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IMC 2011 report
Solar longitude tables
Comae Berenicids explored
30 years of Geminid observations
August–September video meteors

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Front cover photo

This bright Northern Taurid fireball appeared on 2011 November 16 at $23^h13^m03^s$ UT while Slovenian meteor observers were covering the Leonids from Grmada, Slovenia. The author used Nikon D80 equipped with 18-mm $f/3.5$ lens for a 60 s exposure at ISO 1000. Photo courtesy: Rok Pucer.

Writing for WGN This Journal welcomes papers submitted for publication. All papers are reviewed for scientific content, and edited for English and style. Instructions for authors can be found in WGN **31:4**, 124–128, and at `http://www.imo.net/articles/writingforwgn.pdf` .

Cover design Rainer Arlt

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Editorial

Javor Kac

This issue completes the 39th volume of WGN. While it again comes out somewhat delayed, we are on the right track to catch up with the usual schedule starting with the next issue. We again apologize to our readers for the late publication of our journal.

Completing the volume calls for a short review of the activities involved in producing the journal. Of course, the authors submitting their work for publication in our journal make it all possible in the first place. Maintaining the quality of articles appearing in WGN would not have been possible without a number of people helping in the process. Special thanks go to thirteen members of the Editorial Board who helped me by acting as handling editors, science and language reviewers. In addition, William Cooke and Robert Lunsford offered their help reviewing articles. When editing of individual articles is finished, the complete issue gets assembled. Printing and mailing of the journal takes place in Potsdam, Germany, where several more people are involved in packing and mailing the journal to our members. At the same time, the PDF version of the issue is put on the IMO web page with the help of Luc Bastiaens and Geert Barentsen, along with an announcement. I would like to thank all above for making it possible.

Finally, if you wish to share your meteor related work with others, we will be happy to consider it for publication in WGN.

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From the Treasurer — IMO Membership/WGN Subscription Renewal for 2012

Marc Gyssens

We invite all our members/subscribers to renew for 2012. The fees are as tabulated below. We are happy that we can offer WGN at the same cost as last year. We also continue to offer an electronic-only subscription at 5 euros or 10 dollars less than the standard rate.

IMO Membership/WGN Subscription 2012				
Electronic + paper with surface mail delivery:		€26		US$ 39
Electronic + paper with airmail delivery (outside Europe only):		€49		US$ 69
Electronic only:		€21		US$ 29
Supporting membership:	add	€26	add	US$ 39

It is possible to renew for two years by paying double the amount.

General payment instructions can be found on the IMO's website, at `http://www.imo.net/payment`. Members and subscribers who have not yet renewed will find enclosed a leaflet where these payment instructions are further detailed. Please follow these instructions! Choosing the most appropriate payment method results in low or even no additional costs for you as well as the IMO. The IMO strives to keeping these costs low in order to control the price of the journal!

When you renew, give a few minutes of thought to becoming a **supporting member**. Every year, the IMO helps active meteor workers to attend the annual International Meteor Conference, who would otherwise not have been able to come. Our ability to provide this help depends primarily on the gifts we receive from supporting members!

Another way to help meteor workers with limited funds is to offer them a gift subscription.

We already thank all our members that will renew for their continued trust in our Organization!

One final request: every year, a lot of members renew late. As a consequence, back issues that already appeared have to be sent out to these members. Please support our volunteers in their bimonthly effort to have WGN shipped to you by renewing promptly! Thank you for your understanding and cooperation!

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Conferences

Romania and IMC 2011 – *a timeless beauty...*

Thilina Heenatigala [1]

Received 2011 December 9

As a first timer to both Romania and to the International Meteor Conference (IMC), I was quite touched by the whole experience. It was nothing like I was expecting, but rather more. I have heard numerous stories about the IMC, how it's different than a usual conference and filled with a warmer atmosphere. I'm glad I was able to experience these at first hand. The IMC definitely has its own charm.

This year brought the 30th edition of the IMC and to celebrate this, it couldn't be a better place than Romania – a timeless beauty and rich in picture-postcard views. Taking the train from Bucharest to Sibiu – the conference city – was interesting. Bucharest, a city entwined with modern and historic touches, both in surroundings and in people. Along the route to Sibiu, you get to see a more traditional Romanian environment surrounded by the beautiful Carpathian Mountains, replacing cars with horse carriages, and modern clothes with more farming-clothing. And arriving at Sibiu – a city rich in culture – I was greeted by the LOC warmly.

From starting to the end, the conference was well planned by the "Romanian Society for Meteors and Astronomy" (SARM), the local organizers of the IMC 2011 and one of the most dedicated and active amateur astronomy groups in Europe. I should also not forget the workload carried out by the "Organizational Support Team" of the IMC 2011 which consisted of a group of quite young students who are members of SARM as well. Of course all this was headed by one person, my good friend Valentin Grigore (the IMC 2011 LOC chair) whom I believe to have the strength of 10 people.

There were quite a lot of organizational and individual pieces of meteor research presented at the IMC 2011. As a non-frequent meteor observer myself, I enjoyed the talks thoroughly. However coming from an Education and Outreach field, I felt the lack of presence in these fields. As mentioned in my talk during the IMC 2011, meteors are something that can grab the attention of students and the general public; it's something that we can use to get more people interested in Astronomy and Science in general. Also it's important to communicate the science you do today, so that someone will be able to follow it up in the future. I hope that the lack of Education and Outreach will be filled in future IMCs.

It's always interesting when you share science, and it's more interesting when you share science live. As a social media enthusiast, I was quite happy to see some more social-media-friendly people present at the IMC 2011, sharing live updates via Twitter and Facebook. There was also an attempt to webcast the talks from time to time. Social media usage and webcasting is definitely something the IMC should consider for future use as it gives the opportunity to be a part of the conference for those who couldn't make it.

Figure 1 – Valentin Grigore and the author holding the offical IMC 2011 flag.

Apart from the Science that took place, the wonderful excursion to the Făgăraş Mountains and lunch at Lake Bâlea was a perfect mixture to the IMC 2011. Not forgetting the Astropoetry evening which is quite unique to the IMC and even I got to play a part as "Leonid Thilina".

In a final note, I'm glad that I made it to the IMC 2011. It surely was a unique conference with a wonderful experience. By the end of it I made some good friends, and true enough, the IMC does give a good feeling of belonging to a family and makes you want to return again next year, or as Paul Roggemans explained to me, it's the "IMC virus or IMC spirit, it keeps everyone together."

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Figure 2 – IMC 2011 participants in front of the ASTRA library.

Solar Longitudes for 2012

Compiled by Rainer Arlt

A conversion table of dates to solar longitudes using (Steyaert, 1991) is given as every year. The longitudes are given on the next page; they are only valid for 2012. The conversion formulae for any time of the day are repeated here for your convenience.

If you want to calculate the solar longitude $\lambda_\odot$ of a specific time of the day, you may use a linear interpolation between two dates. Suppose you have a certain *Date* and the *Time* in hours (UT), you get the solar longitude by

$$\lambda_\odot = \lambda_{\odot,\mathrm{Date}} + (\lambda_{\odot,\mathrm{NextDay}} - \lambda_{\odot,\mathrm{Date}}) \times \frac{\mathrm{Time}}{24^{\mathrm{h}}}.$$

Alternatively, if you want to convert a certain solar longitude $\lambda_\odot$ into a time of the day, look up the *Date* with the next-smaller solar longitude in the table and calculate

$$\mathrm{Time} = \frac{(\lambda_\odot - \lambda_{\odot,\mathrm{Date}})}{(\lambda_{\odot,\mathrm{NextDay}} - \lambda_{\odot,\mathrm{Date}})} \times 24^{\mathrm{h}}.$$

The solar longitudes of 1988–2020 are given in two-hour increments and with three decimals at `http://www.imo.net/data/solar`.

References

Steyaert C. (1991). "Calculating the solar longitude 2000.0". *WGN, Journal of the IMO*, **19:2**, 31–34.

IMO bibcode WGN-396-arlt-solarlong
NASA-ADS bibcode 2011JIMO...39..157A

Solar longitudes 2012. Dates refer to 00^h UT.

Jan	1	279.79	Mar	1	340.64	May	1	40.86	Jul	1	99.40	Sep	1	158.79	Nov	1	218.79
Jan	2	280.81	Mar	2	341.64	May	2	41.83	Jul	2	100.35	Sep	2	159.76	Nov	2	219.79
Jan	3	281.83	Mar	3	342.64	May	3	42.80	Jul	3	101.30	Sep	3	160.72	Nov	3	220.79
Jan	4	282.85	Mar	4	343.65	May	4	43.77	Jul	4	102.26	Sep	4	161.69	Nov	4	221.80
Jan	5	283.87	Mar	5	344.65	May	5	44.73	Jul	5	103.21	Sep	5	162.66	Nov	5	222.80
Jan	6	284.89	Mar	6	345.65	May	6	45.70	Jul	6	104.16	Sep	6	163.63	Nov	6	223.80
Jan	7	285.91	Mar	7	346.65	May	7	46.67	Jul	7	105.12	Sep	7	164.60	Nov	7	224.80
Jan	8	286.92	Mar	8	347.65	May	8	47.64	Jul	8	106.07	Sep	8	165.57	Nov	8	225.81
Jan	9	287.94	Mar	9	348.65	May	9	48.60	Jul	9	107.02	Sep	9	166.54	Nov	9	226.81
Jan	10	288.96	Mar	10	349.65	May	10	49.57	Jul	10	107.98	Sep	10	167.52	Nov	10	227.82
Jan	11	289.98	Mar	11	350.65	May	11	50.54	Jul	11	108.93	Sep	11	168.49	Nov	11	228.82
Jan	12	291.00	Mar	12	351.65	May	12	51.50	Jul	12	109.88	Sep	12	169.46	Nov	12	229.83
Jan	13	292.02	Mar	13	352.64	May	13	52.47	Jul	13	110.84	Sep	13	170.43	Nov	13	230.84
Jan	14	293.04	Mar	14	353.64	May	14	53.43	Jul	14	111.79	Sep	14	171.41	Nov	14	231.84
Jan	15	294.05	Mar	15	354.64	May	15	54.40	Jul	15	112.74	Sep	15	172.38	Nov	15	232.85
Jan	16	295.07	Mar	16	355.63	May	16	55.36	Jul	16	113.70	Sep	16	173.36	Nov	16	233.86
Jan	17	296.09	Mar	17	356.63	May	17	56.33	Jul	17	114.65	Sep	17	174.33	Nov	17	234.87
Jan	18	297.11	Mar	18	357.62	May	18	57.29	Jul	18	115.61	Sep	18	175.31	Nov	18	235.87
Jan	19	298.13	Mar	19	358.62	May	19	58.25	Jul	19	116.56	Sep	19	176.29	Nov	19	236.88
Jan	20	299.15	Mar	20	359.61	May	20	59.22	Jul	20	117.52	Sep	20	177.26	Nov	20	237.89
Jan	21	300.16	Mar	21	0.61	May	21	60.18	Jul	21	118.47	Sep	21	178.24	Nov	21	238.90
Jan	22	301.18	Mar	22	1.60	May	22	61.14	Jul	22	119.43	Sep	22	179.22	Nov	22	239.91
Jan	23	302.20	Mar	23	2.59	May	23	62.10	Jul	23	120.38	Sep	23	180.20	Nov	23	240.92
Jan	24	303.22	Mar	24	3.58	May	24	63.06	Jul	24	121.34	Sep	24	181.18	Nov	24	241.93
Jan	25	304.24	Mar	25	4.58	May	25	64.02	Jul	25	122.29	Sep	25	182.16	Nov	25	242.94
Jan	26	305.25	Mar	26	5.57	May	26	64.99	Jul	26	123.25	Sep	26	183.14	Nov	26	243.96
Jan	27	306.27	Mar	27	6.56	May	27	65.95	Jul	27	124.20	Sep	27	184.12	Nov	27	244.97
Jan	28	307.29	Mar	28	7.55	May	28	66.91	Jul	28	125.16	Sep	28	185.10	Nov	28	245.98
Jan	29	308.30	Mar	29	8.54	May	29	67.86	Jul	29	126.11	Sep	29	186.08	Nov	29	246.99
Jan	30	309.32	Mar	30	9.52	May	30	68.82	Jul	30	127.07	Sep	30	187.06	Nov	30	248.00
Jan	31	310.33	Mar	31	10.51	May	31	69.78	Jul	31	128.03						
Feb	1	311.35	Apr	1	11.50	Jun	1	70.74	Aug	1	128.98	Oct	1	188.04	Dec	1	249.02
Feb	2	312.36	Apr	2	12.49	Jun	2	71.70	Aug	2	129.94	Oct	2	189.03	Dec	2	250.03
Feb	3	313.38	Apr	3	13.47	Jun	3	72.66	Aug	3	130.89	Oct	3	190.01	Dec	3	251.04
Feb	4	314.39	Apr	4	14.46	Jun	4	73.61	Aug	4	131.85	Oct	4	190.99	Dec	4	252.06
Feb	5	315.41	Apr	5	15.44	Jun	5	74.57	Aug	5	132.81	Oct	5	191.98	Dec	5	253.07
Feb	6	316.42	Apr	6	16.42	Jun	6	75.53	Aug	6	133.77	Oct	6	192.97	Dec	6	254.09
Feb	7	317.43	Apr	7	17.41	Jun	7	76.48	Aug	7	134.72	Oct	7	193.95	Dec	7	255.10
Feb	8	318.45	Apr	8	18.39	Jun	8	77.44	Aug	8	135.68	Oct	8	194.94	Dec	8	256.12
Feb	9	319.46	Apr	9	19.37	Jun	9	78.40	Aug	9	136.64	Oct	9	195.93	Dec	9	257.14
Feb	10	320.47	Apr	10	20.36	Jun	10	79.35	Aug	10	137.60	Oct	10	196.91	Dec	10	258.15
Feb	11	321.48	Apr	11	21.34	Jun	11	80.31	Aug	11	138.56	Oct	11	197.90	Dec	11	259.17
Feb	12	322.49	Apr	12	22.32	Jun	12	81.26	Aug	12	139.52	Oct	12	198.89	Dec	12	260.18
Feb	13	323.51	Apr	13	23.30	Jun	13	82.22	Aug	13	140.48	Oct	13	199.88	Dec	13	261.20
Feb	14	324.52	Apr	14	24.28	Jun	14	83.18	Aug	14	141.44	Oct	14	200.87	Dec	14	262.22
Feb	15	325.53	Apr	15	25.26	Jun	15	84.13	Aug	15	142.40	Oct	15	201.86	Dec	15	263.24
Feb	16	326.54	Apr	16	26.24	Jun	16	85.09	Aug	16	143.36	Oct	16	202.86	Dec	16	264.25
Feb	17	327.55	Apr	17	27.21	Jun	17	86.04	Aug	17	144.32	Oct	17	203.85	Dec	17	265.27
Feb	18	328.56	Apr	18	28.19	Jun	18	87.00	Aug	18	145.29	Oct	18	204.84	Dec	18	266.29
Feb	19	329.57	Apr	19	29.17	Jun	19	87.95	Aug	19	146.25	Oct	19	205.83	Dec	19	267.31
Feb	20	330.58	Apr	20	30.15	Jun	20	88.91	Aug	20	147.21	Oct	20	206.83	Dec	20	268.33
Feb	21	331.58	Apr	21	31.12	Jun	21	89.86	Aug	21	148.17	Oct	21	207.82	Dec	21	269.34
Feb	22	332.59	Apr	22	32.10	Jun	22	90.81	Aug	22	149.14	Oct	22	208.82	Dec	22	270.36
Feb	23	333.60	Apr	23	33.07	Jun	23	91.77	Aug	23	150.10	Oct	23	209.81	Dec	23	271.38
Feb	24	334.61	Apr	24	34.05	Jun	24	92.72	Aug	24	151.06	Oct	24	210.81	Dec	24	272.40
Feb	25	335.61	Apr	25	35.02	Jun	25	93.68	Aug	25	152.03	Oct	25	211.81	Dec	25	273.42
Feb	26	336.62	Apr	26	36.00	Jun	26	94.63	Aug	26	152.99	Oct	26	212.80	Dec	26	274.44
Feb	27	337.62	Apr	27	36.97	Jun	27	95.58	Aug	27	153.96	Oct	27	213.80	Dec	27	275.46
Feb	28	338.63	Apr	28	37.94	Jun	28	96.54	Aug	28	154.92	Oct	28	214.80	Dec	28	276.47
Feb	29	339.63	Apr	29	38.91	Jun	29	97.49	Aug	29	155.89	Oct	29	215.80	Dec	29	277.49
			Apr	30	39.89	Jun	30	98.45	Aug	30	156.86	Oct	30	216.79	Dec	30	278.51
									Aug	31	157.82	Oct	31	217.79	Dec	31	279.53

Ongoing meteor work

Comae Berenicids and related activities

Masahiro Koseki[1]

The Comae Berenicids have been considered as a winter shower but lower meteor activities continue the whole year round in this region. It might be called the meteors of Coma Sororum Medusae (CSM) instead of Comae Berenicids (COM). The CSM radiant passes the zenith twice in lower latitudes of the northern hemisphere and CSM activities vary with the altitude of the radiant. December Leonis Minorids (DLM) and September ε-Perseids (SPE) are distinct from the CSM background meteors, but July Pegasids (JPE), δ-Aurigids (DAU) and ν-Aurigids (NAU) are buried in this complex. The conglomeration of DLM, COM and JCO (January Comae Berenicids) has caused confusion in meteor observations as to whether they are three distinct sources or should be considered as one. A simple model of meteor stream structure shows the clear profile of their activities. Although their radiant drifts are overlapping, they might have different parent objects.

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1 Introduction

The activity of the meteor shower we call the 'Comae Berenicids' is very complex (Koseki, 2009). Although they are known as a winter shower, there is strong evidence of lower meteor activity thoughout the year from the same radiant region. We can reduce the influence of radiant drift by using ecliptic coordinates, i.e., $(\lambda - \lambda_\odot, \beta)$. The distribution of photographic meteor radiant points (RP) on Hammer's projection clearly shows several major showers and the anti-helion source (Figure 1). We can find some other concentrations on the map, too. Particularly the 'Comae Berenicids Area' at $230^\circ \le \lambda - \lambda_\odot < 255^\circ$ and $+10^\circ \le \beta < +30^\circ$ (hereafter called CBA) may be one of these concentrations. Figure 2 shows the geocentric velocity distribution of the CBA meteors obtained by photographic observations and seven IAU MDC showers within the CBA (IAU MDC, 2008). Photographic observations suggest that meteor activities in CBA might be active not only in winter but all year round. The December Leonis Minorids (DLM) and the September ε-Perseids (SPE) are distinct cases and other weaker showers constitute a widespread background. Jenniskens listed seven meteor showers, summarized in Table 1, which may be related with the region under study (Jenniskens, 2006). Here we will study activities of the CBA throughout the year in detail, using video meteor data.

The radiants under discussion are not too far from the sporadic apex source (Campbell-Brown & Jones, 2006) which is also composed of meteoroids on high inclination orbits with variable rates (see, e.g. Rendtel, 2007). Therefore, care needs to be taken to distinguish between probable individual showers and the sporadic source. This can be done by imposing a certain requirement on radiant distance (as, for example, Rendtel & Molau, 2010). The CCD and photographic data used for this study are based on brighter meteors which clearly show the DLM and SPE radiants and allow to distinguish them from the sporadic apex meteors.

2 Comae Berenices or Comae Sororum Medusae?

Meteors from the CBA appear all year round and, of course, the center of the CBA moves parallel to the ecliptic through constellations as shown in Figure 3. We cannot call the entire complex Comae Berenices. We could better name them meteors from the Hairs of Medusa's Sisters. Perseus killed Medusa and the bereaved immortal sisters Stheno and Euryale are wandering about the world. We now find the traces of them as Hairs of Medusa's Sisters (Comae Sororum Medusae, hereafter CSM), i.e., DLM and SPE. The September ε-Perseids are rich in bright meteors and better known in optical than radar observations. It is very natural that both DLM and SPE are rich in bright meteors and lack faint ones, because they are very old. CSM meteor activities are not predominant in radar observations (Figure 4). The two mentioned showers, DLM and SPE, are the only distinctive showers from this region. Currently, there is no reliable relation to a parent object known.

3 Nature of CSM activities

SonotaCo published a large number of CCD data covering the period 2007–2009 (SonotaCo, 2010) and his observations confirm CSM meteor activities. Figure 5 shows the geocentric velocity distribution of CSM meteors within $230^\circ \le \lambda - \lambda_\odot < 255^\circ$ and $+10^\circ \le \beta < +30^\circ$ observed by CCD cameras and seven IAU MDC showers. It is clear that DLM is the most intense shower in CSM, and SPE is the second.

