying to use the AutoCAMS scripts for his stations and a few others. He believed that automation was the key to getting consistent and reliable results.

4 CAMS 2

During 2015–2017, there was a long-protracted period when I was away and it was nearly impossible for me to support remote CAMS stations. I either had very poor and intermittent access through a mobile hot-spot or I was at work behind a corporate firewall, which blocked my ability to support CAMS sites. Steve Rau stepped in and helped out quite a bit and he saved the day, taking over for me in keeping everything up and running. It was during this period (circa 2016–2017) when Pete Gural released CAMS 2. CAMS 2 expanded the camera number format from 3-digit to 6-digit camera numbers and he changed the file format and a few other things that made the AutoCAMS scripts incompatible. After Steve got tired of waiting for me to return and fix AutoCAMS to adjust to CAMS 2 format changes, he reverse-engineered the AutoCAMS scripts using Delphi – Pascal. You could say that the “open-source”

nature of AutoCAMS was successful due to his ability to do that.

5 AutoCAMS 2

Steve’s goal was to use Delphi/Pascal and create parity with the AutoCAMS checklist style menu system while making his system compatible with Pete’s new CAMS 2 format. As he worked on things, his understanding of how I had coded the algorithms increased and he started coming up with good ideas on how to improve the workflow. Eventually, Steve had LaunchCapture.exe and CamsGUI.exe working, which appears to be what he still calls “AutoCAMS” in his documentation. I wished there was a way to keep Steve’s code open-source too, but that is entirely up to Steve.

I eventually returned home from my trip and I started working closer with Steve to get everything working smoothly. One of the issues we had was that the BeNeLux workflow was different than the rest of the world’s CAMS workflow. This is in part because, in BeNeLux, they were required to do manual meteor confirmation. This made it impossible to fully automate and run autonomously. So, there were differences between his system and mine.

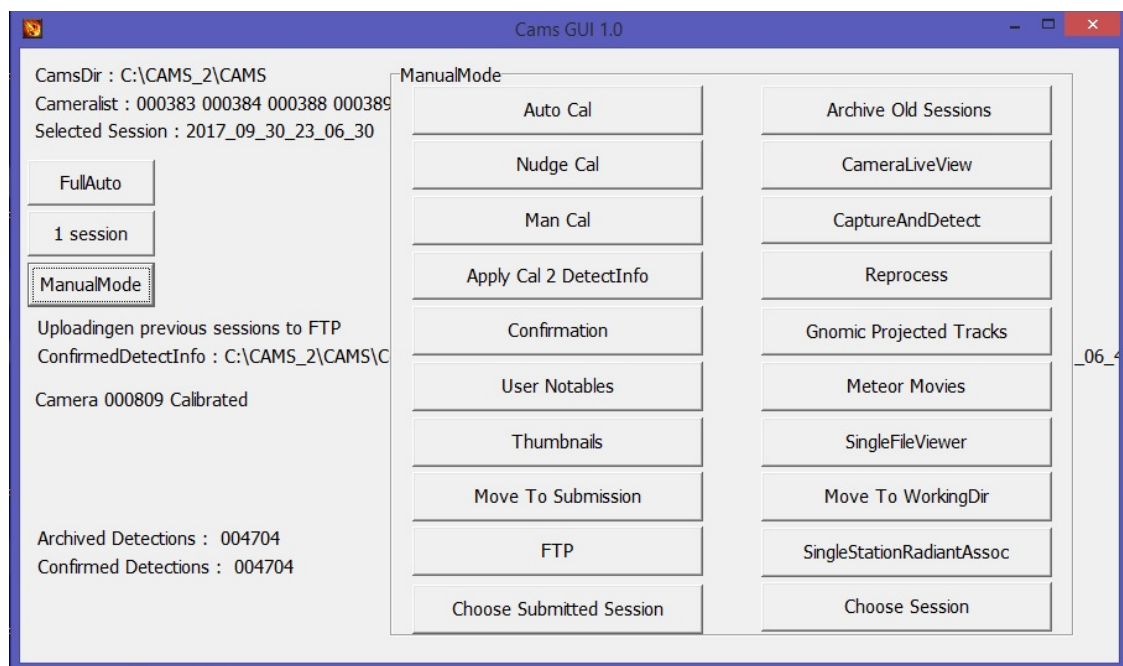


Figure 13 – Screenshot of CamsGUI.exe. Notice how the buttons are in approximately the same order... to create parity with AutoCAMS.bat. Reprocess is the same as Meteor Scan or Meteor Detect.

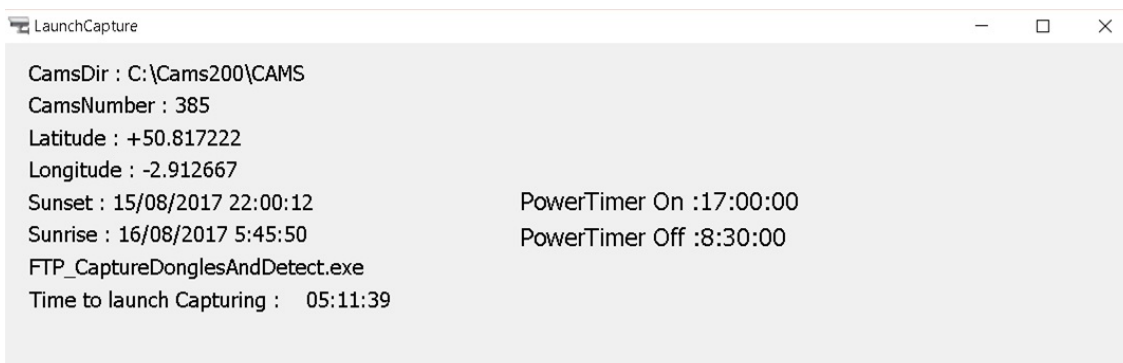


Figure 14 – Steve’s LaunchCapture.exe for board 0 waiting to start the capture program.

We collaborated and we made the necessary changes to allow us (non-BeNeLux) to be able to use Steve's LaunchCapture system. So BeNeLux uses the LaunchCapture.exe and CamsGUI.exe to perform all of their duties, where there are some manual steps required to perform using CamsGUI each day. They don't use any of my AutoCAMS scripts anymore. The rest of the world (except DC and Sunnyvale) use a hybrid of LaunchCapture along with my AutoCAMS scripts, without much use of CamsGUI, for full autonomous operation. So, what should we call them? I think they can both be called AutoCAMS, since to me, AutoCAMS means to automate CAMS operations. How do we differentiate one from the other? I'm not quite sure and it probably doesn't matter.

Ideally, all configuration changes are governed through .ini files. Steve and I worked together to decide on which variables to use for these configuration variables and how they'd be used. Steve's LaunchCapture.exe and CamsGUI.exe programs are governed using a CamsGUI.ini file. There is also a backup of CamsGUI.ini that is used in case you lose network connection while modifying it. There is one of these INI files for each CAMS instance. My AutoCAMS scripts now mostly use the "...\cams2_queue\RunFolder\Cams2Global.ini" file, although they do read the CamsGUI.ini file variables and adapt accordingly. The non-BeNeLux systems do not use CamsGUI.exe very often much. But it is still there and configured.

Steve and I worked out a way for his program to deal with multiple Sensoray capture cards, as each board would have its own "instance" of LaunchCapture.exe and CamsGUI.ini. Since none of the BeNeLux stations had multiple Sensoray boards at the time, it was difficult for Steve to visualize the issues and test his code. So, you have to appreciate what Steve accomplished. Steve's solution was for his LaunchCapture program to keep track of how many boards there are running and, during post-capture processing, one LaunchCapture instance sleeps until the next higher one ends before it starts doing its own post-capture processing.

My thoughts about how the workflow should work also evolved over time as to how to make the system more resilient to power outages and unexpected restarts.

6 LaunchCapture

Like the original LaunchCapture.bat script, LaunchCapture.exe is a program that is somewhat sophisticated. Unlike the original LaunchCapture.bat script, which was a script called by a scheduled task, the LaunchCapture.exe program is called directly from a scheduled task. There will be one scheduled task for each CAMS instance. A CAMS instance is a copy of the entire CAMS working directory tree, complete with a copy of the main capture programs, DLL libraries, star database, CAL files, runtime libraries, and a few other things. There is no need in a CAMS instance to use my scripts or a RunFolder, my .BAT scripts, or configuration files to be copied to the CAMS instance directory. Those files are in a separate

common directory structure used across all CAMS instances.

Steve's LaunchCapture.exe program does a lot. Let's just outline its workflow:

1) It launches at the same time each afternoon (around 5 pm), reads the configuration files, and it checks the time and the sun-angle defined in the CamsGUI.ini file. The SunAngle variable defines the angle of the Sun when we want to start capture. Effectively, we want to wait until it is dark enough to capture before launching the FTP_Capture8andDetect.exe programs. Pete Gural's FTP_Capture... programs do the same thing; except they interfere with the user's keyboard, once a minute, during the time between when it started and the time capture actually begins. LaunchCapture.exe's method of waiting for the Sun angle is a workaround for an issue with Pete's waiting algorithm. An example is like this: Let's say it's June 20 – shortest night of the year. If we run LaunchCapture at 5pm each day (a time before it is astronomically dark all year), then the time to start capturing video would be, let's say, 9 pm. So, for 4 hours, the program needs to wait before cameras start capturing. Meanwhile, you are free to use the computer during this time.

2) When it is finally time to start capturing, LaunchCapture awakens, and calls the FTP_Capture... program specified in the .ini file, with the correct command line arguments. Then it does a well-behaved wait until the child capture process ends (that will likely be just before sunrise the next morning, as determined by Pete's capture program using the Sun angle passed to it from LaunchCapture). While it is waiting, LaunchCapture instance is not consuming any CPU resources. It is not polling, it is waiting.

3) Whenever capture ends, LaunchCapture awakens and performs post-capture processing from the highest board number to the lowest. It starts with the most recent capture session in the CapturedFiles directory, then it works backward and performs post-capture processing for any backlog of unprocessed capture sessions until the CapturedFiles directory is empty.

4) LaunchCapture's post-capture processing is done in phases for each capture session for that board:

- Validation
- AutoCal
- Detection
- Apply calibration to detect file
- Manual Confirmation (only for BeNeLux users)
- Migrate to SubmissionFiles
- Create the Transmission zips (only for BeNeLux users)
- Upload the Transmission zips (only for BeNeLux users)
- Archive (only for BeNeLux users)

Once it is done with the Apply step, it "moves" all the files to a directory that uniquely identifies the board number and the capture session under SubmissionFiles. Each

SubmissionFiles directory will have subdirectories for ArchivedFiles, CapturedFiles, optionally ConfirmedFiles, FTP, and Logs. If you are a BeNeLux user, you are required to use the CamsGUI program to launch the Confirmation program, do the confirmation step, and then manually upload the files to the server (by selecting the appropriate button in CamsGUI). If you are not a BeNeLux user, then confirmation is not performed and all the steps are handled autonomously.

Then it repeats these steps for each capture session if there is a backlog of capture sessions remaining in the CapturedFiles directory.

When it is able to complete all its work, then the CapturedFiles directory for that CAMS instance should be empty.

5) Once LaunchCapture has completed post-capture processing for all the capture sessions in the instance's CapturedFiles directory, it ends.

6) Once LaunchCapture ends, if there are multiple CAMS instances, the remaining LaunchCapture instances will have been polling the system processes every 5 minutes to see how many LaunchCapture.exe instances there still are.

7) If there are multiple CAMS instances, there will be 2–3 instances of the LaunchCapture.exe process to start with. When each LaunchCapture.exe process started, it kept a count of how many other LaunchCapture processes there were at the time and it assigned itself a number based on that count. The post-capture processing happens from the highest CAMS instance to the lowest (as determined by board number starting with 0). When a higher board number's LaunchCapture instance is performing post-capture processing the lower board number's LaunchCapture instances poll once every 5 minutes to see if the instance count has dropped and if it is that LaunchCapture instance's turn to run.

8) If the instance count drops to its assigned count number, then that LaunchCapture instance awakens and performs its own post-capture processing, using the same steps as above.

Non BeNeLux sites have been using a hybrid of Steve's LaunchCapture.exe with the addition of my AutoCAMS scripts, which are now all situated in the "...\cams2_queue\RunFolder". Unlike with LaunchCapture.exe and CamsGUI.exe, the queue system is one system for the entire computer, no matter how many CAMS instances there are. Each CAMS instance location is specified in the Cams2Global.ini file, which contains the variables used by the queue-based scripts to locate all the CAMS instances.

7 Storage management/archiving

A huge issue to deal with is the massive amount of data produced by a CAMS station. Each camera can produce about 6.5 GB of data files during capture each winter night. Less on summer nights. While most of the BeNeLux sites didn't have 16–20 camera sites with dual or triple Sensoray boards, most of my sites did. By "my sites", I am only using that term as a way of referring to the stations that I've been managing. With a 20-camera site producing over 120 GB per night, and with some of their cameras being noisy because of faulty wiring, even a 6 TB hard drive couldn't hold enough archived data. With a background in working for EMC, which was a leader in the n-tier storage world, I realized that AutoCAMS needed similar storage management – some 2-tier or 3-tier storage management.

You see, I kept getting pulled into fixing people's disk-full issues. So, I redesigned the Archiving scripts and protocols to keep the data management under control using an n-tier strategy. Originally, we would wait until MaxDaysToKeep INI file parameter to trigger culling of the CapturedFiles directory. Culling the CapturedFiles directory at that time was possible because a copy of any FF file that had an event (meteor) was stored in the ArchivedFiles directory. Then we would ZIP the remaining files of the capture session into a zip file and move it to the archive drive/directory. That way, if it was ever needed, we could unzip a capture session and do research on it as needed. Ideally, the archive drive is a removable hard drive that, when full, can be swapped out for a new one. The Arizona stations were the first to

```

Select Skipping - Not Removing: "f:\cams_Archive\archived_SubmissionFiles\2018_08_15_924_02_55_01.zip"
done with ZipCams2FromFTP.bat
[CALL archive_allbut_n_sessions.bat:REMOVE_ARCHIVEDIR_SUBMISSION]
Culling the archive of old archived sessions in order to save disk space.
Only remove archived_SubmissionFiles zips that:
- Have aged out beyond bat_CAMS2ARCHIVE.MaxYears_archived_SubmissionFiles
- Exist in the archive.
Iterate through all the "cams_Archive\archived_SubmissionFiles" dir
and remove all that are older than "bat_CAMS2ARCHIVE.MaxYears_archived_SubmissionFiles".
The default is 2 years. Therefore, if it's 2020, we'd delete all that are
2018_12_31 and older.
[archive_allbut_n_sessions.bat:LOGEXEC] "E:\cams2_queue\RunFolder\du64.exe" -nobanner -q "f:\cams_Archive\archived_SubmissionFiles\2018_08_15_924_02_55_01.zip"
Files: 6945
Directories: 30
Size: 754,987,321,073 bytes
Size on disk: 755,011,469,312 bytes
[RETURN archive_allbut_n_sessions.bat:LOGEXEC] [errorlevel=bat_logexec_returncode=0] ["E:\cams2_queue\RunFolder\du64.exe"
bat_submission_file_full=f:\cams_Archive\archived_SubmissionFiles\2018_08_14_916_02_55_49.zip

```

Figure – 15 Screenshot of the Archive program just getting started. This Mars Hill station has drive E: as the CAMS drive and F: as the Archive drive.

implement my external archive drive design, and that has proven to be effective... and recommended. Eventually, I learned that the archive scripts should instead create the zip file as soon as it was possible instead of waiting `MaxDaysToKeep`. It was only the culling that needed to wait. Then I leave a flag file, marking the capture session as “`AlreadyArchived.txt`”, so that it does not need to be zipped and archived again – only the session’s `CapturedFiles` dir need to be culled. This makes the archiving more resilient to power outages, aborts, and other interruptions and it protects against not getting a chance to run when there is a backlog (*Figure 15*).

