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Composite photo with Perseids of 2016 August 12, 01h30m-02h30m UT (including peaks at 1h37m and 2h15m UT). Exposure time 29 sec. with 2000 ISO at F 4.0. Camera Canon EOS6D with Canon EF 8-15 mm F 4.0 fish eyelens, set at 9mm

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Front cover picture: Composite photo with Perseids of 2016 August 12, 01^h30^m-02^h30^m UT (including peaks at 1^h37^m and 2^h15^m UT). Exposure time 29 sec. with 2000 ISO at F 4.0. Camera Canon EOS6D with Canon EF 8-15 mm F 4.0 fish eyelens, set at 9mm. Author: Koen Miskotte.

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The magnificent outburst of the 2016 Perseids, the analyses

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Enhanced Perseid activity had been predicted for 2016 as a result of a sequence of encounters with some dust trails as well as the effect of perturbations by Jupiter which made Earth crossing the main stream deeper through more dense regions. Visual observations resulted in a detailed activity profile and population index profile, the observed features in these profiles could be matched with the predicted passages through the different dust trails. The 4 Rev (1479) dust trail in particular produced a distinct peak while the 7 Rev (1079) dust trail remained rather at a somehow disappointing low level. The traditional annual Perseid maximum displayed enhanced activity due to the 12 Rev (441) dust trail.

1 Introduction

Since a few years it was known that the 2016 Perseids could produce an exceptional display. Several outbursts were expected due to the presence of a number of dust trails from the parent comet 109/P Swift-Tuttle, thanks to the perturbations caused by the planet Jupiter. The very same perturbations would cause the background component (the annual activity) to produce a better than usual display as Earth would pass through the more dense parts of the meteor stream.

And yes, we did not get disappointed! During the night of 11 on 12 August the Perseids performed full strength above Europe and America. This analysis presents the calculated results for the nights 11–12 and 12–13 August, completed with a few impressions from the field.

2 The predictions

An overview of the different predictions is presented in *Table 1*.

3 Weather circumstances Europe

Unfortunately the weather wasn't everywhere very cooperative: 11–12 August happened to be totally cloudy for the BeNeLux. That was very unfortunate as we had liked to have CAMS data for this night. The next night was a perfect clear night and Jos Nijland was able to observe the Perseids from Drenthe. Both authors stayed in the famous hamlet Revest du Bion. Although cirrus clouds were predicted, the circumstances were better than expected and we had a nice clear night. The night 12–13 August happened to be clear as well. The group at Petnica couldn't observe that night due to clouds and rain. This was a great pity as this group includes several good and active observers. The next night Petnica had clear sky.

Table 1 – 2016 Perseid predictions.

Name	Dust trail Rev.	Dust trail Year	Date	Time	Remarks
Maslov M.	1	1862	11-8-2016	22:34 UT	ZHR 10–20 background activity, faint meteors
Vaubaillon J.	1	1862	11-8-2016	22:36 UT	ZHR 1
Cooke B., et al.	1	1862	11-8-2016	22:47 UT	?
Maslov M.	4	1479	11-8-2016	23:23 UT	Up to tenths of meteors on top of background
Vaubaillon J.	2	1737	12-8-2016	~ 00:00 UT	Unusual high activity
Cooke B., et al.	# Revs		12-8-2016	~ 00:36 UT	ZHR ~200
Cooke B., et al.	7	1079	12-8-2016	04:36 UT	?
Vaubaillon J.	7	1079	12-8-2016	04:43 UT	ZHR 580
Jenniskens	Filament		12-8-2016	~ 06:00 UT	ZHR 113
IMO cal. 2016			12-8-2016	13:00-15:30 UT	Traditional maximum ZHR 90–100
Cooke B., et al.	12 Rev	441	12-8-2016	13:00 UT	Combined with traditional maximum

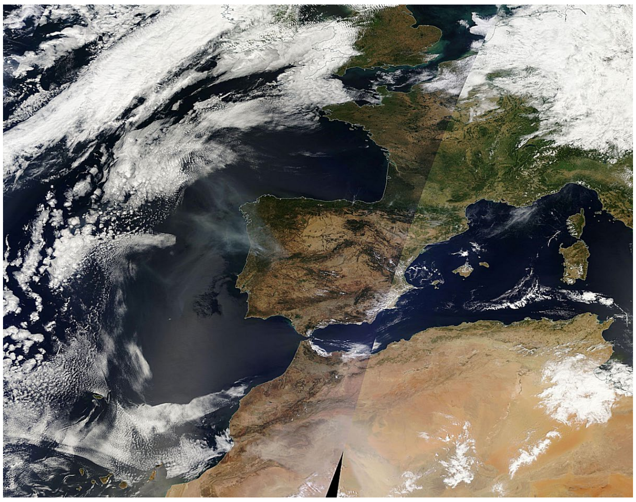

Figure 1 – Terra Modis picture of 11 August 2016 of Southern France, North Africa, Madeira and La Palma.

The group at La Palma included *Klaas Jobse, Carl Johannink, Sietse Dijkstra, Felix Bettonvil, Thomas Weiland* and photographer *Casper ter Kuile*. They suffered in first instance from Calima, but 11–12 and especially 12–13 August were clear nights. *Peter van Leuteren* could very well observe the night of 11–12 August from the island Madeira in spite of large forest fires.

4 Collecting data, which data to use?

A large number of observations were provided through IMO. The number of Perseids used for the analyses totals 20946 and can be found on the IMO website[1]. In the IMO ZHR profile a population index of 2.0 and a radiant elevation correction of 1.0 have been assumed. For this reason we cannot compare this analysis with our work.

Collecting the data happened in a slightly different way than during previous analyses. First of all we looked for observers for who we already had a reliable perception coefficient (C_p). For this purpose we used the list of the 2015 global Perseid analyses (Miskotte, 2015). Then, we searched for data provided by these observers for the period 10–13 August. Additional selection criteria for data included the radiant elevation (minimal 25° or higher) and the limiting magnitude (lm minimal 5.9 or better). Unfortunately many observations did not pass this quality control, only 50% of the data survived the selection criteria. Especially the bad weather above South-East Europe was responsible for the loss of a lot of data: especially the absence of data from the large group in Petnica, Serbia, had a great effect. There was also a large group of new and occasional meteor observers which did not qualify due to the lack of a reliable C_p value. We checked for people in this group who observed at least 15 to 20 hours during August 2016 in order to obtain a C_p coefficient, but unfortunately this was not the case.

It was striking that a considerable number of observers were active in China, but also in this case it concerned people with only few hours of observations. There is a great observing potential in China and it would be very helpful if these people would make some more observations end of July or during August.

The complete list of observers who reported Perseid data can be found on the IMO website[2].

5 Methodology

First of all, the data on the IMO website has been screened and checked on the perception coefficient C_p and the limiting magnitude. When the criteria were fulfilled the data was downloaded. This data was imported into the ZHR and magnitude distribution checking spreadsheet. For the magnitude distributions the following rule has been applied (Miskotte, 2016): The difference between the average limiting magnitudes should be smaller than 4.5 magnitudes. Normally we keep this limit at 4 magnitudes, but because the Perseids were on average brighter than usual we choose to set the limit at 4.5 magnitudes.

The remaining magnitude distributions allowed calculating the r-values. These r-values were imported into the ZHR spreadsheet with the meteor counts. Next all data were sorted on solar longitude while data with too low radiant elevation (until 25° elevation) and a couple of outliers were removed. The ZHR was computed according to the formula of Peter Jenniskens (Jenniskens, 1994; Miskotte and Johannink, 2005a):

$$ZHR = \frac{n \cdot F \cdot r^{6.5-LM}}{(\sin h)^{\gamma} \cdot C_p \cdot T_{eff}} \quad (1)$$

6 11–12 August 2016: Europe and America

We decided to use shorter intervals for the ZHR analyses because of the rapidly fluctuating activity during the night of 11–12 August 2016. Periods of 15–20 minutes have been used calculated as a sliding mean for every 5 minutes. The ZHR was calculated using the available r-values and the result is displayed in a graph (*Figure 2*). Data has been used for the period 11 August 2016, 21^h UT until 12 August 2016 12^h UT. The entire analyses and *Figures 2 to 8* are based on the data of 11610 observed Perseids.

To have a better view on the activity pattern above Europe we zoom in on the graph of *Figure* 2 in *Figure* 3.

Both graphs show very clearly that the ZHR was enhanced over the entire period, when we compare with what a normal ZHR used to be at these solar longitudes. Unfortunately there exist no ‘standard ZHR profile’; therefore we looked at the DMS data from 2007, 2010 and 2012. The years 2004 and 2008 were not taken into account because these were years with outbursts (Johannink et al., 2008; Miskotte and Johannink, 2005b;

[1] http://www.imo.net/members/imo_live_shower?shower=PER&year=2016

[2] http://www.imo.net/members/imo_live_shower?shower=PER&year=2016

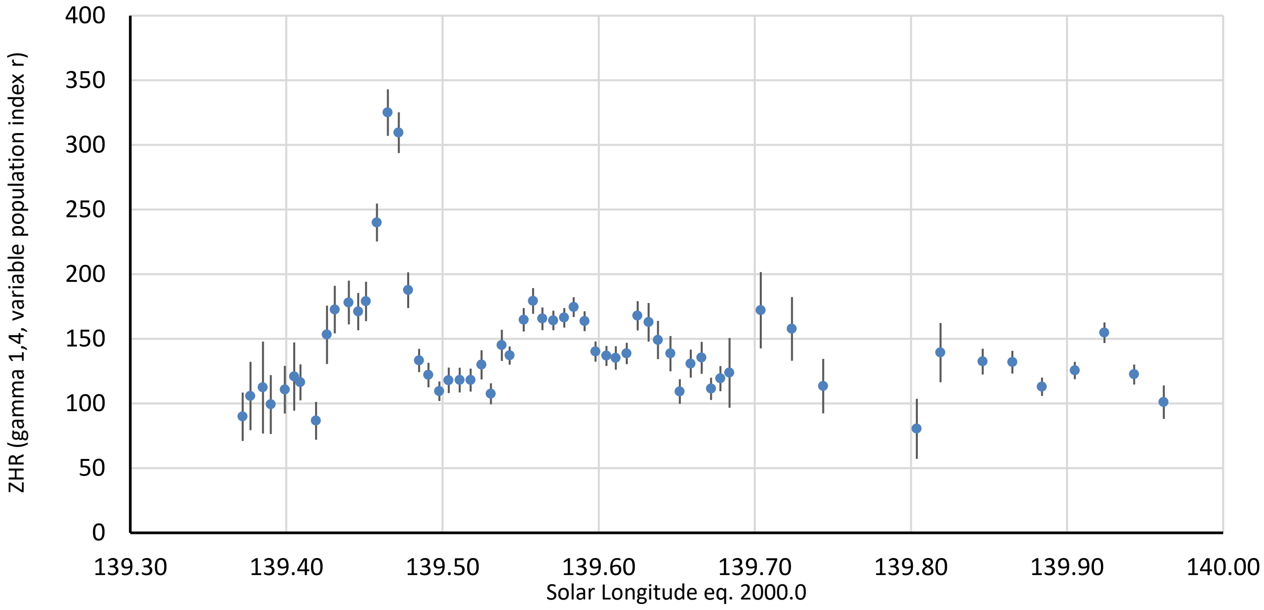

Figure 2 – ZHR profile for the Perseids 2016 from 11 August 2016 21ʰ UT until 12 August 2016 12ʰ UT.

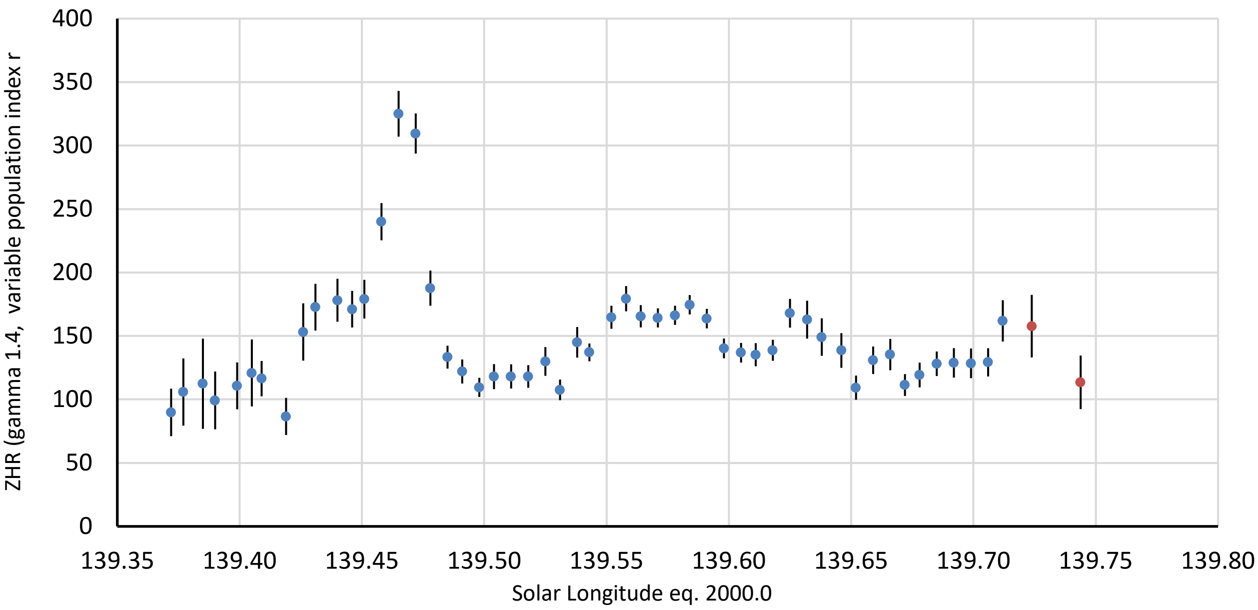

Figure 3 – ZHR profile for 11–12 August 2016, between 11 August 21ʰ UT and 12 August 07ʰ UT. The orange dots are computed with American data. See also the description in *Section 6*.

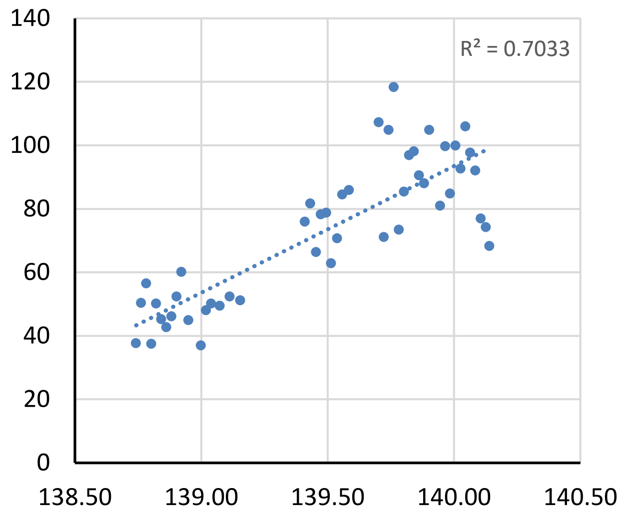

Figure 4 – ZHR values calculated from the years without Perseid outbursts, 2007, 2010 and 2012. This trendline was used in *Figure 5*. Source: DMS electronic visual archive.

2005c). The result is displayed in *Figure 4*. The trend line obtained for the years 2007, 2010 and 2012 has been used in *Figure 5*. *Figure 6* displays the time when peaks occurred.

When we pay attention to the ZHR profile of 11–12 August 2016 (*Figure 6*), it is obvious that the ZHR was already enhanced at the start of the night with ZHRs of about 100 while 60–70 are 'normal' values. The next feature is a sharp increase of the activity around 22^h20^m UT reaching ZHR values of 150. The activity remains stable at this level until 23^h00^m UT when a spectacular increase occurs with peak ZHR values of 320 at 23^h17^m UT. The display around this time was most impressive. The activity quickly drops to a ZHR of 185 at 23^h36^m UT and another 10 minutes later the ZHR had been lowered to 130.

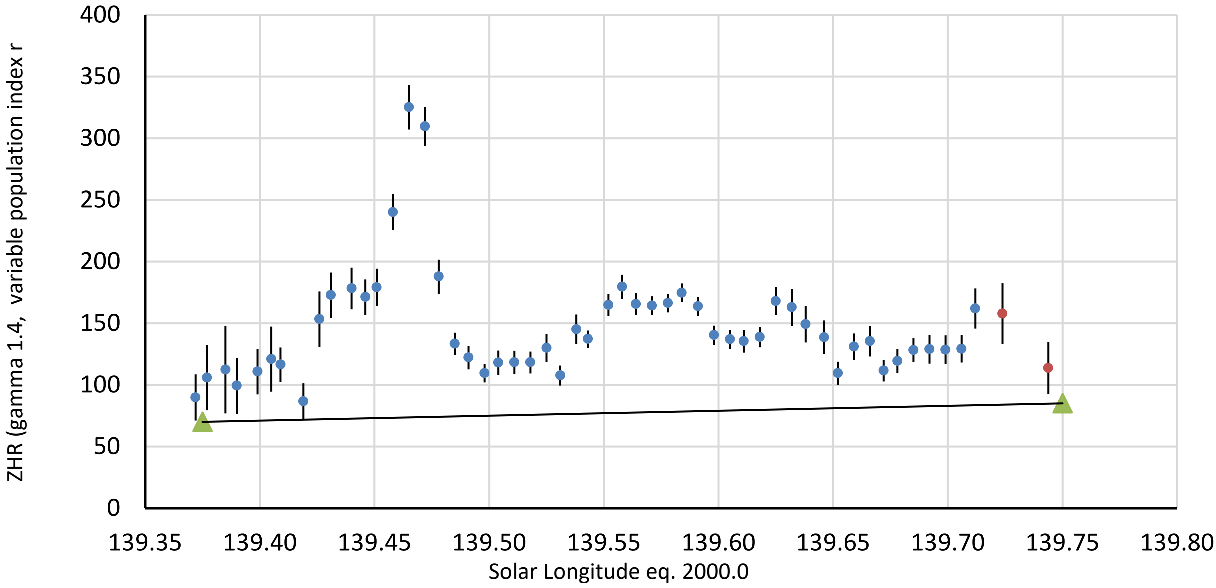

Figure 5 – The ZHR profile 2016 for 11 August, 21^{h}00^m UT to 12 August, 06^{h}00^m UT, 139.350°< λ < 139.750°with the trend line for 2007, 2010 and 2012 added. It is obvious that the activity remained at a significant higher level all the time, compared to the reference years.

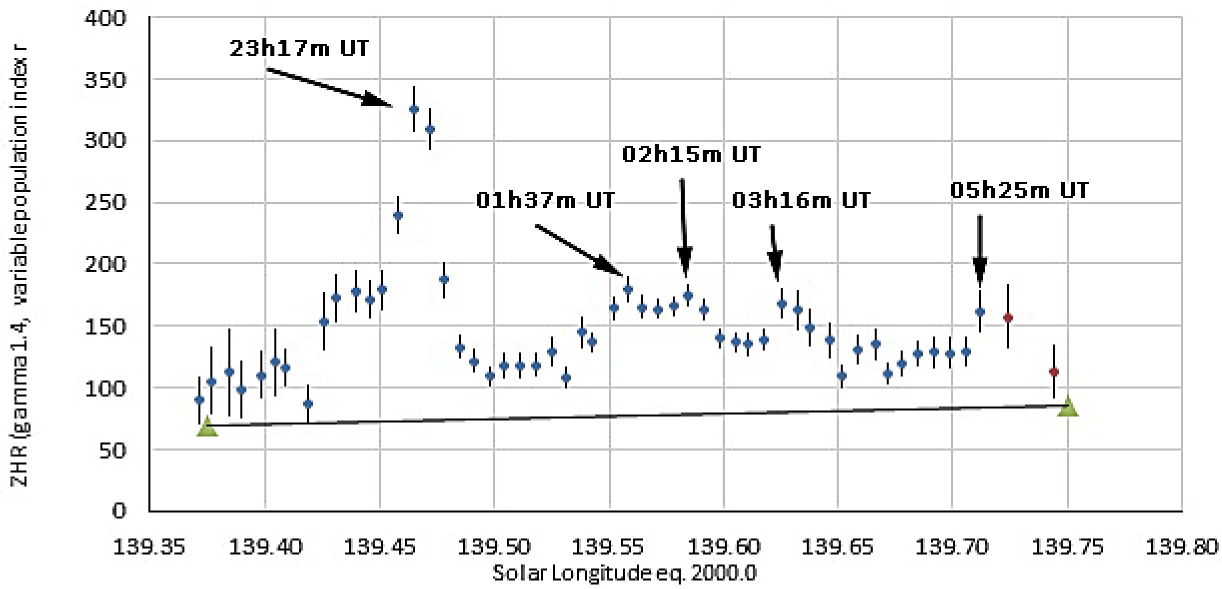

Figure 6 – The same ZHR profile as Figure 5, but with the timing of the different peaks.