Figure 6 shows the recorded number of CSM meteors by CCD cameras in each 5° bin of solar longitude and also the altitude of CSM at its transit. The CSM area passes the zenith twice in Japan, that is at $\lambda_\odot = 158^\circ$ and $\lambda_\odot = 258^\circ$ (see Figure 6). The two showers SPE and DLM are active close to these good opportunities for observations. Meteor rates change clearly with the

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Table 1 – Seven CSM streams in the IAU MDC. All occur at the descending node and the solar longitude of the maximum coincides with the ascending node, i.e. $\lambda_{\max} = \Omega$.

	a (au)	q (au)	i (°)	ω (°)	Ω (°)	R.A. (°)	Dec. (°)
COM	14.6	0.56	136	262.2	283.1	175.7	+24.7
JCO	∞	0.512	137.3	267.8	300.5	188.9	+16.8
DLM	11.9	0.554	133.8	265.6	262.2	156.1	+32.7
SPE	31.1	0.742	138.9	241.9	171.3	50.2	+39.4
NAU	1.298	0.267	134.3	311	208	87.9	+39.6
JPE	(44)	0.536	131.6	267.2	107.5	340	+15
DAU	24.1	0.845	130.2	226.7	191	83.5	+50.4

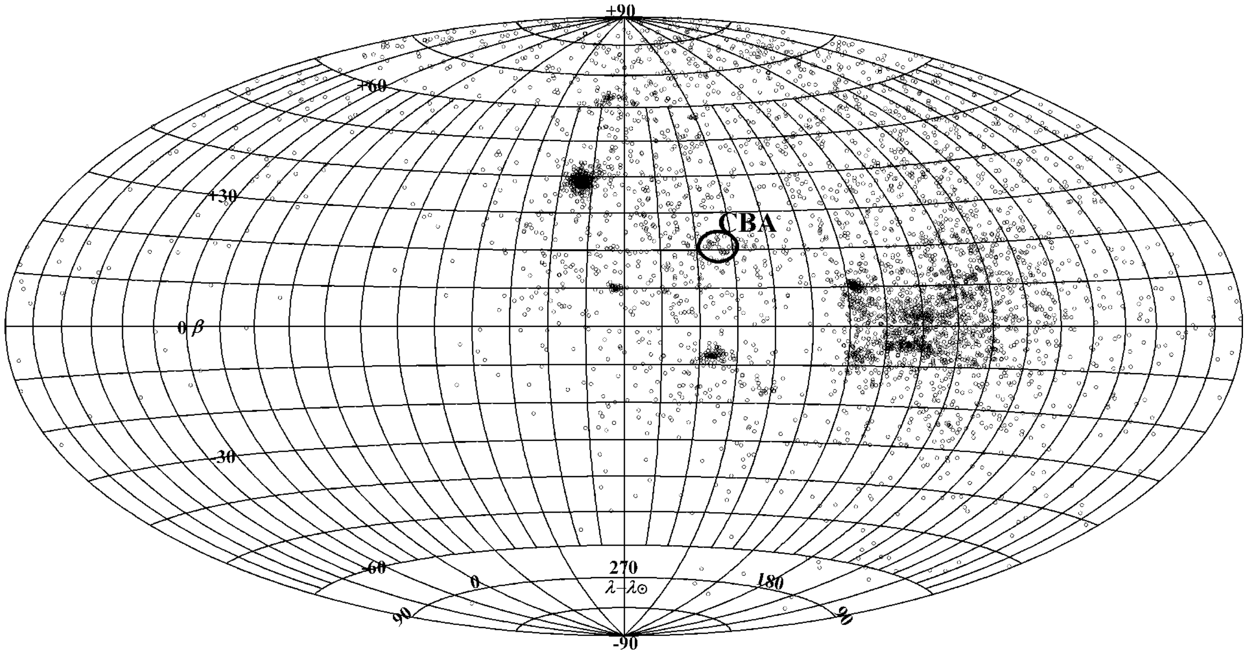

Figure 1 – Photographic radiant distribution in $(\lambda - \lambda_{\odot}, \beta)$ coordinates.

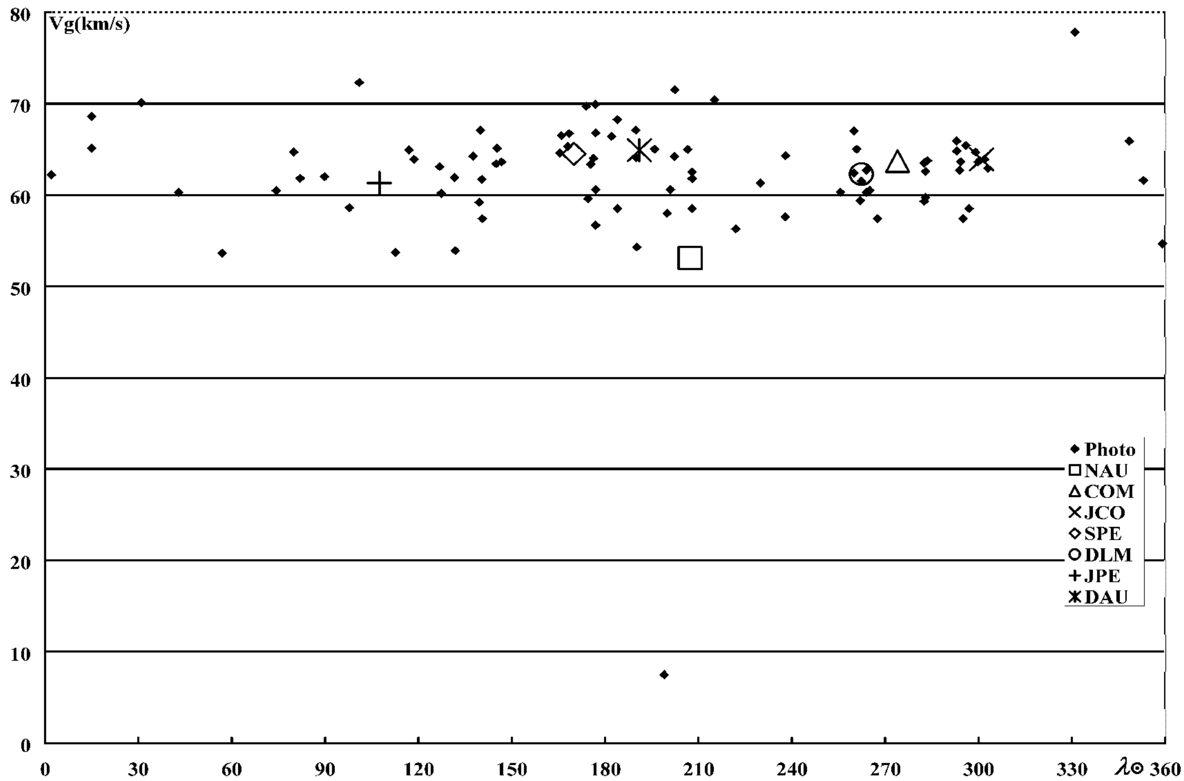

Figure 2 – Geocentric velocity distribution of photographic CSM meteors and seven IAU MDC showers.

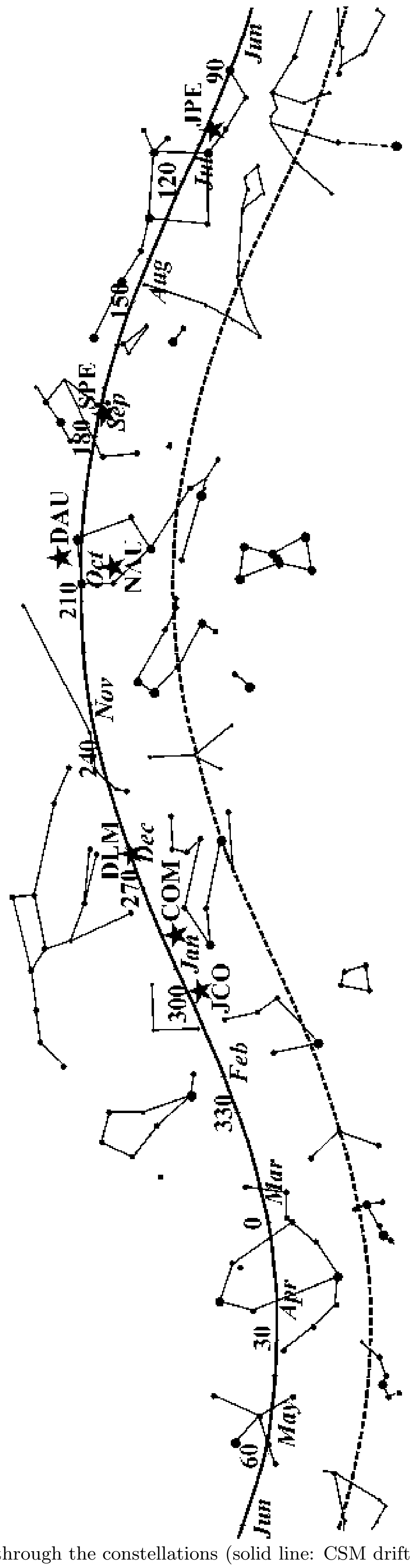

Figure 3 – Drift of the CSM center through the constellations (solid line: CSM drift, dotted line: ecliptic).

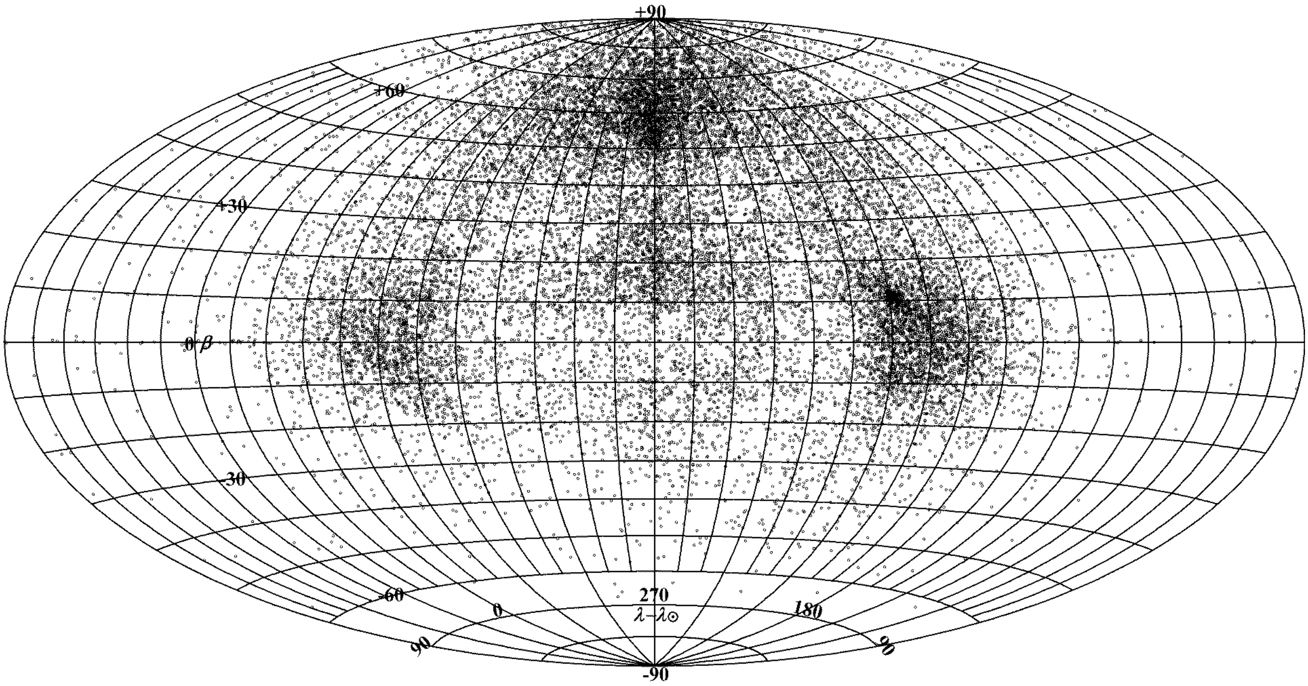

Figure 4 – Radiant distribution of radar meteors (Harvard 1961–1965) in $(\lambda - \lambda_\odot, \beta)$ coordinates.

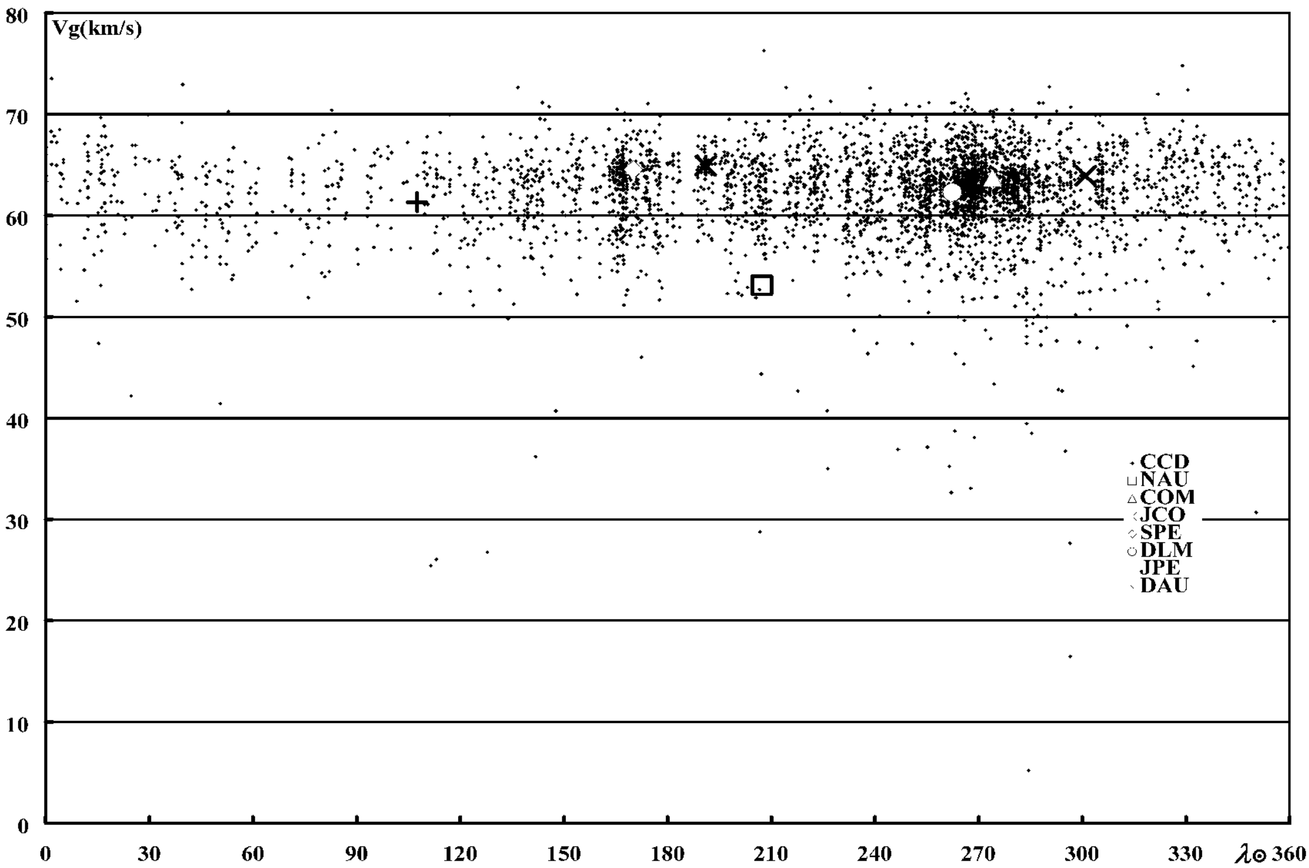

Figure 5 – Geocentric velocity distribution of CSM meteors by SonotaCo and data for seven IAU MDC showers.

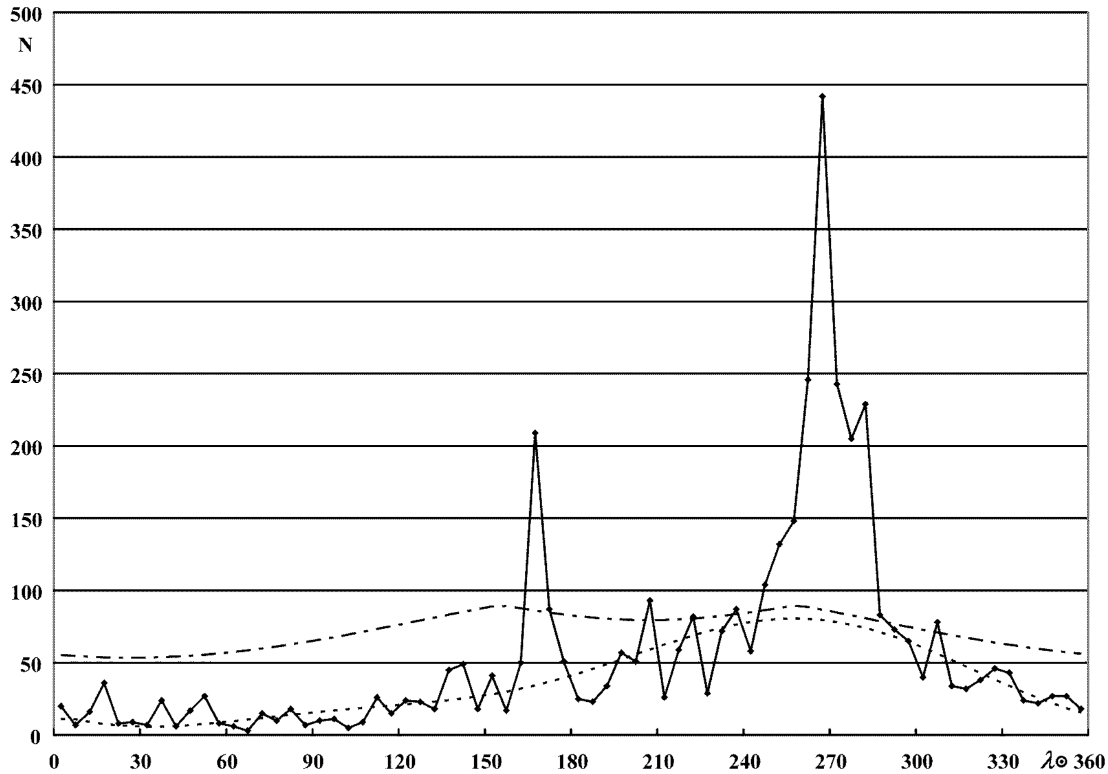

Figure 6 – Meteor rates of each 5° in solar longitude (solid line: CCD meteors by SonotaCo, dotted line: modified meteor activity level, see text, dash-dotted line: altitude of the CSM radiant).

altitude of CSM. If we assume the following equation, we could estimate the meteor activity from the CSM which is shown as the dotted line in Figure 6.

$$N = 80\cos^4\left(\frac{\lambda_\odot + 102}{2}\right) + 20\cos^4\left(\frac{\lambda_\odot + 202}{2}\right)$$

Here, 102° and 202° are selected in order to express the two peaks of the CSM transits but other parameters are selected to represent the change of meteor rates. The CSM source is active during the whole year but its appearance varies by radiant altitude basically. This background activity does not have two even peaks, but rather the winter peak around CBA (corresponds to the first term) is much higher than the autumn peak around SPE (the second term). This background CSM activity conceals weak streams, i.e. NAU, JPE and DAU from our point of view.

In Table 1 we briefly summarize the seven meteor showers which may be related to (Jenniskens, 2006). The velocity of the NAU might be underestimated (see Figures 2 and 5) and, therefore, its elements might be different from the real ones.

CSM meteors have peculiar orbital characteristics. They have a highly inclined orbital plane, elongated shape and crossing point with Earth's orbit at the argument of perihelion about 270 degrees. They seem to be descended from typical long period comet(s).

4 Is CBA one or composed by three?

CCD observations suggest that the CSM activity observed in the winter period (consisting of the DLM, COM and JCO showers) is one continuous stream (Figure 7) and the center of radiants moves in $(\lambda - \lambda_\odot)$ coordinates. We may adopt
$\lambda - \lambda_\odot = -0.0473 \times (\lambda_\odot - 240) + 244.33$ and
$\beta = -0.0794 \times (\lambda_\odot - 240) + 23.18$
from least square calculations and can show RP drift in equatorial coordinates as Table 2.

The numbers of meteors, the radiant of which locates within 5 degrees from the mean radiant (Table 2), are enumerated in each one degree of solar longitude and are converted into meteor rates in Figure 8. The initial meteor numbers are the total of three years observations and we can estimate hourly meteor rates of CBA activities by dividing by 24 hours. We may suppose three years make it possible to construct a continuous data set without daytime interruption and the total number may correspond to one whole day, that is, 24 hours. Meteor rates in Figure 8 are the supposed hourly meteor rates. It is natural that these meteor rates do not mean exact HR of CBA activities because the total number were observed from a large area of Japan and not by one observer (SonotaCo, 2009). Because of the variable conditions and the different camera systems included in the complete video data set it is difficult to calculate meaningful error margins. Hence care needs to be taken to not overinterpret apparent structures in the activity profiles.

The points (labelled 'SonotaCo') in Figure 8 suggest that the CBA is composed either of one continuous activity or of several streams. But, meteoroids that have been distributed on the orbital plane of the parent body might meet Earth during one or two weeks and not last over a month. The DLM orbit is highly inclined and crosses Earth's orbit nearly at $\omega = 270°$ (Table 1).