To re-archive a session, simply delete the `AlreadyArchived.txt` file from that capture session’s `CapturedFiles` directory. If needed, you can always unzip the archive zip file to its location in the `SubmissionFiles` directory.

Using this storage management scheme, we have some 16 camera stations with 1 TB hard drives that have run for months or nearly a year, without having to intervene. Note: 16 camera stations are difficult if they only have 1 TB of storage, so we recommend obtaining more storage for the CAMS drive in those situations. Sadly, we can’t archive all the data like this forever. We have also found that we cannot depend on humans to periodically cull their archives or to move them off-site. So, I also had to implement the ability to automate the culling of very old archive zip files when the hard drive starts to fill up with archive files. We have automated this too. We delete everything that is a too old (about 2 years), from the archive’s `Transmitted`, `CAL`, and `SubmissionFiles`. We use the INI file setting `[CAMS2ARCHIVE].MaxYears_archived_SubmissionFiles`, and `MaxYears_archived_TransmittedFiles`. The `CAL` files are always archived when they are older than `MaxDays_Cal` days.

8 Uploading

The upload routines are another set of routines that have evolved over the years. When we upload to the NASA server, we have always collected just a very small part of

the capture session, compressed it into a zip file, and uploaded it to the NASA server to a directory specific to the station’s CAMS network. This is why a reliable internet connection is required. That file is called the “transmission zip file”. The file consists of the detect file, `CAL` files that were used in this session, local-midnight `FF` files, and a few other files that indicate how it was configured during that session. An 8-camera zip file is typically about 2 MB – 5 MB. With a noisy camera, these can be 50 MB – 80 MB.

Originally, we had used the Microsoft FTP program to upload the transmission zip files to the NASA server. However, we learned that we needed a tool that is more resilient. FTP had many issues and was not reliable at all. We switched to WinSCP for that. It performs retries and it returns error codes. But, WinSCP can still fail. We have encountered numerous situations where the FTP upload failed for all manner of reasons. The reasons range from local network being unavailable, to power outage in the middle, to NASA server being down for a few days. I wanted to design a system that could handle this automatically. So, I developed the “queued” upload (*Figure 16*). Regardless of the ability to upload successfully, all transmissions that are ready are placed in the queue directory. Along with the zip file is an MD5 hash file for that zip file. (A hash file is a small text file with a number that uniquely represents the contents of a file. It uses cryptographic algorithms to come up with the hash number). The upload script creates a text file that lists all the transmission zip files in the queue. Then it sorts them and then uploads them from oldest to newest. Once a transmission zip file is uploaded, it is immediately downloaded to a local temp directory for validity testing. For validity testing, we rehash the downloaded zip file with MD5 and compare the two before/after hash files. If they are different, then we know the file got corrupted and we move on to the next transmission zip file, leaving the original transmission zip still in the queue, since we don’t really know the reason the upload failed. The failed zip file will be handled on the next go-round. If the MD5 matches, then the temporary zip file is unzipped. If the unzipping

Name	Ext	Size	Date
[.]	<DIR>		05/30/2021 15:17
[Logs]	<DIR>		05/29/2021 12:02
[RunFolder]	<DIR>		05/29/2021 11:50
[Temp]	<DIR>		04/22/2021 09:49
[Transmitted]	<DIR>		05/30/2021 15:17
[Updates]	<DIR>		01/24/2019 17:50
[weather]	<DIR>		01/15/2020 12:59
2019_01_19_000549_01_53_41_01.zip		5,136,088	01/19/2019 11:30
2019_01_19_000549_01_53_41_01.zip.md5.txt		69	01/20/2019 03:00
BytesThisBillingCycle.txt		216	03/27/2020 11:29
cams2_queue.txt		35	05/30/2021 15:19

Figure 16 – `cams2_queue` directory with one transmission zip (not yet transmitted) and its corresponding `.md5` file. Also shown is the `cams2_queue.txt` file with the name of the zip file. Once upload is verified, the zip and its `.md5` file will be moved to the `Transmitted` directory. All the scripts are placed in the `RunFolder`.

function fails, then we know that the zip file is corrupt in some other way. Otherwise, the upload succeeded. If the upload succeeded, then we upload the transmission zip files .md5 file to the NASA server and then move the transmission zip file and its .md5 file into the Transmitted directory. The people at NASA/SETI could write scripts such that if a zip file is present but its matching .md5 file is not present, then they'd know either the zip file on the server is corrupt or it is not finished uploading – in other words, they shouldn't use it. They should be able to use the .md5 files to do their own hash-check before incorporating the data into the day's Coincidence processing. Before a zip is added to the queue, the Transmitted directory is checked to ensure that it is not already there... to avoid uploading it a second time. If you really want to upload it a second time, then you must delete its md5 file and zip file from the Transmitted directory first.

This protocol is not too dissimilar to the Amazon AWS S3 upload protocol (a fact not discovered until years after I developed it). However, since Amazon's server is based on web services, Amazon avoids the download step and just compares the hashes. We can't do that because our server is just a dumb FTP server. Because of that, Amazon AWS S3 upload protocol is much faster. So, I had to come up with a different workaround with all the logic on the client-side. Once the queue is processed, we wait about an hour and then check the queue for any remaining zip files in the queue directory. The queue might not be empty due to failure to upload one or more zip files the first time or, while we were processing the queue, other scripts had completed post-capture processing and new transmission zip files would be available in the queue. If the queue is empty, then uploading is done for that day. If there are still zip files in the queue, then we keep trying every hour until 3 pm, when we need to start getting ready for the next night's capture.

Two other features that were designed with our uploading protocol, one is that the zip files that we upload can be sequenced with a sequence number suffix. We might need this if we had to upload to a server that was read-only. The other feature is the ability to send split zip files. A split zip file is a zip file that is sent in small chunks and reassembled by someone at the receiving end. This prevents the need to re-transmit very large files in the case of an upload failure. At some sites, it is more likely to be able to consistently transmit ten 2 MB files than one 20 MB file. And if the 20 MB file had an issue during the transmission, only the failed split files would need to be retransmitted. Both these features of the protocol are built-in to the uploading scripts; however, we almost always disable them in the INI file. Especially since, at the server end, they have not written the code to be able to handle sequenced file names or to reassemble the split zips.

This protocol has proven to be reliable and resilient. Anyone else, such as RMS, could adopt a similar protocol to ensure reliable uploads.

What's cool about this approach is that if there is a problem, then it kind of fixes itself. We recently had an issue at

Fremont Peak, where there was about 1.5 months of data that had not been processed. I don't remember the exact reason why. But once the problem was resolved, the AutoCAMS routines simply started working as they should. It took 7 days for the system to automatically catch up by itself. One of the issues we were having at the time was that the cameras had gotten so noisy, that each capture session was expanding to about 200+ GB and taking too long to do post-capture processing. We fixed the problem with ground-loop baluns, because the wiring was already in place. However, moving forward, using Cat6 with Video Baluns at each end instead of coax with ground loop baluns is recommended.

9 Unique naming convention

A lot of thought was put into the naming convention for the archives and the transmission files that we upload to NASA. This is something that has also changed and evolved from 2011 – about 2014. The naming convention is important because (A) it must allow us to upload multiple sessions in a night in case there were power glitches or other restarts, either expected or unexpected; (B) it had to allow these multiple uploads without them overwriting previous uploads; (C) it allows the Coincidence process to include all of the capture sessions, no matter how short, for its triangulation procedure; (D) a similar naming convention was created for the archive files.

For capture sessions, transmission zips, and archive zips, the convention is to use the capture session start time with a unique camera number:

“yyyy_mm_dd_<camera>_hh_mm_ss.zip”.

We separate the start date from the start time with the camera number in order to facilitate sorting and grouping. For “camera”, we use just the first 6-digit camera number for the CAMS instance. The files do not need to have the entire camera list as we once tried. Neither do they need the first and last camera numbers. All we are trying to accomplish, and this is important, is to come up with a unique name that does not conflict with a file name from our own or from another site. So, for other capture session-related files, such as a detect file, a unique naming convention uses something like this:

“[prefix]_yyyy_mm_dd_[camera]_hh_mm_ss_[suffix]”

where <prefix> is the name of the file, such as “FTPdetectinfo”. <suffix> would be any other information that needs to be conveyed and/or the type/extension of the file. It's important to add a “.ccc” extension on the file so it can be sorted, grouped, and/or associated with an appropriate application. The CAMS date/time format uses only underscore “_” as separators instead of “:” or “.” or “;”, etc. That way, no localization of parts of dates and time values is required. “yyyy_mm_dd” would be the capture session UTC date of the start of the capture session and “hh_mm_ss” would be the capture session UTC time of the start of the capture session. Capture session directories in CapturedFiles are already named like this:

“yyyy_mm_dd_hh_mm_ss”, where that indicates the UTC time of the start of the session. So, you can determine the capture session start time by parsing the directory name.

For non-capture session related files, a unique naming convention would be something like this:

“[prefix]_yyyy_mm_dd_[station]_hh_mm_ss_[suffix]”

or “[prefix]_[station]_[suffix]” for files that don’t require date/time. Where “yyyy_mm_dd” and “hh_mm_ss” would be the date/time, in CAMS format, when the file was created and [station] would be some code that uniquely identifies the station. For example, you could use the first camera of the first CAMS instance or something like the “CODE” column in the CameraSites.txt file, or the lat/long of the site, or anything else, just as long as it uniquely identifies the site worldwide. Another option, if the time is not important, is to use this convention:

“[prefix]_[station id]_[suffix]”

For example:

“Status_000957_MC_Meteor Crater.txt”

It’s important to use a naming convention that performs its own grouping when sorted. For example, sorting by station name would not group all the Arizona stations together. However, including their first camera accomplishes that.

10 Rebooting

We have also repeatedly learned, through troubleshooting, that we needed to reboot the computers just before archiving and also before LaunchCapture each day so that (a) post-capture processing of backlogs will not interfere with current archiving procedures or capture. I have only implemented that at a few test sites so far. Rebooting before archiving solves a few problems that have been experienced. When backlog processing is active, it can slow the archiving procedure to the point where it could take more than we’ve given it (usually about an hour) to complete. (b) Remember, the computer reboots again each day at 4pm to clear the system of rogue applications in order to avoid dropping frames from the video grabber during capture. Rebooting the system also clears any issues with computer locking up due to electrical glitches and such. You can always remotely regain control after 4pm.

11 Status reporting

In 2018, I introduced the GetStatus.bat script. The GetStatus script reports on the status of the station. Calling GetStatus.bat is incorporated within the Upload_Queue.bat script. Each station runs the status report several times per day. After it is run, its report is uploaded to the NASA server to a shared location where all status reports are kept worldwide. Each status report has a unique name according to the station name, not according to the session name. Therefore, status reports on the server will overwrite the previous status report.

A status report contains a lot of information. It will contain information about your system, such as windows version number, disk space, when the report was created, how much network data you have used in this billing cycle, and when it was most recently rebooted. An issue detected here will be cause to take action, for example, to free up some disk space.

It also contains a list of the 10 most recent Transmission files and their MD5 files. This gives you an opportunity to determine if your upload procedures have been successful. If they are not, then you’ll need to take action to determine why and resolve it.

It reports on how many unprocessed Capture sessions there still are in the CapturedFiles directory. If there are any that appear, then you will be approaching a disk space issue. This is an indication that some action needs to be taken to correct the problem.

A big part of the report is the SubmissionFiles section. In this section, each of the most recent 10 capture sessions are listed for each CAMS instance. For each capture session, you will see the entire size of the capture session in MB, how many files there are (you can compare these numbers with other sessions), the session name, the total number of detections, and whether the Validation, AutoCal, Detection, and Transmitted phases of post-capture processing have completed or failed.

In addition to that information, each camera’s information is listed to help you identify trouble spots. For each camera, we show the capture session, the camera number, the number of detections for that camera, the FOV and image scale, the CAL file, and dropped frames information. Too many detections points you to a noisy camera. Too many dropped frames points you to a CPU contention problem in the computer. If the image scale is different than previous capture sessions, then you might have a scale flip/flop problem.

A list of the 20 most recent CAL files is then shown in the CAL files section. A camera that consistently fails to calibrate indicates that some manual calibration intervention is needed.

The archive settings are displayed, indicating how long you intend on keeping session data around outside the archive. If you are running out of disk space, you can examine these figures and look at whether to modify the MaxDaysToKeep setting. MaxDaysToKeep applies to the number of days to keep CapturedFiles FF_*.bin files before culling them.

There is also a list of the 10 most recent archive zip files, along with their sizes. Excessive sizes will inform you of issues related to archiving sessions with noisy cameras and it is possible that it takes so long to process, that you never get a chance to complete the ever-important disk management part of daily processing. Also, a list of each of the cams_Archive subdirectories and their sizes in case the information is helpful.

There is a list at the bottom that indicates which processes were still running at the time the report was generated.

The final step is to upload the report to the status folder in the server. This provides a central place to access station status without having to connect to each station. It is helpful to network coordinators so they don't have to remotely connect to stations to determine if they are OK. Also, you should be able to configure your phone or tablet to access this information when you are away from your computer. Lastly, they are used by the `Status_Check.bat` scripts.

12 Status_check report

Sometimes, the `GetStatus` reports contain too much information for you to quickly see issues that you might be having. So, some `Status_Check` reporting scripts were created to only report on the alerts that you need to consider taking action on. The `Status_Check.bat` scripts download and read the `GetStatus` report(s) from the collection of status reports on the server. If nothing is wrong, they will simply list that the status report was found and read OK.

However, the `Status_Check` scripts were created to “read” the `GetStatus` reports of the stations in your network and to alert you of issues, such as disk space getting too low, noisy cameras, and cameras with excessive dropped frames. Excessive dropped frames and excessive detections per camera have three alert levels: *warning*, *watch*, and *critical*.

In addition, it will report if the station has not uploaded a status report after 2 or more days, indicating that someone needs to attend to the station to make sure that it is up and running. There are a few other things that are reported in the `status_check` reports, but I don't remember right now. One of them is whether the power is off to individual cameras. This is a common condition when people are trying to use Christmas tree timers in timer mode instead of day/night mode to power the cameras and the timer is not set to the correct time.

The status report is generated as a text file, then it is converted to an HTML file with hyperlinks to the full `GetStatus` report that was downloaded from the server. This is a very useful tool.

The `Status_Check` reports are not uploaded to the server. They are kept locally. They can be run from any Windows computer that has the AutoCAMS scripts configured. They are also only run when you tell them to.