Figure 7 – Composition picture of 11 August 2016 taken during the peak related to the 4 Rev dusttrail. The interval covers 23^{h}17^m–23^{h}25^m UT. 10 Perseids are visible, the brightest –3 Camera: Canon 5D with Canon EF 35 mm F 1.4 (F=1.8), ISO 1250, exposuretime 29 s. Location: Revest du Bion, Povence, France.

Michel Vandeputte describes the display very well (Vandeputte, 2016):

"*A nice –4 and a –3 started the top activity. Perseus spews literary meteors hither and thither across the sky, sometimes with 3 meteors at once! It was difficult to keep track at some moments to record everything correctly, such a high rate. This peak activity lasted for a quarter of an hour in the period 23^{h}15^m–23^{h}30^m UT with the strongest concentration shortly after 23^{h}20^m UT. This was completely in line with the expected peak of the 4 revolution old dust trail from 1479 (Maslov with peak time 23^{h}23^m UT!). The activity fluctuated a lot during this crazy time lapse, but on average 5 meteors per minute were counted during these insane 15 minutes of observing time with perhaps moments with 7-8 meteors per minute! All this appeared with the radiant at only 36° above the horizon. The decrease after the peak was even more* *impressive. Just like they appeared out of nothing, they were suddenly gone, followed by awful silence at the dark sky. Wow and wow again! Both observers were strongly impressed by the intensity of this display!*"

Thereafter the ZHR remained for a while around 110–120. During this time a number of nice fireballs up to magnitude –8 were observed. From 01^h00^m UT the ZHR increases again to culminate at peak values at 01^h37^m UT and 02^h15^m UT (ZHR ~ 170–180). Then more bright Perseids appeared, within a few minutes around 02^h15^m UT a number of events of magnitude –4, –5, –6 and –8 were seen from Revest du Bion. After a drop in the activity level another peak was observed one hour later around 03^h16^m UT. Twilight had started in France but still an impressive activity is being observed. Also this peak was accompanied with a fireball with a –8 end flare. The observers at La Palma and Madeira were perfectly positioned for this peak. After this peak the activity dropped back to a ZHR of 130, but the observers at La Palma saw again a rapidly increasing activity in the last 15 minutes. The observations during this period have overlap with the American observations reported by *George Gliba* and *Paul Jones*. They report many bright Perseids while the radiant is still low above the horizon, observations that concur very well with the reports from La Palma.

The last two (orange) dots in *Figures 3, 5 and 6* are based on data from *George Gliba*. Unfortunately we couldn't include the data of *Paul Jones* due to the presence of 25% cirrus clouds and the reporting in one hour intervals (too long).

Paul Jones wrote: "*The first couple of hours were somewhat slow as the moon sank and the cirrus dissipated. Still, we were able to catch several long-pathed early Perseids streaking up from the radiant which was grazing the northeast horizon at that time. We saw them all over the sky, even in the west and SW - many bright and colorful, leaving spreading trains behind them*".

In spite of the 25% cloud cover, a number of calculations were done with the data of *Paul Jones*. Based on these hourly counts a ZHR of about 180–200 could be obtained for this period. For reasons of clarity, this data has not been taken into account for the final ZHR calculations because of the too large portion of obscured sky. This calculation was done to check if his observations confirm the increased activity reported by *George Gliba*.

Thereafter we notice a decrease in activity to an almost normal level after the peak at 05^h25^m UT above America, followed by a new increase in activity up to ZHR values of 150 on 12 August around 10^h45^m UT. After this peak, activity decreases again to a normal level with a ZHR of 100 at 11^h45^m UT.

7 The r-values during the outburst

A nice population index r profile could be reconstructed. According to IMO the normal r-value for the Perseids is 2.2 (Vandeputte, 2016). The r-value remained inferior to this value for most of the time of the outburst. *Table 2* lists the computed values.

Table 2 – The calculated r-values, based on the magnitude interval of [–2,+5].

Date & time (UT)	$\lambda_{[2000.0]}$	r[-2;5]	n Per
11-08-16 21:30	139.394	2.48	291
11-08-16 22:30	139.434	2.22	304
11-08-16 23:30	139.474	2.12	743
12-08-16 0:30	139.514	2.11	662
12-08-16 1:30	139.554	2.03	1079
12-08-16 2:30	139.594	2.05	883
12-08-16 3:30	139.634	2.05	408
12-08-16 4:30	139.674	1.83	244
12-08-16 5:30	139.714	2.05	175
12-08-16 6:30	139.734	1.92	228
12-08-16 7:30	139.794	2.11	101
12-08-16 8:30	139.834	1.93	232
12-08-16 9:30	139.874	1.96	324
12-08-16 10:30	139.914	2.30	334
12-08-16 11:30	139.954	2.78	211

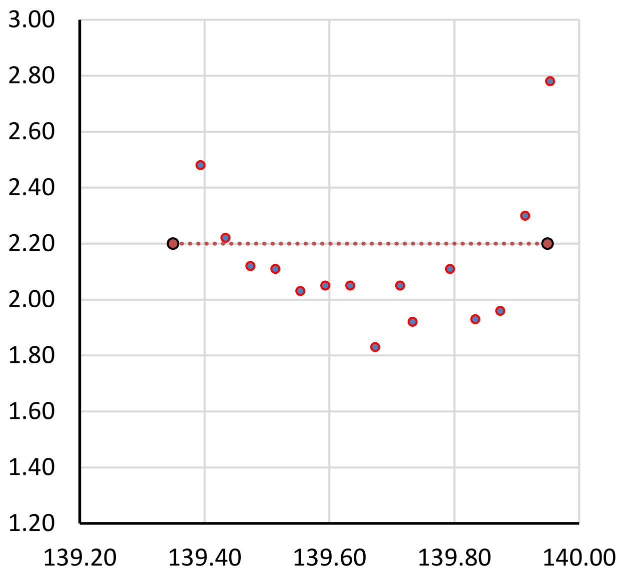

Figure 8 – The population index r for the Perseids during the outburst, August 11, 2016 at 21^h00^m UT until August 12, 2016 at 12^h00^m UT. This graph is based on *Table 2* (in total 6229 Perseids). De line (orange) marks the standard r-value of 2.20.

Observers at Revest du Bion, France (the authors) and in Poland (e.g. Jürgen Rendtel and Sirko Molau) mentioned several bright Perseids just before the major peak at 23^h17^m UT. This had no effect on the r-value. A possible explanation follows in a next section. During this peak the population index r had a normal value of 2.2, see also *Figure 9*.

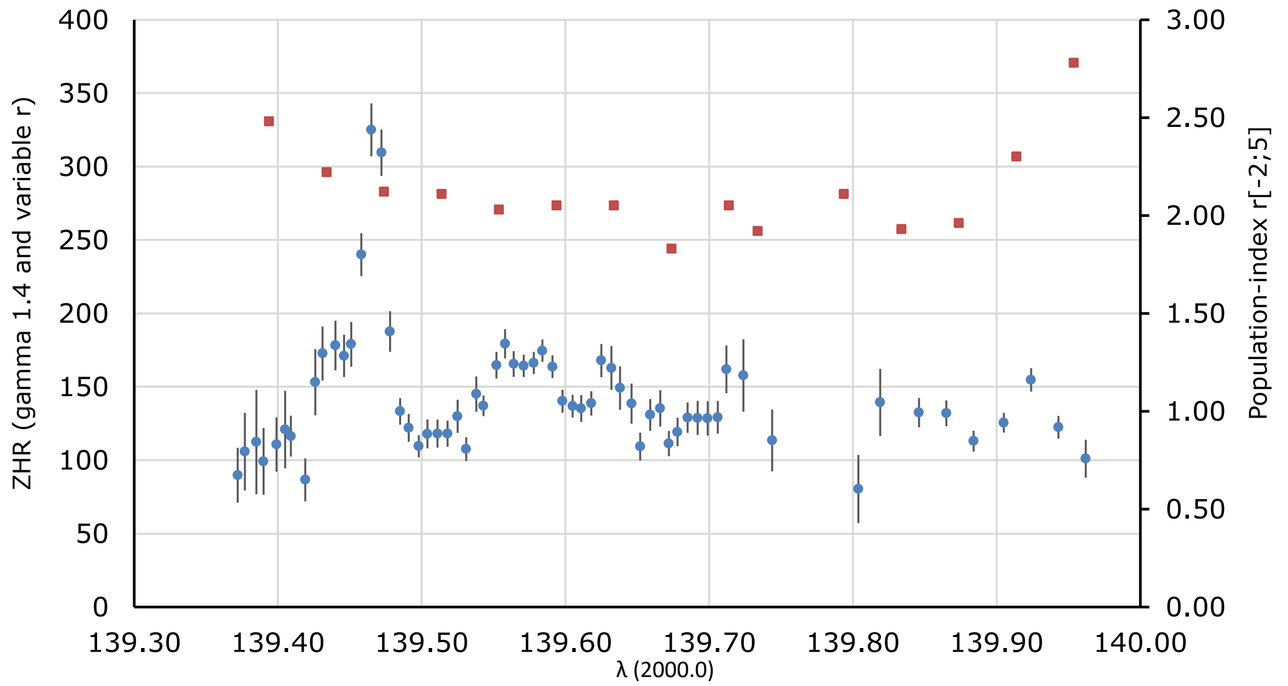

Figure 9 – ZHR and population index r combined in a single graph in function of solar longitude λ, covering 11 August 2016 20^h30^m UT until 12 August 2016 12^h00^m UT, or 139.370°< λ < 139.715°.

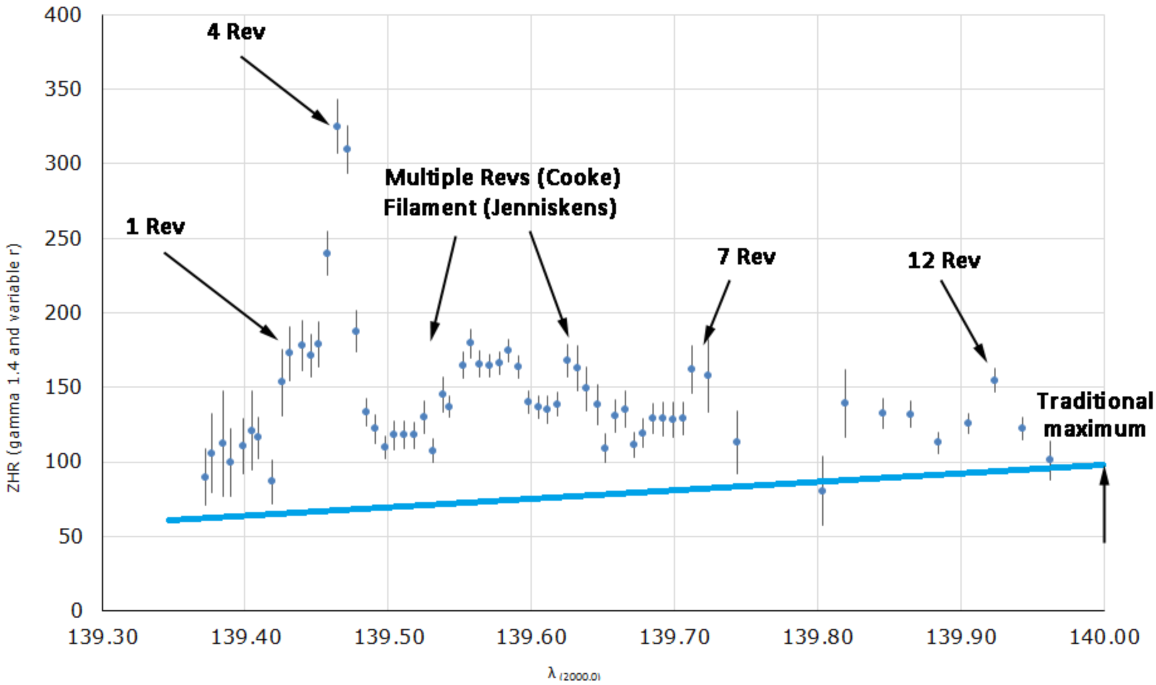

Figure 10 – The ZHR profile for the Perseids 2016 with a possible explanation for the peaks. The annual recurrent peak was predicted at solar longitude 140°. The blue line represents the averaged annual activity.

8 What did we see?

The 1 (1862) and 4 Rev (1479) dust trails

In *Figure 10* we can see that a first indication of enhanced activity occurred around λ = 139.4°, or about 22^h UT, according to a number of observers, more rich in bright events. This does not show up in our calculations of the population index r, see also *Figures 8 and 9*. The IMO video data shows this very well with a dip of 1.8 while the r-value remains for the rest of the night at 2.0 (Molau et al., 2017). However it is unclear to us how the r-value has been calculated from all the different video systems being used.

At about λ = 139.43° we see a bulging increase towards the 4 Rev. This is the 1 Rev which is interweaved within the 4 Rev. The 1 Rev occurred half hour later than predicted, but its activity was wider and higher than expected, it is visible between λ 139.4° and 139.5°. The sharp 4 Rev peak follows exactly at the predicted time at λ = 139.460° with an even more spectacular decrease. When we got through this dust trail, we also got through the 1 Rev. This Rev 1 dust trail was less striking as seen from the Provence in France due to its large proportion in faint meteors. There was still some moonlight involved and the radiant was a little bit lower at the sky. The 4 Rev dust trail appeared very pronounced in the visual observations.

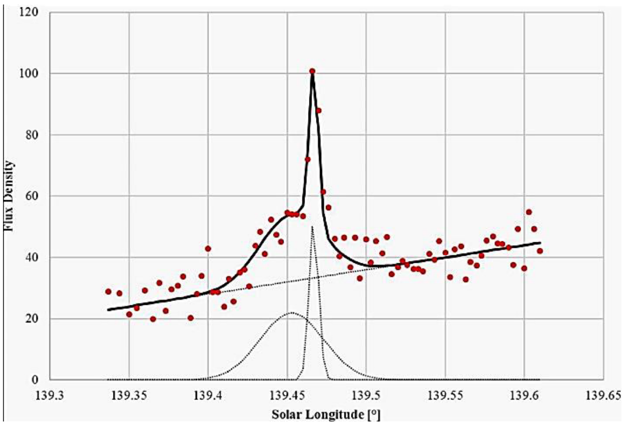

Figure 11 – The IMO video profile for the Perseids (Molau et al., 2017), represented by red dots. The black curve presents the theoretical profile based on two Gaussian curves, the first for the 1 Rev dust trail, the second for the 4 Rev dust trail. The linear line marks the average annual activity. The video activity profile fits very well with the theoretical profile (black line), especially during the passage through the dust trail.

The visual ZHR profile found from our analyses matches very well with the video Flux Density profile of the IMO (Molau et al., 2017), see also *Figure 11*. However we cannot compare these results straight forward as calculations have been done using different parameters. For the visual analyses we used a variable population index r and a radiant elevation correction exponent (γ) of 1.4. In the video analyses these parameters were respectively a constant population index r of 2.2 and γ = 1.5.

We believe that our computation of the r-values allow to claim the presence of the 1 Rev dust trail, partly interweaved in the 4 Rev peak. We notice significant higher, up to normal r-values before and during this period compared to later that night. Higher r-values indicate more faint Perseids. The fact that we obtain no lower r-values in spite of the brighter meteors shortly before 23^h UT can be explained from the calculation method for the population index which is limited to meteors in the magnitude range of –2.0 until +5.0. The bright meteors in this period were to a large extent in the magnitude –2.0 or brighter magnitude classes. Furthermore these bright meteors may belong to the 4 Rev peak or perhaps they marked the start of this dust trail.

The fact that we are dealing with a relative young dust trail (1 Rev) means that it still contains a large number of small meteoroids and thus faint meteors. That was also the picture for the passage through the 1 Rev trail in 2004 (Miskotte and Johannink, 2005b; 2005c). A short lived outburst with a ZHR of 200 with mainly faint meteors (+2 to +5) has been observed at this occasion. In 2004 we obtained from German and Dutch DMS observations respectively r values of 3.01 and 2.40 for this 1 Rev peak (Miskotte and Johannink, 2005b; 2005c). That the r value with 2.20 obtained for 2016 is a bit lower can be explained as “pollution” by the older 4 Rev dust trail. This contains larger meteoroids which mean more bright meteors.

This means that we have effectively observed at this solar longitude what we had expected. First a bit higher r-value due to the 1 Rev trail followed by a decreasing r-value due to the increasing influence of the 4 Rev trail. This decline continues further after the passage through the 4 Rev peak, caused by the influence of still older trails (the filament) later that night.

The filament, several old dust trails

After a dip in the activity, but with the ZHR still at an enhanced level, follows a build-up towards a broader plateau of enhanced activity with several peaks from solar longitude 139.60°. This includes the peaks with many bright events around 01^h37^m, 02^h15^m and 03^h16^m UT. What could be responsible for this?

It is rather difficult to resolve this, but thanks to the MSFC model (Cooke) we find some suspect elements such as the 10 Rev (698), 11 Rev (569), 5 Rev (1348) and 2 Rev (1737). This is a cluster of old dust trails, hence it is logic that it contains a lot of brighter stuff. Peter Jenniskens (2017) believes that this was the “filament”, a collection of old dust trails containing only large meteoroids and thus more bright meteors. The calculated r-values confirm this picture as these were the lowest for this time interval until the peak of the 7 Rev dust trail. The description as the filament is the same story as in the MSFC model of Bill Cooke, here it is listed as older dust trails (e.g. the 5, 10 and 11 Rev dust trails).

The disappointing 7 Rev (1079) peak

And then there is also the peak in the activity profile at solar longitude 139.7°, beyond doubt the contribution of the 7 Rev (1079) dust trail although this did not perform as intensely as what had been predicted by Jérémie Vaubaillon (ZHR 580). In the MSFC model it can be seen that the cluster of the 7 Rev remains at a larger distance while in the model of Vaubaillon the Earth orbit literary crosses though the trail. Peter Jenniskens concluded from the disappointing activity produced by older dust trails, that the dust particles disintegrate little bit by little bit

Figure 12 – Photo composition of August 12 between 02^h14^m and 02^h24^m UT. This photo shows 7 Perseids with a very bright eye catching Perseid of –8. Camera: Canon 5D with Canon EF 35 mm F 1.4 (F=1.8), ISO 1250, exposuretime 29 s. Location: Revest du Bion, Povence, France.

(Jenniskens, 2016; 2017). This could also be a possible explanation for the disappointing activity of the 7 Rev trail. The calculated r-value also confirms the picture of an old dust trail, the r-value was rather low in this time interval.

Traditional maximum and the 12 Rev (441) dust trail

The peak at 139.93° is most likely the traditional maximum. However, with a ZHR of 150 also this part was far above the normal level of activity. If we assume that the model of Cooke is correct, we may assume that this was a combination of the traditional maximum at solar longitude 140.0°–140.1° with some contribution from the 12 Rev (441) dust trail. We know this dust trail from the unexpected outburst in 2008 during the night 12–13 August (Johannink et al., 2008). This dust trail from 441 also produced a strong outburst in 2009 with a ZHR of 200 which has been observed above the USA (Miskotte et al., 2009).

The r-value was normal (2.20) around this peak, while the contribution from the 12 Rev (441) dust trail would suggest to have more bright meteors. However as said above a rather small contribution had been predicted from the 12 Rev dust trail.