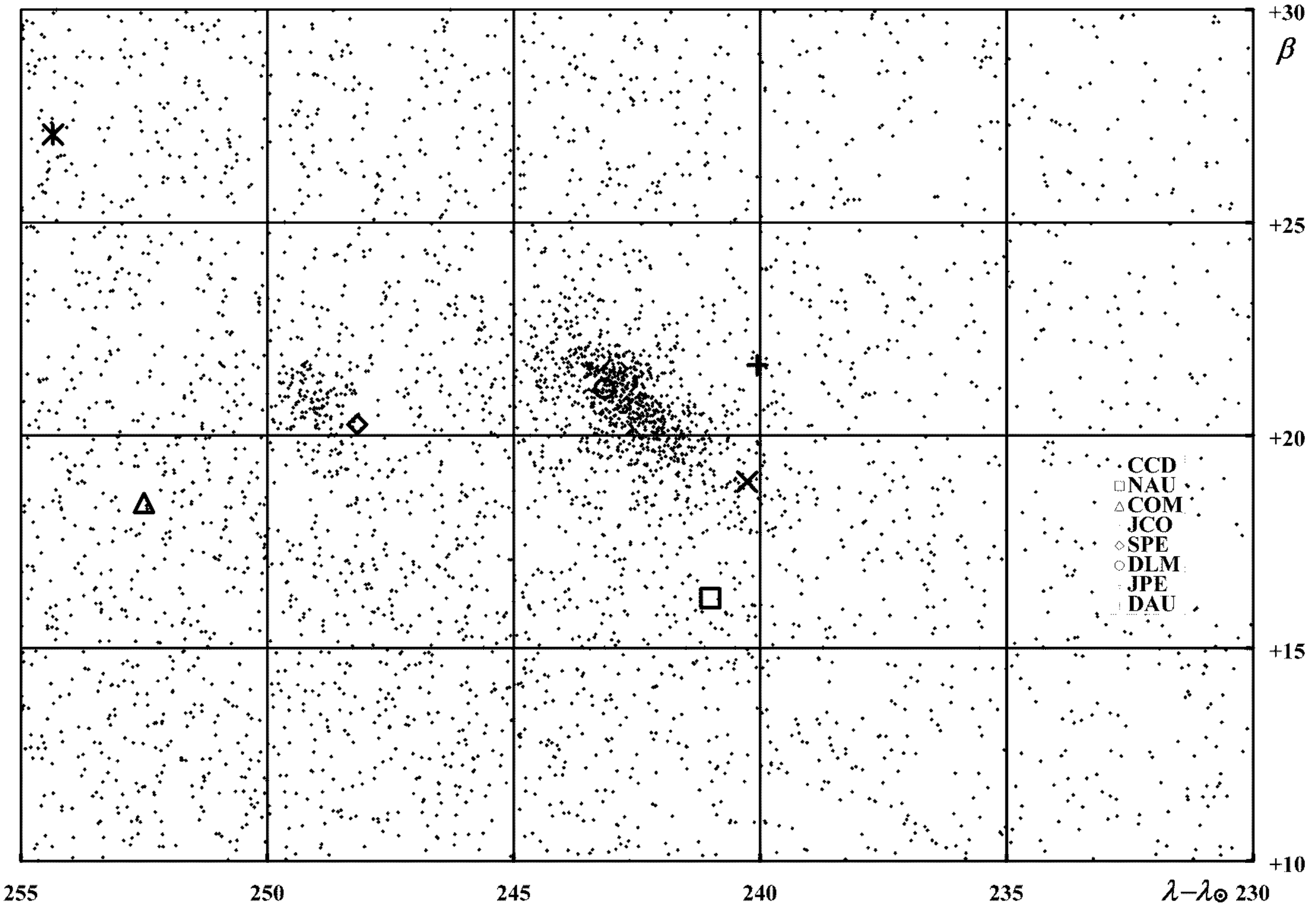

Figure 7 – Radiant distribution of all supposed CBA meteors calculated from CCD observations over the entire year. The corresponding shower radiants are labelled on the right.

Table 2 – Radiant drift of the center of CBA activities (DLM, COM and JCO).

$\lambda_\odot$	240°	245°	250°	255°	260°	265°	270°	275°
RA Dec	133.°8 +41.°5	139.°2 +39.°8	144.°3 +37.°9	149.°3 +36.°0	154.°1 +33.°9	158.°8 +31.°8	163.°3 +29.°7	167.°8 +27.°5

$\lambda_\odot$	280°	285°	290°	295°	300°	305°	310°	
RA Dec	172.°1 +25.°3	176.°4 +23.°0	180.°6 +20.°8	184.°8 +18.°5	188.°9 +16.°3	193.°0 +14.°0	197.°1 +11.°8	

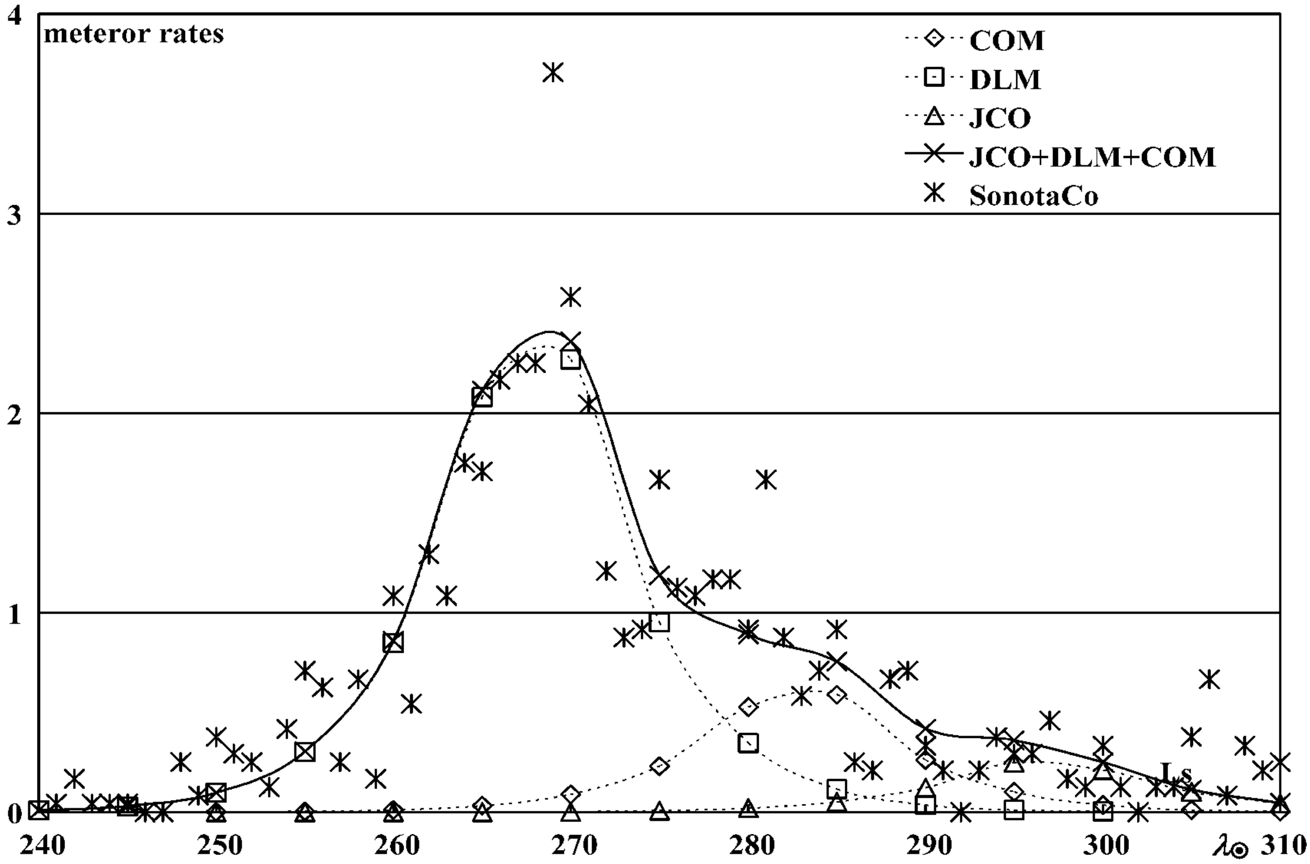

Figure 8 – Meteor rate profiles of CBA activities. The solid line shows the estimated meteor activity level by the simple model of a meteor stream structure as described in the text.

We can estimate meteor rates for any meteor streams using a simple assumption (Koseki, 1975). It is very probable that the axis of the meteor stream is kept within certain limits, that is, its semi-major axis (a) and the direction of the perihelion (λ_0, β_0) in ecliptic coordinates remain almost constant over several thousand years. We might estimate a meteor shower activity as follows on this assumption.

We must calculate the series of orbits of meteoroids, which have a fixed axis (λ_0, β_0) and the same size as the initial orbit, at different intersection positions. At first, we consider the changes in the argument of the perihelion ω and the inclination i when the intersection node varies from Ω to Ω'.

We use

$\lambda'_0 = \lambda_0 - \Omega'$,

$\cos\omega' = \cos\lambda'_0 \cos\beta_0$, and

$\cot i' = \sin\lambda'_0 \cot\beta_0$.

An ellipse is described by the expressions

$R = \frac{q(1+e)}{1+e\cos\vartheta}$ and

$q = a(1-e)$.

Here, R is the radius of the orbit, q the perihelion distance and e the eccentricity. Next, we require that the semi-major axis of the meteoroid, which intersects with the Earth's orbit, remains unchanged. It is possible to show that this implies the following relation between the meteoroid's modified eccentricity e' and argument of perihelion ω':

$$e' = \frac{(-R\cos\vartheta) \pm \sqrt{(R\cos\vartheta)^2 - 4a(R-a)}}{2a}$$

Here, R is the radius of the Earth's orbit and ϑ is the encounter angle between the Earth and the meteor shower's perihelion; $\vartheta = 180° - \omega'$ (before perihelion) or $\vartheta = \omega'$ (after perihelion). In case of a hyperbolic orbit, we apply the plus-minus sign as minus. The intersection angle I between the mean orbit and modified orbit is given by the following equation

$$I = \frac{\sin\Delta\Omega \sin i}{\sin\omega'}.$$

It is natural to expect that the spatial density of meteoroids decreases exponentially from the initial orbit

$$N = N_0 \exp\big(-(A\sin|I| + B|e-e'|)^C\big)$$

with N_0 the maximum meteor rate and A, B and C being determined empirically from observations. If we adopt $A = 10$, $B = 30$ and $C = 1.2$, we would obtain a fine profile of major meteor showers, including the CBA activities.

Orbital data for the three CBA streams are calculated from photographic observations (Tables 3 and 4). Abbreviations in Table 3 are the same as in my former paper (Koseki, 2009). The ascending node of photographic DLM was possibly influenced by the Geminids' observation period, because the main concern in photographic observations was Geminids then. Therefore,

Table 3 – List of possible members of CBA streams in photographic meteors. Meteor designations taken from Koseki (2009).

DLM:	H5-1193, H1-9559, H1-9593, H5-2343, H5-2578, H1-5988, H2-6011, H1-9802, H1-6027, H1-6038, D2-573287
COM:	H2-9948, H3-9951, D6-680103a, H1-9950, H3-10012
JCO:	H1-10083, H1-10075, H1-6152, H4-12843, H1-6191, H1-6195, H1-6243, H2-6264, H5-1918, D3-630215, H1-6332

Table 4 – Orbits of three CBA streams calculated from photographic observations; $\lambda_{\max} = \Omega$.

Shower	R.A. (°)	Dec. (°)	V_g (km/s)	e	q	i (°)	ω (°)	Ω (°)	$\lambda - \lambda_\odot$ (°)	β (°)	N
DLM	155.9	+32.4	62.0	0.906	0.546	134.5	267.1	262.0	243.5	20.8	11
COM	171.8	+24.9	61.8	0.950	0.468	133.2	274.5	282.9	239.4	19.6	5
JCO	187.5	+19.0	63.0	0.974	0.539	134.7	265.7	296.9	242.1	20.4	11

meteor rates for DLM in Figure 8 are calculated for the ascending node as $\Omega = 268°$ instead of $\Omega = 262°$.

N_0 for DLM is set here as $N_0 = 3$ in order to compare the profile with CCD observations by SonotaCo and estimated values of N_s (meteor rate) are shown in Figure 8 as boxes with dotted line. It is clear that the simple model gives lower meteor rates of DLM after $\lambda_\odot = 280°$ than the observed ones. We can calculate N_s for COM and JCO in the same way. If we assume the activity levels of COM and JCO are a quarter of DLM and a tenth of DLM respectively, we could find the profile of CBA total activities (solid line in Figure 8).

Figure 8 indicates that CBA meteor activity is not one but consists of three components. But meteor rates suggest that COM and JCO could not be detected by visual observers, because the activity levels indicate that meteor rates might be 0.75 for COM and 0.3 for JCO at the maximum. Even DLM is difficult for visual observers because meteor rates do not mean visual HR. Meteor rates in Figure 8 only show the meteor number observed from all Japanese stations per hour and the DLM seems to lack faint meteors. It is natural that meteor rates of the CBA activities fluctuate over some range and might rise up to HR > 2 occasionally and experienced visual observers could catch them.

We know that the activity of the CSM is highest in the winter period and that SPE is the second in strength. Other CSM activities, such as the JPE, could not be observable especially in the range of fainter meteors. CSM activities are rich in bright meteors and are best for CCD observations but not well suited for visual or radio.

5 Conclusions

CSM meteors seem to be related to long period comets with highly inclined orbits, and appear the whole year round. Of the showers, only the DLM and SPE show distinct meteor activities while the other IAU MDC showers are almost buried in the CSM background. CBA activities are made up from three dependent streams judging from consideration of orbital properties. JCO and COM may not be separable from the DLM and from the CSM background, though photographic records suggested some sudden activity rise in the past.

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Geminids: 30 years of observations (1980–2009)

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Observers of the Dutch Meteor Society successfully watched several Geminid returns in the period 1979 – 2009. The data was analysed to verify if any evolution in the activity level can be detected. According to our data, the activity during the 1980s was less than in the 90-ies and the last decade. The next few years are crucial to find out if the tendency for an increasing activity continues or if the activity will weaken.

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1 Introduction

The Geminid meteor stream is known among active meteor observers as the most reliable shower that can be observed. The activity period occurs mid December which has both advantages and disadvantages. The fact that winter nights are long and that the stream can be observed all night long is an advantage. During a crystal clear night of December 13–14, depending upon the perception of the observer, observing conditions and duration, one can count hundreds if not more than a thousand meteors. However, the unreliability of the weather in December especially in Western Europe is a disadvantage: In the Netherlands there is less than 10% chance for a clear night while at more favorable locations such as Spain or Portugal this percentage is still only 50%.

The most interesting fact for the Geminids is that the stream was discovered in the 19th century and gradually became more active. During the past few decades the Geminid displays have become one of the most active annual showers and scientists wonder whether or not this evolution will continue to increase or rather stabilize or decrease. Some researchers concluded that the highest level was achieved around the year 2000, but there are other theories which predict further increasing hourly rates for the next decades. Peter Jenniskens (2006) suggests that the highest hourly rates will occur around 2050 and the ratio of bright Geminids will increase significantly.

In recent years the Geminids peaked with a ZHR of $\sim$ 120–140 meteors an hour. This is more than a usual Perseid return (ZHR of 80). That the activity is actually still increasing or decreasing is a question that requires a good dataset for a long period of time. Just like in climatology conclusions will be possible on basis of many years of intensive observing efforts and this preferably by the same observers.

The Dutch Meteor Society is active since 1979, and in a number of years the Geminids could be very well observed. The evolution of the Geminid activity is rather slow but in a time interval of 30 years some indication of this evolution may have been recorded. In this article we consider an overview of the Geminid activity between 1983 and 2009 and we attempt to verify if any of the proposed models can be supported with our data. In other words, is there anything of this predicted evolution reflected in our data?

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NASA-ADS bibcode 2011JIMO...39..167M

2 The Dutch Meteor Society and the Geminids

Table 1 – Summary of the Geminid years for the period 1979–2009. The numbers mentioned are the number of meteors effectively used in this analysis while the number of observed meteors was much higher. The 1980 data has not been analyzed. A “good” Geminid year requires a good amount of clear sky during the nights of December 13–14 and 14–15. The 1980 data is just mentioned for completeness.

Year	n Geminids	N obs
1980	38+?	2
1983	1659	5
1984	310	6
1985	1660	2
1987	217	2
1990	2483	6
1991	4194	11
1994	580	6
1996	2995	6
1998	238	1
1999	239	1
2001	2739	9
2004	4088	8
2006	1009	1
2007	5806	7
2008	746	5
2009	4181	10
Total	33144	

During the past three decennia we managed regular observations of the Geminids and this in spite of the often poor weather conditions in December. This was the case the last decennia especially due to short observing expeditions abroad. In general these projects abroad produce a lot and good data. Table 2 lists the number of Geminids per decennium used in these analyses.

3 Analyzing method 1983–2009

Although detailed analyses were made by Rudolf Veltman, Peter Jenniskens, Marco Langbroek and the authors for most Geminid years, we decided to recalcu-

Table 2 – Number of Geminids per decennium.

Decennium	n Geminids
1980–1989	3846
1990–1999	10729
2000–2009	18569
3 decennia	33144

late all data and where possible to include extra data from the DMS database or from the VMDB of the IMO. Then the data was validated with a rigid selection process. Some data from former analyses were rejected. This could be because of too poor limiting magnitudes but also the use of different observing methods was a reason to exclude the data from the new analyses.

The aim of all this was to obtain ZHR graphs derived from exact the same methodology, observational and computational, to look how the stream developed in these 30 years.

First of all, the visual Geminid data was selected from the DMS database. Also where necessary the archives of IMO were searched. All together this resulted in an amount of data for over 40 000 Geminids. After the strict selection process data for more than 33 000 Geminids were left (see Tables 1 and 2). The selection procedure considered the radiant elevation, only data with radiant heights from 30 degrees were allowed, the degree of experience of the observer, the limiting magnitude and the observing intervals. The dataset was restricted to the two nights of December 13–14 and 14–15. Only hourly counts were used for this analysis. In the database many quarter of an hour counts were recorded which were merged into one hour intervals.

Table 3 lists the names of all observers whose data was used in this analysis. For some observers only a single data was used in the analyses but with consideration of the observing experience of the observer. Hans Breukers is such an observer from whom only 1983 data was used. In the period 1981–1986 Hans Breukers was a very active observer who, unfortunately, could observe the Geminids in 1983 only. All the relevant data was entered into one spreadsheet, a job managed between different other tasks.

In a next step accurate ZHRs were calculated for each year. The ZHR graphs were computed with an assumed population index r; 2.50 before solar longitude $262\overset{\circ}{.}2$ and 2.30 after solar longitude $262\overset{\circ}{.}2$, according to the averaged values from IMO. Further for reasons explained by Johannink and Miskotte (2008) a γ-correction of 1.0 instead of 1.4 was used. The result of all these efforts are the many ZHR graphs used in this article.

We also made a literature search for Geminid papers. In some papers we read about the existence of a double main peak structure (Betlem, 1997; Jenniskens, 2006; Spalding, 1982). Research by George Spalding (1982) for the period 1969–1980 revealed very little shift in solar longitude for the ZHR peaks. Peter Jenniskens determined solar longitude $261\overset{\circ}{.}01 \pm 0\overset{\circ}{.}02$ and solar longitude $262\overset{\circ}{.}34 \pm 0\overset{\circ}{.}01$ from analyses on 1983–1985 data.

Figure 1 – Photograph with two Geminids in the night of 1980 December 13–14 from Harderwijk, Netherlands. During the exposure the camera got pushed which explains the shift in the star trails. Camera: Practica LTL 3 with a 28 mm wide angle lens, film: Tri-X. Courtesy: Koen Miskotte.

IMO determined solar longitude $262\overset{\circ}{.}12 \pm 0\overset{\circ}{.}02$ (ZHR 140) and solar longitude $262\overset{\circ}{.}34 \pm 0\overset{\circ}{.}01$ for the years 1988 to 1997.

4 The Geminids in the 1980ies

The Geminids of 1980 were the very first DMS observations for this stream (Betlem, 1981). Unfortunately there are only data for MISKO in the DMS database for only two hours with 38 Geminids counted. ZHR graphs were made for the years 1983, 1984, 1985 and 1987, with 1984 and 1987 being of an average quality because of too little data and the disturbance of moonlight.

4.1 The first successful Geminid project of DMS in 1983

Moon: Just past First Quarter disturbing the first part of the night.
Weather: December 13–14 partly or complete clear sky according to the observing site and entirely clear sky for December 14–15.
Location: the Netherlands.

Table 3 – Summary of all observers whose data were used in this analysis. Years with available data are marked with "×". The years marked with "o" were not used.