The `Status_Check` reports are designed to also be able to work with a `Status_Check_<network>.txt` file. When the `status_check` script is told to use the file, it produces its report for all stations in the local CAMS network. For example, `status_report_AR.txt` to produce a status report for all stations in the Arkansas network.

You can create a shortcut on your desktop to launch the script with your network file.

13 CAMS pointing tools

While it's not specifically part of AutoCAMS, around September, 2014, I developed the CAMS Pointing Tool¹⁷. It can be used to create a Laydown before setting up your AutoCAMS.

The tool takes time to get used to, but it is a useful tool for site operators to help in determining where to point their cameras to attain the best overlap with other cameras. It can be used to create, what we call a “laydown” for one or many cameras from one or more sites (*Figures 16, 17, 18 and 19*).

Thanks to Chris Veness for providing the haversine functions and the basic layout for the page. The input fields arranged in the order that they appear in a CAL file.

While not part of AutoCAMS, it has proven to be a useful tool by many CAMS users.

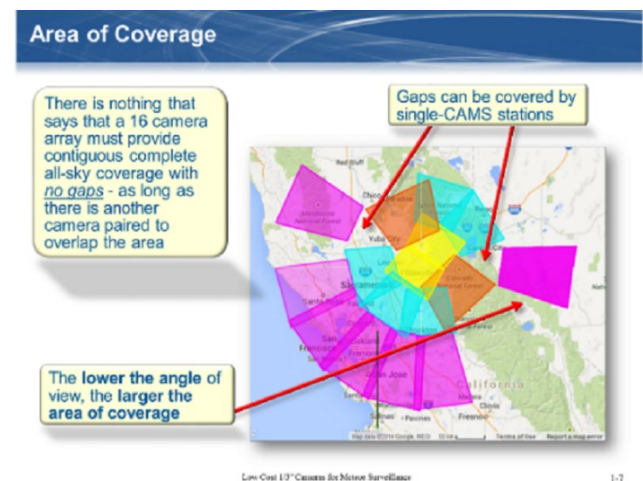
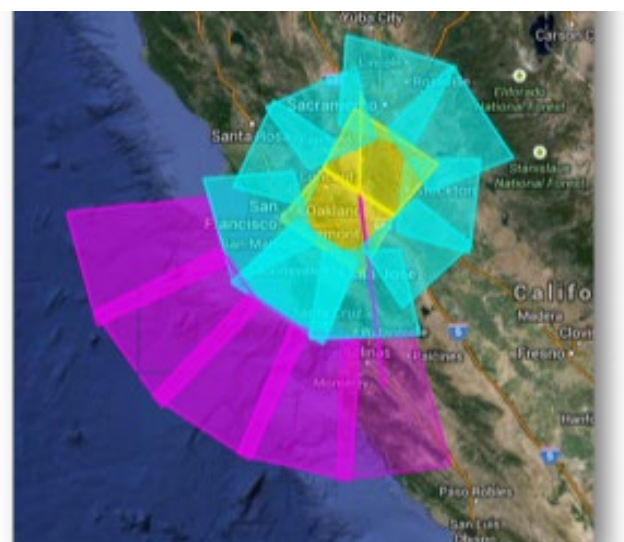


Figure 16 – An alternative Laydown can be more flexible.



¹⁷ <http://davesamuels.com/cams/camspointing/scripts/latlong.html>

Figure 17 – This image shows a Laydown of one of two 16 camera stations. When designed for each other, can achieve full-sky coverage.

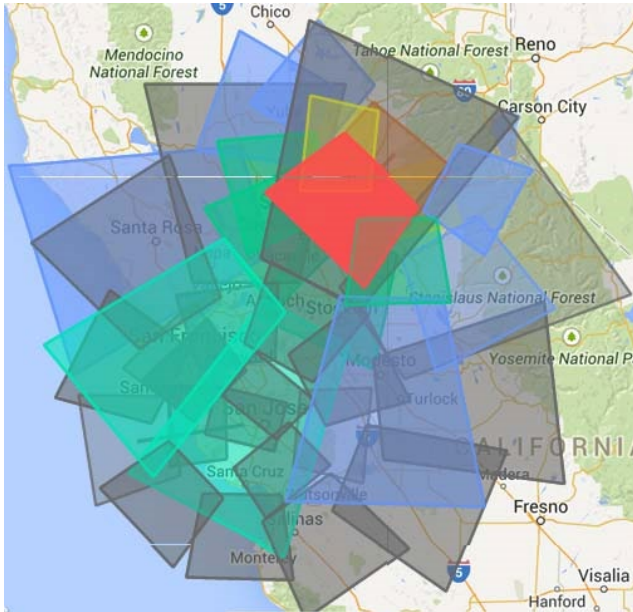


Figure 18 – Laydown of the overlap between Sunnyvale and Jim Wray’s station in Forest Hill after Jim tilted his box toward Sunnyvale. Gray is Sunnyvale.

... Toggle map off. You should toggle the map off before making field changes.

Site 1:	38.96715	-120.87845	Clear	<input checked="" type="checkbox"/>	Camera or Site ID:*	FH 215	Recommended pointing for camera 2 to point to camera 1:	
					Height above WGS84 (km):	0.07	Site 2: 37.94811 -121.72492	
					Azimuth 1:	250	-->Az 2:	5.84229
					Elevation Angle 1:	52	-->Elev 2:	44.32104
					Target Altitude 1 (km):	90.0	-->Area 2(km^2):	4205 km^2
					Color 1:	F000F0		
Lens:								
					Focal length (mm):*	8		
					FOV 1 Width (width) (deg):	34.0		
					FOV 1 Height (height) (deg):	25.5		
					FOV 1 Plate roll (deg):*	0		
Sensor:								
					Sensor 1 format (inches):*	1/3		
					Sensor 1 width (mm):*	4.88		
					Sensor 1 height (mm):*	3.6556		
Site 2:	37.94811	-121.72492	Clear	<input checked="" type="checkbox"/>	Camera or Site ID:*	BW 213	Recommended pointing for camera 1 to point to camera 2:	
					Height above (WGS84 km):	0.0290	Site 1: 38.96715	
					Azimuth 2:	1.048	-120.87845	
					Elevation Angle 2:	47.822	-->Az 1:	244.76595
					Color 2:	F0F000	-->Elev 1:	52.00194
					Lens 2:			

Figure 19 – CAMS Pointing Tool web page. Used for creating “laydowns” and figuring overlap with other cameras.

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April Lyrids and η -Aquariids 2021 with Worldwide Radio Meteor Observations

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Worldwide Radio Meteor Observations recorded the meteor showers of the April–Lyrids and η -Aquariids 2021. The April-Lyrids showed the same activity level as usual in ordinary years. The peak time occurred at $\lambda_{\odot} = 32.35^{\circ}$ (April 22nd 13^h UT). The ZHR_r was estimated to be around 23 ± 4 . On the other hand, η -Aquariid activity was weaker than usually in other years. The peak occurred in the time lapse of $\lambda_{\odot} = 45.1^{\circ}$ to 45.8° (May 5th 17^h – 6th 9^h UT). The ZHR_r was estimated to be around 35–40.

1 Introduction

Worldwide radio meteor observation data were provided by the Radio Meteor Observation Bulletin (RMOB)¹⁸ (Steyaert, 1993) and by the radio meteor observation network in Japan (Ogawa et al., 2001). Radio meteor observations are possible even with bad weather and during daytime.

2 Method

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

3 Results

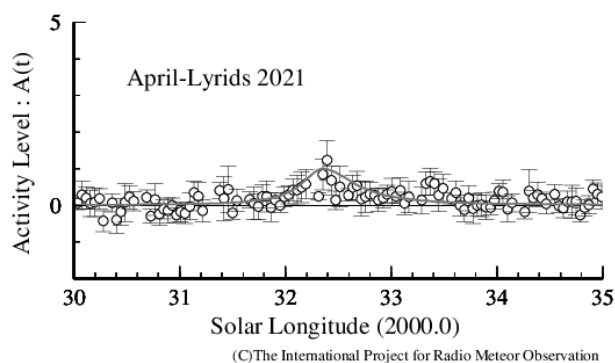


Figure 1 – The Activity Level Index by radio meteor observations from all over the world (the line is the average obtained for the period of 2007–2020).

3.1. April-Lyrids

Figure 1 shows the result of the April-Lyrids based on the calculation of the Activity Level Index $A(t)$. The solid line shows the average for the period 2007–2020. Some high activity was seen around $\lambda_{\odot} = 32.2^{\circ}$ – 32.6° . The maximum activity level was observed with values of 1.3 ± 0.5 at $\lambda_{\odot} = 32.39^{\circ}$ (April 22, 14^h UT). The peak time using the Lorentz profile was estimated at April 22nd 13^h with $A_{max} = 1.0$, $FWHM = -6.0\text{hr} / +9.0\text{hr}$. This activity level is the same as the annual level.

ZHR_r is shown in Figure 2 (calculated by Sugimoto). The April-Lyrids 2021 show the same activity as the average annual activity, just like the Activity Level index. The solid line shows the average for the period 2012–2021. The maximum ZHR_r was estimated to be 23 ± 4 at $\lambda_{\odot} = 32.35^{\circ}$ (April 22, 13^h UT).

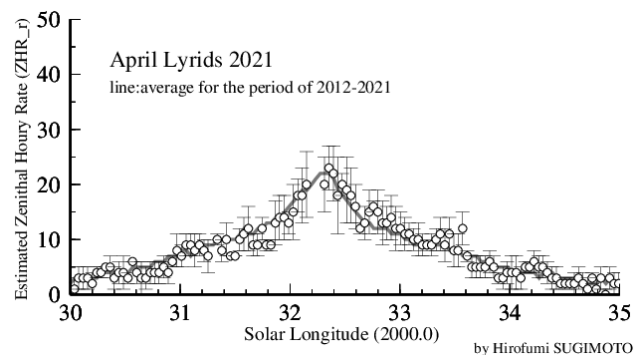


Figure 2 – The estimated ZHR by radio meteor observations from all over the world (the line is the average obtained for the period of 2012–2021).

¹⁸ <http://www.rmob.org/>

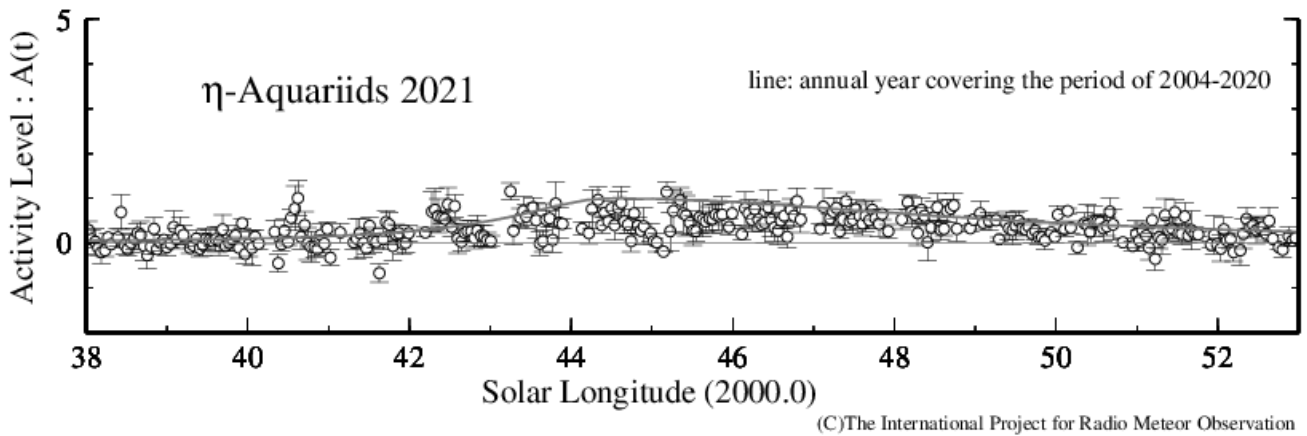


Figure 3 – The Activity Level Index by radio meteor observations from all over the world (the line is the average obtained for the period of 2004–2020).

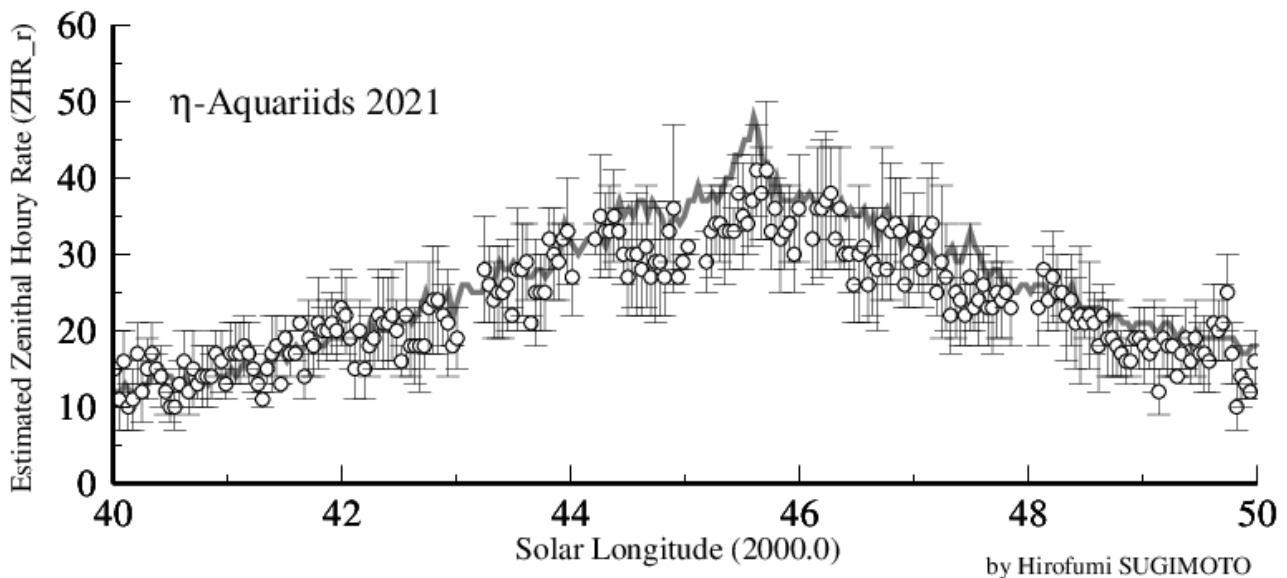


Figure 4 – The estimated ZHR by radio meteor observations from all over the world (the line is the average obtained for the period of 2012–2021).

3.2. η-Aquariids

Figure 3 shows the result for the η-Aquariids 2021 based on the calculations with the Activity Level Index. The line represents the average for the period of 2004–2020. The maximum was estimated $A_{max} = 0.7$ at around $\lambda_{\odot} = 45.15^{\circ}$ (May 5, 17^h UT). In 2021 the η-Aquariid meteor shower displayed a weaker activity level than in normal years (annual $A_{max} = 1.0$). The number of long meteor echoes of more than 20 seconds was also poor as recorded by the Japanese radio meteor observers.

ZHR_r is displayed in Figure 4 (calculated by Sugimoto). The average for the period 2012–2021 (solid line) shows a maximum ZHR_r around 50. In 2021, however, the maximum ZHR_r was estimated to be around 35–40 at $\lambda_{\odot} = 45.4^{\circ} - 45.9^{\circ}$ (May 5, 23^h – May 6, 9^h UT).