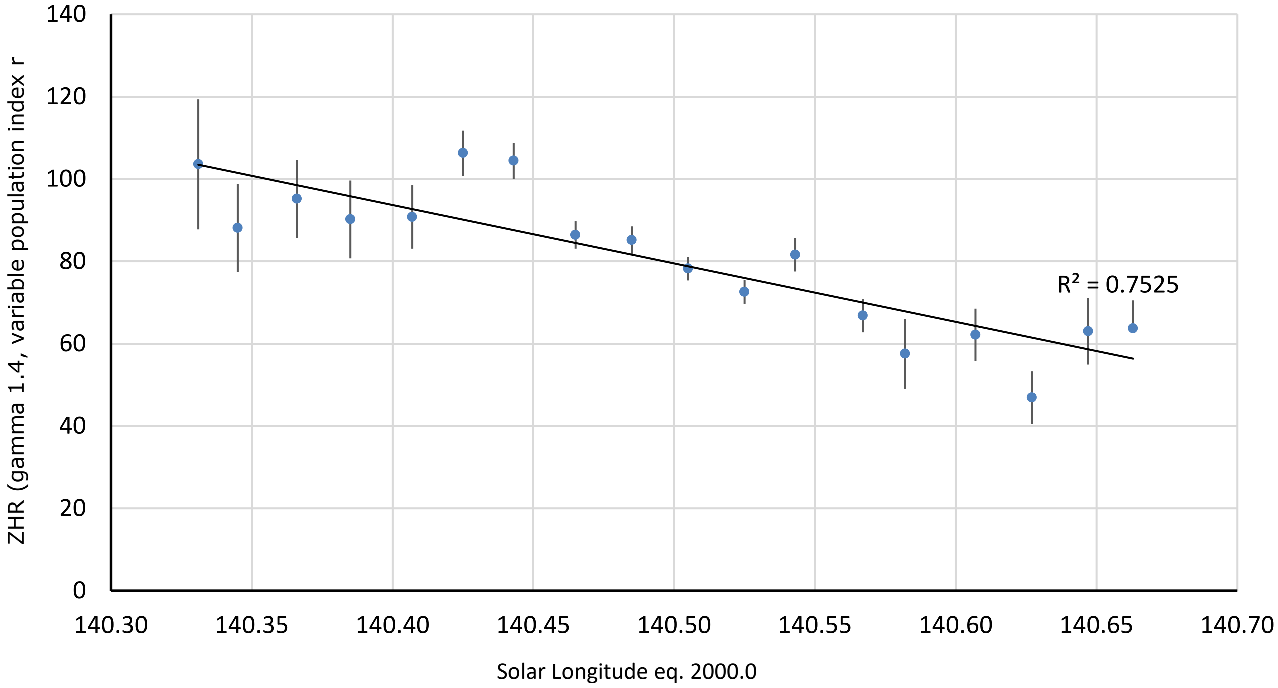

Figure 13 – The ZHR of the Perseids during the night of 12–13 August 2016 between 20^h00^m and 05^h00^m UT. This profile is based on 5115 Perseids.

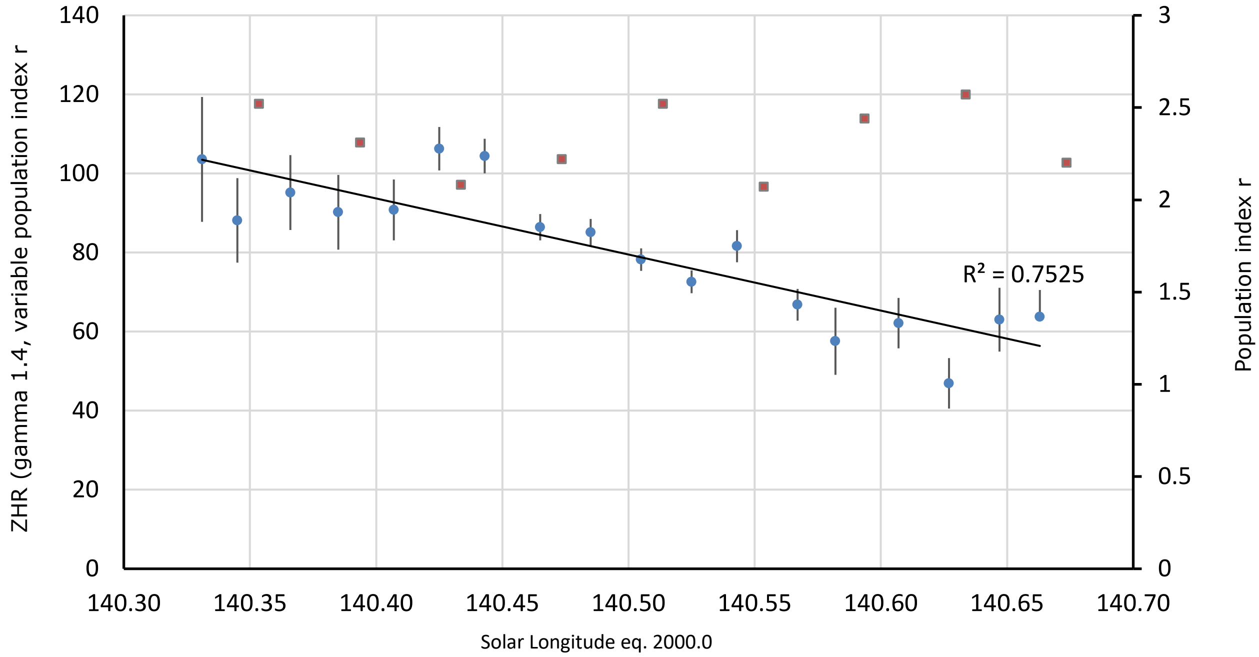

Figure 14 – The same graph as in *Figure 13*, but now with the r values added. It is remarkable that the r-value displays a dip at the small peaks at solar longitude 140.43° and 140.55°. It isn't clear if this is just by accident or if it is relevant.

We presented our conclusions to Peter Jenniskens (2017) and he confirms our picture of the Perseid activity during this night.

9 12–13 August 2016: Europe

In this analysis we restrict our attention for this night to Europe. In total 5115 Perseids could be used for this night for this analysis. It was good to see that data from the group in Petnica (Serbia) could be used for this night. This night clearly shows the decline in activity during the night. This was in line with the expectation since the regular Perseid maximum was expected at solar longitude 140.0°–140.1° while the European observing window covered the period in solar longitude from 140.33° (Eastern Europe) until 140.67° (La Palma).

The calculated r-values display a rather scattered picture with values between 2.07 up to 2.52. Luckily this did not make much difference with the ZHR calculations done for a standard r-value of 2.2 (Vandeputte, 2016). The differences remained well within the error margins.

Based on the calculated population index r the ZHR values were computed. As expected a declining activity occurred during this night. On 12 August 2016 between 20^h and 23^h UT a ZHR around 90–100 was found, declining towards the morning from 90 to 60 by 5^h UT. The result is shown in *Figure 13*.

10 Conclusion

The Perseids displayed an impressive activity in 2016. This analysis allowed identifying different peaks of the activity profile with a number of dust trails of comet 109P/Swift-Tuttle from 1862, 1479 and 1079. On top of this the regular annual maximum displayed enhanced activity as the Earth passed deeper through the meteoroid stream due to perturbations by planet Jupiter.

All in all we can look back at a magnificent Perseid return. The next interesting display is planned for 2028.

Acknowledgment

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Visual observations from California April – May 2017

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Two reports on visual meteor observations are presented, one covering the 2017 Lyrids on April 22, a second session covering the night 1 May 2017.

1 Lyrids 22 April 2017

I managed to view the Lyrid maximum for 2 hours from my new house located 20 miles east of San Diego. This was the first meteor observation from my new vantage point and I have found that it gives me an increase of at least 1 full magnitude right out the front door! Anyway, I faced toward the NE at an elevation of 60 degrees between the hours of 2:15 PDT to 4:15 PDT (9:15-11:15 UT). I counted 29 meteors, 16 of them belonging to the Lyrid shower. The limiting magnitude ranged from +6.11 at the start to +5.86 at the end. There were lots of bright Lyrids with the brightest being a –2 that appeared low in the east. The most impressive meteor of the session was a 0 magnitude sporadic that shot through the center of my field of view and left a nice train. I'm looking forward to many more sessions from home!

Date: 17-Apr 22 Mean Solar Long: 032.234
Beginning Time (UT) 0915 Ending Time (UT) 1115
Total T_{eff}: 2.00
LOCATION: Blossom Valley, CA, USA
LONG: 116 51′ 37″ W LAT: 32 51′ 44″ N
Elevation: 290 m Bortle Scale: Class 4: Rural/suburban transition
Beginning Temperature/Relative Humidity: 58F (14C) – 60%
Ending Temperature/Relative Humidity: 59F (15C) – 53%
METHOD: Visual Recording on Tape/Video Recording

Showers observed:

- ANT 14:56 (224) –17 01-00 1 Total
- LYR 18:08 (272) +33 07-09 16 Total
- SPO 04-08 12 Total
- Hourly Counts 12-17 29 Total

Period 1 0915-1015 UT

F = 1.00 (0% Clouds) Mean LM 6.06
FOV 270 +50 TOTAL T_{eff}: 1.00
Mean Solar Long: 032.206

Meteor data: ANT 1, LYR 7, SPO 4 TOTAL 12

Magnitude Distribution:

- ANT +2 (1) Mean +2.00
- LYR 0 (2) +2 (1) +3 (1) +4 (2) +5 (1) Mean + 2.57
- SPO +3 (1) +4 (3) Mean + 3.75

Period 2 1015-1115 UT

F = 1.00 (0% Clouds) Mean LM 5.94
FOV 285 +50 TOTAL T_{eff}: 1.00
Mean Solar Long: 032.246

Meteor data: LYR 9, SPO 8 TOTAL 17

Magnitude Distribution:

- LYR –2 (1) –1 (2) +1 (1) +2 (1) +3 (2) +4 (2) Mean + 1.44
- SPO 0 (1) +1 (2) +2 (3) +3 (1) +4 (1) Mean + 1.88

Total Magnitude Distribution:

- ANT +2 (1) Mean +2.00
- LYR -2 (1) –1 (2) 0 (2) +1 (1) +2 (2) +3 (3) +4 (4) +5 (1) Mean + 2.19
- SPO 0 (1) +1 (2) +2 (3) +3 (2) +4 (4) Mean + 2.50

2 Observations of 01 May 2017

I was off work Monday morning so I thought I would take advantage of the clear skies and view some meteor activity. Despite the good sky I was a bit disappointed in the rates as I only counted 11 meteors during the 2 hour session. 9 of these meteors were sporadic, 1 Anthelion, and only 1 eta Aquariid were seen. I was especially disappointed in the ETA rates as I thought for sure that they would be in the 3-5 per hour range. The highlight of the session was the first meteor seen, a 1st magnitude sporadic that mimicked an ETA but was much too short and fast to be an ETA at that hour.

Date: 17-May 01 Mean Solar Long: 040.999
Beginning Time (UT) 0930 Ending Time (UT) 1130
Total T_{eff}: 2.00
LOCATION: Blossom Valley, CA, USA
LONG: 116 51′ 37″ W LAT: 32 51′ 44″ N
Elevation: 290 m Bortle Scale: Class 4: Rural/suburban transition
Beginning Temperature/Relative Humidity: 58F (14C) 28%
Ending Temperature/Relative Humidity: 58F (14C) 32%
METHOD: Visual Recording on Tape/Video Recording

Showers observed:

- ANT 15:32 (233) –19 01-00 01 Total

- ETA 22:20 (335) –02 00-01 01 Total
- SPO 04-05 09 Total
- Hourly Counts 05-06 11 Total

Period 1 0930-1030 UT

F = 1.00 (0% Clouds) Mean LM 6.13
FOV 285 +20 TOTAL T_{eff}: 1.00
Mean Solar Long: 040.987

Meteor data: ANT 1, ETA 0, SPO 4 TOTAL 05

Magnitude Distribution:

- ANT +3 (1) Mean +3.00
- SPO –1 (1) +1 (1) +2 (1) +4 (1) Mean + 1.50

Period 2 1030-1130 UT

F = 1.00 (0% Clouds) Mean LM 6.12
FOV 300 +20 TOTAL T_{eff}: 1.00
Mean Solar Long: 041.027

Meteor data: ANT 0, ETA 1, SPO 5 TOTAL 06

Magnitude Distribution:

- ETA +3 (1) Mean + 3.00
- SPO +1 (2) +2 (1) +3 (2) Mean + 2.00

Total Magnitude Distribution:

- ANT +3 (1) Mean +3.00
- ETA +3 (1) Mean + 3.00
- SPO -1 (1) 0 (0) +1 (3) +2 (2) +3 (2) +4 (1) Mean + 2.50

Visual observing reports: Eta Aquariids 2017

Paul Jones

A summary of observing reports for the 2017 Eta Aquariids has been compiled.

1 May 6/7 2017 final η Aquariids (ETA) observations from north Florida

On this last night/morning of dark sky viewing for the 2017 ETAs, Dave Branchett and I did them up right with a great pair of sendoff observing sessions in the pre-dawn this morning. Dave was in Deltona and I was at Matanzas Inlet (MI), neatly sandwiching our sessions as we did between moonset and morning twilight. As usual, the ETAs did not disappoint!

My one hour session at MI began in moonlight, had a nice albeit brief period of lovely dark skies in the middle and then ended in rapidly brightening morning twilight. It was a most unusual session, yet one that produced some stunning and memorable meteors throughout, both ETAs and non-ETAs.

Here's my data:

Observed for showers:

- ETA: eta Aquariids
- ELY: eta Lyrids
- ANT: Anthelions
- GAQ: gamma Aquilids
- SPO: sporadics

Date: May 6/7, 2017, Observer: Paul Jones, Location: Matanzas Inlet, Florida, Lat:29.75 n, Long: 81.24 w, LM-variable (5.0 – 6.5), sky conditions: clear with some haze and high humidity, facing: southeast

0435 – 0535 EDT (0835 – 0935 UT) T_{eff}: 1.0 hour, no breaks.

- 17 ETA: -2, 0(2), +1(2). +2(4), +3(4), +4(3), +5
- 2 ELY: +2, +3
- 1 GAQ: +4
- 8 SPO: +1(2), +2(2), +3(2). +4, +5
- 28 total meteors

9 of the ETAs left trains (all of the brighter ones), the –2 ETA as a bright golden yellow and some faint blue tints were seen in some of the other brighter ETAs.

In addition to the several bright, stunning ETAs, I also caught two gorgeous, slow-moving, earthgrazing sporadics that lasted several seconds on the sky. One was noticeably orange in color and the other one was silvery white. I had a good burst of nice ETAs near the end of the hour as several fast streaks splashed across the twilight sky in awesome fashion all headed generally NW from the radiant. The session was rounded out nicely by a pass of the ISS low in the northwestern sky. All in all it was an awesome hour's session!!

Here is Dave's report from Deltona:

Well I really learned a valuable lesson this morning and that is you really never know what to expect! I awoke much earlier than intended so got everything ready to begin at 03^h45^m EDT the moon was setting but I could easily see the milky way and right off the bat I had meteors popping left right and center, no eta's but there was something going on up in Lyra and also activity in a triangle region bound by Alpha, gamma and zeta Cygni. I really didn't expect to see many eta's , much to my amazement in a two hour period I counted 32 eta's.

The interesting thing that I noticed this morning that there were none brighter than 0 magnitude and very few with long trails and lingering trains. The vast majority popped in a sudden burst or flash, on one occasion I had an eta pop a little east of Atair then right after a sporadic burst just below in the same location. However the moment that astounded me and most certainly got my juices flowing happened just a few minutes into the second hour when an eta popped just below Beta AQRii, shortly followed by a second and a third all in the same area but varying in brightness. With that said below is my report for this morning.

Observer: Dave Branchett
Location: Lat 28.8766 deg N Lat 81.1803 deg W, Private residence Deltona Florida.

Date: 05/07/2017, Time: 07:45 – 08:44 UT Duration: 1 hour, one 3 min break, limited magnitude 4.5, sky conditions: excellent, facing East South East, damp and chilly.

- Eta Aqr 13
- Eta Lyr 5
- Sporadics 13
- Total 31

Time: 08:45-09:44 UT Duration: 1 hour, one 3 min break, limited magnitude 4.5, sky conditions: excellent, facing south, the air damp and chilly

- Eta Aqr 19
- Eta Lyr 0
- Sporadics 4
- Total: 23

Note: No eta Aqr brighter than 0 magnitudes, very few with long trails and dust train. Most appeared as sudden bursts, most notably shortly after the start of the second hour three almost simultaneous bursts appeared just below beta Aqr.

2 Early May, 2017 ACAC observations of the η Aquariid meteor shower from north Florida

Members of the ACAC have already been out a few times in the pre-dawn (0400 – 0600 a.m.) monitoring the build-up of the 2017 eta Aquariids (ETAs) towards their maximum activity level over the next several mornings.

Dave and Brenda Branchett have led the way from Deltona, Florida with several observations of moderate ETA activity so far. I managed one hour's observation from the "meteor roof" of my home yesterday morning. Here is the report on what we've been seeing:

Observed for radiants:

- ETA: eta Aquariids
- ANT: Anthelions
- ARC: April rho Cygnids
- SPO sporadic meteors

May 3/4, 2017 Observer: Paul Jones. Location: 3609 Crazy Horse Trail, St. Augustine, Florida, Lat: 29.89.11 N, Long: 81.30.31 W (5 miles SW of St. Augustine, Florida). 0430 – 0530 EDT (0830 – 0930 UT) T_{eff}: 1.0 hour, no breaks, LM: 5.2 sky conditions: clear, slight haze, facing: south

- 5 ETA: 0, +3(2), +4(2)
- 2 ANT: +2(2)
- 9 SPO: +1, +2, +3(3), +4(4)
- 16 total meteors

All the ETAs were short-pathed (which is unusual for them). The zero magnitude ETA flared a pretty golden color and left a short train. The two ANT meteors were both long, slow and bright – very pretty meteors.

Here are Dave and Brenda's reports:

Observer: Dave Branchett. Location: Lat 28.8766 deg N Lat 81.1803 deg W, Private residence Deltona Florida. Date: 05/01/17, Time: 09:12 – 09:42 UT Duration: 30 minutes, no breaks, limiting Magnitude 3.0, sky conditions: fair, scattered clouds, facing East South East

- Eta Aqaurids 5
- Sporadics: 3
- Total: 8

Observer: Brenda F. Branchett, Location: Same as above. Date: 05/01/2017, Time: 09:27 – 09:42 UT Duration: 15 minutes, no breaks, limited magnitude 3.0, sky conditions: fair, scattered clouds, facing East South East.

- Eta Aquarids 3
- Sporadics: 2
- Total: 5

Notes: Both Dave and I observed a couple of simultaneous meteors.

Observer: Dave Branchett. Location: Lat 28.8766 deg N Lat 81.1803 deg W. Private residence Deltona Florida. Date: 05/03/2017, Time: 08:00 – 08:59 UT Duration: 1 hour, no breaks, limited magnitude 3.0, sky conditions: fair, mostly cloudy, facing East South East

- Eta Aquarids 4
- Sporadics 0
- Total 4

Notes: Not five minutes into the hour clouds rolled in from the south, it was not a solid mass but had several breaks only to clear out completely as the hour wound down. The meteors observed were faint swift ending in a bright burst like a fire work.

Time: 09:00-09:30 UT Duration: 30 minutes, no breaks, limited magnitude 4.0, sky conditions: fair and clear.

- Eta Aquarids 3
- Sporadics 1
- Total 8

Notes: All three Aquarids observed during this session were classic swift bright long duration two had fine dust trails.

Observer: Dave Branchett. Location: Lat 28.8766 deg N Lat 81.1803 deg W, Private residence Deltona Florida. Date: 05/04/2017, Time: 08:45 – 09:30 UT Duration: 45 minutes, no breaks, limited magnitude 4.0, sky conditions: fair, facing East South East.