	Year		80	83	84	85	87	90	91	94	96	98	99	01	04	06	07	08	09	Tot
	Code	Name																		
1	BENPA	P. Bensing							×											1
2	BETFE	F. Bettonvil															×		×	2
3	BETHA	H. Betlem								×									×	2
4	BIEJE	J.M. Biets													×				×	2
5	BREHA	H. Breukers		×																1
6	LIGMA	M. de Lignie						×	×											2
7	DIJSI	S. Dijkstra												×	×		×	o	×	5
8	GRIAR	A. Grinwis			×															1
9	HAARO	R. Haas	o		×				×	×										4
10	JENPE	P. Jenniskens						×	×											2
11	JOBKL	K. Jobse		×	×	×		×	×	×										6
12	JOHCA	C. Johannink	o	×					×		×			×	×		×	o	×	9
13	KEERO	R. Keeris													×				×	2
14	LANMA	M. Langbroek							×	×	×			×						4
15	LEUPE	P. van Leuteren															×	o	×	3
16	LEVJA	J. van 't Leven								×	×									2
17	MILOL	O. van Mil									×									1
18	MISKO	K. Miskotte	o	×	×				×	×	×			×	×		×	o	×	11
19	NIJJO	J. Nijland		×							×						×		×	4
20	OSVDA	D. van Os												×				o	×	3
21	RISBA	B. Rispens		×	×		×		×											4
22	ROGPA	P. Roggemans				×	×	×	×											4
23	SCHAL	A. Scholten							×	×		o		×					×	5
24	TUKAR	A. Tukkers													×					1
25	VANMC	M. Vandeputte											×	×	×	×	×		×	6
26	VANSI	S. Vanderkerken												×			×			2
27	VERRI	R. Verhoef												×	×					2
Total			3	6	5	2	2	4	11	7	6	1	1	9	8	1	8	5	12	91

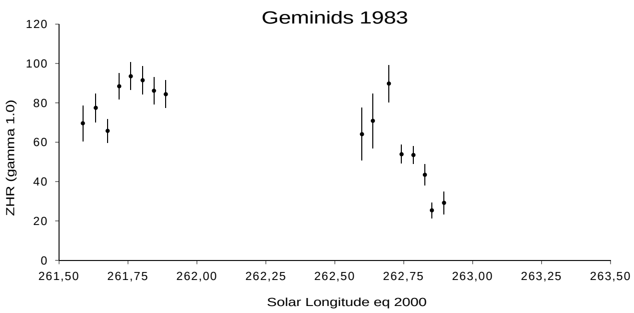

Figure 2 – Geminids 1983 based on data for 1659 Geminids observed by BREHA, JOBKL, JOHCA, MISKO, NIJJO and RISBA.

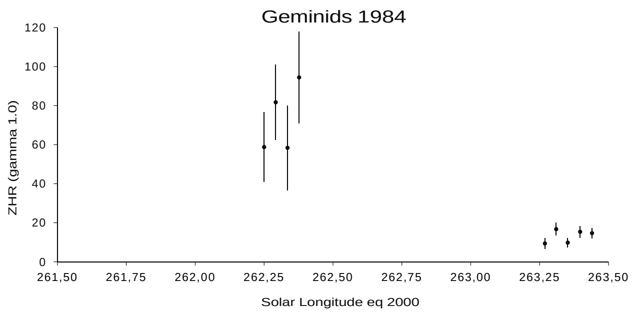

Figure 3 – Geminids 1984 after correction of the original limiting magnitudes. Based on data for 310 Geminids observed by GRIAR, HAARO, JOBKL, KELER, MISKO and RISBA.

Before the maximum some partly clear nights occurred. The night of December 13–14 passed completely clear in the eastern part of the country. Unfortunately a long extended cloud cover moved slowly from the west to the east. The night of December 14–15 was clear all over the Netherlands and many bright Geminids were seen among which a number of fireballs (Betlem et al., 1984).

The ZHR-graph for the year 1983 seems to show clearly a double peak, however we must consider that the dataset is based on a limited number of data as the second peak is based on just two observers with moonlit sky. It is obvious that especially the first ZHR values for 1983 December 14–15 suffered from moonlight interference (large error bars). Also all the bright stuff occurred in the night of December 14–15. The analyses by Rudolf Veltman indicated a maximum ZHR of 130 by the morning of December 14 (Veltman, 1986). These ZHRs were much higher that the values found in this analysis. In 1983 no perception coefficients were taken into consideration and a zenith exponent of 1.4 was used instead of the 1.0 used in this analysis for reasons explained by Johannink and Miskotte (2008). The current analysis gives a maximum ZHR of 95.

4.2 High ZHR values in 1984?

<u>Moon</u>: An almost Full Moon the entire night above the horizon.
<u>Weather</u>: Only local clear skies.
<u>Location</u>: the Netherlands.

A gap of clear sky moved slowly from west to east over the Netherlands followed by another cloud cover. An almost Full Moon lit the observing sites. The observers in the west had to quit early but the observers in Harderwijk could continue till 01$^{\text{h}}$00 UT. At this site three bright Geminids of −4, −8 and −7 were observed and photographed (Miskotte, 1985; Betlem et al., 1985).

Very high ZHR values were found in the analyses of 1984 with values up to 150 (Jenniskens, 1986). In 1984, the observations suffered a lot from the excessive moonlight and observations took place with limiting magnitudes between 4.8 and 5.4 (Miskotte, 1985). The data from the Western observing sites with very low radiant elevations (less than 30 degrees) was taken into account in the original data reduction which resulted in a large scatter on the ZHR values. The big problem with such low limiting magnitudes derived from the star count areas is that missing one of the few stars results in a limiting magnitude of a few tenths less. The uncertainty on low limiting magnitudes is reflected in a much larger uncertainty on the ZHR values.

Figure 4 – The team Delphinus in action on the roof of the water tower near Harderwijk, the Netherlands during the Geminids 1984. From left to right Olaf Miskotte, Arjen Grinwis, Bauke Rispens and Koen Miskotte.

Further verification of the limiting magnitudes observed in 1984 revealed another, more important problem. E.g.: Koen Miskotte counted 7 stars in lm-counting area 2 which corresponded to a limiting magnitude of 5.1 in the old conversion table in the 1988 visual handbook of the DMS (Jenniskens, 1988). The current IMO conversion table corresponds to a limiting magnitude of 5.55 and with these limiting magnitudes we obtain much lower ZHR values between 80 and 100. Fortunately the differences in limiting magnitudes better than 6.0 are much smaller and can be ignored. It is an almost impossible job to redo all these limiting magnitude derivations.

We finally obtain the graph in Figure 3 with error bars that reflect the disturbance by the Moon. The ZHR values are more in line with the results for the years 1983 and 1985. It is obvious that this kind of moonlight meteor data is rather unsuitable for serious analyses and for comparison with recent years to answer the question whether or not the ZHR is higher or lower than in the 1980s.

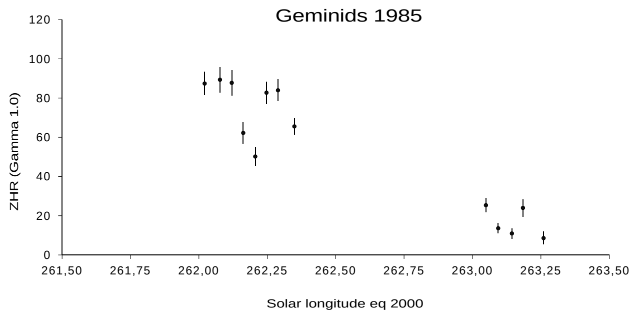

Figure 5 – Geminids 1985 based on data for 1660 Geminids observed by JOBKL and ROGPA.

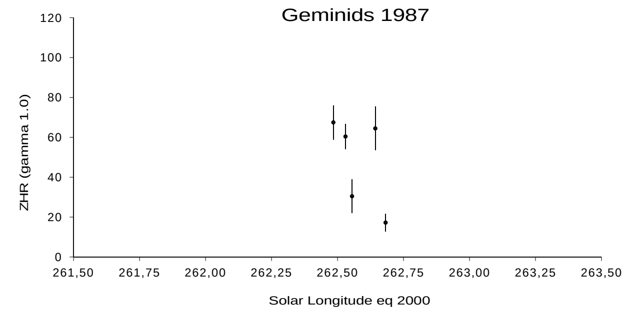

Figure 6 – Geminids 1987 based on data for 217 Geminids observed by RISBA and ROGPA.

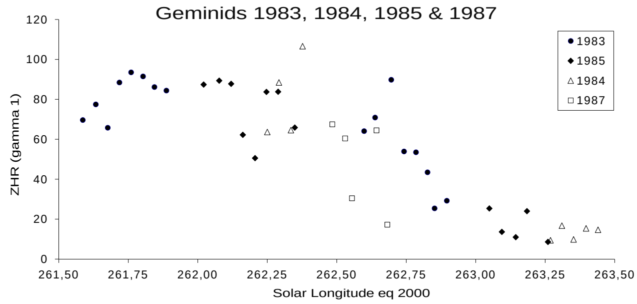

Figure 7 – Combined ZHR curves for 1983, 1984, 1985 and 1987.

4.3 The Geminids 1985 in Southern France

Moon: New Moon December 12, no moonlight interference.
Weather: Clear sky.
Location: Puimichel, Southern France.

In 1985 Klaas Jobse and Paul Roggemans observed from Puimichel in Southern France. They observed the same number of meteors as the five observers did in two nights two years earlier in the Netherlands. Their data shows a significant dip in the activity during two hours in the night of December 13–14 with ZHRs reduced to about half of their initial values. Reading the report (Jobse, 1986) probably gives a partial explanation for this sudden decrease in activity: a passing part of cirrus cloud is logged between $23^{\rm h}00^{\rm m}$ and $02^{\rm h}00^{\rm m}$ UT. The limiting magnitude dropped as well indeed.

A perception coefficient Cp was again calculated for both observers JOBKL and ROGPA. Both had observed a lot during the summer in Puimichel and sufficient data was available for a good Cp calculation. This resulted in a Cp of 1.43 for ROGPA and 1.45 for JOBKL. Rudolf Veltman found a maximum ZHR of 126 for this night (Veltman, 1986). Also this analyses yield lower ZHRs of about 80 to 90, using the perception coefficients and a zenith exponent of 1.0 instead of 1.4.

The article by Peter Jenniskens (1986) was based on this double peak observed in Puimichel. This feature is confirmed in the new analyses too although it remains a question to which extend the passage of the cirrus cloud influenced the ZHR values. However, the peak compares very well with the double peak found by IMO for the period 1988–1997 at solar longitude $262\overset{\circ}{.}12 \pm 0\overset{\circ}{.}02$ and $262\overset{\circ}{.}33 \pm 0\overset{\circ}{.}02$. A double maximum appeared also in 1983 but the time lapse between these two peaks is much wider. The double peak in 1983 corresponds very well with e.g. the curves for 1991 and 2007.

4.4 The Geminids 1987 in Southern France

Moon: A Last Quarter Moon disturbed a lot during much of the night.
Weather: A complete clear sky.
Location: Lardiers, Southern France.

Also in 1987 two observers stayed in Southern France, this time near the village of Lardiers. An observing team with Paul Roggemans and Bauke Rispens were camping there between December 14–25 to observe the Geminids and the Ursids. This expedition resulted in a good number of Geminids. Due to the moonlight and poor observing circumstances, this year is unsuitable to compare ZHR values.

4.5 Conclusions for the 1980s

Altogether we can conclude that the ZHR of the Geminids such as observed in the 1980s from DMS and partly from IMO data was not higher than between 80 and 100. Finally we also present the combined ZHR graph 1983, 1984, 1985 and 1987 (Figure 7). It is noteworthy that the end of 1983 December 13–14 connects well with the start of 1985 December 13–14. This is also valid for the end of the night 1983 December 14–15 and the begin of the night 1985 December 14–15.

5 The Geminids during the 1990s

5.1 The 1990 Geminids in Southern France

Moon: Few days prior to New Moon, no moonlight interference.
Weather: Both nights clear.
Locations: Lardiers, Le Thouron and Quinson, Southern France.

In December 1990 a number of DMS members (Casper ter Kuile, Marc de Lignie, Peter Jenniskens, Paul van der Veen, etc.) travelled to Southern France where a network of three photographic stations was set up (Jenniskens et al., 1991; ter Kuile, 1991). Many Geminids were recorded under crystal clear sky but under extreme weather conditions with temperature of −10°C and gusts of the Mistral. The expedition proved to be a big success because dozens of Geminids were photographed simultaneously (Betlem et al., 1993; de

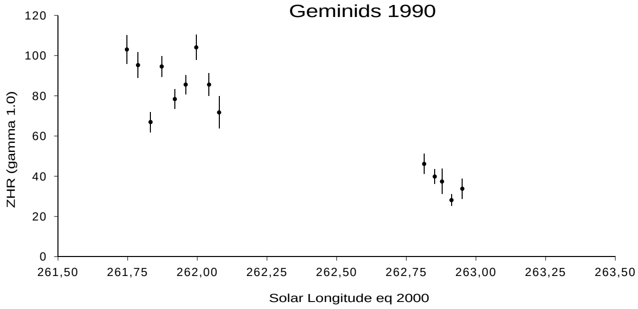

Figure 8 – Geminids 1990 based on data for 2483 Geminids observed by JENPE, JOBKL, LIGMA and ROGPA.

Voogt & Veldman, 1993; Betlem et al., 1994). Also a team of visual observers was operational. For Dutch observers the number of observed meteors was rather high. Peter Jenniskens mentioned that almost 7000 Geminids and 2000 sporadic meteors were recorded (Jenniskens, 1991). More data from a group at Loosdrecht, Netherlands was left unused for this analysis because their observing method was incompatible. The data for the group of Bernard Koch has not been used either because it is missing in the DMS database or no data is available for personal perception coefficients *Cp*.

2483 Geminids recorded by 4 observers, 3 in France and 1 in the Netherlands, were used for this analyses. The result is presented in a graph (Figure 8) which shows a rather scattered ZHR distribution. Also the graph in (Jenniskens, 1991) shows a cloud shape distribution. The curve for the night of December 14–15 is smoother and descending.

Impressions of Peter Jenniskens as observer in 1990 (Jenniskens et al., 1991)

The journey brought me to the neighborhood of Quinson. On the plateau I noticed a field track that led to the edge of a forest in a few hundreds of meters. The trees tempered the Mistral wind and the nearby hills obscured the first few degrees of the night sky, a perfect place. With the forest and the car in my back I got a free outlook from 40 degrees in the North till deep into the South. While I got the camera sets out of the car I saw 5 meteors in just 3 seconds. At $19^{h}43^{m}20^{s}$ UT all cameras were operational.

The number of meteors was a phenomenal. Taking a break to drink a coffee inside the car did not happen. The just 20 degrees free view through the car window was enough for the meteors to catch the attention of the observer. A bright −3 Geminid enlightened the tired face of the observer followed by three fainter meteors. Enough for that break, the observations had to be resumed. The observations took place under rather comfortable circumstances. The site was situated at much lower altitude than Le Thouron and the snow had almost completely melted. The only discomfort was the operation of the cameras every half hour. Contrary to Marc de Lignie in Le Thouron I could manage this on my socks. After a most satisfying night, twilight suddenly occurred at a quarter before six local time. A small moon circle had appeared above the hill shortly before. With the camera mounting on the seat in front I tried to sleep on the back seat, dreaming of the 648 meteors recorded in 6.3 hours of effective observing time.

Figure 9 – Peter Jenniskens and Marc de Lignie watching amused at the content of the car of Casper ter Kuile: filled with camera batteries. . . Courtesy: Casper ter Kuile.

5.2 Volcanic dust versus the dust of 3200 Phaethon in 1991?

Moon: First Quarter on December 15, moonlight interference in the first part of the night.
Weather: Both nights were mostly clear.
Location: the Netherlands, Puimichel, France.

This was a most successful project in the Netherlands with both maximum nights clear sky. Peter Jenniskens made a detailed analysis of these Geminids (Jenniskens, 1992). This analysis yielded remarkable lower ZHR-values than these of the 1980s and 1990. The maximum ZHR at the end of the night of December 13–14 is close to 75 (see Figure 10).

Comparing the ZHR-curve for 1991 December 13–14 with the one for 1983 December 13–14, it is clear that the structure looks the same, but the ZHR values for 1991 are about 20% lower. The next night the ZHR values are about at comparable level, be it that the ZHR curve of 1983 seems to decrease a bit later. This may be due to the fact that the Geminid maximum occurs in a time lapse of about 3 hours before and after the maximum (around solar longitude $262\overset{\circ}{.}2$). Both curves for 1983 and 1991 show a similar pattern.

A possible explanation for the lower ZHR values in the night of the maximum could be the eruption of the volcano Pinatubo on the Philippines. This volcano had a number of explosive eruptions from 7 till 15 June 1991 with the ash column reaching at an elevation of 38 km. The emission of as much as 17 million tons of SO_2 of ash and dust was probably the largest quantity since the outburst of the Krakatau in 1883. The Pinatubo emission reduced the sunlight by 5% due to which the worldwide temperature decreased by 0.5 degrees. Another remarkable effect caused by the dust in the atmosphere occurred during lunar eclipses. Normally the Moon remains visible during the totality of the eclipse, but the year after the Pinatubo eruption the eclipsed Moon was barely visible. In this period the estimates for the Moon eclipses on the Danjon scale (with 0 being faint and 4 being bright Moon) were 0 or 1 because of the absorption of the reflected sunlight by the dust particles in the atmosphere.

How to account for the influence of this dust on the visibility of faint meteors of +4 and +5 which appear at low altitude at the sky? Furthermore "purple" twilight was seen worldwide during months which is a typical phenomena for important volcanic eruptions.

The Geminid maximum has always been characterized by the large number of faint meteors. It is assumed that the faintest (+4 and +5) meteors were barely observable because of the dust, especially the meteors that appear at relative low elevation for the observer. Of course this is partly compensated by the limiting magnitude determination; however the atmospheric extinction is much more important due to the volcanic dust compared to other years. At lower elevation the limiting magnitude decreases faster than in normal circumstances. The limiting magnitude determination is done at counting areas at about 50 degrees or higher. This means that at high elevation near the zenith few faint meteors are missed compared to a normal volcanic dust free year, but that the lower the faint meteors occur the more faint meteors are missed compared to normal circumstances. That would also explain why in the night of December 14–15 the ZHR was almost at the same level as in 1983. That night is characterized by brighter meteors which are easier visible. Unfortunately there are no magnitude distributions until 1994 in the DMS database, otherwise it would be easy to look at the proportion faint Geminids in 1991 and in 1990. Unfortunately a comparison with other showers in 1991 is not possible. The Perseids 1991 were only observable in the first part of the night of August 12–13, the Orionids were hampered by moonlight and in 1992 there were barely successful observing projects.

We also checked if the much lower ZHRs could be caused by a few observers who provide systematically much lower ZHRs. This is not the case as the individual ZHRs in general show very little deviation.

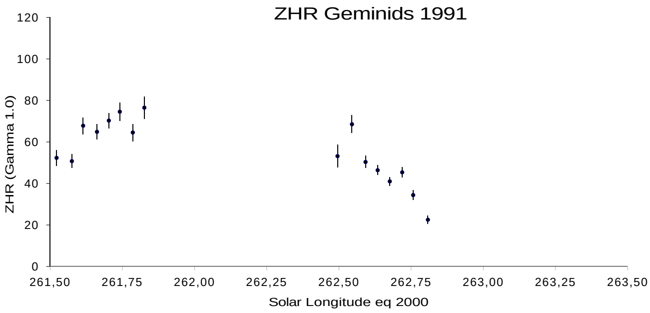

Figure 10 – Geminids 1991 based on data for 4194 Geminids observed by BENPA, HAARO, JENPE, JOBKL, JOHCA, KELER, LANMA, LEVJA, LIGMA, MISKO, RISBA, ROGPA and SCHAL.

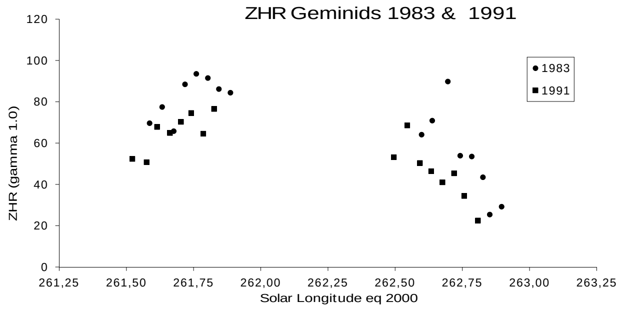

Figure 11 – Geminid curves for 1983 and 1991 in the same graph show clearly the much lower ZHR in 1991.

A bad-luck Geminid maximum for Koen Miskotte

"Arrived at the water tower, Koen decided to install his cameras immediately on the roof, ready to start. As soon as the sky cleared up the cameras were ready. Every now and then there were some gaps in the clouds as the Moon shined through the cloud cover. Koen stayed downstairs and checked the sky every 15 minutes. He also did so at about 21^{h} UT, but the free standing ladder made a slide dumping the author down with a lot of clamor. Because of this fall he also got the 30 kilogram heavy hatch on his hand which was pull out instantly by the fall. The result was a bruised hand with rubbed off pieces of skin.

Anyway, still waiting for clear sky, the hand became more painful and thicker. As it was still cloudy at $21^{\mathrm{h}}30^{\mathrm{m}}$, it was decided to quit the session at the tower and to return home to care the hand. Later this crash in the tower got a nasty sequel with an infection at the ankle resulting in a week of sickness days at home with a swollen foot.

At 01^{h} UT another look outside learned that the sky was clear. It would take too much time to go back to the tower by bicycle and install everything again and therefore it was decided to observe from the balcony at home. The automated all-sky was running that night from the evening twilight and the negatives showed it must have been clear from about $00^{\mathrm{h}}30^{\mathrm{m}}$ UT".

5.3 The 1994 Geminids in moonlight

Moon: Almost Full Moon, practically all night moonlight.
Weather: A withdrawing cold front moving to the south followed by very clear sky.
Location: the Netherlands.

In the evening hours there were still heavy showers (rain) caused by a cold front passing by, with nice clear sky after 01^{h} UT (Miskotte, 1995). With six observers being active 603 usable Geminids were recorded. The maximum was expected in the final last hour of the night, but the curve shows a different picture: the maximum seems to occur 3 to 4 hours earlier. However the abundance of the moonlight probably caused a distorted profile. It is something often noticed with meteor observations done with moonlight. On the other hand a good number of bright fireballs were recorded that night which indicates that the maximum was passed. Observer MISKO witnessed a beautiful −8 Geminid and another Geminid of −6.