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The worldwide data were provided by the Radio Meteor Observation Bulletin (RMOB)¹.

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Radio observations in April 2021

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This article presents the results of radio observations made in April 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 active visual or daylight meteor showers in April (Rendtel, 2020). The average approximate background hourly signal activity is 3–15. *Figure 1* shows the hourly rates of radio meteors in April 2021 at 88.6 MHz. *Figure 2* shows the corresponding heat map.

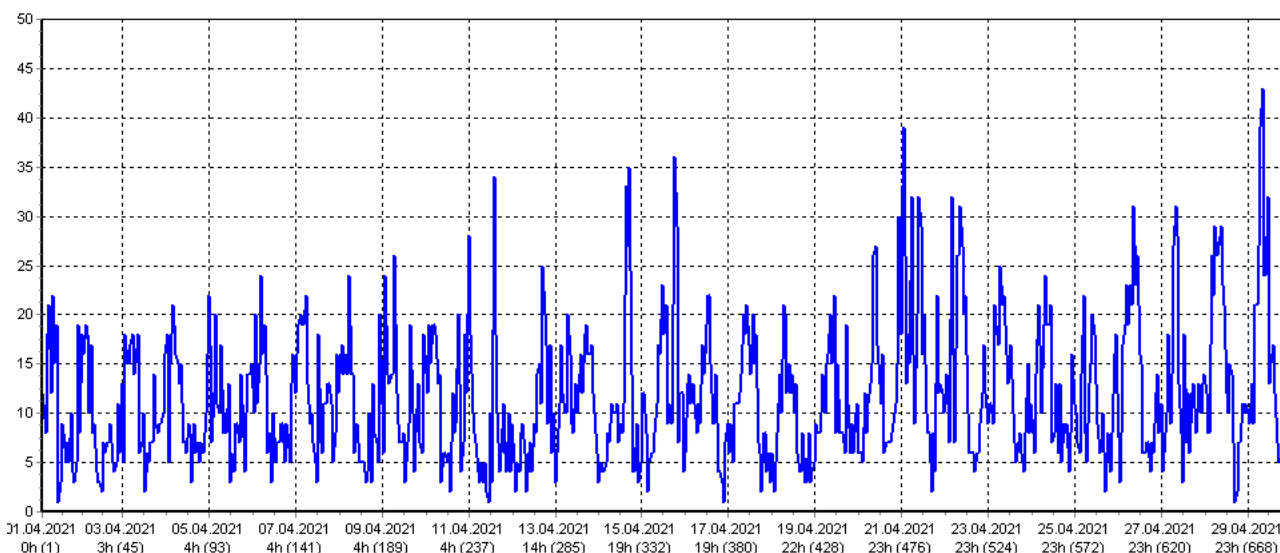


Figure 1 – Radio meteor echo counts at 88.6 MHz for April 2021.

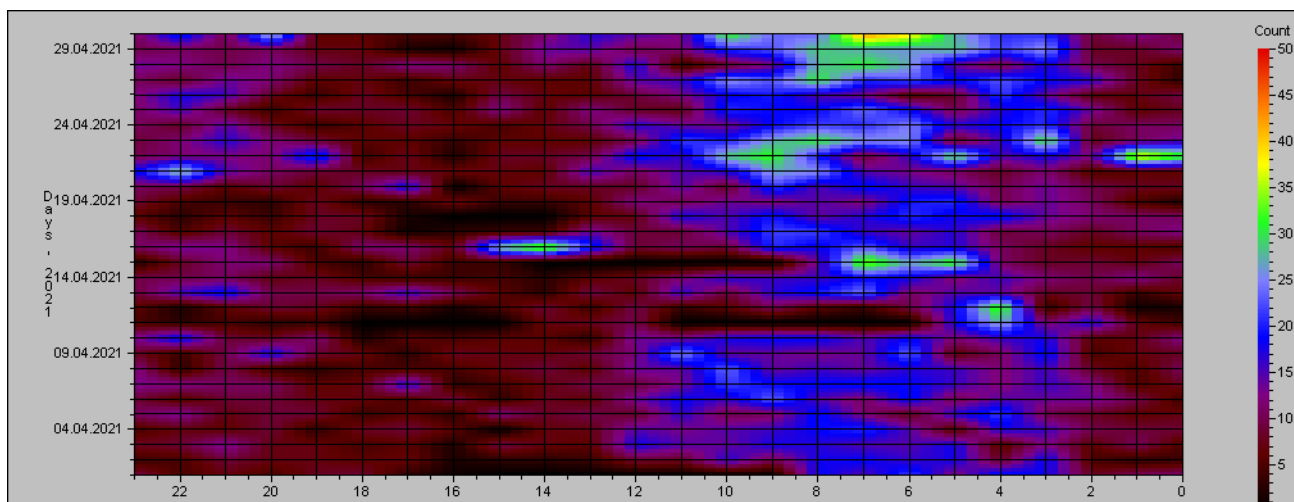


Figure 2 – Heatmap for radio meteor echo counts at 88.6 MHz for April 2021.

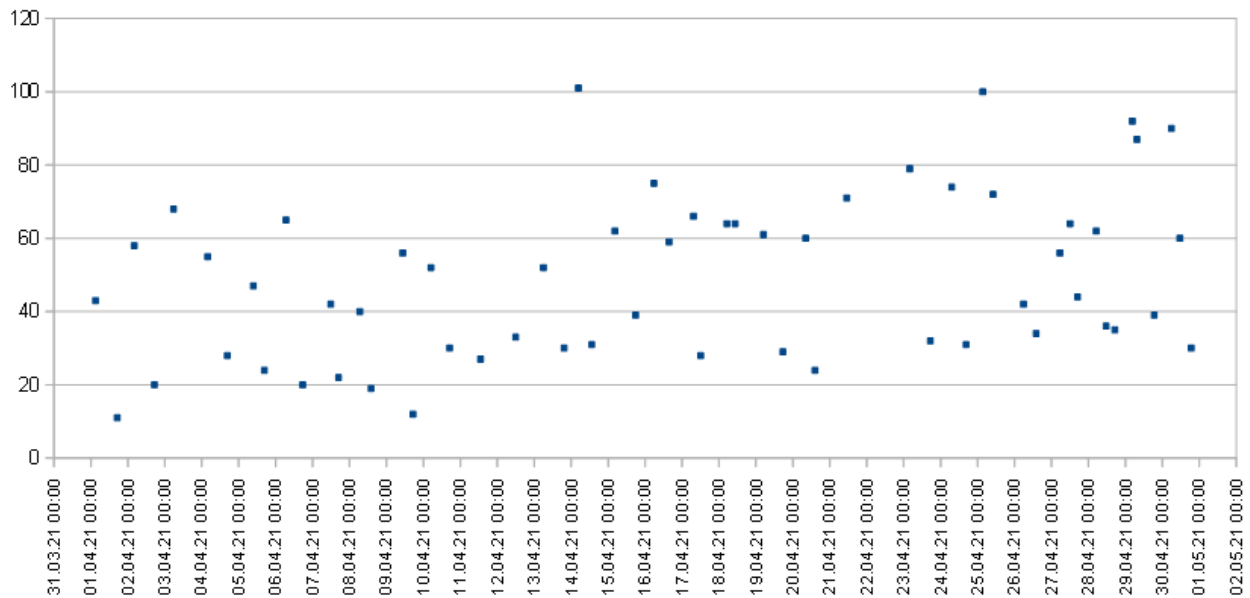


Figure 3 – The result with the calculated hourly numbers of echoes of meteors by listening to the radio signals for April 2021.

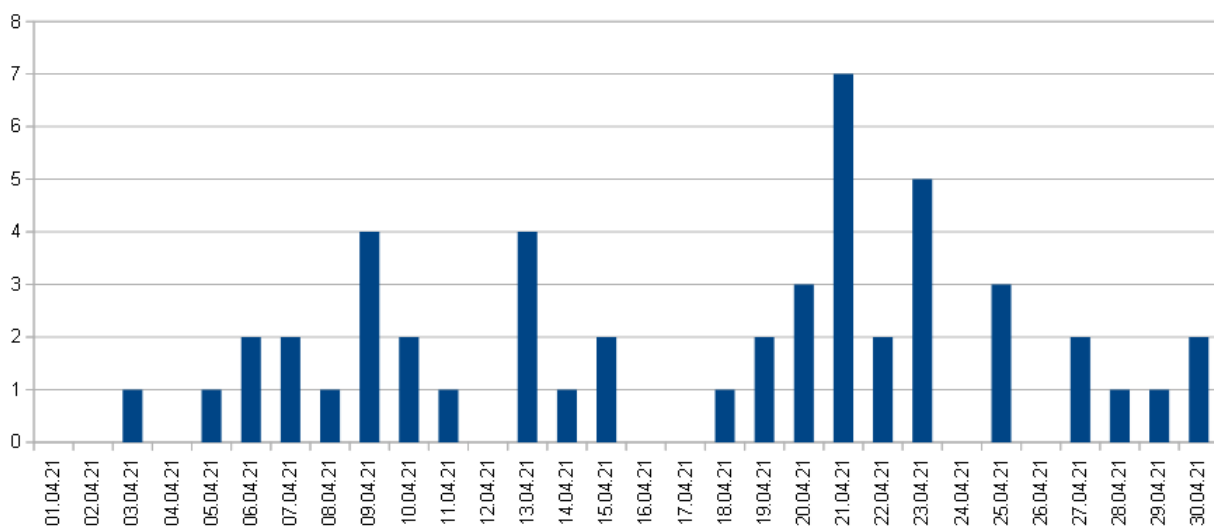


Figure 4 – Daily activity of radio fireballs during April 2021.

Lyrids (#0006) activity has been weakly detected by the automatic method of observation. The maximum of activity could occur between 00^h–10^h UT on April 22, 2021. According to the IMO calendar, the calculated Lyrid peak should occur on April 22 around 13^h UT. For this time, the radiant does not fall within the antenna pattern, as it is located “below the horizon”. The maximum activity of the daily meteor shower APS (#0144), according to the IMO calendar, occurs on April 22. It is impossible to isolate this maximum and to separate it from the Lyrid maximum. The graph of daily activity shows the total activity of all showers.

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 58 hours.

The activity graph by the listening method shows 4 waves of activity. The total activity increases monotonically during the month. The 1st wave is from April 1 to 10, the second from April 11 to 19, the third from April 20 to 27, and the fourth is short after April 27. The Lyrid maximum is not clearly visible, the maximum hourly numbers are about 80 echoes per hour.

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.

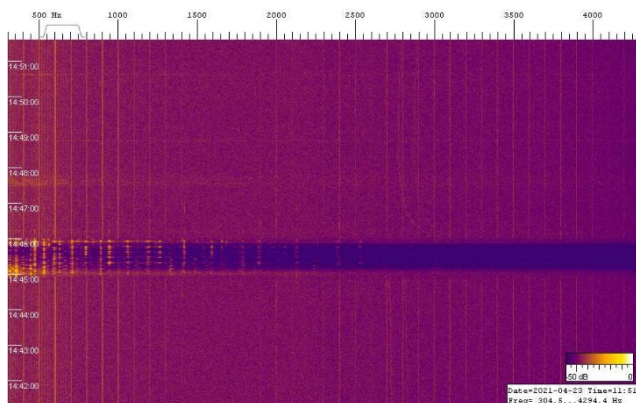


Figure 5 – Radio fireball recorded by SpectrumLab on April 23 at 11^h45^m UT.

Daily activity of fireballs did not exceed 4, indicating a “quiet” month in terms of activity. *Figure 5* displays one of the fireball radio echoes.

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.

A correlation between the activity level of sporadic meteors and showers can be seen on the graph. The maximum of Lyrid and sporadic meteor activity occurs on April 22. This can be explained by the fact that there is no exact boundary between sporadic and shower meteors.

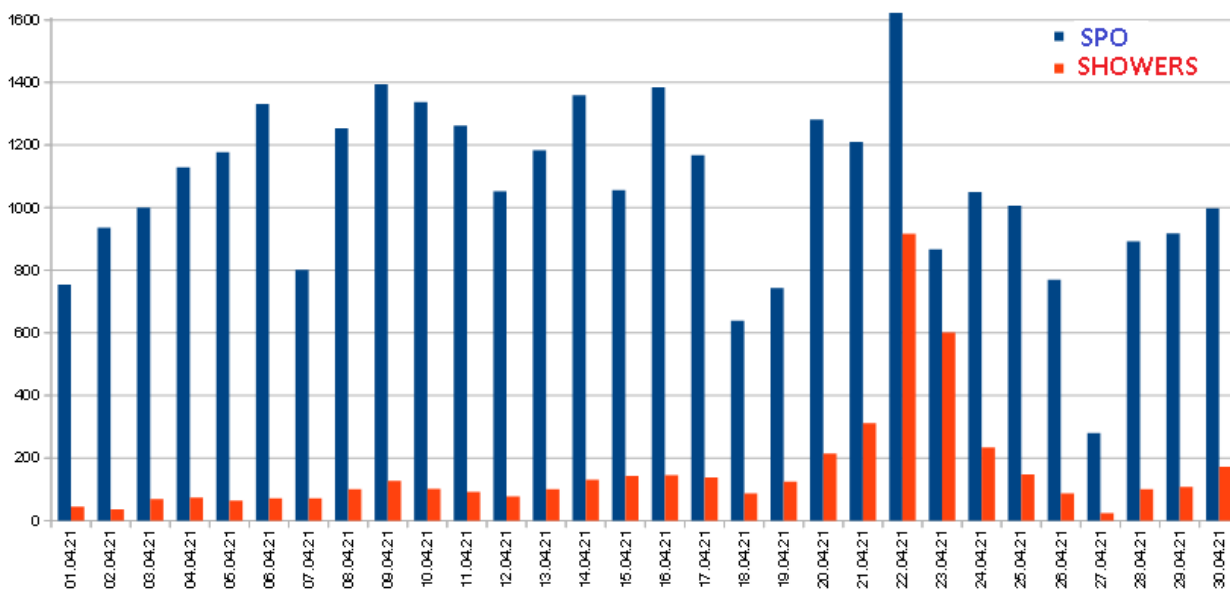


Figure 6 – Daily video meteor activity during April 2021 according to CAMS video networks.

6 Conclusion

The graph of radio fireballs activity has some correlation with the graph of the CAMS video meteors. Thus, on April 9, according to CAMS, there is a weak increase in the meteor shower activity, at which time there is a weak peak of radio fireballs. The increase in meteor shower activity in the CAMS data was due to some increased activity of streams such as OAV (#0651), AVB (#0021), BCO (#0647), NPE (#0827), DHE (#0841).

The Lyrid meteor shower is very poorly detected by my Radio Meteor System. Meteor showers with ZHR < 18 at maximum activity are almost impossible for my Radio Meteor System to detect.

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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Rendtel J. (2020). “Meteor Shower Calendar”. IMO.
 Jenniskens P., Gural P. S., Dynneson L., Grigsby B. J., Newman K. E., Borden M., Koop M., Holman D. (2011). “CAMS: Cameras for Allsky Meteor Surveillance to establish minor meteor showers”. *Icarus*, **216**, 40–61.

Radio meteors April 2021

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An overview of the radio observations during April 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 April 2021.