- Eta Aquarids 9
- Sporadics 3
- Total 12

Observer: Brenda F. Branchett, Location: Same as above. Date: 05/04/2017, Time: 08:45 – 09:30 UT Duration: 45 minutes, no breaks, limited magnitude 4.0, sky conditions: fair, facing East South East

- Eta Aquariids 7 (none brighter than 1st magnitude)
- Sporadics 6
- Total 13

Did see the ISS pass over and a couple of satellites always make it interesting.

Many thanks to Brenda and Dave for these great visual reports! With the front passage and beautiful clear skies now, ETA activity in the morning should be much higher!! Last year, I saw over 20 per hour from them before dawn under the super dark clear skies down at Matanzas Inlet (MI). I plan to be out in the morning at MI to begin observation at 4:00 a.m. If anyone would like to join me, give me a shout via email, call or text. We can meet at our usual MI "star party" parking lot about 3:45 a.m. or so. Would love to have some company…;o).

Radio meteor observations in the world: Monthly Report for April and May 2017

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In April 2017, there was no unusual meteor activity. The 2017 Eta Aquariids displayed enhanced activity compared to previous years.

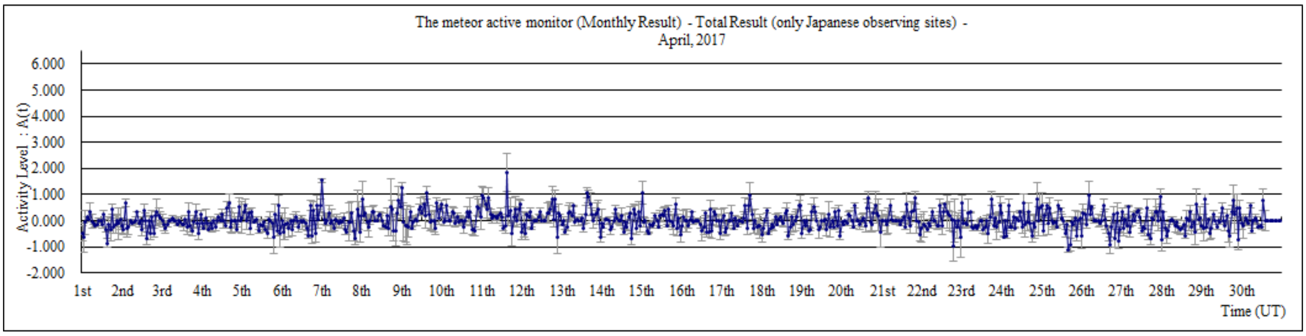

Figure 1 – Monitored result for April (only Japan).

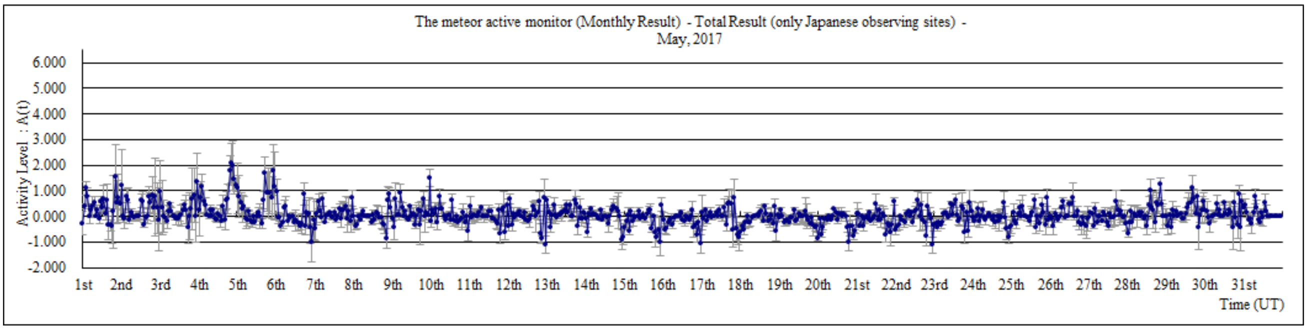

Figure 2 – Monitored result for May (only Japan).

1 April Lyrids 2017

Although one of the annual major meteor showers, the "April Lyrids" was present around 22nd/23rd April, there was no distinct meteor activity of this shower in this year. *Figure 3* was provided by 26 observing stations in nine countries.

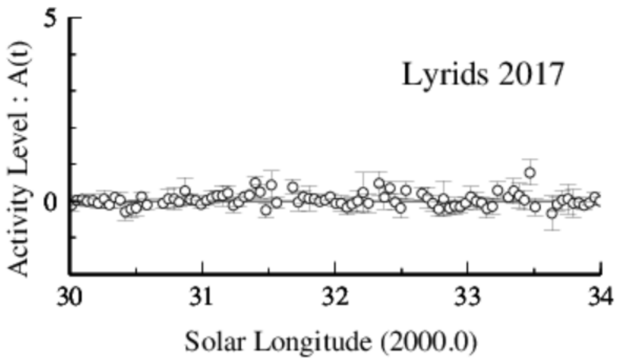

Figure 3 – April Lyrids 2017 using data at 26 observing stations in nine countries.

2 Eta-Aquariids 2017

One of the annual major meteor showers, Eta-Aquariids, was active this month. The activity level was higher than in other years. *Figure 4* shows the comparison between the average annual activity covering the period 2004–2017 (red line) and this year (circle with error).

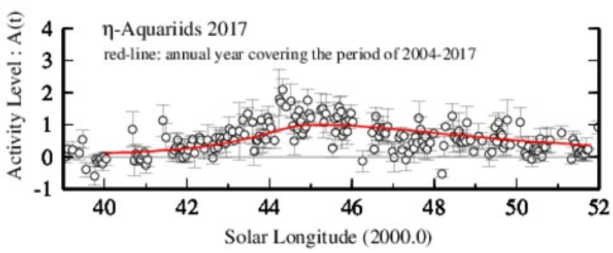

Figure 4 – Eta-Aquariids 2017 using data at 30 observing stations in 12 countries. The comparison between average annual activity (red line) and the 2017 activity (circles with errors).

The peak around Solar Longitude = 44°.3 was the peak predicted by several researchers. This component was estimated as the maximum activity level = 1.1 at Solar Longitude 44°.32 (May 4^{th} $20^{h}30^{m}$ UT) with Full Width Half Maximum (FWHM) -3.0hr / +3.0hr.

The annual peak which has a peak around 45°.5 was shown around 45°.4 – 45°.6. This was considered as the maximum activity level = 1.3 at 45°.41 (May 5^{th} $23^{h}30^{m}$ UT) with FWHM: -48.0hr / +42.0hr. Detailed results can be found on the website[3].

3 May, 2017

The graph (*Figure 2*) shows the monitored result (using ONLY Japanese stations) in May 2017. In Japan, there was no unusual activity except for the period of the Eta-Aquariids. Although some high activity levels occurred which were above the usual level (0.0±0.4), some uncertain weather occurred and some meteor activity may be due to observing errors.

Acknowledgment

- Radio Meteor Observing Bulletin (RMOB)
- Radio Meteor Observation in Japan (RMOJ)
- All radio meteor observers

[3] http://www.amro-net.jp/meteor-results/05_aqr/2017aqr.html

Bright meteor at the sky of Espirito Santo Brazil

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A fireball occurred on 2017 May 4, 01h50m17s UT and was registered by the Exoss network.

1 Introduction

On the night of 3 on 4 May, three Exoss network cameras recorded a bright meteor over the south of Espirito Santo, Brazil.

Figure 1 – The fireball from Sao Jose de Uba.

The fireball entered the atmosphere at a 60 degree entry angle at the place below its initial penetration, above the city Mimoso do Sul at a height of about 80 km, at a low speed, about 18km / sec, covering about 23 km in about 1.7 secs. Its maximum brightness came close to the magnitude of Venus.

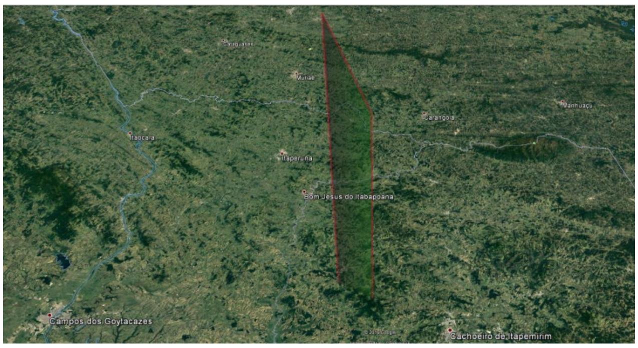

Figure 2 – Plot on Google Earth.

2 The calculations

Applying the usual criteria of the meteoroid source analysis, together with its orbital elements, such as eccentricity, inclination, semi-major axis, indicate that this bolide may originate from a NEA (Near Earth Asteroid).

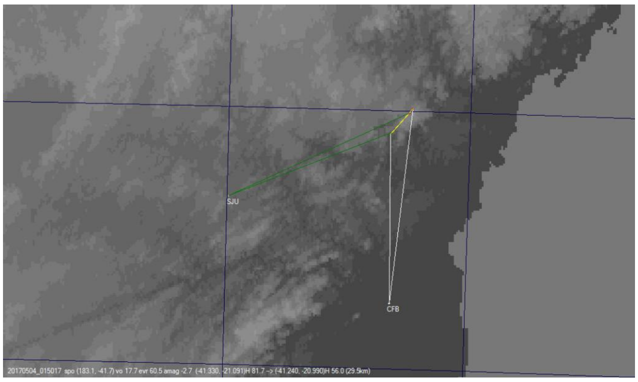

Figure 2 – Ground map São Jose de Uba-RJ station.

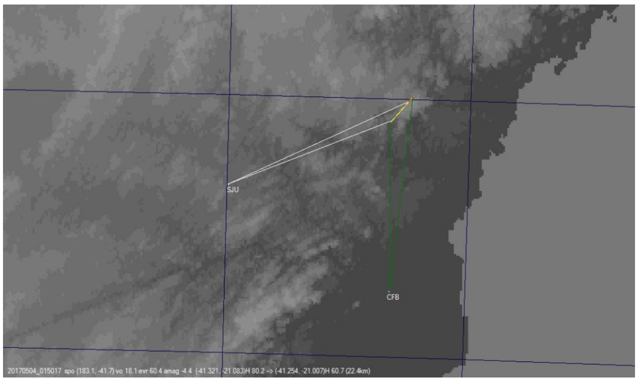

Figure 3 – Ground map Campos dos Goytacazes-RJ station.

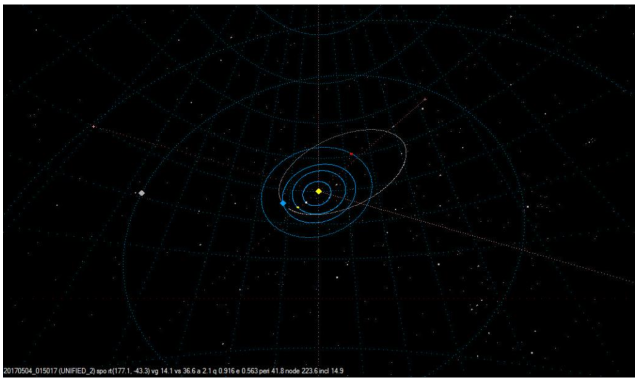

Figure 4 – Orbit calculated with UFO Capture software.

Fireballs from UKMON

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A Fireball has been reported by the public on 27 May, which was captured by the UKMON camera at Exeter. Another fireball was reported on 1 June 2017.

1 The Exeter fireball of 27 May 2017

On 27 May 2017 at 10PM a large meteor/fireball was spotted by members of public. It was warm and clear Saturday evening with many people enjoying the weather when UKMON started to receive first reports. Quick alert was sent through the network with a match from Exeter camera.

Figure 1 – The fireball captured by the Exeter camera.

UK Meteor Observation Network[4] names the fireball events by a station name that reported it first and this is a first one for Exeter. So far over 50 public reports have been collected by IMO Fireball report website, event is marked as Fireball event 1768-2017[5].

The fireball was exceptionally bright; it was just after dusk, but unfortunately since there is no match from any other station we cannot triangulate. Hopefully there is another recording of this meteor in the UK. If you have a recording please contact UKMON directly at ukmeteornetwork@gmail.com.

2 Another fireball for UKMON

Not even a week later UKMON has reported another fireball across the Channel. This time however members of public reported the event first.

On 1 June 2017 just before midnight visitors flooded IMO and UKMON fireball report form and so far 74 reports were gathered about 1808-2017 event[6].

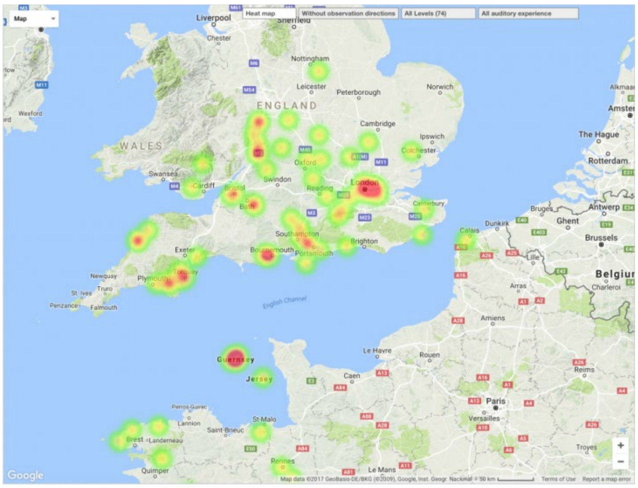

Figure 2 – Heatmap for the fireball of 1 June 2017, based on the IMO online Fireball Report.

Wilcot station captured the fireball from a bit of a distance:

Figure 3 – The 1st of June 2017 fireball at Wilcot station.

The UKMON team will be also looking closely at footage from Dawlish Beach camera[7] to possibly attempt triangulation.

[4] https://ukmeteornetwork.co.uk/fireballs/
[5] http://fireballs.imo.net/imo_view/event/2017/1768
[6] http://fireballs.imo.net/imo_view/event/2017/1808
[7] http://new.dawlishbeach.com/this-is-not-the-moon-so-just-what-are-you-looking-at/

Fireball of 30 May 2017 over NE Italy Preliminary results

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A big fireball has been observed in Northern Italy at 21h09m22s UT on 30 May 2017. The fireball was registered by 3 video cameras of the Italian Meteor Group and observed by many visual people. The preliminary trajectory above the area between Romagna and Veneto regions was calculated.

1 Introduction

On Tuesday 30 May 2017 at $21^h09^m22^s$ UTC, a large meteoroid entered the atmosphere of northern Italy and caused a very brilliant fireball. The meteor has been reported from almost all regions of northern Italy and also from the northeastern boundaries.

The meteoroid, which came into the atmosphere at a very low speed and with a trajectory roughly from south to north, showed a sequence of explosions some of which almost as bright as the Full Moon, if not brighter.

According to the visual witnesses closest to the event, the bright meteor illuminated a large part of the sky, projecting shadows to the ground, and it left a long persistent trail behind.

The flight was visible for several seconds, while the meteor showed a change of color from green to orange. Some witnesses from Emilia Romagna and Veneto regions have reported noises like explosions.

2 The observational data

Figure 1 – Image of the starting part of the fireball, filmed by the videocam JENNI of the IMG-UAIsm network from Faenza (44.28°N 11.89°E) – © Francesca Cineglosso.

The fireball appeared in the early evening, right at the end of astronomical twilight, this explains the large number of visual testimonies, many of which appeared soon afterwards on the internet.

Figure 2 – Image of the starting part of the fireball, filmed by the videocam MARIO of the IMG-UAIsm network from Faenza (44.28°N 11.89°E) – © Mario Bombardini.

Figure 3 – Animated image (click on the image) of the final part of the fireball, filmed by the videocam MET38 of the IMG-UAIsm network from Venezia Lido (45.41°N 12.37°E) – © Maurizio Eltri.

Fortunately, some IMG-UAIsm video surveillance network stations[8] filmed the fireball. From the positional measurements it was possible to get the first astrometric data as well as to estimate the real atmospheric trajectory of the body.

The starting part of the path was obtained from the two Faenza stations (*Figure 1 and 2*), managed by Mario Bombardini and Francesca Cineglosso , while Venice Lido station (*Figure 3*), managed by Maurizio Eltri, filmed the terminal part previous to the final flare of the meteor.

Useful positional indications were also reported by some visual testimonies of amateur astronomers.

3 The calculations

Figure 4 – Projection to the ground of the atmospheric trajectory of the fireball. © IMG-UAIsm.

Calculations were performed with the IMG team software. From the available data it is likely that the meteoroid has entered into the atmosphere with a very slow speed and that the meteor became visible at a height of about 99 km above the skies just south of the city of Faenza (44.20°N 11.82°E) and has ended about 22 km high above the southern Veneto region between the cities of Rovigo and Chioggia (45.09°N -12.04°E).

The meteor was moving with an average azimuth of 190 degrees, with a direction roughly south to the north, from an ecliptic radiant in the Virgin constellation.

The curvature of the long path, due to gravitational force, is very clear from the data.

Figure 5 – Geometry of the atmospheric path seen from the southeast. © IMG-UAIsm.

The map in *Figure 4* shows the ground projection of the atmospheric trajectory of the fireball. The image in *Figure 5* shows instead the geometry of the atmospheric path as seen from the southeast and the viewpoints of the single stations.

Considering the numerous explosions that the bolide has suffered especially in the last part of its path (well visible in *Figure 3*), the dispersion area of possible meteorites, probably located in southern Veneto, could be rather extended, from the surroundings of Berra (44.97°N 12.01°E) to little more than Adria (45.09°N 12.04°E).

One last consideration: the meteoroid, if it did not break into the atmosphere and its mass were much larger, would have impacted in the metropolitan area of Venice, near Mira (45.43°N 12.13°E).

These results are preliminary and are obviously subject for improvement, if other useful observation data could be added.

[8] Italian Meteor Group (IMG) – UAI SezioneMeteore (UAIsm) http://meteore.uai.it

Variation in heights of CAMS meteor trajectories

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The median values for the beginning heights, heights of maximum brightness and ending heights have been obtained for sporadic meteors and for meteors of the IAU established meteor shower list, based on the CAMS dataset 2010–2013. Two layers with larger numbers of events with in between a layer with significant less events were found. A seasonal variation in the geocentric velocity and ablation height for sporadic meteors has been found with maximum values for the median height around solar longitude 225° and minima around 45°. For individual shower meteors there is a significant number of showers that produce meteor trajectories below the 90 km level. To avoid any bias that may affect the number of orbits collected for slower meteors, the 80 km level is recommended as reference level to optimize the pointing of the cameras in the BeNeLux CAMS network.

1 Introduction

The CAMS network uses a standard configuration at each station for both the hardware as well as for the software. The equipment consists of a Watec H2 Ultimate video camera with a Pentax 1.2/12mm lens. The field of view is rather small with about 30° × 22°. This allows capturing fainter meteors and offers a better accuracy than large FoV optics. Initially the concept of the CAMS project was to have all-sky coverage by the combination of 20 cameras at a single station that function as a mosaic of slightly overlapping FoVs, comparable to a facette eye of an insect (Jenniskens et al., 2011).

The first stand-alone single-CAMS were pointed at the sky as extra coverage for the all-sky set-ups in California. Where single-CAMS were applied without any coverage from some main all-sky set-up, the number of simultaneously captured meteors depended on the intersection of the camera fields at a height where most meteors can be expected. To have an optimal number of coincidences, the aiming points for the cameras must be carefully chosen in function of favorable geometrics and an optimal overlap. For this purpose the camera fields are projected on a plane at a chosen height, parallel to the Earth surface. The main question is; at which height can we expect to capture most meteors and how can we be sure to cover the entire population of sporadic and shower meteors without introducing any bias?

2 Camera fields and meteor heights

The volume of the atmosphere that a camera covers increases with the height in the atmosphere. At a level of 100 km we cover significant more square kilometers than at lower heights and therefore some people prefer to organize the camera fields at this range in order to have the largest number of square kilometers covered. However the majority of all meteors is to be detected below 100 km in the atmosphere and some of these meteors risk to be missed at lower elevation in between camera fields. In the past we have been working with 90 km as reference level to overlap camera fields for CAMS, but is this the best option?