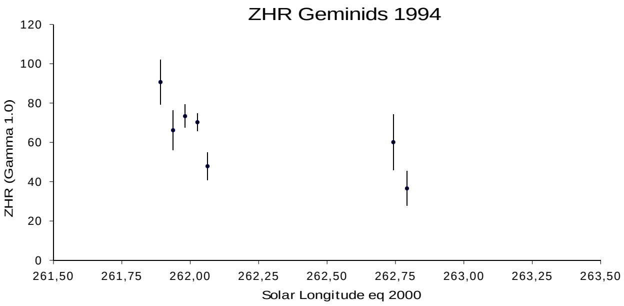

Figure 12 – Geminids 1994 based on data for 603 Geminids observed by BETHA, HAARO, JOBKL, LANMA, MISKO and SCHAL.

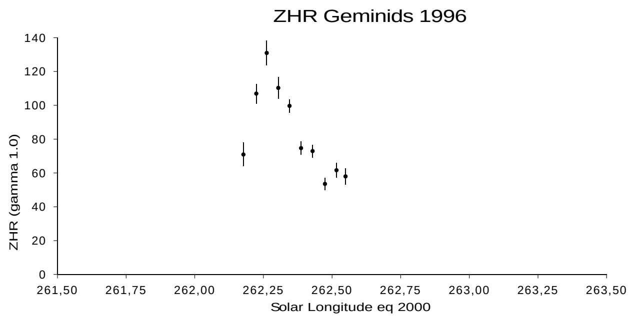

Figure 13 – Geminids 1996 based on data for 2995 Geminids observed by JOHCA, LANMA, LEVJA, MILOL, MISKO and NIJJO.

Figure 14 – A beautiful Geminid of magnitude −5 (04:48 UT) photographed from Biddinghuizen in the night of 1996 December 13–14. Camera: Canon T70 with Canon FD 1.8/50 mm lens. Courtesy Casper ter Kuile.

5.4 The 1996 Geminids during a super observing session from the Netherlands

Moon: Two days after New Moon, no disturbing moonlight.
Weather: After the passage of a weak cold front all night of December 13–14 clear.
Location: the Netherlands.

December 1996 was recorded as a gray clouded month. However the night of December 13–14 was almost entirely clear. The result was a large amount of data (Betlem et al., 1997). It became the best Geminid observation ever until then in the Netherlands (Miskotte & ter Kuile, 1997). Some observers got over the magic total of "1000 meteors in one night" for the first time in their life: LANMA and MISKO from the very dark site near Biddinghuizen. Photographic and video work resulted in many dozens of simultaneous registrations (de Lignie & Betlem, 2010; Betlem, 1997). The ZHR value reached 135 and a distinct peak is visible in the graphs. The brighter stuff appeared soon after the maximum, starting with a −8 Geminid low at the southern horizon. By the end of the night the ZHR dropped to half its value.

A report from Varsseveld by Hans Betlem

"At $00^h48^m30^s$ UT a −6 to −8 Geminid near Sirius brightens the area. Sensational for those who just looked at it. Hour after hour passes. Around 03^h UT fatigue occurs with some of the observers. A team of six continues. Such a night is a rare experience. At some moments two or three meteors are visible at once. It is not possible to notice any distinct evolution in the activity level. A remarkable number of very long meteor paths catch the attention as they look much slower than what the characteristic 36 km/s would suggest, very long paths sometimes till the horizon. An average −2 to −3 Geminid easily takes about 1 second… 50 slices on the negatives, that means a lot of measuring work.

At 05^h30^m the team is another time reduced. Olga and Michelle drop out while the author and Jeffrey start to clean up the equipment. Observing a long night with 10 people causes quite some mess. Some mobile phone contact with Biddinghuizen, where they also struggle with fatigue. Twilight, the final 20 minutes, with still −3 and −4 meteors occurring at the sky. The first farmers traffic appears on the road and the first satellites at the sky.

Some dismay when controlling the video. A very diffuse image on the monitor with big unsharp stars. The lens is warm and the camera runs well. Then the problem becomes clear… ice on the monitor screen. Removing the ice, the sharp star images become visible. At 06^h UT we decide to quit, the cameras are shut down and the video stopped."

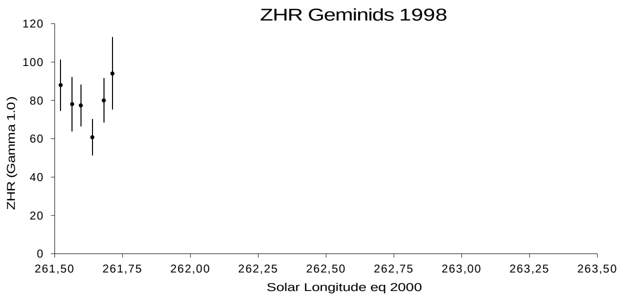

Figure 15 – Geminids 1998 based on data for 238 Geminids observed by SCHAL.

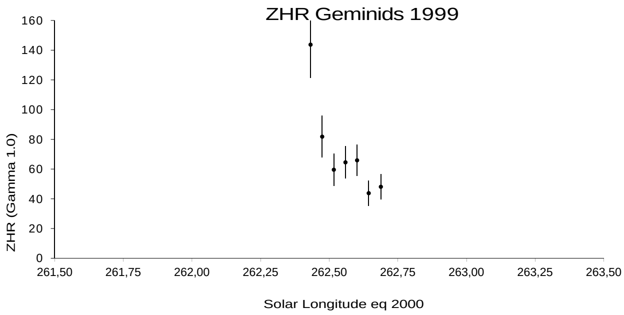

Figure 16 – Geminids 1999 based on data for 239 Geminids observed by VANMC.

5.5 The Ice cold Geminids 1998 from Tibet...

Moon: Few days after Last Quarter
Weather: Clear night, strong cold wind
Location: Tibet, China

During his world tour Alex Scholten arrived in Tibet around 1998 December 14. There he could observe the Geminids from a Sameye monastery at 155 km from Lhasa, the capital of Tibet. He managed to observe a nice Geminid display during a few hours. The strong wind and coldness forced him to observe from a protected site which limited his field of view somehow (Scholten, 1999). For the ZHR calculations Alex indicated that the observing area covered only 50%. We show the entire ZHR curve here, but because of the high correction figures these results were not considered for this analysis.

5.6 The 1999 Geminids observed from Belgium

Moon: A 30% illuminated moon disturbed a bit in the early night.
Weather: completely cloudy in the Netherlands with clear sky in the second half of the night December 14–15.
Location: Belgium.

Good observing series from Michel Vandeputte from Belgium during the second part of the night of December 14–15. A reasonable number of bright stuff but almost no fireballs. The first data point in the graph is rather high but unfortunately there is only data for one observer.

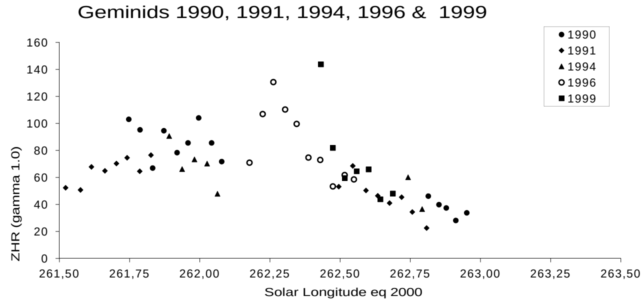

Figure 17 – Combined ZHR curves for 1990, 1991, 1994, 1996 and 1999.

5.7 Combined curves for the 1990ies

Finally we made a combined graph for the 1990ies (Figure 17). The distinct peak from 1996 was observed only one time in the 1990ies. Data for 1992 would be required but unfortunately that was a poor year for the Geminids with a lot of moonlight. Further the low ZHR-values for 1991 catch the attention for which we gave a possible explanation in part 5.2.

For the night December 14–15 all curves are about at the same level although the 1990 activity curves seems to occur a bit later.

6 The Geminids during the first decade of 2000

The best observed Geminid displays are those of 2004, 2007 and 2009. These are also the observing campaigns for which clear sky was found abroad. In 2001, 2008 and 2009 fairly good observations were possible from the Netherlands.

6.1 Successful 2001 Geminid campaign from the Benelux

Moon: New Moon on December 15, no disturbing moonlight.
Weather: Clear sky but a bit fuzzy.
Location: Benelux

Clear sky expanded over the Netherlands in the early evening of 2001 December 13 (Koppejan et al., 2002). Nine observers obtain data for about 2700 Geminids. The result is shown in Figure 18. The ZHR remained most part of the night above 100 and just in the final last hours a rapid decline occurred. At the end of the night the ZHR was halved. Unfortunately due

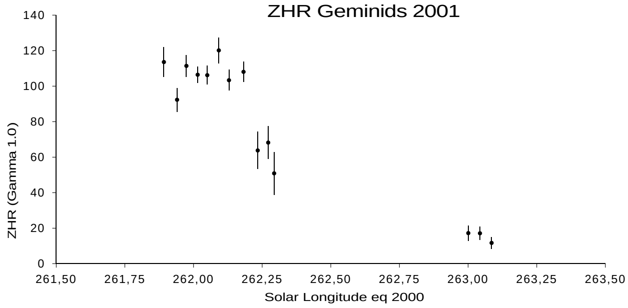

Figure 18 – Geminids 2001 based on data for 2739 Geminids observed by DIJSI, JOHCA, LANMA, MISKO, OSVDA, SCHAL, VANMC, VANSI and VERRI.

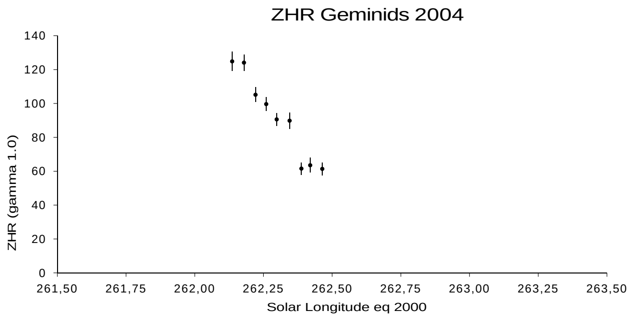

Figure 19 – Geminids 2004 based on data for 4088 Geminids observed by BIEJE, DIJSI, JOHCA, KEERO, MISKO, TUKAR, VANMC and VERRI.

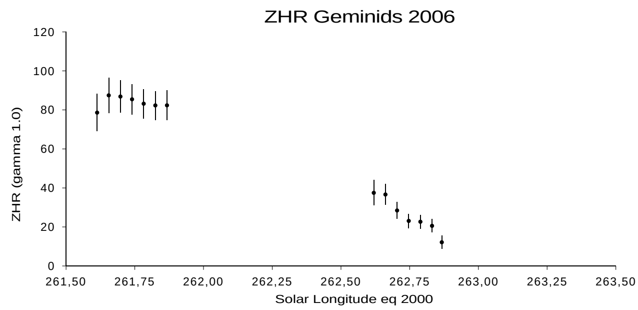

Figure 20 – Geminids 2006 based on data for 1009 Geminids observed by VANMC.

to the large number of photographed Leonids a month earlier no multiple station project could be organized. The night of December 14–15 could only be observed by VANMC from Ellezelles in Belgium.

6.2 2004 Geminid campaign from "Kahler Asten", Winterberg, Germany

Moon: New Moon on December 12, no moonlight.
Weather: High pressure inversion, clear sky above 600 meters.
Location: Kahler Asten, Winterberg, Germany.

A high pressure region above the Netherlands caused inversion with mist, low clouds and air pollution. The inversion limit was situated at about 700 meter and thus a number of DMS members travelled to Sauerland in Germany and moved on the highest hill, Kahler Asten with an elevation of 800 meters (Johannink, 2005).

Once above the inversion the sky was brilliant clear and permitted all night long observing. In this data set we also included the observations of BIEJE (Wilderen, Belgium) and KEERO (Ardens, Belgium) for this analysis. In total this group recorded over 5000 meteors, of which 4088 Geminids that could be used for this analysis. The observations took place at the same solar longitude like in 1996, see also (Johannink & Miskotte, 2005). It was remarkable that the maximum occurred a few hours earlier than in 1996. The ZHR was a little bit lower than in 2004, but this may be explained because the observers started with the highest ZHRs from the moment that the radiant was just at a usable elevation above the horizon (= 30 degrees height).

6.3 VANMC and the Geminids of 2006

Moon: Last Quarter December 13, disturbing in the second half of the night.
Weather: Both nights clear.
Location: Vosges, France.

At a moment that everybody had given up all hope for a successful Geminid campaign, Michel Vandeputte managed a most successful observing expedition in the Vosges, France with a clear night for December 13–14 and for December 14–15 (Vandeputte, 2007). The results were impressive.

Figure 20 displays the result. It is obvious that the ZHR-values are lower than in other years. The ZHR never got at 100. Probably the peaks seen in 1996 and in 2004 occurred during daylight of 2006 December 14. During both nights some beautiful fireballs were noticed (including a −8, −6 and several Geminids of −4). This successful observing expedition of Michel was the start of a series more frequent Geminid campaigns flying by plane to Southern Europe to observe.

6.4 Spectacular Geminids 2007 from Portugal

Moon: New Moon December 10, just some slight disturbing moonlight in the first part of the night.
Weather: Three clear nights in a row in Portugal, some short clear periods in the Netherlands.
Locations: Portugal, La Palma and the Netherlands

Four DMS members took a flight to Portugal to escape from the bad weather in the Benelux in 2007 (Vandeputte, 2008). They managed to observe three nights in a row (December 12–13, 13–14 and 14–15). Sietse Dijkstra and Peter van Leuteren provided a very valuable contribution to the dataset with observations for the night of December 15–16 (van Leuteren, 2008). They had also observed during the night of the maximum but their data could not be taken into consideration for the calculation because of the too low radiant elevation and unstable weather conditions in the Netherlands. Jos Nijland could observe exactly one hour during the night of the maximum before clouds interfered again. The observing campaign in Portugal was a very big success, the night of December 13–14 was characterized by high numbers, but mainly faint Geminids. The brightest Geminids were −3. The next night was very spectacular; especially after 23^{h} UT many fireballs were recorded. A total of 20 different Geminids were

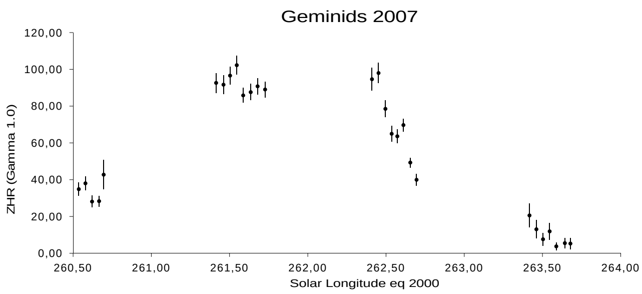

Figure 21 – Geminids 2007 based on data for 5807 Geminids observed by BETFE, DIJSI, JOHCA, LEUPE, MISKO, NIJJO, VANMC and VANSI.

Figure 22 – A compilation of some exposures with e.g. Geminids of −5 (courtesy: Koen Miskotte).

recorded with magnitudes of −3 till −8 (Vandeputte, 2008). These numbers are rather remarkable. Felix Bettonvil could confirm the large number of bright Geminids from La Palma (Bettonvil, 2008).

Figure 21 shows the results. The peak is very well visible followed by a strong decrease in activity: this dip is very well shown in the individual data of each observer in Portugal. Jos Nijland observed exactly that very same hour from the Netherlands and recorded a comparable rate so this dip does not looks like an artifact. The night of December 14–15 starts with a high activity (ZHR 100) but decreases rather quickly to a level of about 30 at the end of the night.

Fireball after fireball, by Michel Vandeputte (Vandeputte, 2008)

"After a number of −2 Geminids the real show started after two observing hours with a blue-white −5 Geminid in Ursa Major. A first primal scream by the author resonanced over the observing site. Good ten minutes later a −3 Geminid appeared from Gemini to Canis Minor: also photographed by Koen. After that several −2 and two −3 Geminids followed between 23^h00^m and 01^h00^m at the sky. More bright stuff, but still not convincing enough at that moment. At 00^h54^m UT a −5 Geminid glittered low in the South (region Eridanus – Horlogium), not photographed by Koen. At 01^h18^m UT a −5 Geminid appeared in Hydra (photographed), missed by the author who noticed a −2 Geminid near Polaris. From then on, it went better and better.

At 01^h47^m UT: a brilliant white −5 Geminid appeared in Hydra (photographed) and just 9 minutes later again −4 in Coma Berenices. 02^h08^m UT: a −3 towards Taurus, 02^h10^m UT a fragmenting −3 close to Polaris, 02^h13^m UT an flame-shaped white −4 Geminid with short trail near the radiant. Hello, yes!

Three bright ones on a little 5 minutes time. Where did we see something like that in the past? And did we get the best of it yet? Absolutely not; at 02^h39^m UT the brightest Geminid of the night appeared in the east. A terminal burst of magnitude −8 brightened the sky. Also other observers, hundreds of kilometers in the Spanish outback observed this bolide (F. Ocaña estimated this at −9). The show must go on. 02^h48^m UT, a −3 in Ursa Major, 03^h24^m UT a green −4 in Draco, 03^h48^m UT a −6 bolide in Ursa Minor. Wow! 04^h03^m UT Ursa Major got a visit of a −5 Geminid... 04^h06^m UT: again bingo in Canis Major with a −4 Geminid. This was the last bright visual record. After this the intensity dropped and the stream activity faded out smoothly. Earth left the denser part of the Geminid meteor stream. At 5^h UT the observations were quit. Happiness all over the observing site."

6.5 The moonlighted Geminids of 2008

Moon: Full Moon on December 13 means all night moonlight.
Weather: Some clear sky from the west, later again clouds.
Location: the Netherlands

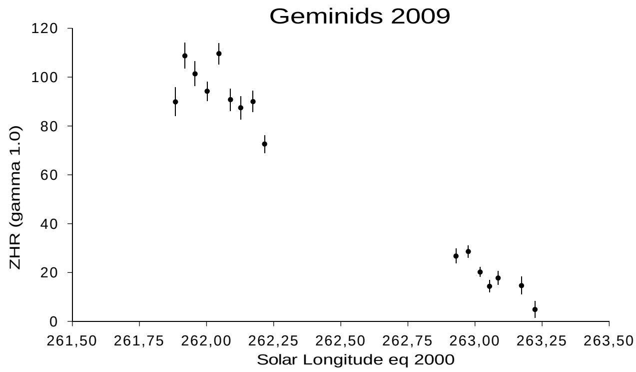

Figure 23 – Geminids 2009 based on data for 4185 Geminids observed by BETFE, BETHA, BIEJE, DIJSI, JOHCA, KEERO, LEUPE, MISKO, NIJJO, SCHAL and VANMC.

An almost Full Moon greeted the observers. Clear sky was chased by clouds coming from the west. In spite of the circumstances a good number of Geminids were seen and especially at the end of the night some fine fireballs till magnitude −6 were seen. ZHR calculations yield extreme high ZHR values between 150 and 230 for each observer. This is probably entirely due to the underestimation of the limiting magnitude and the known problem with counting stars in limiting magnitude fields with low limiting magnitudes: one star more results sometime in a much higher limiting magnitude. No graph is made for this year. Observers in 2008: DIJSI, JOHCA, LEUPE, MISKO and OSVDA. But even with Full Moon circumstances the Geminids remain worthwhile watching, rates between 40 and 50 per hour are no exception. However, this kind of years cannot be used for any serious analyses.

6.6 Beautiful Geminids 2009 from Portugal and the Netherlands

Moon: New Moon December 16, no disturbing moonlight.
Weather: Portugal: clear, Netherlands: local clear sky, at some places partly cloudy.
Locations: Portugal, the Netherlands and Sudan.

Inspired by the result from 2007 a group of DMS observers returned to Portugal to observe the Geminids. They were not disappointed, the nights December 13–14 and 14–15 remained clear (van Leuteren & Miskotte, 2010). Fortunately also from the Netherlands observations were possible (Betlem, 2010; Biets, 2010; Nijland, 2010; Scholten, 2010). Nice numbers of meteors were recorded and a (double?) maximum around solar longitudes $261\overset{\circ}{.}90$ and $262\overset{\circ}{.}046$, followed by a gradual decrease with bright Geminids à la 1996. Also the population index r behaved like in 1996 (Betlem et al., 1997). Few Geminids of −5 and −4 were observed.

The night of December 14–15 produced a significant lower activity, but still with a number of fireballs. Visually a −4 and −6 were spotted and later that night a −10 was recorded with the all-sky camera of Peter van Leuteren.

Also from the Benelux the Geminids could be observed although the weather varied significant from site to site. Also a small dataset from Sudan was used. Figure 23 shows the result. It is remarkable that the activity did not reach the same level in 2009 like in 1996 and in 2004 although we observed mostly at the same solar longitude.

Figure 24 – The observing team for the 2009 Geminids at a Menhir from left to right; Roy Keeris, Koen Miskotte, Peter van Leuteren, Michel Vandeputte, Inneke Verkerken and Sietse Dijkstra (courtesy: Sietse Dijkstra).