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

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

This month quite severe local interference or unidentified noise sometimes disturbed the registrations, while weak lightning activity was recorded on 3 days. Most of this

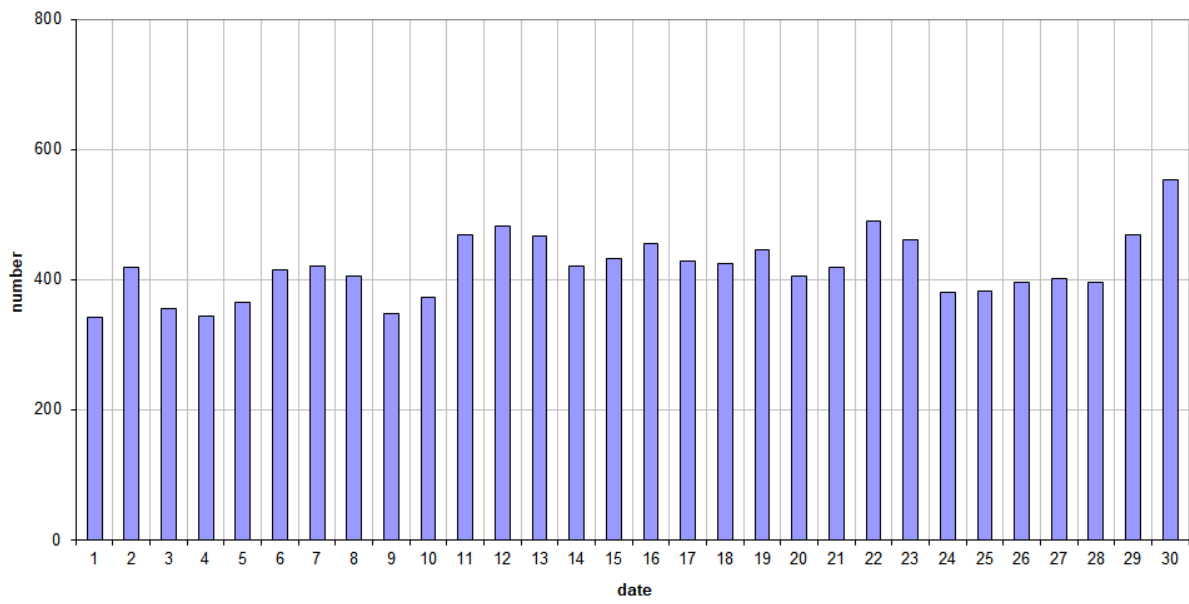
unwanted interference was manually corrected before the automatic counting.

As expected, meteor activity remained relatively low in the first half of the month, but as from April 19th the Lyrids nicely showed up. As expected, they peaked on April 23rd, with quite numerous overdense reflections shorter than 1 minute.

During this month, 4 reflections longer than 1 minute were recorded. A selection of striking or strong reflections is attached. (*Figures 5 to 10*).

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.

49.99MHz - RadioMeteors April 2021
daily totals of "all" reflections (automatic count_Mettel5_7Hz)
Felix Verbelen (Kampenhout)



49.99MHz - RadioMeteors April 2021
daily totals of all overdense reflections
Felix Verbelen (Kampenhout)

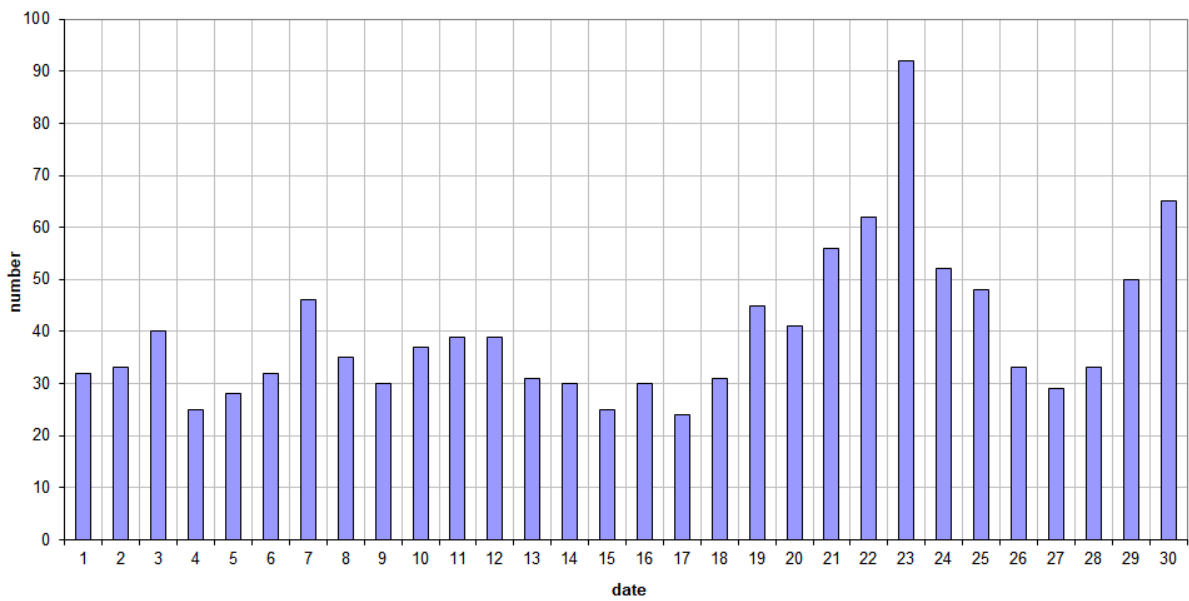
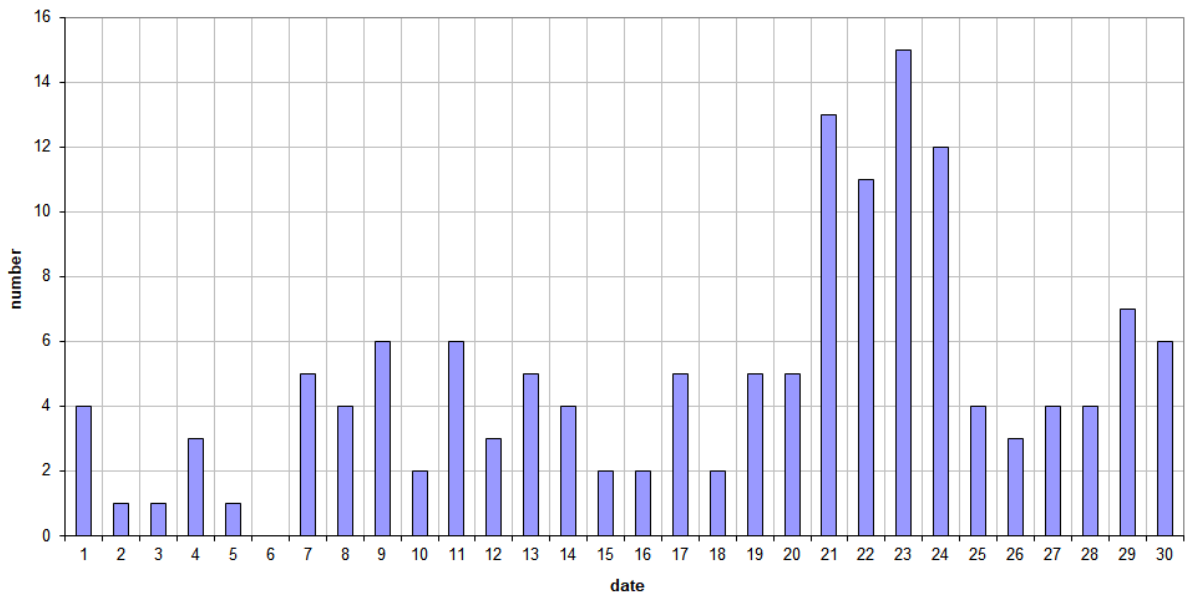


Figure 1 – The daily totals of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during April 2021.

49.99MHz - RadioMeteors April 2021
daily totals of reflections longer than 10 seconds
Felix Verbelen (Kamphenhout)



49.99MHz - RadioMeteors April 2021
daily totals of reflections longer than 1 minute
Felix Verbelen (Kamphenhout)

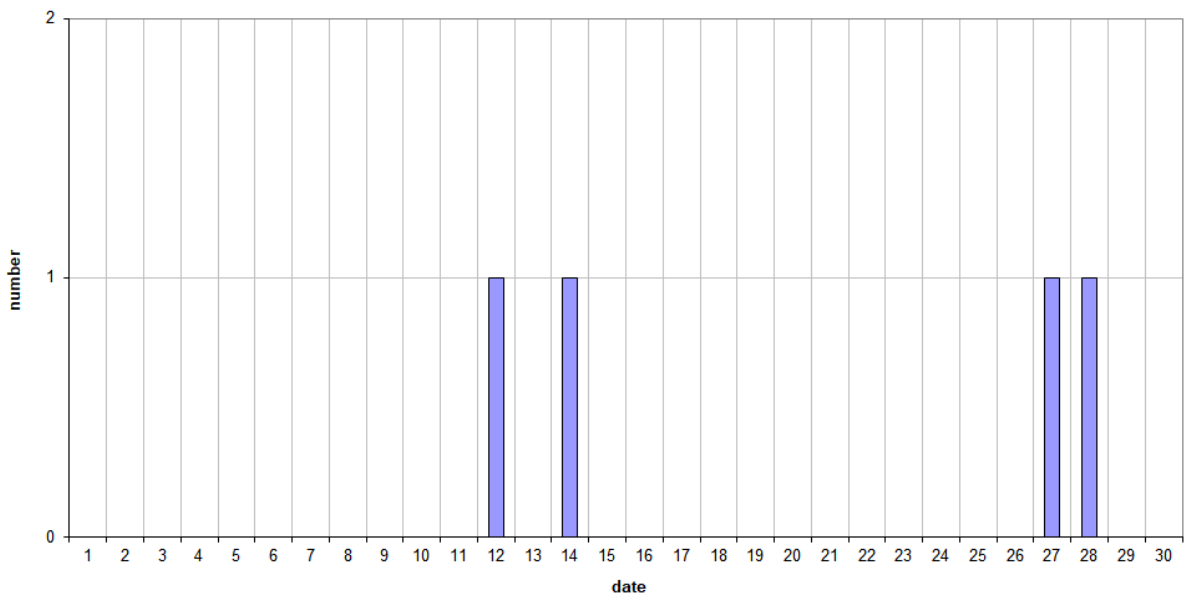
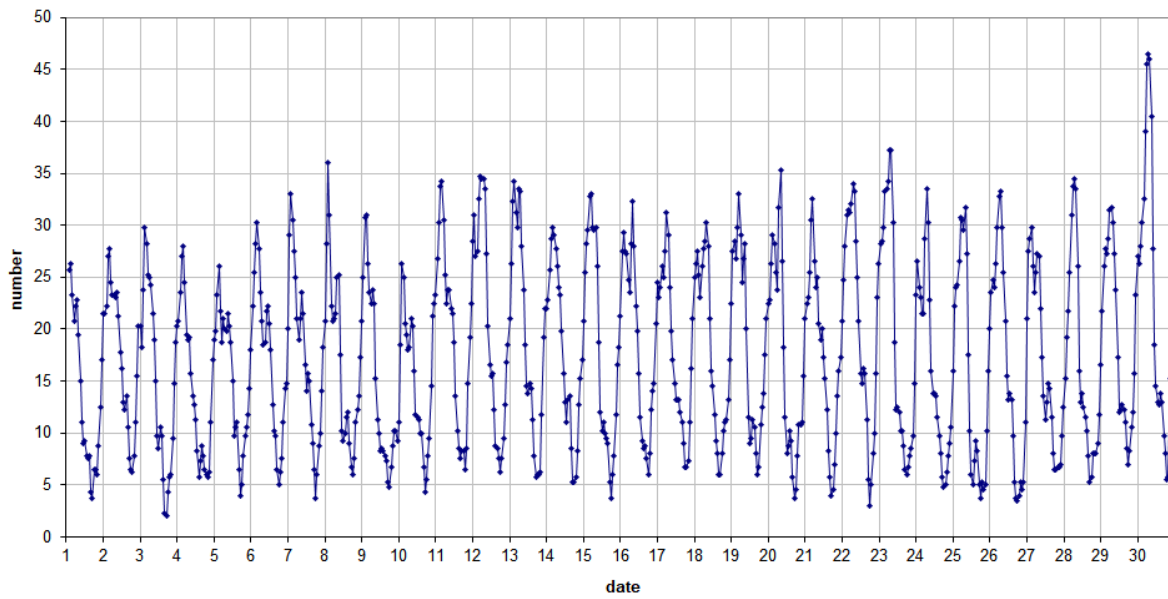


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during April 2021.

49.99 MHz - RadioMeteors April 2021
number of "all" reflections per hour (weighted average) (*automatic count_Mettel5_7Hz*)
Felix Verbelen (Kampenhout)



49.99MHz - RadioMeteors April 2021
number of overdense reflections per hour (weighted average)
Felix Verbelen (Kampenhout)