The level at which the camera fields are optimized should be carefully chosen. The higher in the atmosphere, the larger the volume covered and thus less cameras are necessary to cover such part of the atmosphere (see *Figure 1*). But if the height at which meteors appear is variable throughout the year or proves to be different from one shower to another, then some bias could be created in the sense that part of the meteors that produce their luminous trails at lower heights have less chance to be captured. With other words, part of the meteors will get lost in the uncovered 'gaps' between the camera fields. As a result less orbits will be collected for meteors that appear deeper in the atmosphere, being discriminated by the selection of the optimal level to aim the cameras. In the end the dataset of orbits will not be representative for the total meteor population.

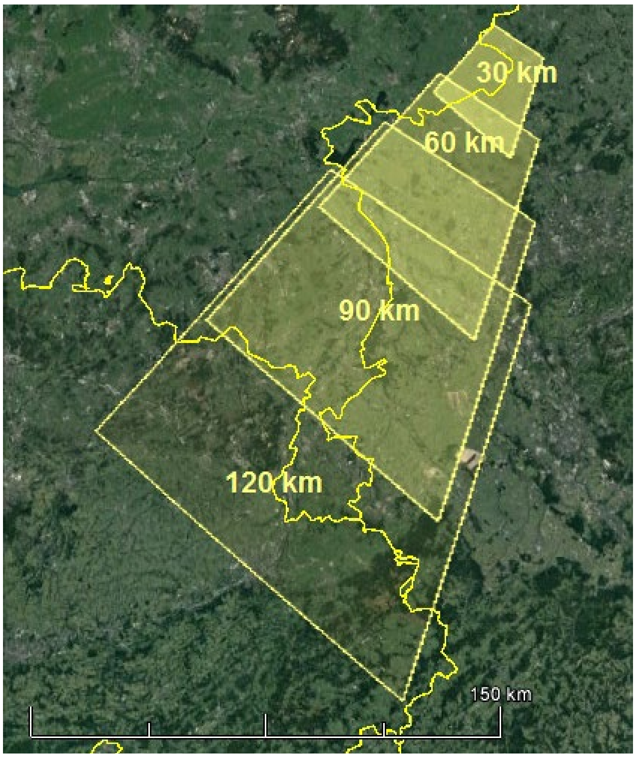

Figure 1 – A FoV of 30° × 22° aimed at an azimuth of 211° and a height of 41° with a tilt of 5.6° intersected with a plane at 30 km, 60 km, 90 km and 120 km.

For a wide expanded and dense camera network such as the BeNeLux network any good combination at a level of 80 km will be even better covered at higher levels by cameras from other stations that reach deeper in the atmosphere at higher levels (see *Figure 2*). This is not true when only few cameras are available at too few stations as in such case the camera fields will overlap at the reference level and diverge at higher levels (see *Figure 3*).

For the BeNeLux network we need to know how the heights of meteors are distributed in the atmosphere to determine the best level at which the camera intersections must be optimized.

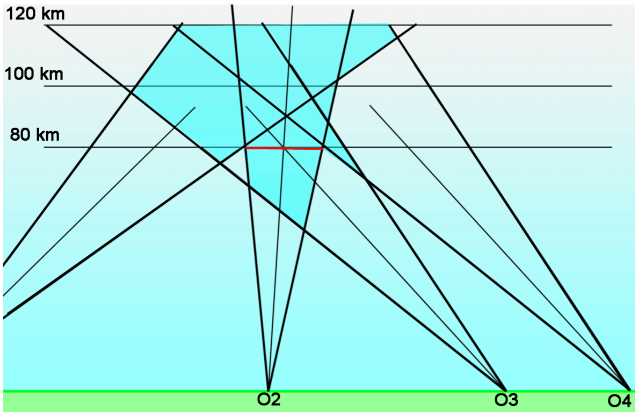

Figure 2 – When a camera network has enough cameras at many participating stations, the number of simultaneous meteors can be increased by optimizing the volume covered from different stations. The level to optimize overlap is important to know. If well covered at lower height, e.g. 80 km, more overlap will be generated by cameras that are further away.

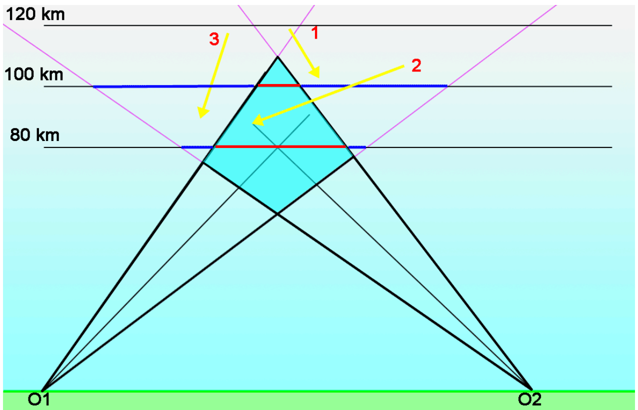

Figure 3 – Observers O_1 and O_2 aiming their cameras at a common point at 80 km height in the atmosphere will capture only simultaneously meteors in their common volume in the atmosphere. Meteors 1 and 2 will appear nice in the picture of O_1, and meteor 3 and part of meteor 2 in the picture of O_2, but only part of meteor 2 will be double station.

3 Meteor heights in the atmosphere

A while ago Pete Gural asked the author to remake the CAMS shower reference list which was based on the IMO Shower Calendar. The purpose is to create a new reference list as source for some future new tools in the CAMS software. It was decided that the new reference list should be based on the IAU Established Meteor Shower List. Some of the shower characteristics that are needed are the heights of beginning, ending and maximum brightness for each shower. The previously used values were taken from IMO where these values had been copied through different editions from research work from the 1960s (Jacchia et al., 1967). With the public available CAMS dataset of 111233 orbits obtained in 2010–2013 (Jenniskens et al., 2016), we have a reliable source to derive statistics on the heights of the calculated trajectories.

We counted the number beginning heights in layers of 5 km thickness each, e.g. higher than 60 km and less than or equal to 65 km, counting this way for all 5 km thick layers until the layer >125 km and <=130 km. Only 0.2% of all meteors started below 75 km elevation and only 0.2% above 125 km. About all beginning points appear in the 50 km thick atmospheric zone between 75 and 125 km height. Doing this for the heights of greatest luminosity and for the end points, the overall majority proves to be situated above 70 km and below 115 km height in the atmosphere. Results are listed in *Table 1* and *Figure 4*.

There is a strange feature in *Table 1* as there are significant more meteors starting between 105–115 km height and between 90–100 km than in between at 100 and 105 km. This effect can also be noticed in the counts for the height of the brightest luminosity (less between 95 and 100 km, and the ending points (less between 90 and 95 km. There is no straightforward explanation for this effect. Major meteor streams cannot really account for this as only 27.6% of the dataset concerned shower meteors, none of which had a particular big weight in the statistics. A possible explanation could be an artifact as a bias in the CAMS configuration that favors detection of double station meteors at certain elevations unless some physical difference in the atmospheric layers occurs.

Table 1 – Number of trajectories for all layers of 5 km thick from 60 km until 130 km height.

km	Start		Brightest		End	
<=60	8	0.0%	34	0.0%	143	0.1%
60-65	2	0.0%	56	0.1%	222	0.2%
65-70	17	0.0%	264	0.2%	907	0.8%
70-75	235	0.2%	1275	1.2%	2907	2.6%
75-80	1772	1.6%	3891	3.5%	7873	7.1%
80-85	4092	3.7%	9140	8.3%	17015	15.4%
85-90	7043	6.4%	18447	16.7%	22226	20.1%
90-95	14283	12.9%	20049	18.1%	17739	16.1%
95-100	21564	19.5%	15688	14.2%	21451	19.4%
100-105	13656	12.4%	22838	20.7%	16558	15.0%
105-110	19156	17.3%	16095	14.6%	3234	2.9%
110-115	21690	19.6%	2628	2.4%	230	0.2%
115-120	5893	5.3%	109	0.1%	16	0.0%
120-125	889	0.8%	6	0.0%	0	0.0%
125-130	169	0.2%	0	0.0%	0	0.0%
>130	52	0.0%	1	0.0%	0	0.0%
	110521	100.0%	110521	100.0%	110521	100.0%

In a private communication Dr. Peter Jenniskens explains the dip as a distinct difference of the Apex and Anti Helion sources. The Apex contributes fast meteors 50-75 km/s, the Anti Helion very slow meteors 12–40 km/s. The dip is situated at 40-50 km/s, which is also visible in the height distribution of meteor trajectories.

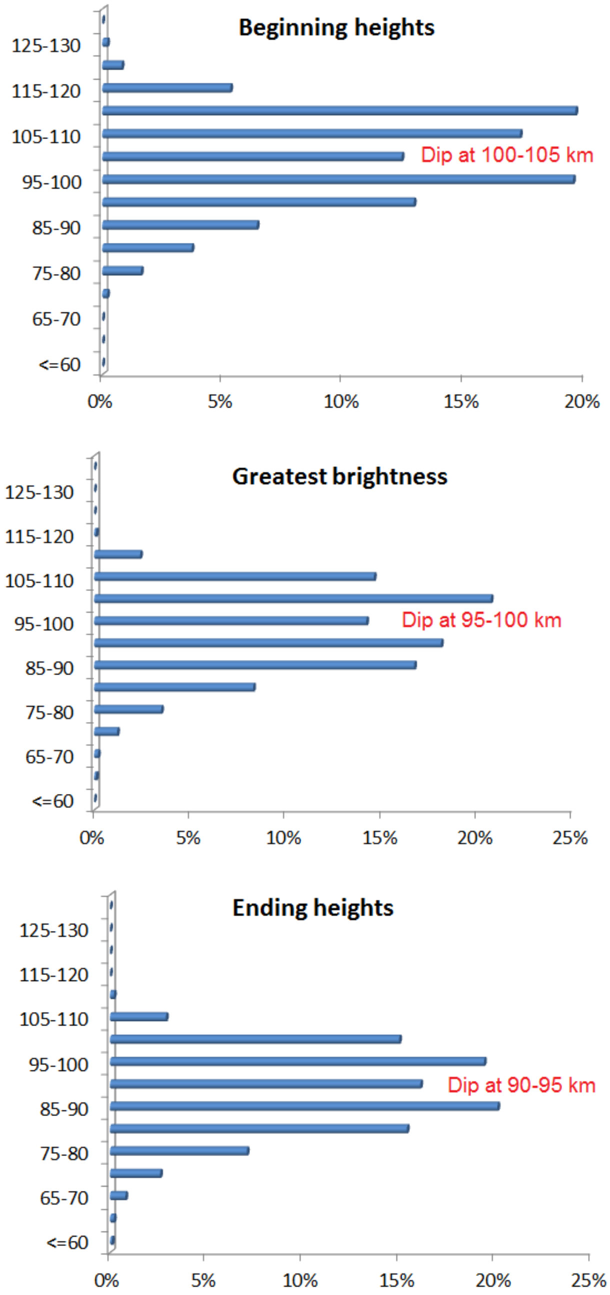

Figure 4 – Graphical presentation of the values of Table 2. The distribution of beginning heights (top), heights of greatest brightness (middle) and the ending heights (bottom) display a remarkable dip in the height distribution. Not any major shower has enough weight in the sample to explain this effect.

4 Seasonal variations for sporadics

79990 orbits concerned sporadics. In an attempt to verify if any seasonal variations could be detected, the dataset was split into 12 intervals, each covering 30° in solar longitude. For each interval the median has been calculated for the beginning height, the height of maximum brightness and the ending height. The results are listed in *Table 2*. Since all individual meteor orbits in CAMS were validated according to strict quality control criteria, these statistics should be reliable.

From *Table 2* it is obvious that the characteristics of the sporadic background show some variation. Around the time of solar longitude 225° the median geocentric velocity of the sporadic background is significant faster with 57.4 km/s than at the opposite position of the Earth on its orbit at solar longitude 45° where the median geocentric velocity is 32.7 km/s (*Figure 5*). The ablation height of a meteor depends on the energy with which it enters into the atmosphere, the higher the velocity the higher the potential energy for a given mass. Fast meteors produce their luminous trajectory much higher in the atmosphere than slow meteors. The reason why the sporadics background appears to be slower around a solar longitude of 45° and faster around 225° is not clear. Perhaps the sporadic background around solar longitude 225° was composed from ancient trails of dispersed dust, left over from unknown long periodic comets such as P/Halley? According to Dr. Peter Jenniskens the elevation of the Apex may be an explanation as main source of fast meteors. Question is if the Southern hemisphere has the opposite effect? Note that the visibility of the Apex is the same at the Spring and at the Autumn equinox, while the median velocity of sporadic meteors is very different.

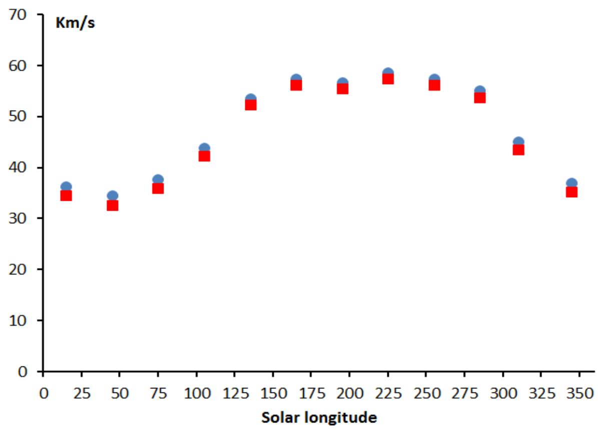

Figure 5 – The variation of the median velocity in function of the solar longitude. The blue dot is the median entry velocity and the red square the median geocentric velocity.

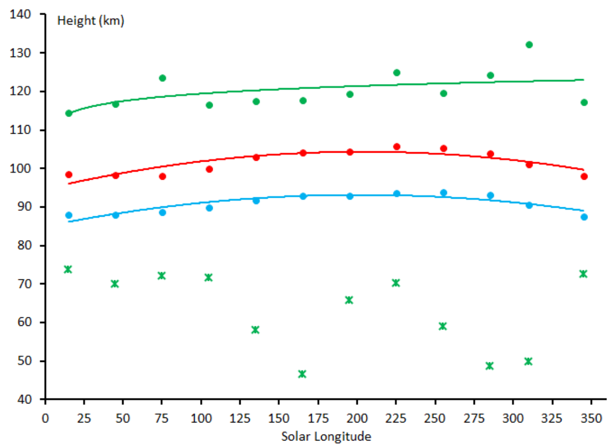

Figure 6 – The median values for sporadic meteors for the starting height (green), the height of maximum luminosity (red), the ending height (blue) and the lowest starting height recorded as outlier in each time span (green x).

Whatever the cause is for this seasonal variation in the velocity and ablation height, we should optimize our camera network in such a way that we create no bias by missing too many slower meteors deeper in the atmosphere. From the median values and standard deviation we can conclude that we should cover the atmospheric layer from about 110±10 to 90±10 km (see *Table 2* and *Figure 6*). Interested in all meteors, also the outliers, I included the most extreme values found for each interval. These individual cases show that some meteors ablate far above or below the preferable elevation in the atmosphere. To choose an optimal level in the atmosphere to capture as many of these meteors as possible is a tradeoff, between the number of available cameras to cover a layer in the atmosphere and the number of outliers that can be ignored.

The CAMS dataset allowed to check for seasonal variations within a calendar year but does not yet cover enough years to check for long term variations in ablation heights. Such variations have been reported before in radar data and were supposed to be linked with the 11 year periodicity of the solar activity, but this is not proven yet and the topic needs further investigation (Porubčan et al., 2012).

Table 2 – Heights in the atmosphere (km) for sporadic meteors, with H_b the starting height, H_m the height of maximum brightness, H_e the ending height, V_g the geocentric velocity and N the number of trajectories in the sample.

$\lambda_{\odot}$	H_b	H_b max	H_b min	H_m	H_m max	H_m min	H_e	H_e max	H_e min	V_g	N
0 – <30	98.6±10.3	125.8	73.8	92.2±9.2	114.4	57.1	87.9±9.1	114.4	49.7	34.5	2366
30 – <60	98.3±10.1	129.5	69.9	92.1±9.2	116.9	55.9	88.0±8.8	111.6	47.8	32.7	4355
60 – <90	98.0±9.8	129.8	72.1	92.2±9.1	123.7	51.9	88.6±8.6	119.5	47.7	35.9	4821
90 – <120	100.0±10.0	131.5	71.6	94.2±9.2	116.6	56.8	89.9±8.7	114.2	50.8	42.3	7355
120 – <150	103.0±9.7	132.3	58.0	96.7±9.0	117.5	50.6	91.8±8.6	115.0	46.8	52.4	9454
150 – <180	104.2±9.7	139.7	46.6	97.7±8.9	117.7	43.4	93.0±8.8	114.2	37.5	56.2	7277
180 –<210	104.3±10.2	136.1	65.7	97.9±9.4	119.4	50.0	93.0±9.0	117.5	46.0	55.5	7691
210 – <240	105.8±10.4	154.5	70.1	98.7±9.8	124.9	63.6	93.7±9.5	116.4	49.9	57.4	7762
240 – <270	105.3±10.4	136.2	58.9	98.7±9.7	119.5	53.4	93.8±9.5	117.7	46.6	56.2	8890
270 – <300	104.0±10.6	143.4	48.7	97.9±9.7	124.4	46.4	93.2±9.6	117.9	40.8	53.8	10338
300 – <330	101.1±10.5	137.3	49.9	94.9±9.8	132.2	53.1	90.6±9.7	114.5	44.6	43.6	6018
330 – <360	98.1±10.4	127.4	72.5	91.8±9.5	117.3	64.9	87.5±9.2	114.7	56.2	35.3	3663
All spor.	102.2±10.3	154.5	46.6	96.2±9.5	132.2	43.4	91.5±9.2	119.5	37.5	47.5	79990
All streams	101.6±8.3	142.7	74.5	94.7±8.1	118.4	54.2	90.2±7.9	116.4	40.7	41.6	29513

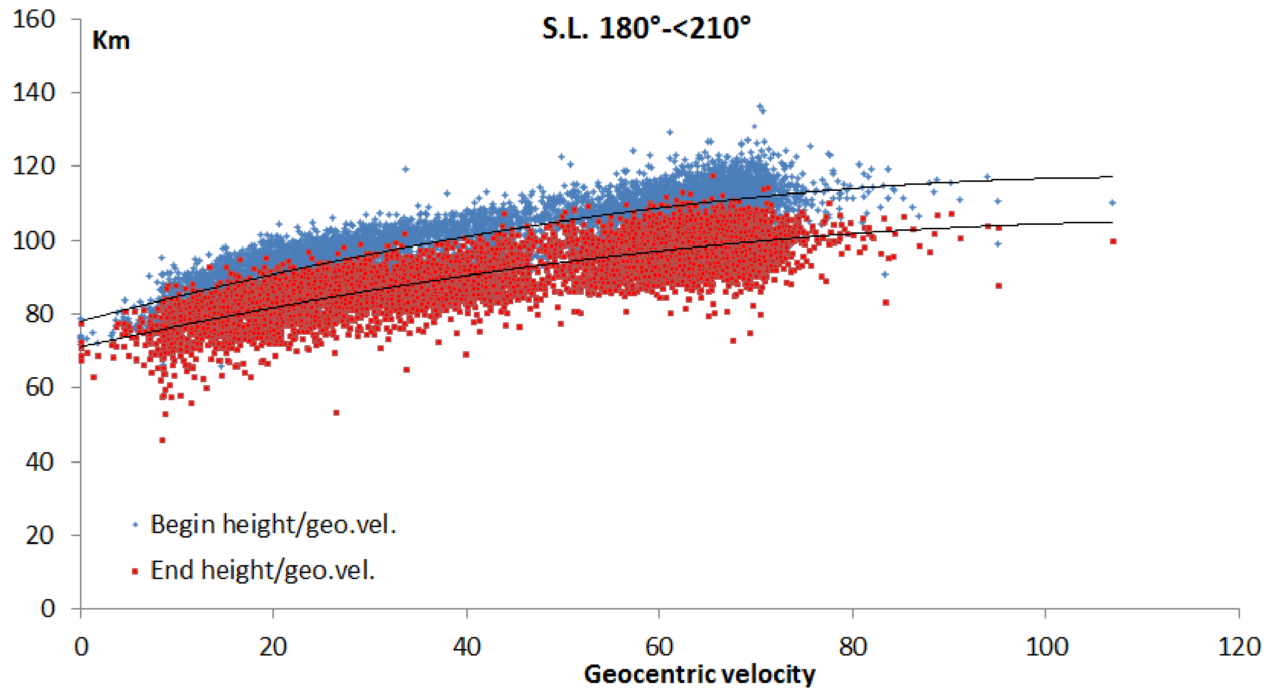

Figure 7 – Plot of individual meteor heigths, beginning and ending heights in function of the geocentric velocity for all meteors registered within the period 180°>= $\lambda_{\odot}$< 210°. This graph shows that the ablation heights increase in function of the geocentric velocity.