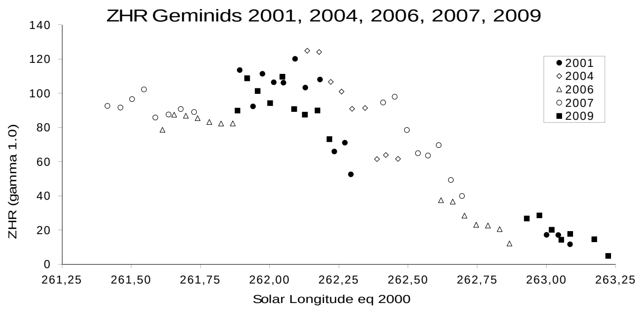

Figure 25 – Combined ZHR curves of the Geminids 2001, 2004, 2006, 2007 and 2009.

6.7 Combined ZHR curves for the first decade of 2000

We present the combined activity profiles for the Geminids 2001, 2004, 2006, 2007 and 2009 (Figure 25. The data for 2006 December 13–14 fits nice at the data of 2007 December 13–14 and 2001/2009. The sometimes significant dips during the maximum appear to be recurrent features, but it is difficult to determine if the observed dips are always the same. The time of the Geminid maximum is variable and takes place within a period of about 6 hours. This causes the entire profile to shift. Looking at the profiles one can see resemblances that appear a bit sooner or later in different years. E.g. the decreasing curve from 2007 looks a lot like the decreasing curve of 2004, but in 2007 this appears to happen a bit later. It is remarkable that the curve for 2009 is significant lower than these for 1996 and 2001. Could that mean we got already at a weakening trend of the Geminids? To answer this question: we need more data (in the future...).

7 Geminid ZHR profiles compared at the same solar longitude

When all the ZHRs were computed we compiled series of years with the same observing window in solar longitude

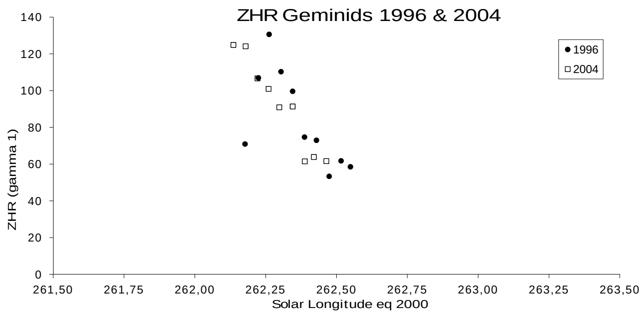

Figure 26 – Geminids 1996 and 2004.

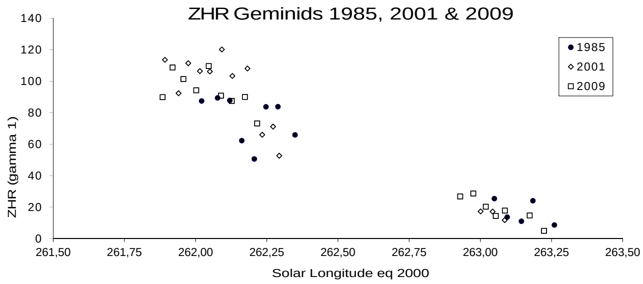

Figure 27 – Geminids 1985, 2001 and 2009.

and similar observing circumstances (moonlight). This happens roughly every eight years. The result is listed in Table 4.

Table 4 – Series of years with observations in the same solar longitude interval and similar moon conditions. The years mentioned in italics are future years with roughly the same conditions. The years per series are most suitable to consider any evolution in function of time within the same series.

	Year	Year	Year	Year	Year
Series 1	1988	1996	2004	2012	
Series 2	1985	2001	2009	2017	
Series 3	1990	1998	2006	2014	
Series 4	1983	1991	1999	2007	2015
Series 5	1994	2002	2010	2018	
Series 6	1984	1992	2000	2008	

In the following series descriptions we introduce two concepts: "the main peak"-series and "the plateau"-series. The "main peak" series indicate that it contains observations with the theoretical peaks in the observing window. There are often one or two peaks visible in this case. The "plateau"-series indicate that it concerns observations when the theoretical peaks occurred during daylight. In such cases a flat ZHR curve appears. This way we compare the theory with the observed facts.

In the literature we found that there exist a double main peak structure (Jenniskens, 2006; Betlem, 1997). George Spalding found very little shift for the time of the peaks from his research for the period 1969–1980 (Spalding, 1982). Peter Jenniskens found from his research for the period 1983–1985: solar longitude $261\overset{\circ}{.}01 \pm 0\overset{\circ}{.}02$ and solar longitude $262\overset{\circ}{.}34 \pm 0\overset{\circ}{.}01$. IMO (period 1988 to 1997) found solar longitude $262\overset{\circ}{.}12 \pm 0\overset{\circ}{.}02$ (ZHR 140) and solar longitude $262\overset{\circ}{.}33 \pm 0\overset{\circ}{.}02$ (ZHR 90 to 110).

7.1 Series 1: 1988 – 1996 – 2004 – (2012)

We describe this series as a "main peak" series. This means that the theoretical peaks occur within our observing window. There were two very beautiful returns in 1996 (Benelux) and in 2004 (Sauerland). Figure 26 gives both curves from 1996 and from 2004.

1988: Unfortunately no data for this return.

1996: A very high and rather sharp maximum appears around solar longitude $262\overset{\circ}{.}25 - 262\overset{\circ}{.}30$. This is about at the theoretical time of the second main maximum and perhaps this was extra strong in 1996. It is somehow curious that the ZHR was rather low at the beginning. One could expect a slightly higher ZHR shortly after the first main peak. Or, may be the first main peak was weaker.

2004: starts very high and was related to the time of the first main peak. There seems to be an indication of a slight enhancement at the time of the second peak, which occurred this time a little bit later at solar longitude $262\overset{\circ}{.}35$. The decrease in population index r was more significant in 1996 than in 2004 but this is rather logic as the 1996 return came a little bit later in solar longitude.

2012: New Moon on December 13 offers the possibility to observe in Europe around both theoretical sub maxima. An observing campaign is required.

Summary: Two beautiful returns in this series. Unfortunately the lack of data for 1980 and 1988 makes this series unsuitable to compare if the ZHR in the 1980s was lower than in the two later decennia. Both years give roughly the same ZHR. With a decreasing tendency the ZHR should be lower in 2012.

7.2 Series 2: 1985 – 1993 – 2001 – 2009 – (2017)

This series is also a typical "main peak" series. This is probably the best series to map the main peak at solar longitude $262\overset{\circ}{.}0 - 262\overset{\circ}{.}1$ and to compare it with ZHRs from the 1980s. We got three good returns available: 1985 (Provence), 2001 (Benelux) and 2009 (Portugal & Benelux). See for the result Figure 27.

1985: Main peak around solar longitude $262\overset{\circ}{.}0 - 262\overset{\circ}{.}1$ followed by a significant dip (be it perhaps slightly influenced by the passage of some cirrus cloud) with a second peak at solar longitude $262\overset{\circ}{.}3$ (second main peak). The ZHR values agree with the literature for that period (ZHR 88 ± 4 in the period 1981–1991).

1993: Unfortunately no data.

2001: Maximum ZHR 120 at solar longitude $262\overset{\circ}{.}1$. A very deep dip at solar longitude $262\overset{\circ}{.}2$ characterized this curve: the ZHR value gets halved in about 30 minutes. Could this be due to fatigue combined with a decreasing ZHR and decrease in the radiant elevation towards the end of the observing night? No, probably not and most likely this is the same dip like in 1985 but 0.1 degrees (2.4 hours) later in solar longitude. See also Figure 28.

2009: Peak between $261\overset{\circ}{.}9$ and $262\overset{\circ}{.}1$. The typical 'little maximum dip'; and then a modest revival around $262\overset{\circ}{.}2$. However, at the end of the night a sharp de-

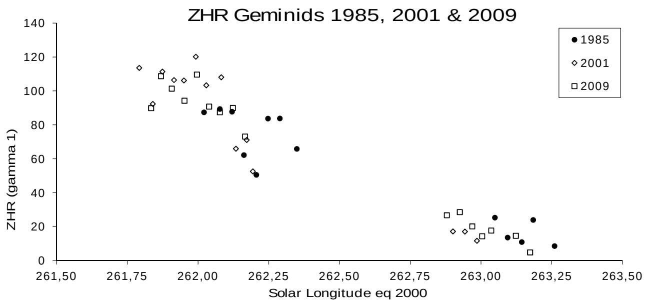

Figure 28 – The same profile as in Figure 27, but with the solar longitude shifted forward by 0°.1 for 2001 and by 0°.05 for 2009. It is remarkable that the profiles become exactly identical in shape with just a differences in ZHR level.

crease: is this the beginning of the same dip as seen in 1985 and 2001? Shifting the solar longitudes of 2009 0°.05 (1.2 hour) forward shows that the activity profiles fit nice together. It is known that the time of the maximum of the Geminids can shift a bit, so probably other structures may shift in a similar way. The maximum ZHR was a bit lower in this year than in 2001.

2017: A good year to verify if the upward trend between 1985 and 2001 continues, or that there is rather a downward trend starting after 2004. The moon cannot be an excuse not to observe as it is just few days before New Moon. At the same time we can verify if the dip observed in 1985, 2001 and probably 2009 gets confirmed. There is still another reason to observe the Geminids carefully in 2017 which we explain in part 8.

Summary: This series is the most beautiful to look at the possible evolution in the ZHR. Obviously 1985 was the year with the lowest activity in the series. The year 2001 scored with the highest ZHRs and in 2009 the ZHR was again a bit lower. In case that the ZHR gets further down in 2017 compared to 2009, then it is obvious that we are again in the downward trend of the Geminid activity. In that case the years with the highest ZHRs are history. The period with the highest Geminid activity would have been between 1996 and 2004 in that scenario. See also part 7.1.

7.3 Series 3: 1990 – 1998 – 2006 – (2014)

This series is described as a "plateau" series. These series are not suitable for the main peaks, but interesting for the descending wing after the maximum. This series is much less impressive than the other "plateau" series 1983 – 1991 – 1999 – 2007. Two bright returns: 1990 (Provence) and 2006 (Vosges). The result is shown in Figure 29.

1990: Well known Provence story: Peter Jenniskens calculates an average ZHR of $77 \pm 8 \pm 1.3$. The night December 14–15 displayed many bright Geminids just like in 1983. This analysis gives ZHRs between 80 and 105.

1998: Unfortunately no data.

2006: Plateau during December 13–14 (solar longitude 261°.6 – 261°.9). December 14–15: more bright Geminids but no fireballs within the fireball interval observed in 2007. However the fireball interval observed in 2007 appeared earlier in solar longitude with a lower radiant elevation.

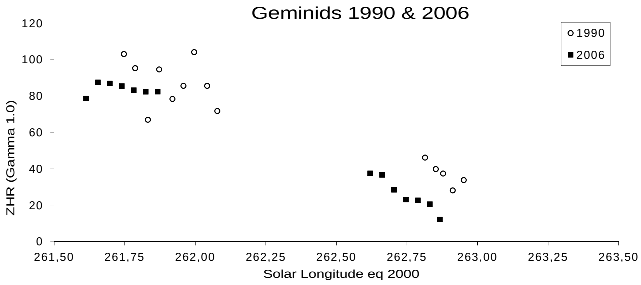

Figure 29 – Geminids 1990 and 2006.

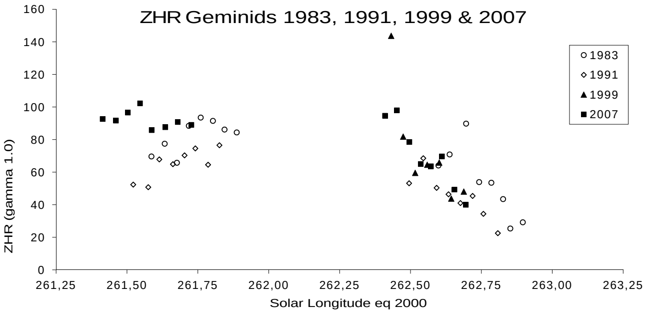

Figure 30 – Geminids 1983, 1991, 1999 and 2007. 2007 has slightly higher ZHRs than in 1983. 1991 is clearly an outlier with considerable lower ZHRs in the night of December 13–14, this effect is less pronounced in the next night. See also part 5.2 for a possible explanation.

2014: Rather poor circumstances that year, Last Quarter on December 14. But, anyway get into the observing field, even with moonlight there are enough Geminids to be seen.

7.4 Series 4: 1983 – 1991 – 1999 – 2007 – (2015)

This series is also characterized as a 'plateau' series. The best of its kind to observe the descending shoulder, shortly after the main maximum. The graph in Figure 30 is the result for this series.

1983: the amount of data is limited. December 14–15 mentions some bright meteors but nothing exceptional like observed in 2007.

1991: known as an outlier. On average some lower ZHRs (influence Pinatubo?). Also rather few very bright Geminids in the descending shoulder.

1999: Only December 14–15 beautiful clear sky over Flanders' fields. Bright Geminids but rather few fireballs. Unfortunately only one contributing observer.

2007: the plateau between solar longitudes 261°.2 – 261°.8. And a fireball parade between solar longitudes 262°.50 – 262°.68.

2015: Excellent year to observe the Geminids with New moon on December 11 and hence just a bit moonlight in the beginning of the night when the radiant is still at low elevation.

Summary: two remarkable features are indeed the lower ZHRs in 1991 and the spectacular fireball display in the night of 2007 December 14–15. In 2007 the ZHR was somewhat higher than in 1983. The ZHR profile of 2007 appears to be shifted forward compared to 1983.

7.5 Series 5: 1994 – 2002 – (2010)

This series represents years with considerable moonlight although 2010 will be reasonable. No real conclusions can be drawn from this series. There is no graph because it makes no sense to compare anything due to the excessive moonlight.

1994: no beautiful profile, highest data point with disturbing moonlight. Moreover, theoretically the activity should increase a lot towards the theoretical main peak at the end of the night. Probably this was undone by the sharp decline in the radiant elevation.

2002: Unfortunately cloudy sky over the Benelux. A last minute dropping expedition by cars with some DMS- and VVS observers failed due to extreme winter weather.

2010: Repair the mistakes from 2002. Without moonlight during solar longitude $261\overset{\circ}{.}7 - 262°$ in the second part of the night. We can experiment with the theoretical highest activity whilst the radiant is decreasing in elevation and compare with the experiences of 1994 and the 2006 situation.

7.6 Series 6: 1984 – 1992 – 2000 – 2008 – (2016)

This series is the Full Moon series. As said before, this kind of years offers no reliable data. These events are just for entertainment, enjoying an impressive display. Also 2016 has Full Moon, good to enjoy from the Netherlands if the sky is clear.

8 The fireball display of 2007 December 14–15 and 3200 Phaethon

About 20 Geminids of magnitude between -3 and -8 were observed in Portugal during the night of 2007 December 14–15 between $23^{\rm h}00^{\rm m}$ and $04^{\rm h}00^{\rm m}$ UT. Felix Bettonvil confirmed these observations with visual and photographic data from La Palma (Vandeputte, 2008; Bettonvil, 2008; van Leuteren, 2008). As (3200) Phaethon was nearby the Earth in December 2007 (0.145 AU on 2007 December 14), the following four questions arise:

- Has this remarkable fireball activity been observed from other locations too?
- Were there any more such fireball displays in the recent past?
- Is there any relationship between the number of bright fireballs and the distance of 3200 Phaethon to the Earth on December 14–15?
- Are there any other close encounters with 3200 Phaethon in the future?

8.1 Observations from other locations

We found a number of observations around the same solar longitude by more experienced observers from the IMO database. We refer to observations from Israel (Shy Halatzi / Anna S Levina), Slovenia (Javor Kac) and Slovakia (Jakub Koubal). The criteria used to select their observations were as follows:

- Sufficient large observing window starting before $23^{\rm h}$ UT and far enough into the time lapse when the abundant number of brighter Geminids were recorded from La Palma and from Portugal ($23^{\rm h}$ – $04^{\rm h}$ UT).
- Good observing conditions.

The result is summarized in Table 5 with on top the Portuguese data.

None of these IMO observers show a significant increase in bright Geminids after $23^{\rm h}$ UT. In fact rather few Geminids brighter than -2 were seen compared to the observers in Portugal and La Palma. We can conclude that the display above the South West of Europe remained invisible for Eastern Europe and Israel. A lower radiant elevation cannot explain this discrepancy.

8.2 Where there any other such fireball displays in the recent past?

A small query in the VMDB of IMO failed to yield a positive answer. Of course the amount of available data is limited to the years from 1982. There were often fireballs reported in the night of December 14–15 but never to an extent like what was observed in 2007 from Portugal. A good example of a "fireball poor" year is 1991, when the observations took place at the same solar longitude: a large number of observers in the Netherlands recorded only a few -3 Geminids while just four observers in Portugal in 2007 counted 20 Geminids between magnitude -3 and -8.

8.3 Is there a relationship between the number of bright fireballs and the distance of (3200) Phaethon to the Earth?

Maybe there are more fireballs when (3200) Phaethon gets close to the Earth? In 2007 (3200) Phaethon was at the closest range from Earth in about 50 years. As suggested by Peter Bus the solar longitudes were calculated for each observed Geminid fireball and plotted into a graph. Attention, these are the individually observed fireballs so when three observers saw the same fireball this was plotted as a single event. For this purpose a survey was made among observations of many observers, reports on the internet, *Radiant* or *eRadiant*. Also the DMS photo database (`http://www.dmsweb.org`) with all double station photographs proved to be a good source of data. In total the times of appearance of 118 individual Geminids of magnitude between -3 and -10 were obtained. The result is shown in Figure 31.

Figure 31 shows clearly that the fireball night of 2007 December 14–15 was an unusual display. The bottom line with open triangles in Figure 31 shows two distinct concentrations. From solar longitude $262\overset{\circ}{.}2$, the maximum of the Geminid stream, a concentration of fireballs is visible. The population index r decreases soon after the maximum and then more bright meteors

Table 5 – Data for observers active during the 'fireball night' of 2007 December 14–15. The increase in bright Geminids in the second half of the night is obvious for the observers in Portugal. Unfortunately these observations are not confirmed by data of other observers who were active at the very same time from other sites: HALSH (Shy Halatzi, Israel), LEVAN (Anna Levina, Israel), KOUJA (Jakub Koukal, Czech Republic) and KACJA (Javor Kac, Slovenia).

		Magnitude distributions													
Observers	Period	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	$\overline{m}$
JOHCA	21:00 – 00:00	0	0	0	0	4	7	13	20	33	38	18	19	0	2.32
	00:00 – 03:30	2	1	2	1	7	10	16	28	25	35	15	10	0	1.59
MISKO	21:00 – 00:00	0	0	0	0	3	4	9	15	42	55	47	10	0	2.66
	00:00 – 04:00	2	2	4	4.0	7.0	14.0	8.0	34.0	44.0	71.0	48.0	9.0	0.0	2.00
VANMC	21:00 – 00:00	0	1	0	2.0	5.0	8.0	14.0	32.0	54.0	85.0	64.0	18.0	0.0	2.52
	00:00 – 04:00	2	1	4	4.0	8.0	9.0	20.0	50.0	78.0	109.0	56.0	9.0	0.0	2.09
BETFE	01:36 – 03:59	0	0	1	5	10	7	23	19	47	45	34	16	3	2.08
HALSH	21:00 – 00:00	0	0	1	4	10	13.5	20.5	20	18.5	24.5	32.5	22	0.5	1.94
	00:00 – 02:50	0	1	1	3	11.5	6	9	20.5	19.5	29.5	20.5	13.5	0	1.86
LEVAN	21:00 – 00:00	0	0	2	3	8	12	22	32	24	37	31	4	0	1.66
	00:00 – 03:00	1	1	1	1	4	9	15	18	31	8	17	2	0	1.36
KOUJA	21:07 – 23:52	0	1	0	0.5	3	5.5	14.5	27.5	34	27	20.5	6.5	0	1.95
	23:52 – 02:38	0	0	0	1.0	1.0	2.5	10.0	15.5	19.0	16.0	14.0	4.0	0.0	2.05
KACJA	23:04 – 00:00	0	0	0	0.0	2.0	0.0	3.0	5.0	10.0	7.0	3.0	0.0	0.0	1.80
	00:00 – 03:12	0	0	1	6.0	3.0	13.0	11.0	22.0	22.0	31.0	29.0	6.0	0.0	1.83

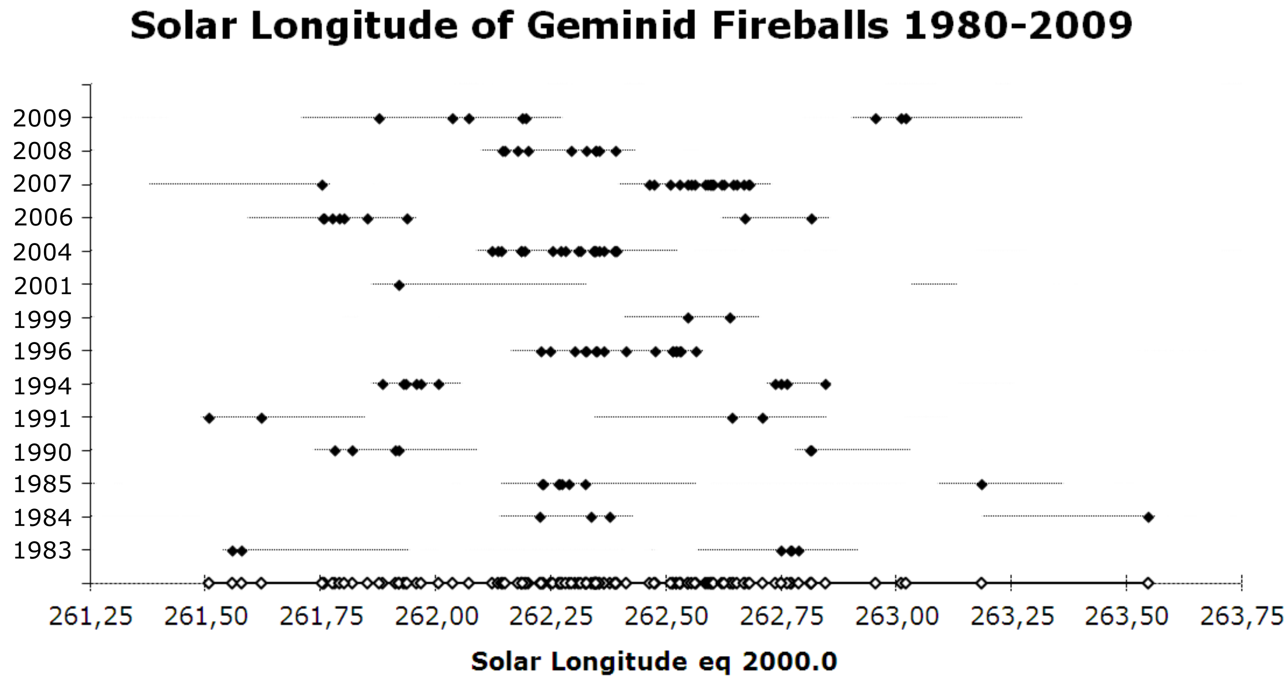

Figure 31 – All Geminid fireballs observed in the period 1980–2009 plotted in function of the solar longitude (eq 2000.0). The bottom line marks all fireballs while the higher lines indicate the fireballs per year in function of the solar longitude.

and fireballs appear as observed in e.g. 1996, 2004 and 2009.