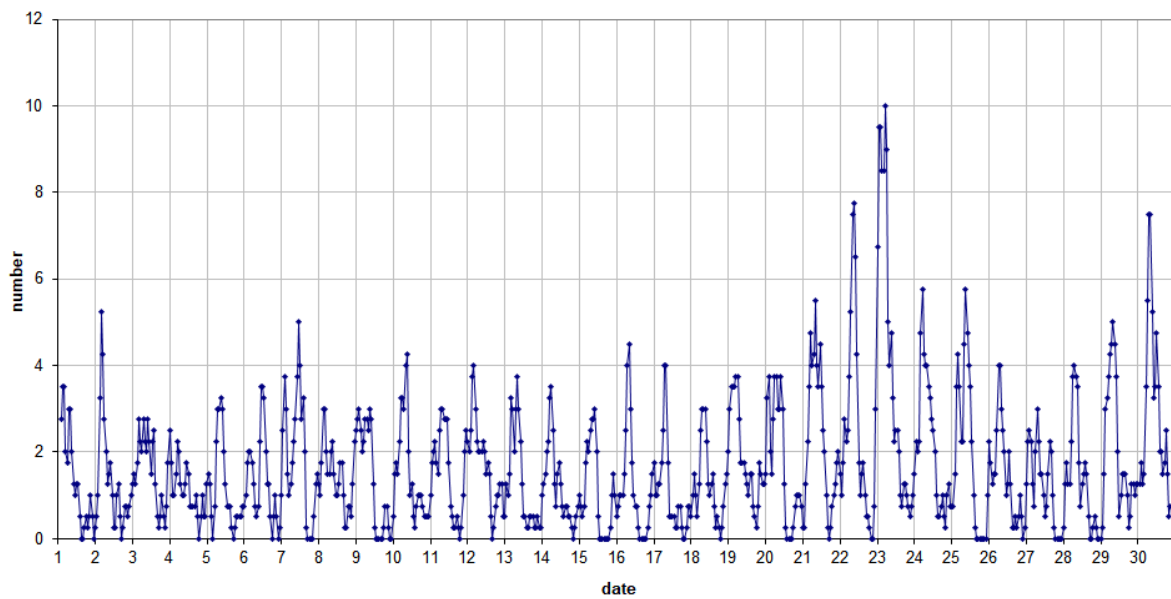
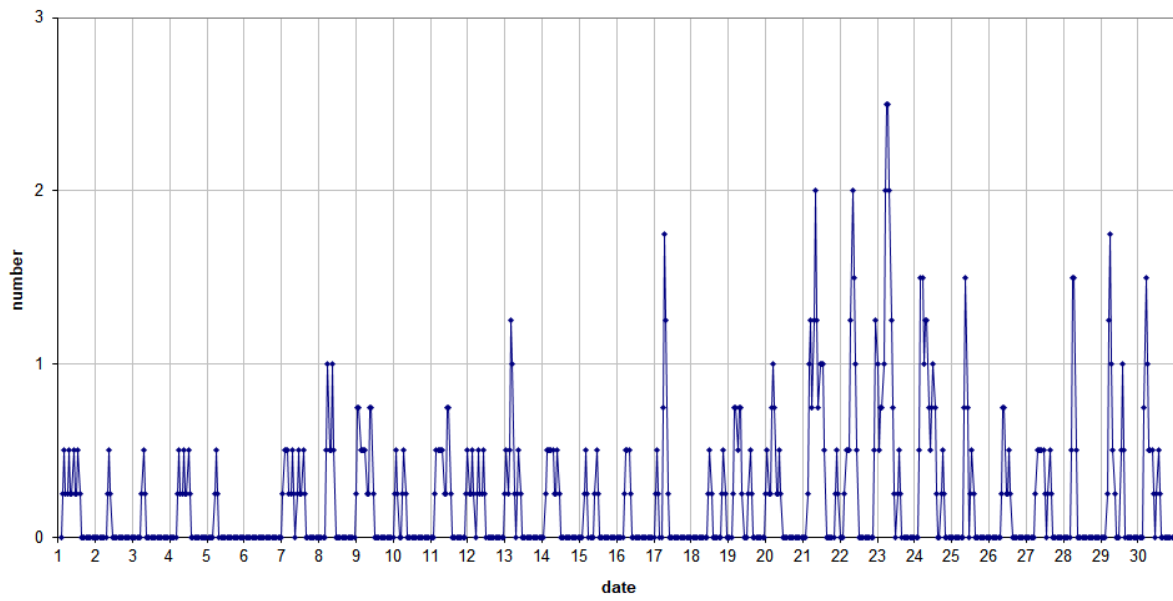


Figure 3 – The hourly numbers of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during April 2021.

49.99MHz - RadioMeteors April 2021
number of reflections >10 seconds per hour (weighted average)
Felix Verbelen (Kampenhout)



49.99MHz - RadioMeteors April 2021
hourly totals of overense reflections longer than 1 minute
Felix Verbelen (Kampenhout/BE)

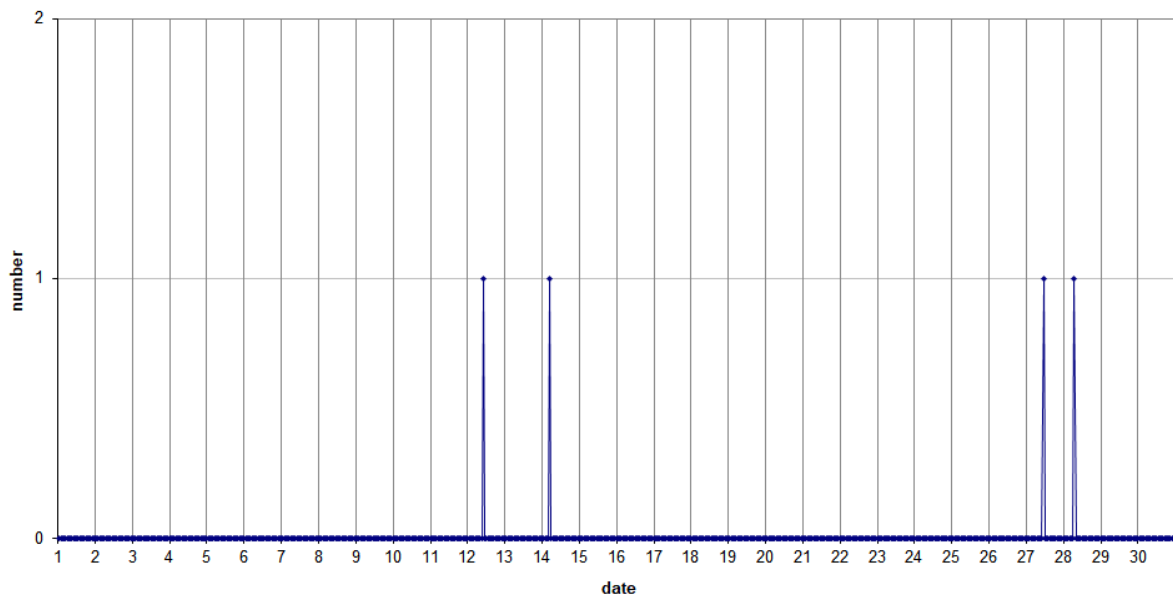


Figure 4 – The hourly numbers of overense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during April 2021.

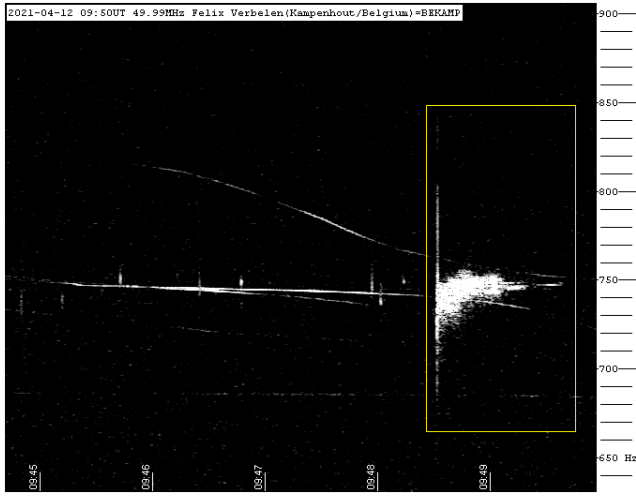


Figure 5 – Meteor reflection 12 April 2021, 09^h50^m UT.

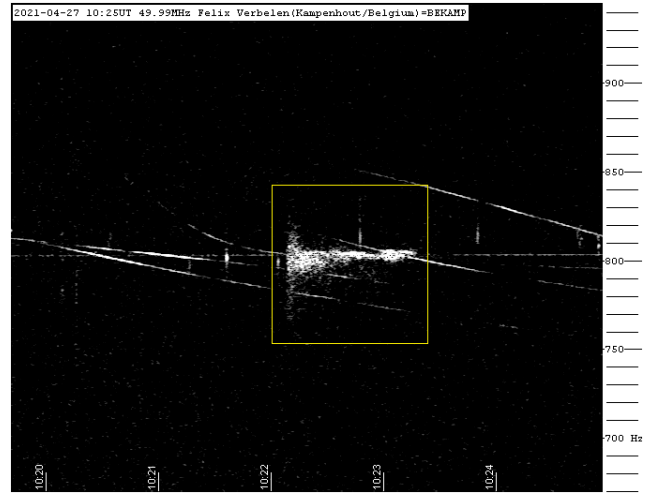


Figure 8 – Meteor reflection 27 April 2021, 10^h25^m UT.

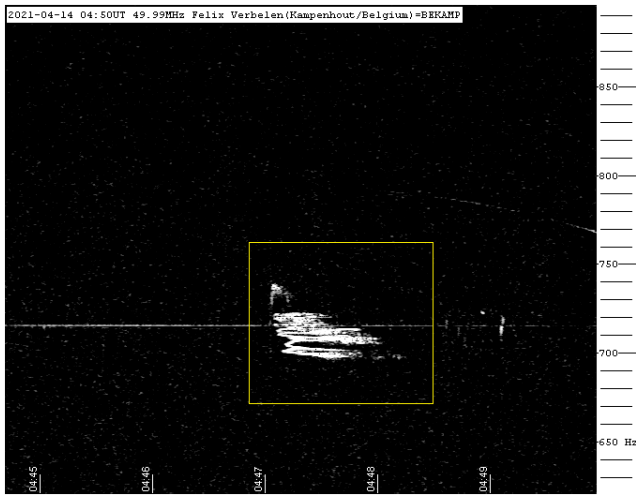


Figure 6 – Meteor reflection 14 April 2021, 04^h50^m UT.

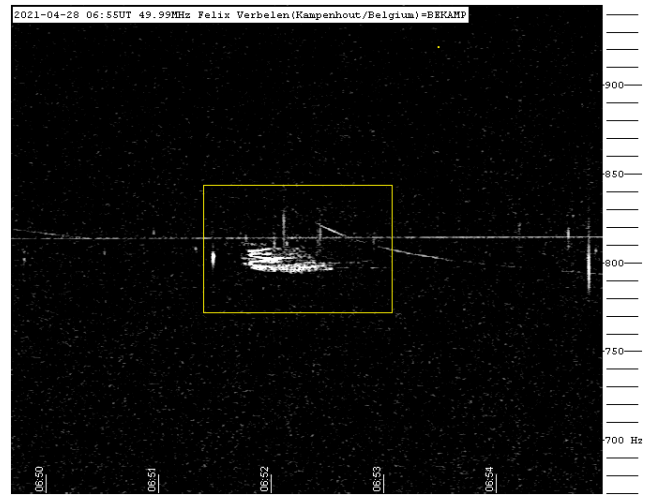


Figure 9 – Meteor reflection 28 April 2021, 06^h55^m UT.

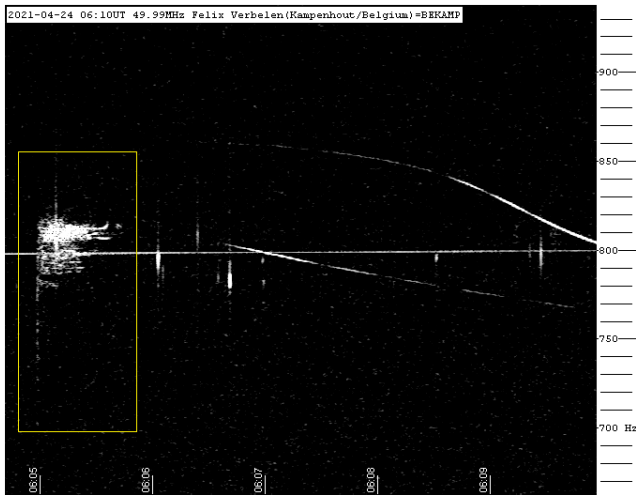


Figure 7 – Meteor reflection 24 April 2021, 06^h10^m UT.

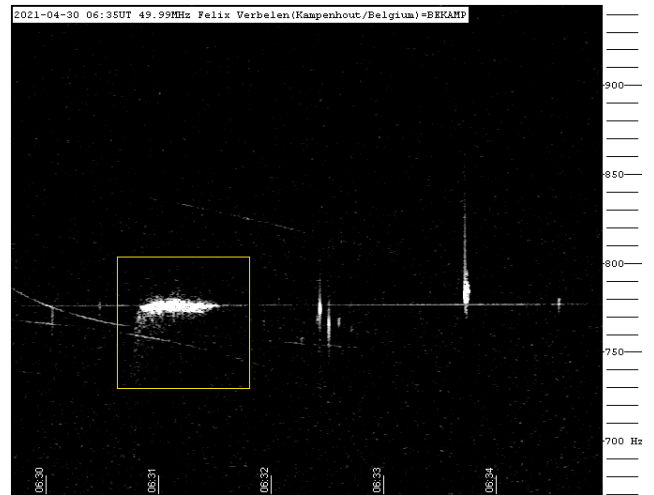


Figure 10 – Meteor reflection 30 April 2021, 06^h35^m UT.

Radio meteors May 2021

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An overview of the radio observations during May 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 May 2021.

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

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

Most of the time the observations were complicated by (mainly) local interference, unidentified noise or by moderate to heavy lightning activity (on 11 different days) and on May 22nd, 23rd and 24th solar activity was so strong that at times the screen was whited out for several

minutes... In order to minimize the effects of these disturbances the automatic counts were corrected manually.

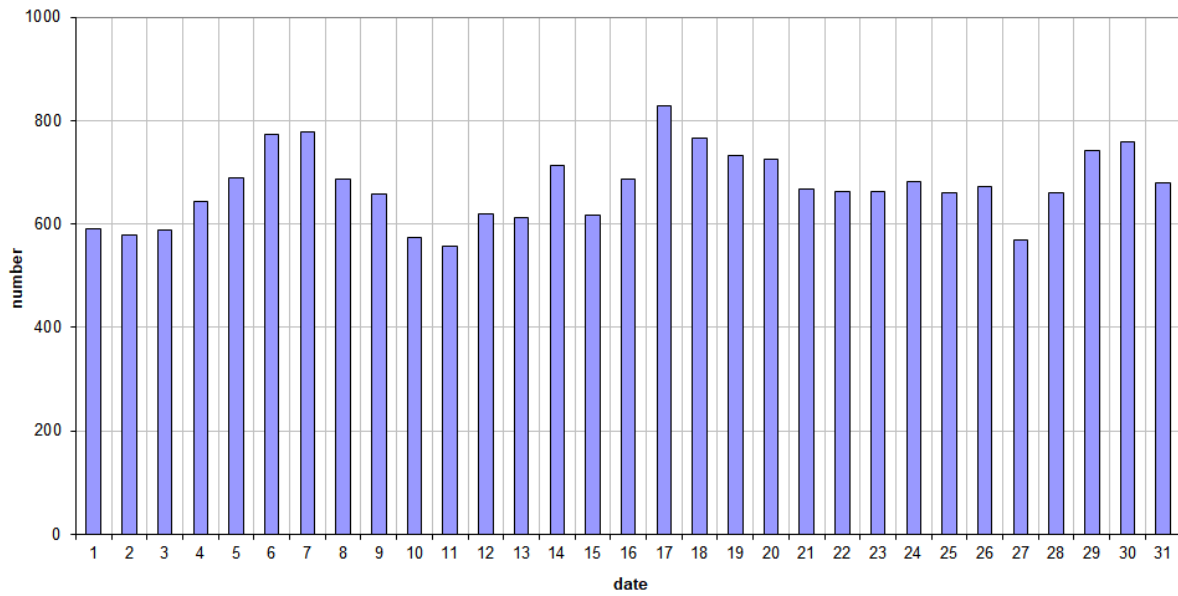
The eye-catchers of the month were, as expected, the eta-Aquariids, which reached their maximum on May 6th and 7th, but remained rather moderate overall.

During the rest of the month, there was markedly increased activity compared to previous months, with several nice minor showers.

Attached is a selection of SpecLab screen captures of some interesting or long meteor reflections during this month (*Figures 5 to 15*).

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.