Table 3 – Heights in the atmosphere (km) for meteors of the IAU established meteor shower list, with H_b the starting height, H_m the height of maximum luminosity, H_e the ending height, V_g the geocentric velocity and N the number of trajectories in the sample.

IAU code	H_b	H_b max	H_b min	H_m	H_m max	H_m min	H_e	H_e max	H_e min	V_g	N
KSE – 27	104.7±6.2	113.8	87.9	96.1±5.6	102.6	82.1	89.0±5.7	99.8	74.4	46.7	C21
AVB – 21	95.1±1.6	96.2	90.7	86.4±2.8	92.2	81.3	83.9±4.2	89.1	72.7	18.8	C12
LYR – 6	107.3±4.7	136.5	91.4	99.7±4.8	109.0	76.9	93.2±5.4	104.4	71.7	46.7	C257
ARC – 348	102.8±3.8	109.9	89.3	97.0±3.2	102.7	86.3	92.6±3.9	99.5	80.8	40.9	C42
HVI – 343	89.7±5.7	99.7	84.1	85.7±5.6	96.5	78.6	80.8±5.9	92.3	75.1	17.2	C11
ETA – 31	113.6±3.6	129.7	98.3	106.6±3.3	116.6	92.2	100.6±4.1	115.9	87.0	65.7	C936
NOC – 152	102.8±2.2	103.7	98.9	98.0±2.4	100.5	95.5	93.3±1.9	95.7	91.0	36.2	C4
ELY – 145	105.5±3.3	113.8	95.5	96.8±4.7	107.5	84.6	92.1±4.7	101.3	83.5	43.7	C39
EAU – 151	92.5±2.1	97.4	90.9	89.7±2.5	96.2	88.0	85.8±3.3	92.4	82.8	31.5	C11
JMC – 362	104.5±5.2	112.0	91.8	96.9±4.3	107.4	90.0	93.2±4.4	100.3	84.8	41.7	C32
ARI – 171	100.7±2.1	104.4	96.2	97.6±2.7	102.3	90.1	93.8±3.6	99.8	87.1	41.1	C31
JRC – 510	110.1±3.9	118.4	104.7	101.1±4.7	107.8	91.5	93.1±4.0	98.8	86.2	50.9	C14
BEQ – 327	93.4±3.0	103.2	88.8	89.4±2.2	96.8	86.4	85.6±1.9	90.7	81.6	33.2	C38
SSG – 69	97.3±2.9	103.3	87.7	92.4±2.9	101.3	84.9	89.9±3.1	99.6	81.1	25.1	C70
COR – 63	79.1±4.5	87.8	75.4	74.0±5.2	84.3	67.8	71.6±6.5	82.8	60.1	8.7	C12
EPR – 324	106.3±1.4	107.7	104.3	99.2±2.6	104.3	98.9	95.2±3.4	101.4	94.2	43.8	C4
JIP – 431	113.0±5.6	128.2	106.8	102.7±4.6	105.6	90.4	96.3±4.8	103.2	84.8	58.5	C11
NZC – 164	95.9±3.0	107.3	87.3	91.3±2.5	99.5	78.5	86.8±2.9	94.6	65.6	38.3	C404
PPS – 372	112.5±3.2	123.5	97.0	105.9±3.7	116.0	88.3	100.2±4.2	114.9	87.0	66.5	C379
SZC – 165	96.9±3.0	106.3	91.3	93.1±2.6	102.1	86.4	88.4±2.8	98.4	82.7	39.2	C89
CAN – 411	108.8±3.3	117.2	95.7	101.3±3.8	110.1	89.8	96.3±4.3	109.3	82.3	57.5	C169
EPG – 326	92.4±2.3	98.8	89.3	89.1±2.6	96.3	83.6	85.7±2.8	90.3	79.9	28.4	C33
ALA – 328	97.8±7.2	102.9	92.7	93.8±7.4	99.0	88.6	88.4±5.4	92.2	84.6	37.4	C2
JXA – 533	114.4±3.7	121.7	107.7	103.3±3.8	112.5	97.5	96.6±4.6	111.1	92.1	68.9	C20
JPE – 175	111.4±4.0	124.3	95.9	102.5±3.8	110.8	89.6	97.6±4.0	106.6	84.1	64.0	C104
FAN – 549	111.2±3.9	123.7	99.7	104.9±4.9	114.1	85.5	98.2±4.7	107.5	81.8	60.2	C76
PCA – 187	98.5±5.3	111.6	91.2	92.8±3.9	101.3	85.8	88.3±3.4	96.7	82.8	42.0	C36
GDR – 184	98.3±2.6	103.9	93.4	90.3±3.1	96.7	83.8	86.5±3.1	91.0	78.1	27.5	C40
CAP – 1	96.2±2.4	104.6	84.3	89.8±3.1	99.0	73.5	86.5±3.4	93.4	69.8	23.0	C646
SDA – 5	97.1±2.6	106.9	88.9	93.3±2.4	103.7	79.8	87.7±2.8	103.3	72.2	41.3	C1382
PAU – 183	97.0±3.6	104.9	92.0	93.9±2.6	99.6	88.5	89.4±2.9	94.4	84.8	43.9	C23
ERI – 191	112.1±3.7	129.8	97.8	105.6±3.7	116.0	92.7	101.3±4.4	111.2	81.3	64.5	C214
PER – 7	110.9±4.0	142.7	89.4	103.0±4.6	116.7	79.6	98.0±4.8	115.8	65.8	59.1	C4366
NDA – 26	96.1±3.0	104.0	89.5	91.8±2.6	101.2	82.7	87.0±2.9	96.8	79.3	38.4	C251
KCG – 12	93.7±2.4	98.1	88.5	86.5±4.5	95.1	71.1	84.2±4.6	88.0	68.2	20.9	C25
AUD – 197	95.1±2.9	97.4	85.2	86.3±2.3	89.7	81.5	83.9±3.4	88.0	74.2	21.1	C17
NIA – 33	96.2±4.3	106.3	83.7	89.6±3.9	99.0	79.5	85.6±3.7	95.8	78.3	31.3	C94
AUR – 206	111.5±3.7	119.4	103.4	105.4±4.8	114.1	92.5	101.9±5.5	113.7	89.6	65.6	C19
SPE – 208	111.9±5.1	131.3	102.7	102.9±5.1	111.0	87.4	97.8±5.0	106.0	83.5	64.8	C291
NUE – 337	112.7±4.1	130.5	96.2	106.3±4.1	116.1	90.4	101.3±4.5	114.2	83.4	67.1	C85
DSX – 221	98.4±2.5	105.1	96.3	93.0±3.5	99.9	88.9	90.4±4.6	98.0	81.5	32.9	C14
DRA – 9	97.8±2.2	102.6	94.7	93.8±3.1	99.0	87.7	90.1±3.4	94.6	81.0	20.7	C30
EGE – 23	113.4±3.1	118.8	103.3	104.0±4.2	113.8	96.5	97.8±3.6	109.7	92.3	69.6	C31
OCU – 333	115.4±5.3	119.1	102.0	106.3±3.3	110.9	100.4	97.0±3.6	101.2	91.7	55.6	C9
ORI – 8	113.1±3.6	133.9	96.1	105.6±4.0	118.4	79.5	99.4±4.1	116.4	77.1	66.3	C3024
LMI – 22	115.4±4.6	124.1	102.3	107.9±4.4	115.6	88.2	98.3±4.2	110.4	87.5	61.9	C64

IAU code	H_b	H_b max	H_b min	H_m	H_m max	H_m min	H_e	H_e max	H_e min	V_g	N
LUM – 524	114.2±3.9	117.0	108.5	106.5±7.9	108.0	91.3	99.0±5.1	103.0	90.8	60.9	C4
STA – 2	97.4±3.8	109.5	82.2	88.7±4.3	101.0	63.4	84.4±4.9	98.8	59.0	26.6	C916
NTA – 17	97.5±3.8	110.4	83.6	88.3±4.6	105.0	65.3	83.8±5.0	98.5	60.7	28.0	C509
CTA – 388	96.4±4.0	104.8	88.6	91.1±4.2	100.1	79.3	86.4±4.3	97.4	72.1	41.1	C52
SLD – 526	109.6±4.6	113.8	94.6	104.5±4.6	109.4	94.0	98.0±4.3	103.2	88.4	49.1	C13
OER – 338	99.3±3.5	110.6	88.5	90.6±4.4	102.7	71.1	86.8±4.7	97.2	67.3	29.1	C94
AND – 18	95.9±4.0	105.3	86.5	89.9±4.1	97.2	79.2	86.0±4.5	96.7	74.7	18.2	C39
KUM – 445	117.6±4.3	124.3	113.1	107.7±2.9	113.6	105.8	100.2±5.7	112.8	96.4	65.7	C8
RPU – 512	114.0±3.4	121.1	107.3	104.9±3.9	109.8	91.1	100.0±3.9	107.6	89.7	57.8	C22
LEO – 13	115.9±4.1	132.1	100.1	108.1±4.3	116.0	88.8	99.9±4.3	110.1	82.0	70.2	C268
ORS – 257	98.1±4.0	106.1	85.6	88.6±3.6	99.1	81.6	83.8±4.4	97.0	69.3	65.7	C97
THA – 390	94.8±3.5	106.5	88.7	89.2±3.4	98.0	79.4	84.2±3.8	93.9	72.5	32.5	C82
NOO – 250	101.1±5.5	114.6	88.5	93.3±4.2	107.1	72.9	88.2±4.2	100.4	70.8	42.5	C369
DKD – 336	107.2±2.9	110.6	95.4	101.4±3.5	107.7	90.1	97.6±3.6	102.1	87.2	43.8	C36
DPC – 446	96.3±3.5	103.9	87.6	92.1±3.8	97.8	76.1	86.9±3.9	95.8	74.4	16.5	C68
PSU – 339	112.5±3.1	120.7	106.6	106.4±3.1	110.8	98.8	98.5±3.9	106.0	91.2	61.7	C18
DAD – 334	100.1±3.9	108.3	94.1	93.9±4.2	106.2	88.0	88.8±4.8	102.9	82.7	40.8	C47
EHY – 529	110.5±3.7	123.2	97.1	101.6±3.9	110.8	91.5	97.6±4.2	105.0	84.6	62.4	C83
MON – 19	103.5±2.9	117.9	91.7	96.3±3.3	102.7	80.6	91.4±3.7	100.2	78.8	41.4	C240
DSV – 428	114.3±4.2	124.0	107.7	104.3±5.8	114.9	92.5	100.3±6.0	114.4	87.3	66.2	C22
GEM – 4	97.0±2.5	117.6	85.3	89.8±3.8	114.9	56.1	85.5±4.4	114.4	54.1	33.8	C5103
HYD – 16	109.5±3.2	122.6	97.1	101.2±4.0	111.8	79.9	96.6±4.8	109.9	73.4	58.9	C529
XVI – 335	114.7±4.5	131.0	102.3	107.0±3.7	112.8	94.8	101.5±4.3	112.7	92.2	69.1	C46
URS – 15	103.0±3.0	119.9	99.0	97.5±4.6	102.2	76.4	93.2±4.6	99.7	75.5	32.9	C62
ALY – 252	101.4±6.6	106.1	93.1	91.3±6.3	100.9	88.9	88.2±5.8	98.2	88.1	49.5	C3
SSE – 330	100.7±1.9	101.1	97.7	94.0±3.3	98.5	92.1	89.8±2.1	90.6	86.7	45.5	C3
COM – 20	112.0±3.9	129.5	95.9	104.3±3.6	113.8	87.4	97.3±4.0	111.5	82.0	63.3	C497
OSE – 320	106.6±2.2	108.1	105.0	101.7±3.3	104.0	99.3	98.2±3.7	100.8	95.5	45.0	C2
JLE – 319	95.8±2.8	104.3	94.3	91.7±1.8	93.7	87.5	88.3±2.3	91.8	83.9	51.4	C11
AHY – 331	105.1±4.1	112.3	91.5	98.2±3.9	104.4	87.7	93.8±4.5	101.3	81.4	43.3	C119
QUA – 10	101.0±2.9	112.3	89.5	94.4±3.7	107.3	74.6	89.3±4.3	106.7	71.2	40.7	C1029
SCC – 97	96.5±5.0	101.9	83.5	88.5±4.6	96.4	73.3	84.3±5.1	93.0	68.3	27.0	C69
XCB – 323	97.1±3.9	107.0	91.1	94.0±2.9	103.5	89.8	88.8±3.9	102.5	83.4	45.1	C26
NCC – 96	96.9±4.5	104.1	85.0	88.0±4.2	95.9	70.5	83.1±5.3	93.5	64.8	27.2	C74
GUM – 404	96.9±3.0	104.5	92.4	88.9±4.2	96.2	80.5	84.0±4.2	91.2	76.3	28.8	C26
XUM – 341	92.9±3.4	104.6	89.6	87.7±3.8	97.8	79.6	83.1±3.2	93.9	75.0	40.9	C30
ECV – 530	113.6±4.3	119.0	100.5	106.1±3.0	109.5	99.3	102.7±3.2	106.5	93.1	68.1	C15
AAN – 110	95.1±3.7	108.8	91.8	91.9±2.3	98.1	89.0	86.8±2.4	93.6	83.1	45.0	C34
OHY – 569	109.7±3.1	114.3	104.5	104.2±2.2	108.6	101.0	101.0±2.3	104.9	97.4	58.2	C12
FEV – 506	110.1±3.7	116.2	95.6	103.4±3.1	111.5	94.4	98.4±3.5	108.7	89.9	62.9	C55
FED – 427	105.1±1.1	105.7	102.7	98.3±3.1	100.8	91.2	95.7±4.2	99.5	85.6	35.1	C9
XHE – 346	97.6±2.0	100.6	95.8	86.6±3.0	89.8	83.5	82.6±2.8	87.6	81.4	35.2	C4
EVI – 11	93.6±3.3	101.3	87.1	86.0±5.0	94.2	61.9	81.7±6.9	94.2	56.0	26.6	C55

5 Established meteor showers

The median values for all shower meteors are in the same range as these for the sporadics in *Table 2*. From this *Table 2* we may conclude that optimizing our network at a level of 90 km in the atmosphere, like we did, could be a fair compromise. However, 90 km is fine for a median velocity of 41.7 km/s but what about meteor showers with significant smaller velocities? According to the counts listed in *Table 1*, 12% of all meteors start at less than 90 km, 30% have their greatest luminosity below 90 km and 46.3% of all meteors have their ending point below 90 km elevation.

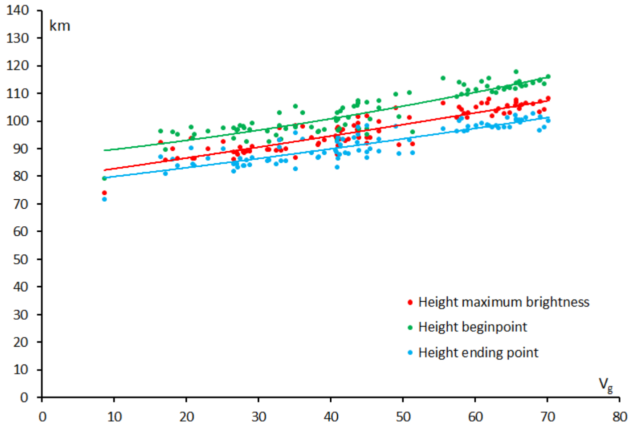

Figure 8 – The median values for shower meteors for the starting height (green), the height of maximum luminosity (red) and the ending height (blue) against the geocentric velocity.

A query selecting the orbits for all the established meteor showers that were present in the CAMS dataset allowed to compute the median values for the heights for the shower meteors. The shower identification in the dataset we use has been done by Dr. Peter Jenniskens and the method used has been described in a recently published paper (Jenniskens et al., 2016). The results are listed in *Table 3* and in *Figure 8*. A number of meteor showers have a median value for the height of maximum brightness below 90 km, including one of the most active showers, the Geminids (GEM – 4). The terminal heights for meteor streams with low geocentric velocity is often closer to 80 km than to 90 km.

There is one extreme case for the Corvids (COR – 63) with their exceptional low geocentric velocity of 8.7 km/s for which the trajectories appear well below the 80 km level. So far this is the only meteor stream known with such extremely slow meteors. If we want to make sure that the network has no gaps where these Corvids can be missed, we should optimize at 70 km. This would require more cameras to cover the atmosphere above the BeNeLux than currently available. Considering the exceptional nature and the poor activity level of the Corvids, the tradeoff between costs for more cameras and the gain in number of orbits favors a compromise at a level of 80 km to optimize the overlap between the camera fields.

6 Conclusion

The statistics derived from the CAMS 2010–2013 dataset show a seasonal variation in the median value of the geocentric velocity and the related height of the ablation of sporadic meteors. A count of heights in 5 km thick layers indicate two levels with high numbers of events with in between a layer with remarkable less events. The median values for the sporadics and all shower meteors would favor the 90 km level to optimize the camera fields. When we look at the statistics for the individual meteor showers we have to use the 80 km level to avoid creating any bias that could have a negative effect on the number of orbits derived for meteor showers with a low geocentric velocity.

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2017 Eta Aquariids recorded by CAMS

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Despite unfavorable weather conditions CAMS BeNeLux could collect 35 precise orbits of the Eta Aquariids stream in the last days of April and the first decade of May 2017. Radiant positions, radiant drift and orbital elements are in good agreement with the positions in previous work (Jenniskens et al., 2016).

1 Conditions in 2017

It is well known that observing the Eta Aquariids at the latitudes of the BeNeLux CAMS network (50°–53°) has something of playing 'hide and seek'. The observing window for the BeNeLux sites remains restricted to the morning twilight of the first decade of May. This year the waxing moon played its part, be it low at the horizon.

The weather remains always the most uncertain element. The chances for success are the best with a clear transparent sky. These kind of clear nights were rather rare this year. Only the nights 8–9 and 9–10 May were clear for almost the entire BeNeLux. The night 5–6 May had reasonable observing circumstances.

2 The observations

The first ETA has been captured on 30 April at $02^h21^m49^s$ UT by *Bart Dessoy* (camera 397) and *Luc Gobin* (camera 391). Half hour later, at $02^h50^m51^s$ UT, *Robert Haas* (camera 365) and *Steve Rau* (camera 387) got a second ETA.

After a cloudy night 30 April on 1 May, in the early morning of 2 May some clear sky over the South and South-West of the BeNeLux enabled four Belgian (*Hervé Lamy, Bart dessoy, Jean-Marie Biets* and *Paul Roggemans*) and two Dutch CAMS stations (*Robert Haas* and *Klaas Jobse*) to capture in total 5 ETAs. Then again sky remained almost completely cloudy for 3 nights.

Only in the morning of 6 May, right at the maximum of this shower, 6 ETAs could be recorded, again from the South and Southwest of the BeNeLux. This time *Erwin van Ballegoij, Robert Haas, Paul Roggemans, Hervé Lamy* and *Jean-Marie Biets* delivered the ETAs.

The next morning observers in the northern part of the BeNeLux got four ETAs (*Martin Breukers, Robert Haas* and *Carl Johannink*).

7–8 May remained cloudy but in both following nights the entire BeNeLux network enjoyed clear sky, with another respectively twelve and seven ETAs captured, by the above mentioned CAMS fellows together with *Piet Neels, Hans Betlem, Franky Dubois* and *Hans Schremmer*. After another four ETAs during the night 10–11 May, a last ETA for 2017 has been captured on 13–14 May by *Martin Breukers* and *Paul Roggemans*.