After this the concentration of fireballs becomes less dense but from solar longitude 262°5 another concentration appears. This solar longitude coincides with the start of the fireball time-lapse in 2007. Considering the other lines it is obvious that 2007 contributed the largest part of this concentration in fireballs. For instance we can compare the fireball line of 2007 with the lines for 1991 and 1983 when the same time lapse in solar longitude could be observed.

Of course with this kind of analyses we need to pay attention to the observing capacity: were more observers active during a certain time lapse so that more fireballs could be noticed? Therefore the periods covered by observations are indicated with dotted lines in Figure 31 and these show that the observations were rather homogeneous.

It is a pity that our data is not supported by observations from other European observers. Therefore it becomes unlikely that the close encounter of 3200 Phaethon is responsible for the large number of fireballs in the night of 2007 December 14–15.

Few first tentative conclusions

Because of the rather few very well observed Geminid returns, 14 returns observed in 30 years, at this moment it looks like the bright Geminids are uniformly distributed along the orbit of Phaethon with some statistical outliers. However when (3200) Phaethon is about 1 to 6 weeks before the passage through the node on December 14, like in 2007, there could be a weak tendency for larger numbers of bright Geminids. The fact that larger particles tend to remain closer to the parent body contrary to the smallest particles can explain this. However the higher number of observed bright Geminids in 2007 can be just an artifact as statistical outlier. Also because the observations in 2007 from Portugal and from La Palma failed to be confirmed by other good quality observations in the same observing window may indicate it is not statistically relevant. Moreover the time lapse with the bright Geminids lasted only a couple of hours while in case of any correlation with the proximity of the parent body (3200) Phaethon bright Geminids would be expected to appear during a longer time interval. More observations are required to investigate this aspect.

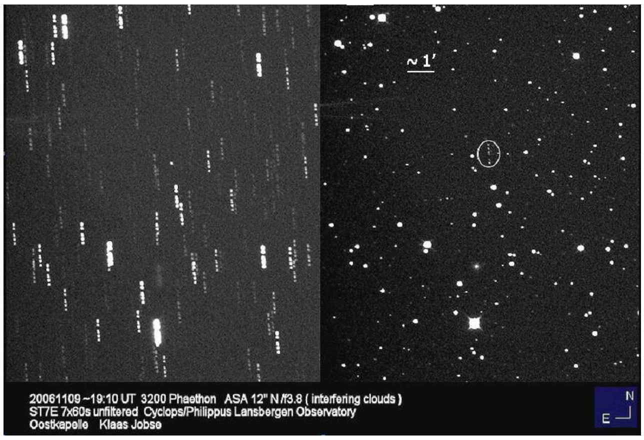

Figure 33 – Images of 3200 Phaethon taken by Klaas Jobse with his ASA 12"N/f 3.8 telescope.

8.4 Are there other close encounters with (3200) Phaethon in the future?

The answer to this is yes, in 2017 there will be a very close approach between Earth and (3200) Phaethon. On 2007 December 14 the distance to Earth was 0.145 AU and on 2017 December 14 this will be only 0.084 AU. We list the distances to (3200) Phaethon together with the phase of the Moon for the coming 10 years in Table 6. Unfortunately the time lapse with the fireball appearances of 2007 will not be visible from Europe in 2017 but from the Western part of the Pacific so that only observers in China, Korea, Japan, Hawaii and Northern Australia can observe this. Because of the many questions in this matter, it is obvious that major observing efforts are recommended for the 2017 Geminids.

8.5 Forecasts for the Geminids 2010–2019

Table 6 lists the moonlight circumstances for all the near future years. This shows that 2012, 2015, 2017 (!) and 2018 offer excellent observing conditions with almost no moonlight. Also in 2010, 2013 and 2014 there are some observing opportunities but the other years suffer badly with moonlight. The years 2011, 2015 and 2019 are years with high Geminid activity for Europe during both nights December 13–14 and 14–15 as the peak appears during daylight on December 14. The other years are suitable to concentrate on December 13–14, the night of maximum activity.

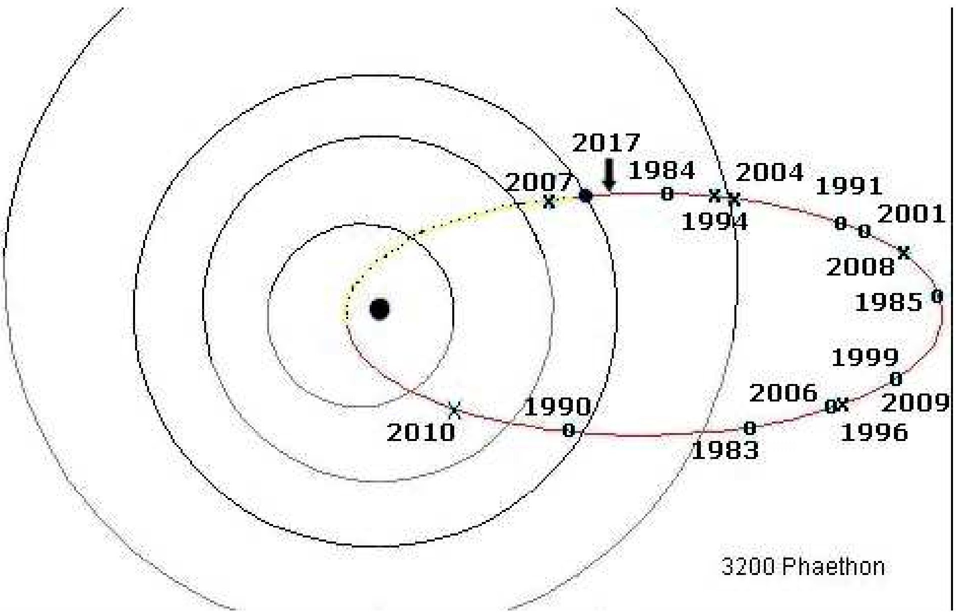

Figure 32 – The positions of 3200 Phaethon are projected on the elliptic orbit for each year when Geminids of −3 or brighter were observed (JPL HORIZONS on-line solar longitude system data and ephemeris computation service. `http://ssd.jpl.nasa.gov/?glossary&term=ephemeris`.), (Orbit Diagram: JPL Small-Body Database Browser `http://ssd.jpl.nasa.gov/sbdb.cgi?sstr=3200;orb=1; cov=0;log=0;cad=0#orb`). The "×" sign indicates 10 or more bright Geminids and "○" less than 10 bright Geminids. The orbits of the planets Mercury till Mars are plotted seen from above, the position of the Earth is given for December 14. The positions for 3200 Phaethon for 2010 and 2017 are also given (courtesy figure Peter Bus).

Table 6 – Distance (3200) Phaethon to the Earth on December 14 at 00^h00^m UT for the years 1983–2019. Also the phase of the moon is mentioned NM, FQ, LQ or FM nearest to December 14 (JPL HORIZONS on-line solar longitude system data and ephemeris computation service. `http://ssd.jpl.nasa.gov/?glossary&term=ephemeris`).

Year	Δ3200	Moon
1983	1.401 AE	FQ (13-12)
1984	0.275 AE	LQ (15-12)
1985	1.579 AE	NM (12-12)
1990	1.136 AE	NM (17-12)
1991	1.002 AE	FQ (14-12)
1994	0.463 AE	FM (18-12)
1996	1.558 AE	FQ (17-12)
1998	1.424 AE	LQ (10-12)
1999	1.668 AE	FQ (16-12)
2001	1.110 AE	NM (14-12)
2004	0.625 AE	NM (12-12)
2006	1.501 AE	LQ (12-12)
2007	0.146 AE	FQ (17-12)
2008	1.487 AE	FM (12-12)
2009	1.651 AE	NM (16-12)
2010	1.113 AE	FQ (13-12)
2011	1.202 AE	FM (10-12)
2012	1.712 AE	NM (13-12)
2013	1.232 AE	FM (17-12)
2014	0.767 AE	LQ (14-12)
2015	1.666 AE	NM (11-12)
2016	1.461 AE	FM (14-12)
2017	0.088 AE	LQ (10-12)
2018	1.534 AE	FQ (15-12)
2019	1.613 AE	FM (12-12)

9 Activity observed near 3200 Phaethon

Simon Green of the University of Leicester reported on 1983 October 14 that on October 11 a fast moving object had been observed with the Infrared Astronomical Satellite (IRAS) (IAUC 3887, 14 October 1983). C.M. Bardwel, Center for Astrophysics, published the first orbital elements which proved it concerned an Apollo-type object with the smallest perihelion distance of any known asteroid at that moment (IAUC 3879, 19 October 1983). F.L. Whipple, Center for Astrophysics reported that the orbital elements of Bardwel for 1983 TB matched well with the average orbital elements derived from 19 photographed Geminids (IAUC 3887, 25 October 1983). From then it has been generally accepted that 1983 TB (= 3200 Phaethon) was the parent object of the Geminids. Some do claim that Phaethon is an extinct comet which surface is sintered by the solar radiation. Others do prefer the theory that it is a solid rocky asteroid that originates from the main asteroid belt. However 3200 Phaethon did not show any kind of cometary activity or particle loss that could feed the Geminid meteor stream since its discovery.

K. Battams and A. Watson (IAUC 9054, 3, 2009) reported that according to the data of the satellite SECCHI HI-1A (STEREO) 3200 Phaethon became a few magnitude brighter couple of hours after its perihelion passage on 2009 June 20. Phaethon was seen as a non-stellar object. Battams and Watson supposed that the increase in brightness was caused by an interaction with the solar wind. When these observations were correct, it would be the first time that mass loss was observed from 3200 Phaethon.

After the announcement by Battams and Watson, D. Jewitt and J. Li used images of NASA's STEREO-A, for 3200 Phaethon from the period 2009 June 17–22 (Jewitt & Li, 2010). From these images they could deduce that 3200 Phaethon got a factor 2 brighter from 2009 June 20.2±0.2. Jewitt and Li assume that this unexpected increase in brightness was caused by a sudden release of dust particle from the surface of Phaethon. According to the authors about 10 of these events are required per orbital revolution in order to feed the Geminid meteor stream to maintain its particle density. It is highly unlikely that the dust emission was caused by an impact. Near its perihelion Phaethon gets too hot with $T = 746$ Kelvin (with a non rotating black body) to let water ice survive (or $T = 711$ Kelvin with a non rotating body with an albedo of 0.17 according to Peter Bus). Therefore the release of dust by sublimation of ice similar to comets is highly unlikely because the surface and the interior of Phaethon become much too hot to maintain water ice. Jewitt and Li therefore propose that Phaethon is a so called "rocky comet", which produces dust by thermal cracks and erosion of water based minerals (clay) exposed at the high temperatures near perihelion. Particles smaller than 1 mm cannot remain captured by Phaethon and resist the radiation pressure near perihelion as this just blows the surface clean.

From all 19 currently known asteroids with a perihelion distance smaller than that of Phaethon, not a single one gets bright enough to be observed by STEREO. Therefore it is important to monitor the behavior of Phaethon near its perihelion in the future to observe the frequency of mass-loss events to determine whether or not the mass of the Geminid meteor stream is maintained.

9.1 Does 3200 Phaethon belong to the Pallas family?

J. Licandro et al. established the connection between the two B-type objects, 2 Pallas and 3200 Phaethon in both composition and in dynamics (Licandro et al., 2007). First of all they compared the visual and near infrared spectra of both objects with all so far known B-type asteroids of the Pallas family. They all contain minerals rich in water (clay). They also looked for similarities between Phaethon and any other B-type asteroid from the minor planet belt. Various simulations were performed to search for some analogy in dynamics between the orbits of Pallas and Phaethon.

The result indicates there is a significant difference between the observable wavelengths of both spectra. However the nine minor planets of the Pallas family and

Phaethon have a good spectral agreement and match less good with the spectra of Pallas. Because of the spectral agreement between Phaethon and the Pallas family members, together with the established dynamic connection, it becomes very likely that Pallas is the parent object of Phaethon and thus also of the Geminid meteor stream. The authors attributed the spectral difference between Pallas and Phaethon to the difference in diameter between both objects.

9.2 Preliminary conclusions

It is very likely that Phaethon is not a so-called dead comet, but a minor planet that probably belongs to the Pallas family. The increase in luminosity observed in 2009 can be attributed to solar radiation energy which blew any dust particles away from Phaethon's surface. Because of the very short orbital revolution of 1.43 years, these particles will quickly spread along the entire asteroid orbit. This is almost certainly one of the reasons why no correlation is found between the close encounters of Phaethon to the Earth and the number of fireballs observed. Peter bus adds to this: "During radio observations in the 1990ies on e.g. 72.11 MHz, the nature of the sound of a Geminid was significant aberrant from meteors of other major showers. Meteors from showers associated with cometary parent bodies such as the Perseids, Draconids, Leonids and Ursids started often "hesitating" while the Geminids almost always immediately popped in. Probably this has to do with the more sintered material compared to meteors from cometary origin which are more fragile.

A few tentative conclusions

1. There is very little variation or shifting found in the occurrence of the maxima. The maximum returns frequently at about solar longitude $261\overset{\circ}{.}1 \pm 0\overset{\circ}{.}1$.
2. However, there are some indications that the time of the peak of the Geminids shifts with time, be it in small steps. More good observing data for the coming 10 years is required to prove this.
3. Evolution in ZHR: certainly increased compared to the 1980ies. The question because of the 2009 return is whether we got already in a trend of decreasing maximum ZHRs? Did we get the highest values around the turn of the century? Of course, one poor Geminid year for ZHRs is not conclusive; the stream has also some slight variations in activity from year to year. When we get one or more strong returns in the future the story is different again...
4. Has the parent body 3200 Phaethon anything to do with the input of bright meteors? We do not think so, but 2017 offers good possibilities to verify this.
5. This analyses will be probably extended with data of the pre maximum night December 12–13. Also adding data from reliable observers who observed for many years (e.g. Jürgen Rendtel, Pierre Martin and Robert Lunsford) is an option.

The main conclusion is that the Geminids are a very interesting stream, also because the composition of the parent body is still discussed. This research does not stop with this article, but this paper is a rather intermediate analysis to prepare for another paper in 5 or 10 years from now. Probably some conclusions can be proven or just disproven. It is obvious that a number of people will do every effort possible to observe the Geminids by observing campaigns like in 2007 and 2009. Who joins us?

Acknowledgement

First of all we want to thank all the observers for their efforts. Observations took often place under uncomfortable cold circumstances. Nor costs neither efforts were avoided to get at clear sky. Homage for such perseverance! We do hope that more Geminid data will be collected and that this investigation can be continued. Further a word of thanks to Paul Roggemans, also for translating this article for *WGN*, and Casper ter Kuile for looking up data and photographs.

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Preliminary results

Results of the IMO Video Meteor Network — August 2011

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August 2011 was a record month for the IMO Video Meteor Network with more than 53 000 meteors in over 7 300 hours of effective observing time by 62 cameras. Seven new cameras joined the Network this month. Low activity of the κ-Cygnids was detected with a maximum activity at $\lambda_\odot = 141°$. The Perseids were detected between $\lambda_\odot = 111°$ and 153° with a peak at $\lambda_\odot = 140°$. Daily fluctuations in the calculated flux were apparent. The influence of zenith exponent on calculated flux was explored and $\gamma = 1.6$ seemed to produce the lowest level of daily variation.

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1 Introduction

In August 2011, the observing conditions varied significantly between different observing sites. Whereas observers in southern and eastern Europe enjoyed almost continuously clear skies (the cameras Stg38 in Italy and Huhod in Hungary did not miss even a single night), the summer month was rather rainy farther north. In particular the Perseid maximum was literally rained out. It is only thanks to the high meteor activity, that many cameras still reported so many observing nights. Already the smallest cloud gap is sufficient in August to catch a meteor and thereby collect an observing night. In total, there were 45 cameras with 20 and more observing nights.

Anyhow, August 2011 was once more a record breaking month. 36 observers participated with 62 video cameras in the IMO network – more than ever before. In selected nights, up to 48 cameras were active in parallel. With more than 7 300 hours of effective observing time (Table 1 and Figure 1), we surpassed the previous best result of October 2010 by a whopping 30% (Molau & Kac, 2010). Those more than 53 000 meteors recorded in that time even imply a 35% increase on the previous record. Now that the IMO Video Meteor Database contains almost 900 000 entries we may still celebrate our one millionth meteor in this year!

Once more, our network grew in size. Matrin Breukers started to operate his second camera Mbb4. For Rui Goncalves, Templar3 is already the third active camera, and with Hudeb Antal Igaz even operates five cameras now at five different locations. Thus, he has become the single most diligent IMO network member now.

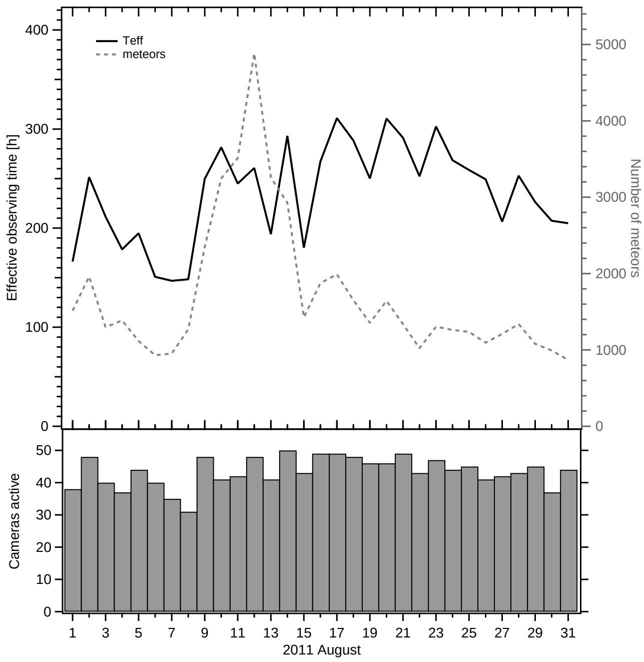

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2011 August.

In Italy, Leo Scarpa joined the IMO network. His camera Leo is based on a Mintron camera with 4.5 mm $f/1.2$ lens. Maciej Maciejewski from the Polish fireball network PFN is also regularly contributing the observations of his three cameras Pav35, Pav36 and Pav43 since August.

2 Results

Let us have a look at the observing results. The Southern δ-Aquariids and α-Capricornids, whose maxima occur in late July but which are active well into August, have been discussed already in the previous monthly report (Molau et al., 2011).