49.99MHz - RadioMeteors May 2021
daily totals of "all" reflections (automatic count_Mettel5_7Hz)
Felix Verbelen (Kamphenhout)



49.99MHz - RadioMeteors May 2021
daily totals of all overdense reflections
Felix Verbelen (Kamphenhout)

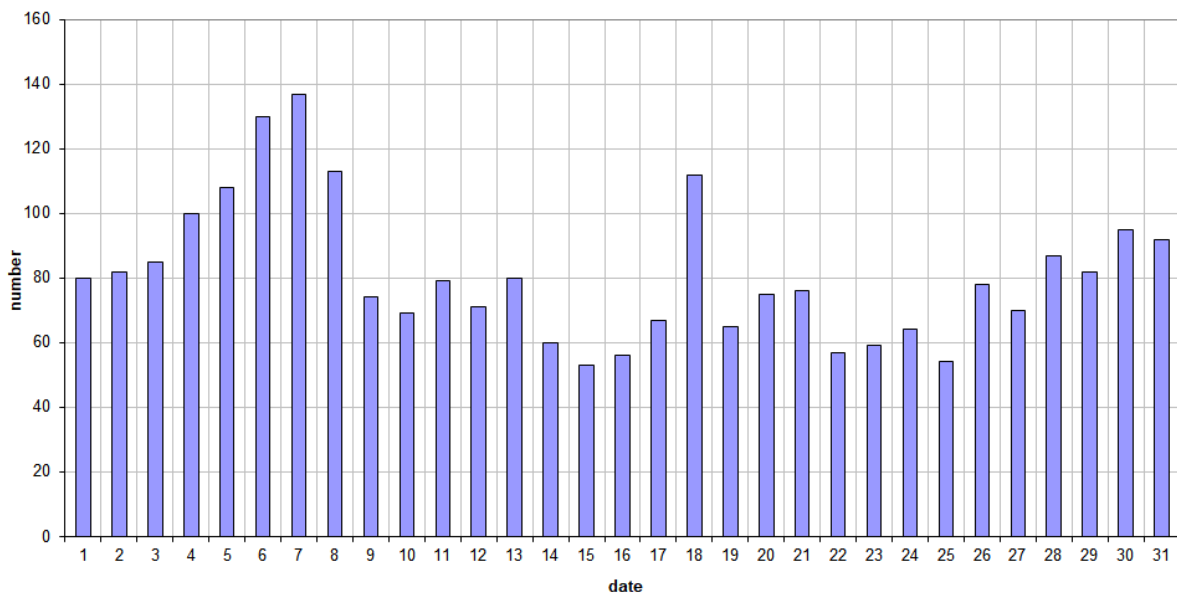
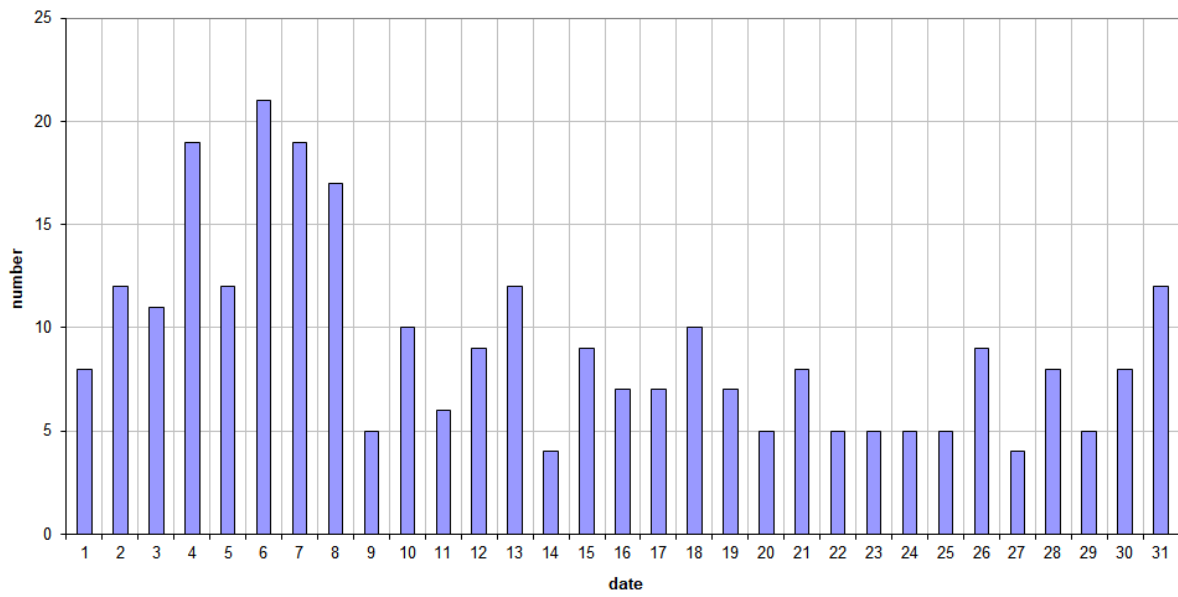


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49.99MHz - RadioMeteors May 2021
daily totals of reflections longer than 10 seconds
Felix Verbelen (Kampenhout)



49.99MHz - RadioMeteors May 2021
daily totals of reflections longer than 1 minute
Felix Verbelen (Kampenhout)

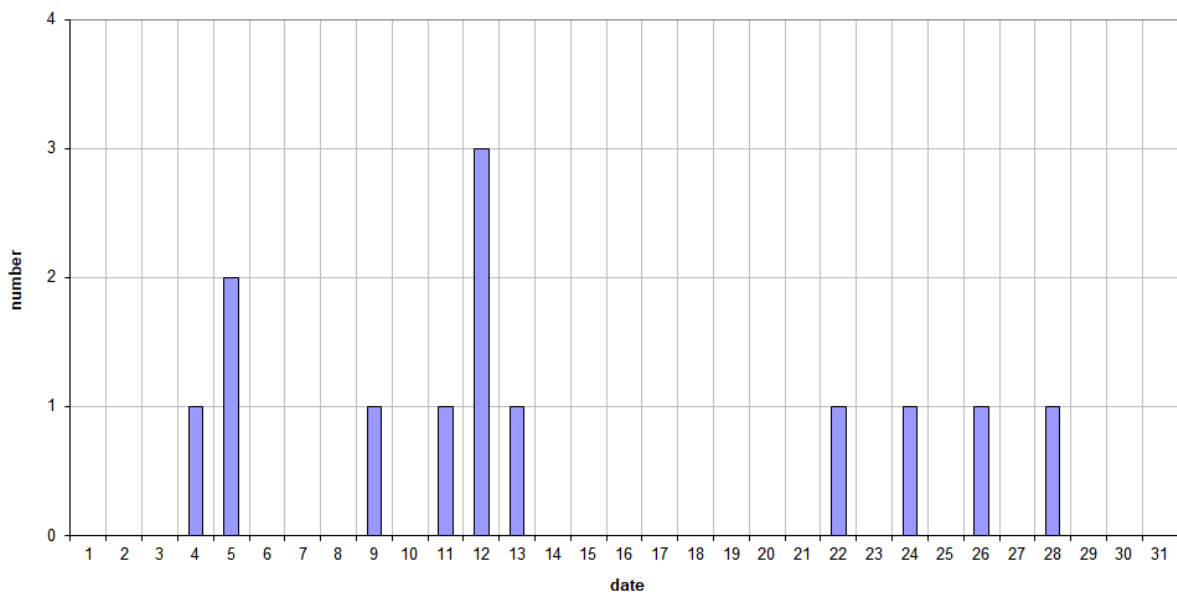


Figure 2 – The daily totals of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during May 2021.

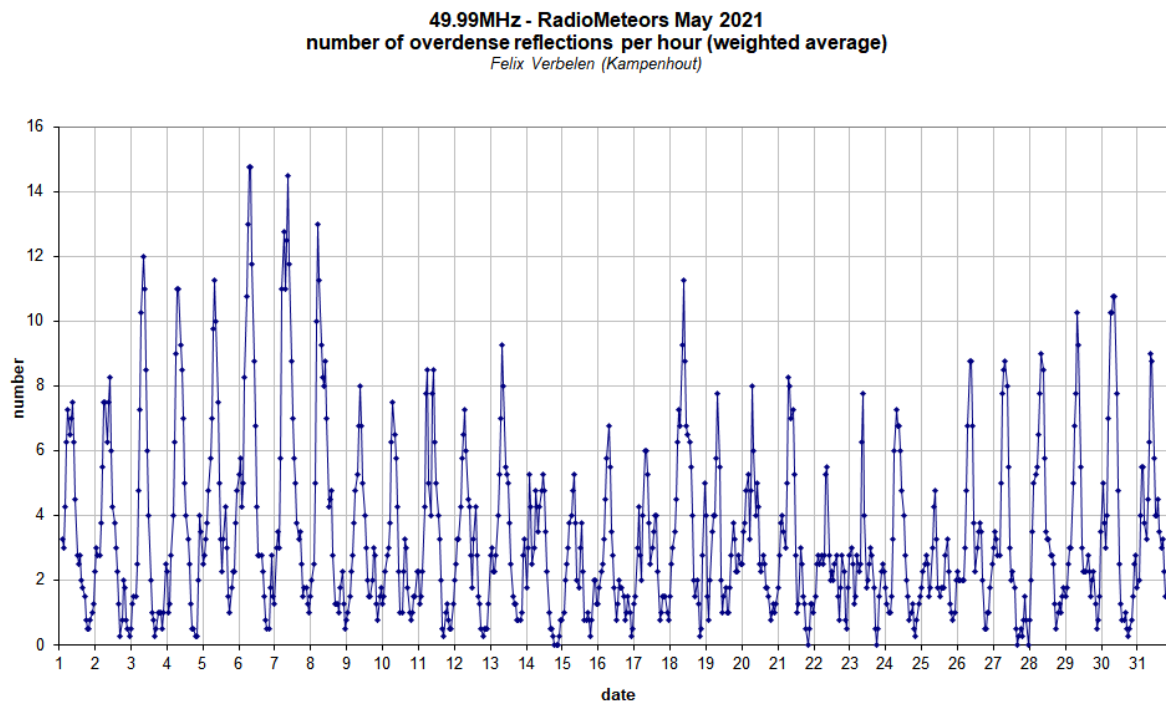
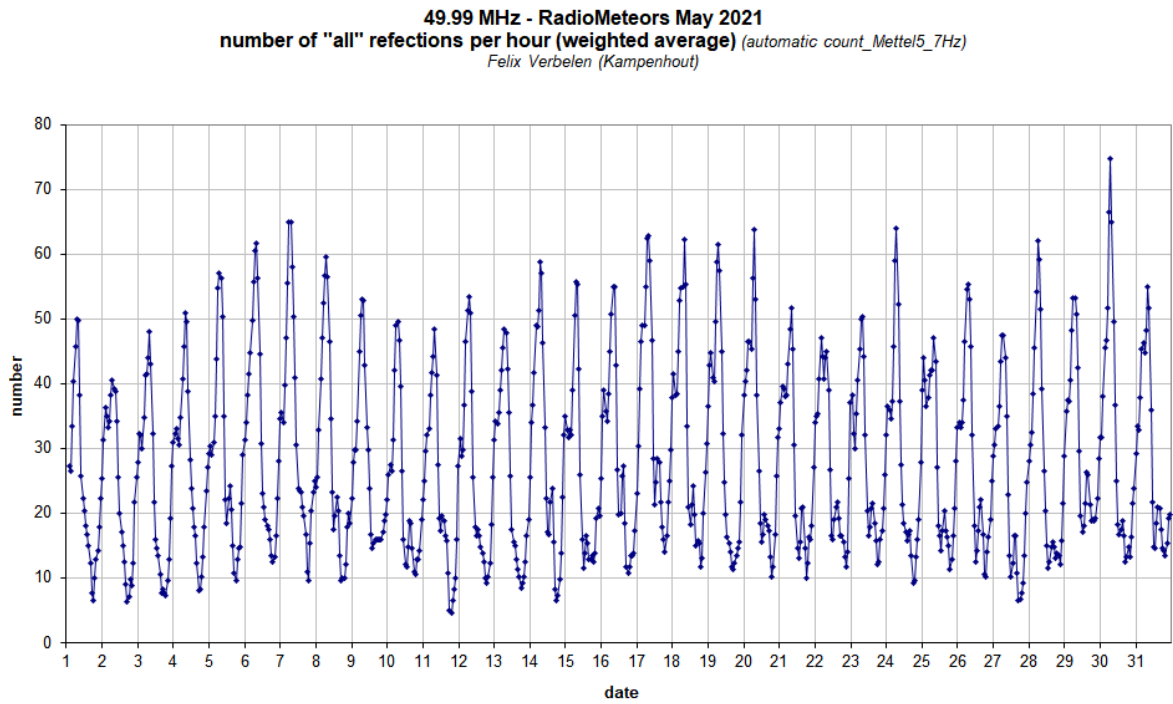


Figure 3 – The hourly numbers of “all” reflections counted automatically, and of manually counted “overdense” reflections, as observed here at Kamphenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during May 2021.