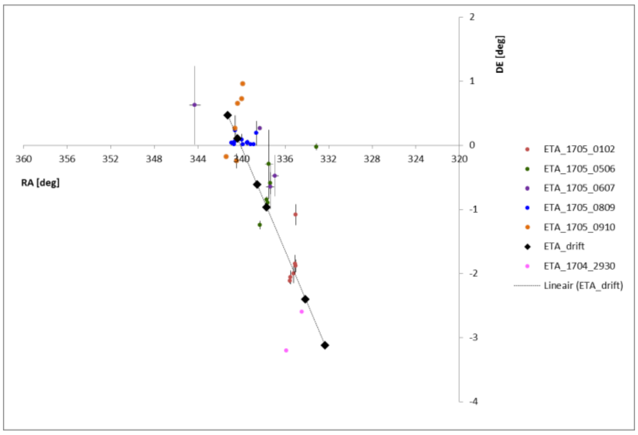

Figure 1 – Radiant positions for the ETAs and radiant drift (Jenniskens et al., 2016).

Figure 1 shows a plot of the radiant positions as obtained during the period of 1 until 10 May 2017. The radiant drift has been plotted using a radiant drift of $\Delta\alpha = 0.92°$/day and $\Delta\delta = 0.37°$/day relative to the time of maximum activity at $\lambda_{max} = 46.0°$ (Jenniskens et al., 2016). *Figure 1* seems to suggest that the drift in Right Ascension is a bit smaller than 0.92°/day, however the small size of our dataset requires caution before drawing conclusions.

3 Conclusion

The results obtained by CAMS BeNeLux for the 2017 Eta Aquariids are in good agreement with the results published by Jenniskens (2016). We thank all CAMS operators for the quick reporting of data.

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The remainders of an old acquaintance: Eta Lyrids from comet IRAS-Araki-Alcock (C/1983 H1)

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Routine CAMS BeNeLux observations during the nights of May 9–10 and May 10–11 collected 26 meteors belonging to the Eta Lyrids (145 ELY), which are associated with comet IRAS-Araki-Alcock (C/1983 H1). Further searches on the nights around this peak produced another 6 candidates. Radiant positions and orbital elements are in good agreement with previous CAMS results (Jenniskens et al., 2016). A short summary of historical visual observations is also given.

1 The origin of the η-Lyrids

The η-Lyrids are the remainders from the long periodic comet C/1983 H1, better known as comet IRAS-Araki-Alcock with a periodicity of about 1000 years. The comet has been discovered in 1983 by the InfraRed Astronomical Satellite, a Dutch-British-American joint venture, as well as by the Japanese amateur Araki and the British amateur Alcock. Alcock discovered this comet by searching the sky with simple binoculars, watching through his window.

The comet passed Earth at a distance of only 4.66 million km on 11 May 1983. It moved at that moment with an angular velocity at the sky of about 40° per day and could be observed as a fluffy object of magnitude +2 with a coma diameter of 2° to 3° (Full Moon has a diameter of 0.5°).

2 Visual observing data

Each year around May 10 some meteor activity is noted from the region Cygnus/Lyra by visual observers. Already in 1985 Peter Jenniskens wrote about possible meteor activity from this comet (Jenniskens, 1985). The maximum should occur around the night 8–9 May.

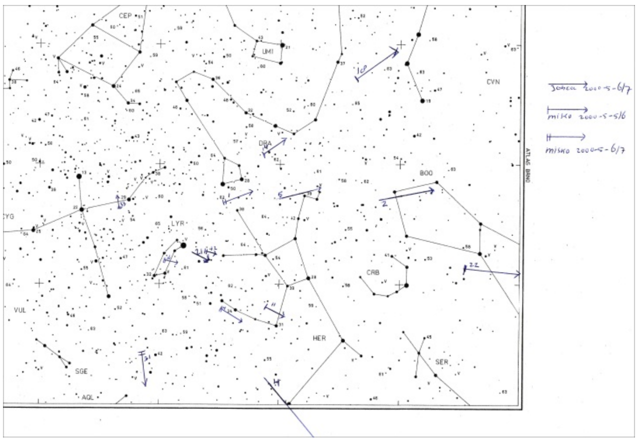

Figure 1 – Part of the plotted Eta Lyrids by Carl Johannink and Koen Miskotte. The data was obtained during the night 6–7 May 2000. Map: Atlas Brno.

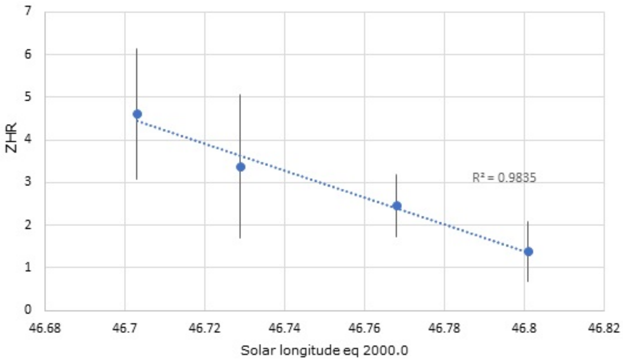

Figure 2 – ZHR profile for the night of 6–7 May 2000, based on 39 Eta Lyrids observed by Carl Johannink, Marco Langbroek and Koen Miskotte.

Peter Jenniskens mentioned in his article a basic investigation across the DMS archive of visual reports for possible observations of Eta Lyrids in 1982 and 1983. A ZHR of 2.0 was derived at 1982 May 9.052. The observations were made by Rudolf Veltman (†). Unfortunately no more attention was paid to this shower in the 1980s and 1990s. Only few shower members were recorded in this period. This situation changed in 2000. In that year a considerable number of Eta Lyrids could be observed during the nights 5–6 and especially 6–7 May at Biddinghuizen and Lattrop under very good circumstances (lm 6.6/6.7). Marco Langbroek calculated a ZHR of 7 for the night 6–7 May. It was striking that the activity was reasonable strong at the beginning of the night but declined during the night while the radiant elevation got higher during the night. *Figure 2* shows a ZHR profile for that night. This ZHR profile has been calculated mid-May 2017 by Koen Miskotte. Of course we should not draw too soon conclusions from this as this is an analyses based on 39 meteors with an assumed population index of r = 2.50.

Koen Miskotte has also searched for ELY data in the DMS visual report archive. *Table 1* lists the data. It is obvious that many ELYs were observed in 2000. This is also the case in 2001, 2008 and 2016. Unfortunately the data for each year is rather fragmentary. The only careful conclusion one can draw from *Table 1* is that 8–9 May

Table 1 – All available ELY data in the DMS electronic visual archive.

	Mei																				
Yr	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	12/13	13/14	14/15	Total	T.eff	OBS				
83	~	~	~	0	~	~	~	~	~	~	~	~	~	~	0	2,80	VELRU				
84	~	~	~	~	~	~	~	0	~	~	~	~	~	~	0	1,12	NIJJO				
85	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
86	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
87	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
88	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
89	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
90	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
91	~	~	~	~	~	~	~	5	~	~	~	~	~	~	5	6,61	JENPE	MISKO			
92	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
93	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
94	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
95	~	~	~	0	~	2	~	~	~	~	~	~	~	~	2	6,10	MISKO				
96	~	~	~	~	~	~	0	2	~	~	~	~	~	~	2	2,54	MISKO				
97	~	~	~	~	~	~	2	~	~	~	~	~	~	~	2	3,55	LANMA				
98	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
99	~	~	1	~	~	~	~	~	~	~	~	~	~	~	1	1,12	MISKO				
00	~	~	~	~	7	28	2	~	~	~	~	~	~	~	37	21,44	JOHCA	LANMA	MISKO	TUKAR	VANER
01	~	~	~	0	~	~	~	~	~	3	10	5	~	~	18	19,13	JOHCA	MISKO	VANMC	TUKAR	
02	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
03	~	~	0	0	~	7	~	~	~	~	~	~	~	~	7	8,17	JOHCA	MISKO	VANMC		
04	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0						
05	~	~	~	~	~	~	1	1	1	5	~	~	~	~	8	8,93	MISKO	VANMC			
06	~	~	0	~	~	~	~	2	~	~	~	~	~	~	2	2,34	MISKO	VANMC			
07	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0	0,00					
08	~	~	3	14	14	5	11	9	4	1	2	~	~	~	63	45,35	JOHCA	LEUPE	MISKO	NIJJO	VANMC
09	~	~	3	~	~	~	~	0	~	~	~	~	~	~	3	5,86	DIJSI	LEUPE	JOHCA		
10	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0	0,00					
11	4	3	6	6	~	~	~	~	2	~	~	~	~	~	21	34,45	DIJSI	LEUPE	MISKO	VANMC	
12	~	~	~	~	~	~	~	~	~	~	~	~	~	~	0	0,00					
13	~	~	~	5	4	~	~	~	~	~	~	~	~	~	9	11,56	LEUPE	MISKO	VANMC		
14	~	~	3	4	~	5	~	~	~	~	~	~	~	~	0	9,17	VANMC				
15	~	~	~	~	2	0	~	~	0	~	~	1	2	~	5	8,66	MISKO	VANMC			
16	1	~	4	3	1	7	~	7	~	~	~	~	~	~	23	26,40	MISKO	VANMC			
17	~	~	~	~	~	~	~	~	~	~	~	~	~	1	1	1,50	MISKO				

is not necessarily the night of maximum activity. Significant numbers of ELYs were reported as well before as after the time of maximum activity.

3 Conditions in 2017

After a rather unstable first week with poor weather a period with several clear nights made observations possible for most of the BeNeLux region. As a result more than 300 double station meteors were collected by the CAMS systems during 8–9, 9–10 and 10–11 May.

4 The observations

While reducing the data for the night of 9–10 May a number of meteors with a radiant position near the η-Lyrids (145 ELY) caught attention. The orbits obtained for these meteors were compared to the orbit of comet C/1983 H1 (MPC 8272), using the D-criterion of Drummond (Drummond, 1981).

- perihelion date 1983-05-21.25287
- argument of perihelion ω (°) 192.84937
- ascending node Ω (°) 49.10225
- inclination i (°) 73.25340
- eccentricity e 0.9901147
- perihelion distance q (AU) 0.9913412

A quick survey indicated that the first ELYs were captured on 6 May. At $0^h09^m38^s$ UT, a shower member was recorded by the stations Oostkapelle (339, *Klaas Jobse*), Mechelen (391, *Luc Gobin*), Uccle (393, *Hervé Lamy*) and Wilderen (380, *Jean-Marie Biets*). At $01^h28^m00^s$ UT the stations Oostkapelle (331, *Klaas Jobse*) and Ooltgensplaat (342, *Piet Neels*) got the next shower member. Finally at $01^h35^m55^s$ UT another possible candidate (see *Table 2*) was captured by stations Oostkapelle (331, *Klaas Jobse*), Alphen a/d rijn (368, *Robert Haas*), Ooltgensplaat (342, *Piet Neels*) and Mechelen (389, *Paul Roggemans*).

Two more orbits followed in the night of 8–9 May. A first candidate ELY (see *Table 2*) was captured at $21^h41^m42^s$ UT by the stations Ooltgensplaat (341, *Piet Neels*), Mechelen (389, *Paul Roggemans*) and Oostkapelle (332, *Klaas Jobse*). At $23^h15^m20^s$ UT a second candidate shower member has been recorded by the stations Mechelen (388, Paul Roggemans), Hengelo (323, *Martin Breukers*), Oostkapelle (332, *Klaas Jobse*) and Burlage (802, *Robert Haas/Edwin van Dijk*).

During the next two nights, 9–10 and 10–11 May, as many as respectively 9 and 17 meteors were captured for which the orbits fit the D-criterion to be related to the dust of the comet. Finally in the night of 13–14 May at $23^h49^m22^s$ UT a last candidate was registered by the stations Ermelo (352, *Koen Miskotte*) and Alphen a/d Rijn (360, *Robert Haas*).

These numbers are remarkable when we compare these with the numbers recorded during previous years with CAMS. The smaller numbers of ELYs captured in the years 2013 – 2016 can be explained by the fact that in the early years less cameras were available. However, the favorable weather around 10 May in 2017 definitely made a big difference. In other years the weather was rather unstable, but still we feel like we cannot completely explain the higher number of ELYs in 2017 by the better weather or extra cameras alone. It looks like the annual activity of this shower is variable from one year to the other.

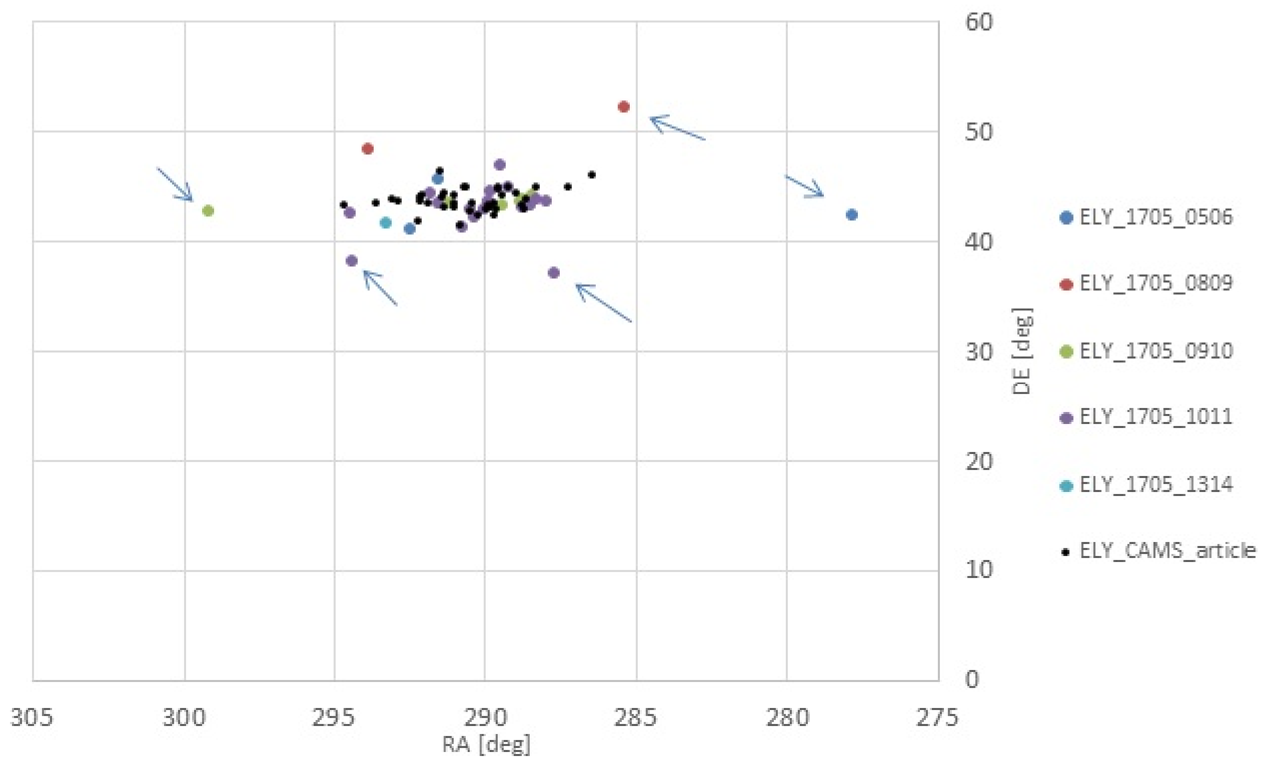

Figure 3 – Radiant positions for the period 2011 – 2012 of ELYs recorded by CAMS (Jenniskens et al., 2016). With the radiant positions of our 2017 data (nights 5–6, 8–9, 9–10, 10–11 and 13–14 May) marked as colored dots. The arrows indicate uncertain candidates (see text).

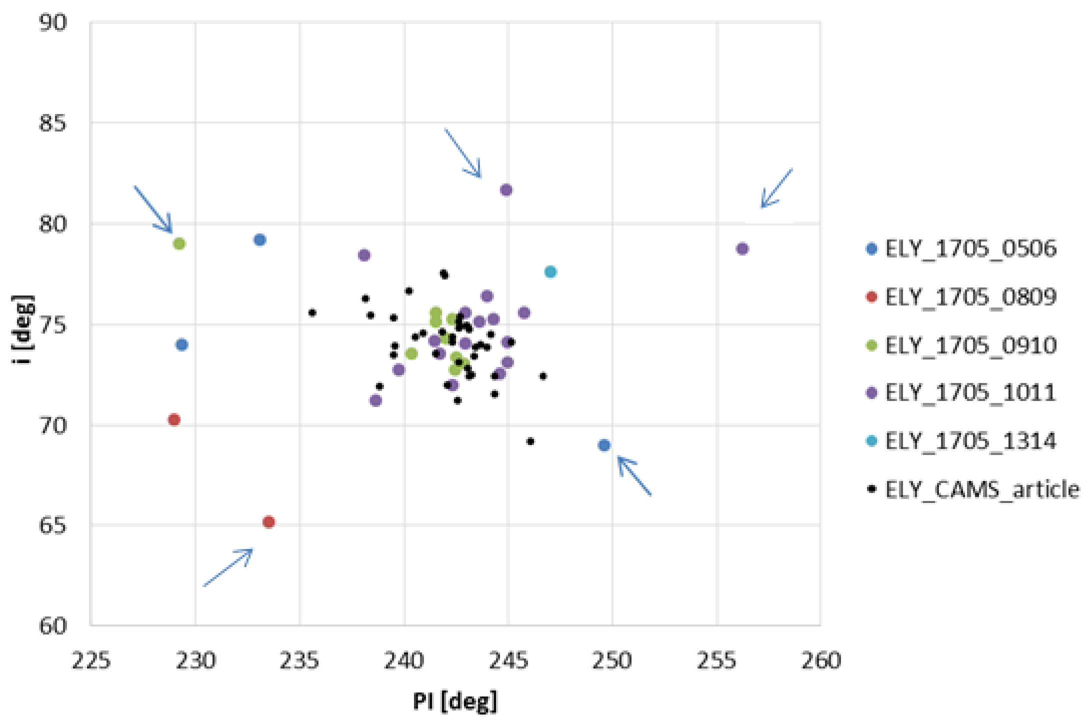

Figure 4 – Plot of the orbital element Π versus i for the ELYs recorded by CAMS in the period 2011–2012 CAMS (Jenniskens et al., 2016). With the positions of our 2017 data (nights 5–6, 8–9, 9–10, 10–11 and 13–14 May) marked as colored dots. The arrows indicate uncertain candidates (see text).

There is a possibility that CAMS California registered some slightly enhanced activity from the ELYs in 2012 (Jenniskens et al., 2016). CAMS California collected 7 ELY orbits in 2011 and 32 ELY orbits in 2012, 11 of which on May 10, 2012. The radiant positions of these meteors and our 2017 candidates are plotted in *Figure 3*. CAMS data of this shower from 2011–2012 did not enable to derive any radiant drift. No radiant drift could be derived from our 2017 data either.

Figure 4 shows the plot of Π against i for these meteors. We see a nice compact concentration of ELYs around Π ~242° (result of ω + Ω) and i ~74°. It is obvious that this is dust from comet IRAS-Araki-Alcock.

Table 2 – Radiant position and orbital elements Π and i for 32 ELYs (© CAMS BeNeLux).

Date	UT	RA	+/-	DE	+/-	Sol.long.	i	+/-	PI	+/-	D crit.
06.05.2017	00:09:37.85	292,457	0,549	41,034	0,523	45,44469	79,164	0,447	233,114	1,004	0,0595
06.05.2017	01:28:00.22	291,574	0,709	45,665	0,672	45,4974	73,988	0,643	229,397	1,314	0,0670
06.05.2017	01:32:54.56	277,821	0,197	42,417	0,269	45,5007	68,989	0,236	249,636	0,581	0,0656
08.05.2017	21:41:41.87	285,379	1,067	52,175	0,496	48,24867	65,125	0,549	233,525	1,203	0,0998
08.05.2017	23:15:19.78	293,878	0,091	48,34	0,072	48,31156	70,225	0,064	229,026	0,143	0,0779
09.05.2017	22:50:42.84	289,448	0,134	43,298	0,096	49,26192	75,551	0,108	241,551	0,247	0,0381
10.05.2017	00:01:19.27	288,597	0,107	43,429	0,111	49,30932	75,24	0,082	242,342	0,233	0,0509
10.05.2017	00:42:53.85	288,817	0,167	43,738	0,184	49,33723	74,304	0,217	242,049	0,39	0,0214
10.05.2017	01:33:20.40	291,205	0,219	43,517	0,217	49,37109	73,527	0,184	240,373	0,468	0,0808
10.05.2017	01:40:02.46	299,176	0,492	42,798	0,56	49,37559	78,956	0,532	229,274	1,07	0,0962
10.05.2017	01:56:09.08	288,69	0,073	43,696	0,071	49,38641	73,054	0,067	242,896	0,149	0,0298
10.05.2017	02:02:52.35	289,912	0,314	43,273	0,433	49,39092	75,096	0,407	241,559	0,859	0,0126
10.05.2017	02:28:48.04	288,754	0	43,81	0	49,40832	73,319	0	242,541	0	0,0152
10.05.2017	02:45:06.38	288,446	0	44,157	0	49,41927	72,709	0	242,493	0	0,0171
10.05.2017	20:23:55.59	291,828	0,324	44,439	0,096	50,12988	72,702	0,183	239,789	0,456	0,0816
10.05.2017	21:06:49.00	289,486	0,445	47,007	0,239	50,15866	71,153	0,247	238,659	0,594	0,0399
10.05.2017	21:23:58.74	288,782	0,103	43,088	0,091	50,17018	75,216	0,07	244,286	0,181	0,0387
10.05.2017	22:36:12.71	288,333	0,341	43,886	0,222	50,21865	72,496	0,287	244,602	0,62	0,0314
10.05.2017	22:46:20.74	294,459	0,674	42,539	0,657	50,22545	78,393	0,726	238,109	1,41	0,0399
10.05.2017	22:54:06.02	290,497	0	42,901	0	50,23065	75,544	0	242,971	0	0,0149
10.05.2017	23:21:53.80	290,364	0,455	42,224	0,357	50,2493	76,389	0,34	243,984	0,952	0,0204
10.05.2017	23:39:24.63	287,979	0	43,736	0	50,26105	73,087	0	244,977	0	0,0150
10.05.2017	23:43:47.74	290,734	0	41,391	0	50,264	75,575	0	245,779	0	0,0825
10.05.2017	23:48:40.38	290,032	0,269	42,944	0,225	50,26727	75,104	0,255	243,619	0,565	0,0149
11.05.2017	00:33:25.38	291,527	0,207	43,513	0,17	50,2973	74,178	0,156	241,511	0,377	0,0562
11.05.2017	01:18:00.92	289,907	0,088	43,684	0,104	50,32722	74,024	0,091	242,988	0,176	0,0164
11.05.2017	01:27:04.06	288,507	0,062	43,29	0,08	50,33329	74,119	0,067	244,972	0,159	0,0173
11.05.2017	01:57:51.20	289,251	0,362	44,898	0,47	50,35394	71,93	0,457	242,379	0,908	0,0304
11.05.2017	02:14:55.71	294,426	0,302	38,218	0,335	50,3654	81,674	0,349	244,921	0,731	0,0969
11.05.2017	02:15:43.40	287,735	0,411	37,182	0,407	50,36593	78,706	0,405	256,275	0,964	0,0972
11.05.2017	02:33:18.29	289,853	0,329	44,612	0,36	50,37773	73,505	0,34	241,719	0,63	0,0157
13.05.2017	23:49:22.32	293,3	0,461	41,619	0,43	53,16445	77,617	0,39	247,094	1,117	0,0461

Both *Figure 3* as well as *Figure 4* displays a rather dense cloud of dots.

The radiant positions and the values of the orbital elements Π and i for the 32 ELY meteors are listed in *Table 2*. A few of the double station meteors proved to be at the limit of the D-criterion of Drummond, ($D_d < 0.105$). These have been marked in red in *Table 2*. For the remaining 27 ELY-orbits the average value of the D-criterion of Drummond is $D_d = 0.038$, significant less. We can therefore state that we registered 27 ELYs with certainty and 5 more possible ELYs.

5 Conclusion

CAMS BeNeLux managed to register a nice activity of the Eta Lyrids. The activity seems to have been higher in 2017 than in the period 2013 until 2016. Having more cameras available and the better weather alone cannot explain the higher number of ELY orbits. It seems that Earth passed through a more dense concentration of dust this year. No radiant drift could be detected. Both radiant positions and orbital elements are in very good agreement with the predicted values.

Acknowledgment

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MPC 8272.

The meteor masses detected by RAMBo and the Newcomb-Bedford law

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The Newcomb-Bedford law describes a very strange behavior for "natural" data distributions: looking at the first significant digit if that is not random but follows a logarithmic behavior. We have examined if the meteors mass index measured by RAMBo follows this law and what it means about our data.

1 Introduction

Mathematics has sometimes extraordinary mysterious or difficult explanations that make it one of the most fascinating sciences. One of these is the *Newcomb-Bedford's* law. The Newcomb-Bedford law, or Newcomb-Bedford distribution, also known as *Benford*'s law or law of the first digit, examines numerical data collections from physical measurements. This law does not have an intuitive explanation and at a first glance seems to come out more from the esoteric world than from the statistics world. Let's see what it is.

2 Newcomb-Bedford law

If we extract the first significant digit in each number from a numerical data distribution, we will get a distribution of numbers ranging from 1 to 9. *Table 1* shows an example.

Table 1 – Example with a distribution of numbers.

Number	First significant digit
54	5
38	3
361	3
753	7
17	1
76	7
40	4
118	1
521	5
161	1
16749	1
51	5
13	1
74	7

One would expect from this distribution that the probability to find any of the possible significant first digits is the same for all numbers from one to nine. This probability is:

$$P_n = \frac{100}{N}$$

Where P_n is the probability of a nth number. For 9 numbers with N = 9, P_n = 11.1.

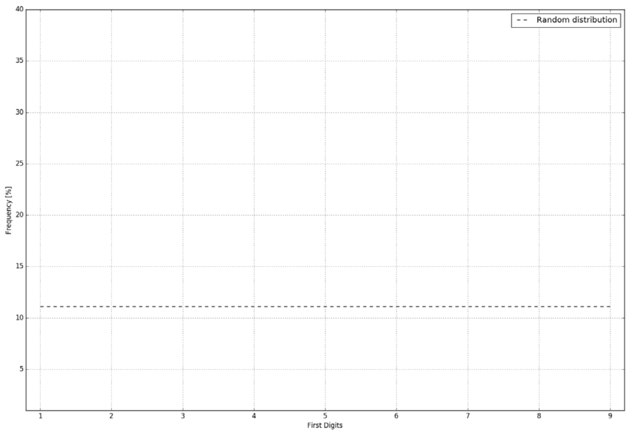

Figure 1 – Random distribution: output probability $P_n = 11.1$.

The surprising reality is that this is not the case, if the distribution under review obeys the following three conditions:

1. It is composed of a large amount of real data from a sample of physical quantities (lengths of rivers, pulsar periods, star masses, sports scores, agricultural productions, stock indices, the Fibonacci series or the power series of the two).
2. It consists of numbers distributed over several orders of magnitude.
3. It represents a unity of samples coming from different origin (Livio, 2003).

The probability to find a "1" as first significant figure is about 30%, to find a "2" is about 17%, while a "3" has a probability of 12% and so on, ending with a miserable 4.6% probability for an output with a "9".

This logarithmic pattern was first discovered by a US astronomer, *Simon Newcomb* (1835–1909) (Dragoni et al., 1999). Analyzing the logarithmic charts of naval almanacs, Newcomb noticed that the first pages were much more dirty and worn out than the last ones.

Therefore, the consultation of the first numbers with 1 was far greater than for the numbers starting with 9. When analyzing this behavior in detail he realized that the probability for the output of the first digits corresponded to a logarithmic law as follows:

$$P_D = log_{10}\left(1 + \frac{1}{D}\right)$$

Where P is the probability and D is the first significant digit in question. By replacing D with the digits from 1 to 9 the nine probabilities P_D become:

- 1 → 30%,
- 2 → 17.6%,
- 3 → 12.5%,
- 4 → 9.7%,
- 5 → 8%,
- 6 → 6.7%,
- 7 → 5.8%,
- 8 → 5%,
- 9 → 4.6%

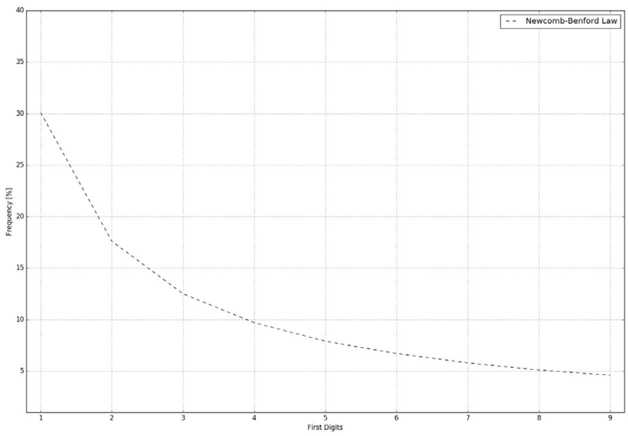

Figure 2 – Actual probability distribution for the first significant digits in a real data sample.

3 Frank Benford's findings

About 50 years later, *Frank Benford*, a physician (1883–1948) and General Electric's employee, rediscovered the curious phenomenon in a completely independent way. However, a singularity is that every sequence of arbitrarily constructed data by humans tends to follow a random distribution and does not follow the Newcomb-Bedford's law.

Consequently, if we "pollute" a "natural" data distribution with some man-made data, the more of this "pollution" we generate, the more the distribution will deviate from the Newcomb-Bedford law. This fact has been clearly highlighted by *Mark Negrini* and *Ted Hill* who were investigating financial fraud and election fraud by analyzing data distributions using the Newcomb-Bedford law. Statistics teach us in which way we can measure how a distribution differs from another distribution taken as a sample. To do this, we have to apply the χ^2 equation.

$$\chi^2 = \sum_{1}^{9} i \frac{(n_i - N_i)^2}{N_i}$$

Where:

- χ^2 is the "distance" of the examined distribution compared to the sample distribution;
- n_i is the frequency of the i[th] number of the examined distribution;
- N_i is the frequency of the i[th] number of the sample series.

If χ^2 is less than 15, then the distribution is considered to approximate the sample distribution with a high degree of fidelity. $\chi^2 \leq 15.51$ is the situation where both distributions are similar to each other.

4 Newcomb-Bedford and Rambo data

RAMBo is a meteor echoes radio observatory, more information can be found on the website[9]. The observatory works continuously since 2014 and it records and measures daily the meteor echo data. Each day about 200 meteors are recorded, hence the data sample in our possession is very large.

Once we knew about the existence of the Newcomb-Bedford law, we wondered if our data fits in a distribution according to the Newcomb-Bedford law or if it follows a random distribution. Our data comes unquestionably from measured physical data and therefore responds to the first condition of Benford. With RAMBo we collect three types of data for each meteor: echo duration, echo amplitude, and the moment (time and date) of appearance. From the multiplication of the amplitude with the duration of the echo, both related to the mass of the meteoroid, RAMBo obtains a third value that we define as the "mass index" from which we estimate the size of the meteoroid that generated the echo. The collection of this data covers 8 magnitude classes and thus satisfies the second condition regarding the Newcomb-Bedford law. Moreover, coming from a combination of two different data collections (duration and amplitude of the meteor echoes) it also satisfies the third condition.

For the reasons outlined above, we decided to use the "mass index" as the data collection for the analyses. Then we took the first significant digit from the "mass index" obtained during the period from January 1 through May 2017. The result follows faithfully close the Newcomb-Bedford law as shown in *Figure 3*.

The calculation done with the equation of the χ^2 method gives a value of χ^2 = 0.49, which is much lower than the limit of 15.51. Even more stunning is the examination of the data from 2016, including 806928 meteor echoes analyzed which yield a value of χ^2 = 0.74.

[9] http://www.ramboms.com

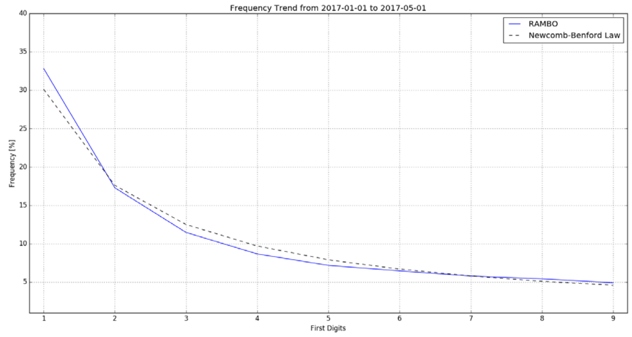

Figure 3 – The solid line is the distribution based on RAMBo data for 2017, the dotted line the Newcomb-Benford Law.

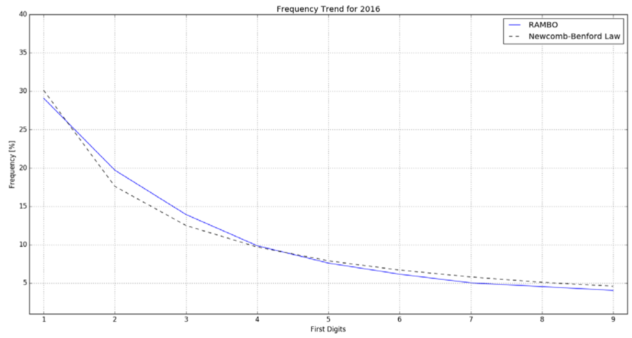

Figure 4 – The solid line is the distribution based on RAMBo data for 2016, the dotted line the Newcomb-Benford Law.

We can conclude that the data measured by RAMBo perfectly follows Newcomb-Bedford's law. Hence, the data is "natural", i.e. the data does not contain human or artificial pollution which would have led to a different distribution than the Newcomb-Bedford one. We can assume that the apparatus that we have designed and constructed does not produce artifacts.

It is of great interest to focus on the merits of the second feature of the Newcomb-Bedford law. Its application was able to detect financial fraud to the detriment of a major US tourism and entertainment company. The presence of thirteen false checks from fraudulently collected sums was discovered with this method. The Brooklyn District Attorney's Office also benefited from the Newcomb-Bedford law proving fraud in seven New York companies (Livio, 2003). Other cases concern the discovery of financial data falsification, company financial statements, tax returns, stock exchange reports, and even electoral frauds (Benegiamo, 2017). Even more interesting is the study by geologists on the geophysical data that preceded the great Sumatra-Andaman earthquake of December 26, 2004, with a magnitude of up to 9. It seems that this data was significantly different from the Newcomb-Bedford's distribution, while those measured twenty minutes later were back to normal. If such a behavior could be confirmed and found in other occasions, it could open up an important field of investigation in the prevention of seismic phenomena (Benegiamo, 2017).

The question arises whether in a stressful situation or in any exceptional case different from the usual situation, a tendency could appear in measured data to deviate from a normal behavior.

At this point we wondered whether the behavior of the data collected during a meteor shower would deviate from the data collected over a period of time dominated by sporadic meteors. If this condition really occurs, it would be a third indication for the presence of a shower, in addition to the two that we already measure, e.g. the HR (Hourly Rate) and the "mass index" of the meteors ablating in the atmosphere.

We have therefore tried to analyze the data from one of the strongest meteor showers, for example the Quadrantids of 2017. We followed the same procedure as previously used for the calculation of some samples from periods dominated by sporadic meteors only.

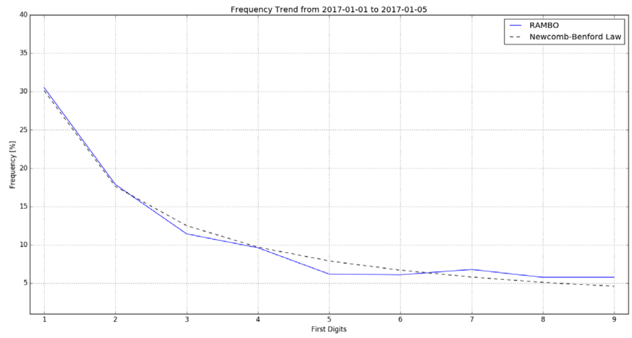

Figure 5 – The solid line is the distribution based on RAMBo data for the 2017 Quadrantids, the dotted line the Newcomb-Benford Law.

The result shows no difference; therefore there is no different behavior in the Newcomb-Bedford analysis between meteor showers and sporadics (*Figure 5*).

Meteor showers cover very short periods of time, thus the amount of the analyzed data is much smaller and therefore it does not follow the first condition of the Newcomb-Bedford law, but it is probably wiser to say that this hypothesis is unfounded.

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Meteor streams study of 1966

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3600 individual photographic orbits of meteor bodies and about 2000 visual meteor radiants with corresponding velocities were compiled and carefully studied in detail. 154 minor meteor streams were detected in the Solar System, their basic orbital and other data are given.
Firstly some remarkable shower and stream properties are established: examples of the large elliptic radiation areas with semi-major axes perpendicular to the Ecliptic; the existence of the Northern (N) , Southern (S) and Ecliptical (Q) branches of some streams; stream-antipodes and radiant-antipodes (symmetrically arranged relatively to the Ecliptic) with angular distances from the Ecliptic to 40-80°; a number of short-perihelion streams (q ~ 0.05-0.07 A.U.); some meteor streams perpendicular to the Ecliptic's plane. There are also some unique meteor bodies with their orbits enclosed within the limits of the Earth's one, or having the clockwise and anticlockwise direction in two similar orbits.
Hyperbolic photographic velocities v_h = 57-88 km /sec are treated as real ones according to the best radar and visual observations. A "bunch" of ecliptical streams, discovered in the USSR in 1950, is a complex of orbits of the mostly massive meteor particles of the Zodiacal Cloud. The stream evolution rate is comparatively high. The total complex of sporadic meteor bodies is not totally chaotic and accidental.

1 Introduction

This work published more than 50 years ago in Russian and relatively unknown among most Western scientists is now available online. With camera networks revealing the structure of minor streams in detail, it is useful to check recent finds with this detailed study published in 1966. To avoid transcription errors we reproduce the original Russian text.

2 Symbols and terminology

The following notations and terms are used in this paper, epoch 1950.0 being used for all orbital data:

D	Diameter of the almost circular radiant area;
D_1, D_2	The major and minor axes of the elliptic radiant area;
ΔS	The distance between the radiants along the arc of a great circle at the hemisphere;
Δ	The value of the diurnal displacement of the radiant along the arc at the hemisphere, Δ > 0 being with a shift toward the east in the direction of increasing longitudes;
n	Number of observations;
МП	Minor shower;
МР	Minor stream;
W	Relative weight of the stream;
N,S,Q	Respectively, the northern, southern, and ecliptical branches of the stream;
v_t	Orbital velocity of the Earth.

For visual data:

R(α, δ)	Apparent geocentric radiant;
n_R	The number of single radiants R(α, δ);
n_h	The observed hourly rate of meteors;
v	Atmospheric velocity of the meteors.

For photographic data:

R_g(α, δ)	Corrected geocentric radiant;
ε_g	Elongation of the radiant R_g(α, δ) from the apex;
v_∞,v_g,v_h	Respectively, pre-atmospheric, geocentric and heliocentric velocity;
a, e, q, q', ω, Ω, i, π	Orbital elements and parameters of the heliocentric orbit of the meteor stream;

3 The original publication

The publication has been scanned and can be consulted in pdf-format.

Camelopardalids in 2019 (meteor shower of the comet 209P/LINEAR)

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After an outburst of Camelopardalids shower in 2014, the next interesting year is 2019, when two small outbursts are possible. The first one with ZHR up to 10 is expected from the 1939 trail of the comet 209P/LINEAR at 7^h44^m UT on 24 May, the second with ZHR up to 5 could be produced by the 1994-2009 trails around 11^h UT on 24 May. Details are here: http://feraj.ru/Radiants/Predictions/209p-ids2019eng.html

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