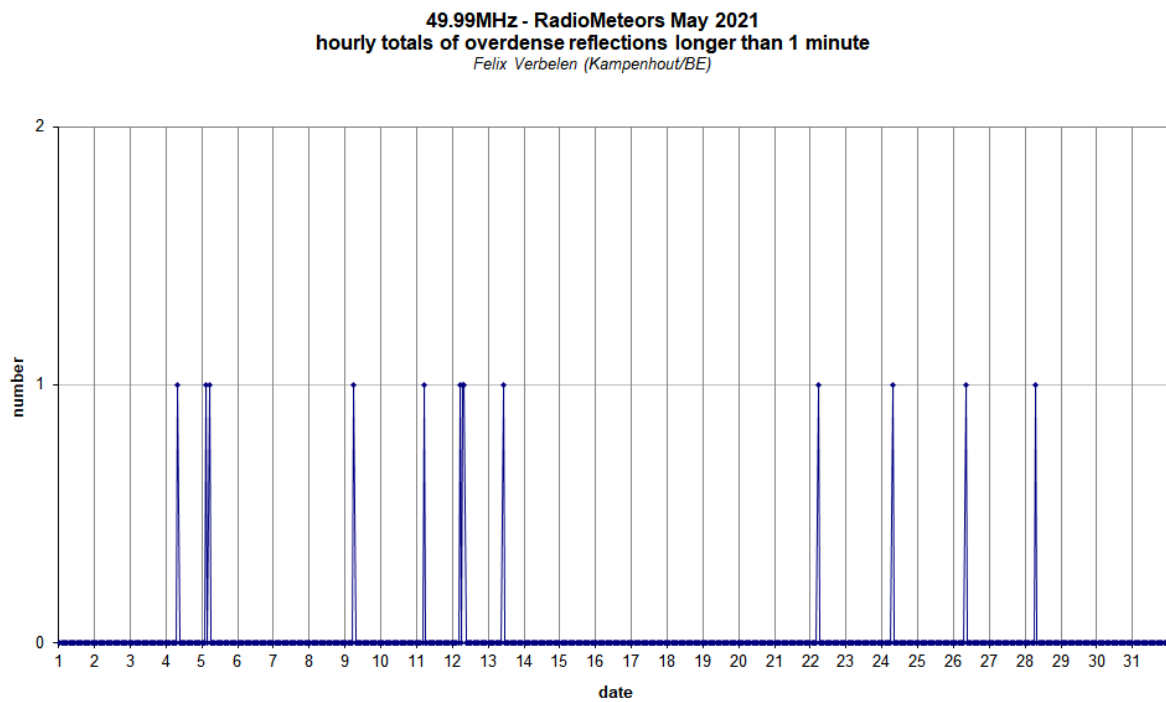
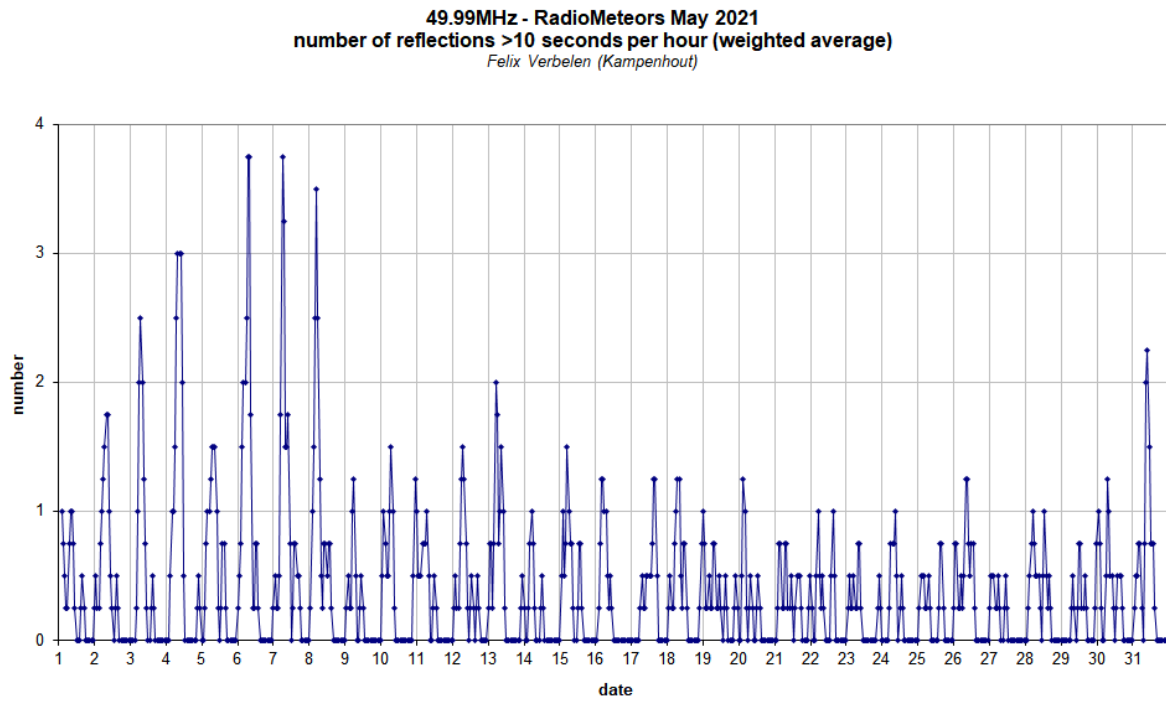


Figure 4 – The hourly numbers of overdense reflections longer than 10 seconds and longer than 1 minute, as observed here at Kampenhout (BE) on the frequency of our VVS-beacon (49.99 MHz) during May 2021.

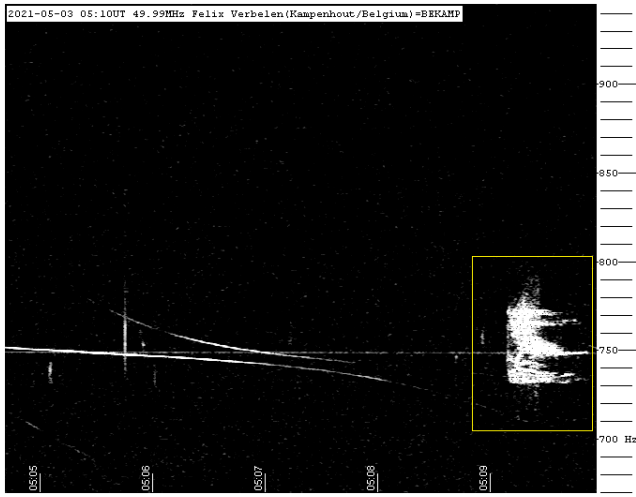


Figure 5 – Meteor reflection 3 May 2021, 05^h10^m UT.

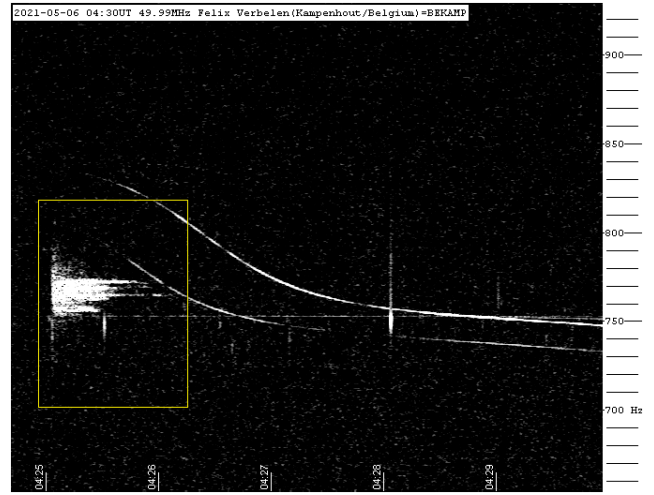


Figure 8 – Meteor reflection 6 May 2021, 04^h30^m UT.

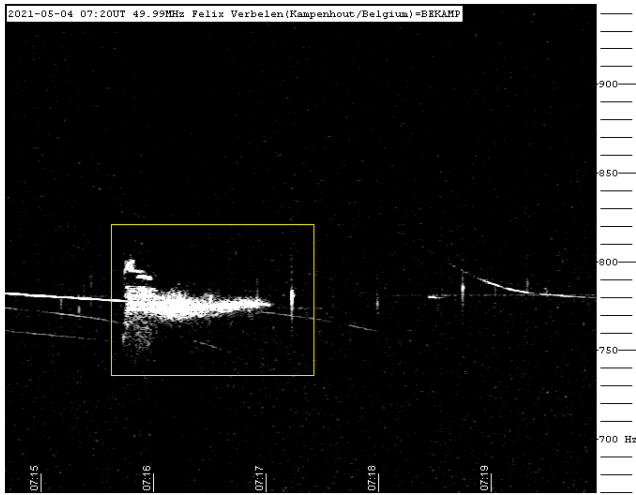


Figure 6 – Meteor reflection 4 May 2021, 07^h20^m UT.

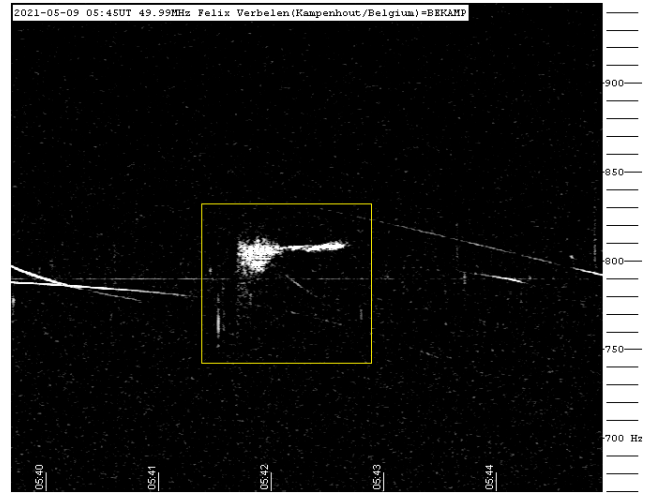


Figure 9 – Meteor reflection 9 May 2021, 05^h45^m UT.

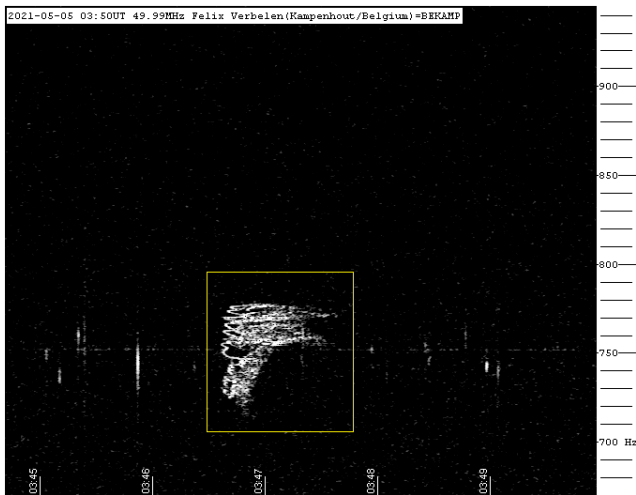


Figure 7 – Meteor reflection 5 May 2021, 03^h50^m UT.

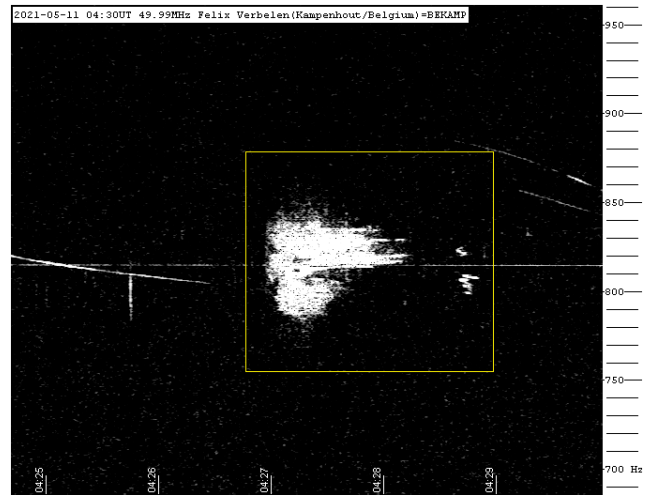


Figure 10 – Meteor reflection 11 May 2021, 04^h30^m UT.

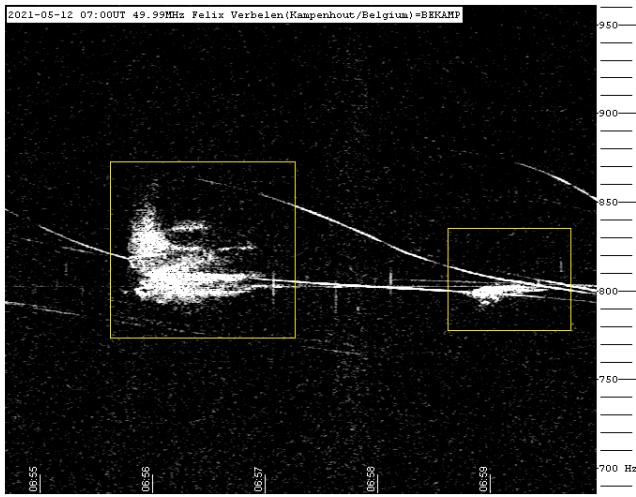


Figure 11 – Meteor reflection 12 May 2021, 07^h00^m UT.

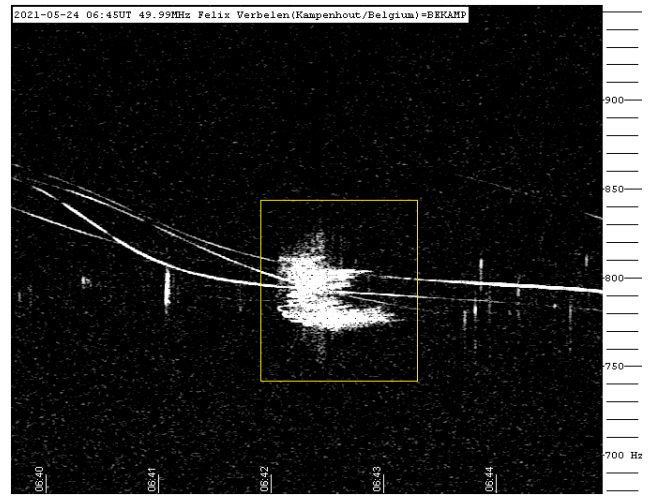


Figure 14 – Meteor reflection 24 May 2021, 06^h45^m UT.

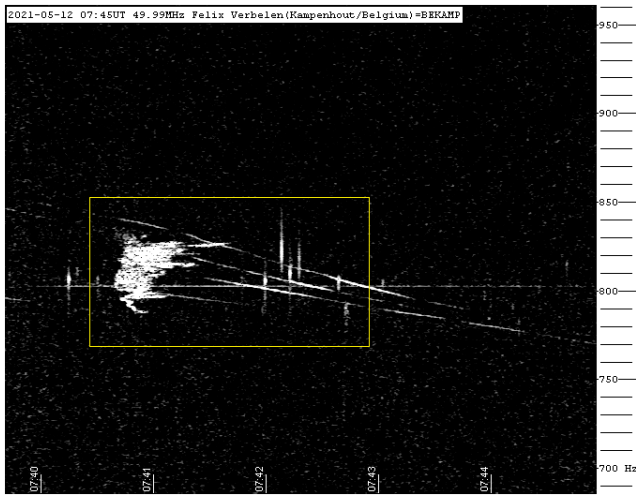


Figure 12 – Meteor reflection 12 May 2021, 07^h45^m UT.

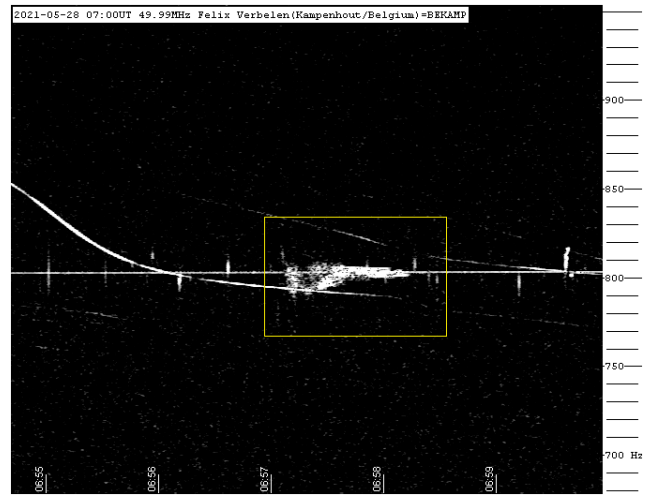


Figure 15 – Meteor reflection 28 May 2021, 07^h00^m UT.

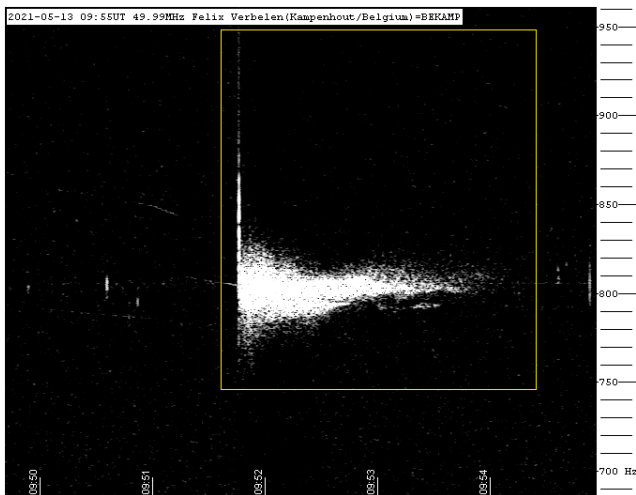


Figure 13 – Meteor reflection 13 May 2021, 09^h55^m UT.

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