2.1 κ-Cygnids

In the 2009 meteor shower analysis (Molau & Rendtel, 2009), the κ-Cygnids were detected in the solar lon-

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NASA-ADS bibcode 2011JIMO...39..187M

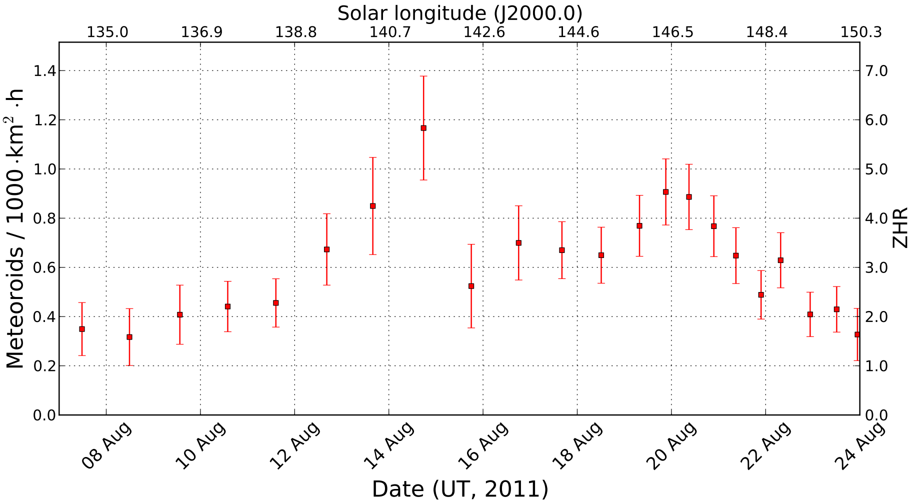

Figure 2 – Flux density profile of the κ-Cygnids, determined from data of the IMO Video Meteor Network in August 2011.

gitude interval 134° (August 7) to 146° (August 19). Their activity profile was flat and showed a barely visible maximum at $\lambda_\odot = 141°$ (August 14). That is confirmed by video data from 2011. The flux density profile (Figure 2) based on 749 shower members (with almost 11 000 SPOs in parallel) shows a rise from the sporadic background starting on August 13. At the maximum, the flux density is about twice the background, and by August 23 the activity has fallen to the background level again.

2.2 Perseids

Highlight of the month were the Perseids, of course. In the 2009 long-term analysis we could identify them between $\lambda_\odot = 111°$ (July 14) and $\lambda_\odot = 153°$ (August 27). Their maximum was reached at 140°, and at the rising edge there was a small "hump" at $\lambda_\odot = 135°$ (August 7). Figure 3 shows first the complete flux density profile of the 2011 Perseids from mid-July until end of August, based on 18 800 Perseids (versus 17 800 SPOs). It shows on the one hand the slow rise in July, contrary to a comparatively steep fall starting in mid-August. Also the small "hump" near $\lambda_\odot = 135°$ shows up again – it seems that this is indeed a real structure.

Looking at the maximum period August 9 to 17 in detail yields a strange picture. As expected, there are clusters of data points in the European night time hours with gaps in between. However, there is no flat overall profile, but instead a steep activity rise at each single night towards the (European) morning hours (Figure 4).

It is obvious that the modelling of the flux density contains a systematic error which correlates to the local observing time. The Moon and linked to it the stellar limiting magnitude can be excluded, because the effect can be observed at different lunar phases both before and after the maximum. The fields of view of the video cameras remained constant in the time interval, but the position of the Perseid radiant changes uniformly in the course of each night. Thus, the variable distance of the radiant from the fields of view could have had an effect, as it results in different angular meteor velocities and thereby different meteor limiting magnitudes. However, the cameras look in many different directions, so that possible effects from this cause should compensate each other to some extent.

As the Perseid radiant raises continuously in the course of the night at mid-northern latitudes, it is fairly obvious to link the systematic variations to the radiant altitude. That altitude affects the calculation of the effective collection area in two ways.

On the one hand, it is an input parameter for the calculation of the meteor layer altitude, at which Perseids typically occur. The altitude of the Perseids varies by about 5% during the night. However, also this has al-

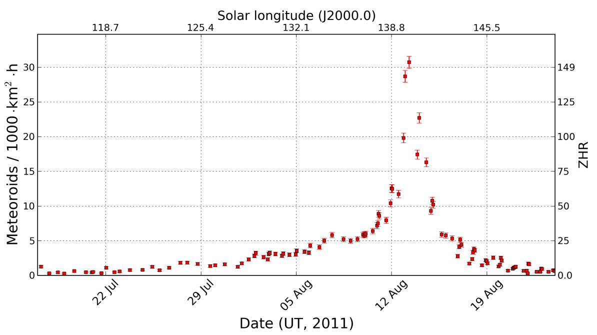

Figure 3 – Complete flux density profile of the Perseids in July and August 2011, based on roughly 18 800 Perseids.

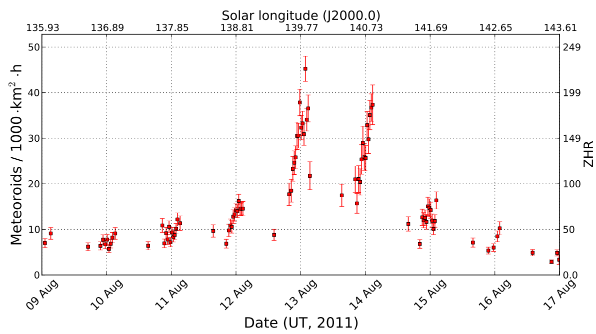

Figure 4 – Detailed flux density profile of the Perseids between 2011 August 9 and 17.

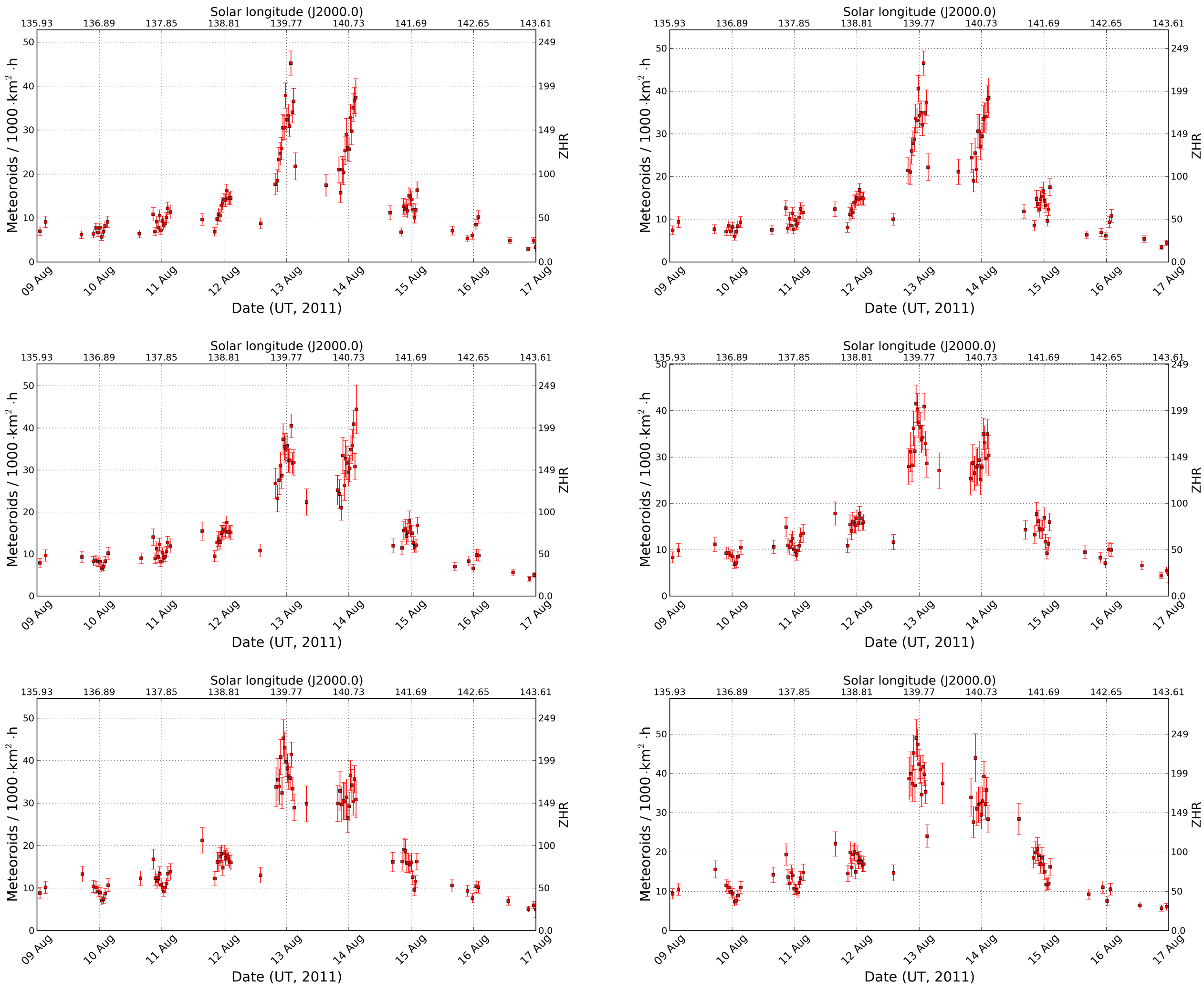

Figure 5 – Flux density profile of the Perseid maximum in August 2011, calculated with zenith exponents between 1.0 and 2.0 (upper left to lower right).

most no effect on the effective collection area, because there are two reverse effects (higher altitude means a larger collection area, but also lower brightness because of larger distance) which almost cancel each other out.

On the other hand, the sine of the radiant altitude (or the cosine of the zenith distance) influences the effective collection area and thereby flux density directly. In the current implementation, a formula of Kresák (1954) is used, which deviates from the pure sine only for radiant altitudes below 10 degrees.

In the past, the so-called zenith exponent was discussed several times. The cosine of the zenith distance will be raised to the power of the zenith exponent γ to account for different entry angles of meteoroids in the atmosphere. In IMO meteor shower analyses, γ is typically set to 1.0, whereas Zvolánková (1983) derived a values of 1.47, and Jenniskens used a value of 1.4 in his meteor shower analyses of the nineties (Jenniskens, 1994). To analyse whether a zenith exponent larger than 1.0 can indeed explain the observed systematic deviations, the flux densities of all cameras between August 8 and 17 were recomputed with different zenith exponents between 1.0 and 2.0. The result is given in Figure 5.

The daily variations become indeed smaller with increasing γ value, and in the end they partly reverse. The value of the zenith exponent cannot be determined exactly from these graphs alone, and it might even be that the cosine has to be transformed by a different function than raising it to the power of γ, but a zenith exponent of about $\gamma = 1.6$ (middle right plot of Figure 5) subjectively seems to level out the daily variations best. This detailed flux density profile of the Perseids with a zenith exponent of 1.6 is shown enlarged in Figure 6. The peak flux density is reached with 40 meteoroids per 1 000 km^2 per hour on August 12 at 23$^{\text{h}}$ UT ($\lambda_{\odot} = 139\overset{\circ}{.}73$). Applying the formula of Koschak and Rendtel (1990) would yield a ZHR of about 200. However, in previous shower analyses we found already that this values are overestimated by a factor of 2 to 3. Thus, the peak ZHR would rather have been of the order of 80 to 100. Visual Perseid observations of 2011 do not yield a clear profile, as the observers were significantly hampered by the Moon. The smoothed quick look profile yields a maximum ZHR of 60 in the night of August 12/13 (International Meteor Organization, 2011), which seems to be systematically underestimated in view of the video data.

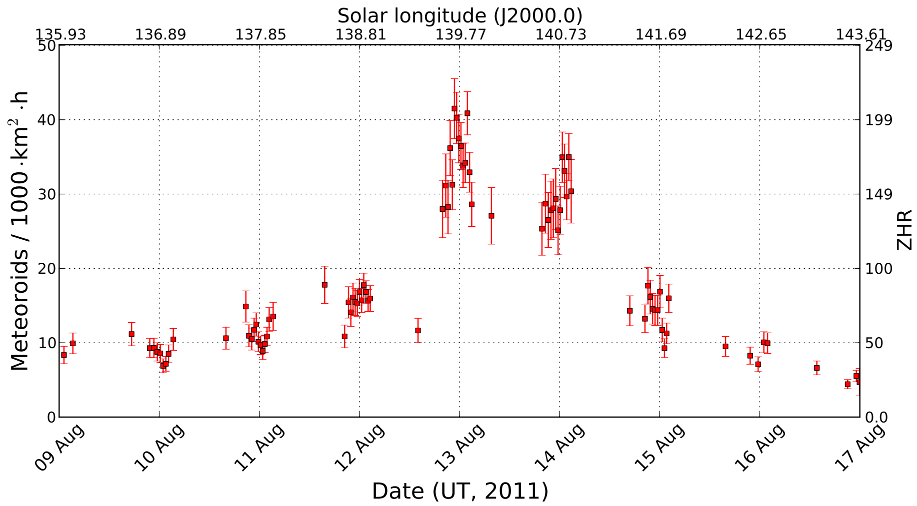

Figure 6 – Detailed flux density profile of the Perseids between 2011 August 9 and 17, obtained with a zenith exponent of 1.6.

Figure 7 – Cluster of seven meteors, recorded with Stefka on 2011 August 14, between $00^h34^m10^s$ and $00^h34^m15^s$ UT. The trail in the upper left was caused by a bright satellite.

Finally, we want to present an unusual meteor cluster, recorded by Javor Kac on the morning of August 14 with his camera Stefka. Within five seconds starting at $00^h34^m10^s$ UT, seven meteors occurred in the lower right quadrant of his camera (Figure 7). MetRec detected all seven of them and classified three as Perseids.

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Table 1 – Observers contributing to 2011 August data of the IMO Video Meteor Network. Eff.CA designates the effective collection area and Tot.CA the total collection area.

Code	Name	Place	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Tot.CA [10³km²h]	Meteors
BASLU	Bastiaens	Hove/BE	Urania1 (0.95/4)*	4545	2.5	237	19	27.5	10.7	91
BERER	Berko	Ludányhalászi/HU	Hulud1 (0.95/3)	2256	4.8	1540	30	190.6	154.6	1821
			Hulud2 (0.75/6)	4860	3.9	1103	29	180.4	91.5	1031
			Hulud3 (0.75/6)	4661	3.9	1052	30	183.5	87.8	804
BREMA	Breukers	Hengelo/NL	Mbb3(0.75/6)	2399	4.2	699	10	53.4	—	268
			Mbb4(0.8/8)	1477	—	—	14	55.7	—	249
BRIBE	Brinkmann	Herne/DE	Hermine (0.8/6)	2374	4.2	678	24	92.5	34.2	424
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	23	88.9	43.9	398
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	—	—	25	172.4	—	898
			Bmh2 (1.5/4.5)*	4243	3.0	371	27	128.2	155.9	613
CRIST	Crivello	Valbrevenna/IT	C3P8 (0.8/3.8)	5455	4.2	1586	29	212.6	275.2	1686
			Stg38 (0.8/3.8)	5614	4.4	2007	31	227.9	414.0	2573
CSISZ	Csizmadia	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	25	122.7	20.1	638
CURMA	Currie	Grove/UK	Mic4 (0.8/6)	2411	5.2	2373	5	17.0	—	154
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	30	222.7	181.0	1706
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	22	134.0	136.3	752
			Templar2 (0.8/6)	2080	5.0	1508	21	139.0	85.5	810
			Templar3 (0.8/8)	1438	4.3	571	24	114.1	64.1	653
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	21	105.7	—	569
HERCA	Hergenrother	Tucson/US	Salsa3 (1.2/4)*	2198	4.6	894	4	22.4	—	99
IGAAN	Igaz	Baja/HU	Hubaj (0.8/3.8)	5552	2.8	403	30	191.9	55.6	1310
		Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	20	124.7	70.9	1037
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	31	192.2	91.3	1418
		Budapest/HU	Hupol (1.2/4)	3790	3.3	475	14	74.0	19.4	551
		Sopron/HU	Husop (0.8/6)	2031	3.8	460	27	179.0	34.6	1094
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	22	122.1	—	849
KACJA	Kac	Kostanjevec/SI	Metka (0.8/8)*	1372	4.0	361	20	148.3	—	655
		Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	29	173.9	112.3	1580
		Kamnik/SI	Rezika (0.8/6)	2270	4.4	840	23	149.1	172.4	2177
			Stefka (0.8/3.8)	5471	2.8	379	22	148.9	45.2	1872
KERST	Kerr	Glenlee/AU	Gocam1 (0.8/3.8)	5189	4.6	2550	24	207.3	514.3	1734
KOSDE	Koschny	Noordwijkerhout/NL	Lic4 (1.4/50)*	2027	6.0	4509	14	62.6	117.9	365

Table 1 – Observers contributing to 2011 August data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Place	Camera	FOV [°2]	Stellar LM [mag]	Eff.CA [km2]	Nights	Time [h]	Tot.CA [10^3km^{2}h]	Meteors
LERAR	Leroy	Gretz/FR	SAPHIRA (1.2/6)	3260	3.4	301	26	69.3	—	216
LUNRO	Lunsford	Chula Vista/US	BOCAM (1.4/50)*	1860	5.1	1719	4	18.2	—	222
MACMA	Maciejewski	Chelm/PL	PAV35 (1.2/4)	4383	2.5	253	27	112.8	19.0	467
			PAV36 (1.2/4)*	5732	2.2	227	26	125.7	19.7	447
			PAV43 (0.95/3.75)*	2544	2.7	176	30	112.8	22.0	412
MOLSI	Molau	Seysdorf/DE	AVIS2 (1.4/50)*	1776	6.1	3817	12	59.9	250.6	1420
			MINCAM1 (0.8/8)	1477	4.9	1084	28	143.4	89.7	893
		Ketzür/DE	REMO1 (0.8/3.8)	5600	3.0	486	29	110.0	—	385
			REMO2 (0.8/3.8)	5613	4.0	1186	30	129.0	53.3	501
MORJO	Morvai	Fülöpszállás/HU	HUFUL (1.4/5)	2522	3.5	532	9	54.4	35.9	409
OTTMI	Otte	Pearl City/US	ORIE1 (1.4/5.7)	3837	3.8	460	29	155.8	—	891
PERZS	Perko	Becsehely/HU	HUBEC (0.8/3.8)*	5498	2.9	460	24	154.8	53.0	1509
ROTEC	Rothenberg	Berlin/DE	ARMEFA (0.8/6)	2366	4.5	911	22	83.7	—	426
SARAN	Saraiva	Carnaxide/PT	RO1 (0.75/6)	2362	3.7	381	21	120.9	—	643
			RO2 (0.75/6)	2381	3.8	459	14	72.0	30.2	415
SCALE	Scarpa	Alberoni/IT	LEO (1.2/4.5)	4133	—	—	17	124.3	—	716
SCHHA	Schremmer	Niederkrüchten/DE	DORAEMON (0.8/3.8)	4900	3.0	409	23	83.2	37.2	361
SLAST	Slavec	Ljubljana/SI	KAYAK1 (1.8/28)	588	—	—	12	57.9	—	177
STOEN	Stomeo	Scorze/IT	MIN38 (0.8/3.8)	5566	4.8	3270	30	221.4	352.9	2581
			NOA38 (0.8/3.8)	5609	4.2	1911	30	215.6	269.7	2196
			SCO38 (0.8/3.8)	5598	4.8	3306	30	217.1	273.4	2769
STORO	Stork	Kunžak/CZ	KUN1 (1.4/50)*	1913	5.4	2778	3	12.8	—	247
		Ondřejov/CZ	OND1 (1.4/50)*	2195	5.8	4595	3	12.6	51.1	328
STRJO	Strunk	Herford/DE	MINCAM2 (0.8/6)	2362	4.6	1152	18	37.9	—	203
			MINCAM3 (0.8/12)	728	5.7	975	22	53.6	—	263
			MINCAM5 (0.8/6)	2349	5.0	1896	24	64.6	53.5	377
TEPIS	Tepliczky	Budapest/HU	HUMOB (0.8/6)	2388	4.8	1607	29	163.6	97.7	1514
TRIMI	Triglav	Velenje/SI	SRAKA (0.8/6)*	2222	—	—	28	166.4	—	741
YRJIL	Yrjölä	Kuusankoski/FI	FINEXCAM (0.8/6)	2337	5.5	3574	23	73.0	63.7	624
ZELZO	Zelko	Budapest/HU	HUVCSE02 (0.95/5)	1606	3.8	390	2	9.0	—	40
						Overall	31	7 300.9	—	53 272

* active field of view smaller than video frame

Results of the IMO Video Meteor Network — September 2011

Sirko Molau[1], *Javor Kac*[2], *Erno Berko*[3], *Stefano Crivello*[4], *Enrico Stomeo*[5], *Antal Igaz*[6] *and Geert Barentsen*[7]

September 2011 was a very successful month for the IMO Video Meteor Network. More than 36 000 meteors were recorded in over 8 600 hours by 62 cameras. Activity profiles of the Antihelion source and sporadics in September are presented. The MetRec function for estimation of limiting magnitude is described in detail.

Received 2011 November 25

1 Introduction

August 2011 was successful, as March had been. And similar to the spring, when a successful month was beaten by an even better successor, the situation repeated in Fall. With respect to the observing conditions, September was close to perfect at almost every observing site. An amazing 42 out of 62 cameras collected twenty or more observing nights. With Stg38 of Stefano Crivello and Hudeb of Antal Igaz, there were once more two cameras successful in every night. The uninterrupted observing series of Stefano lasted from July 20 to October 6. That is, he could observe with Stg38 in 79 consecutive nights, which is an European record!

Between September 21 and 27, more than 50 cameras were in operation; on September 23 and 24 there were 57 cameras. Is there any further proof necessary for the splendid weather? As the nights were getting longer in the northern hemisphere it is not a big surprise that we collected more than 8 600 observing hours in September (Table 1 and Figure 1), which is an increase of 20% compared to the preceding month (Molau et al., 2011a). For comparison, that is more observing time than we collected in the first three years of the camera network combined. With "only" 36 000 meteors, September could not quite rival August due to the missing Perseids, but that is still twice the number of meteors recorded in the year before. In the last third of September we caught as many events as typical only during major meteor showers.

As in the previous few months, we would like to welcome new observers and cameras at this time. With Grigoris Maravelias we have the first Greek observer in our midst. Grigoris is observing from Crete with his camera Loomecon, a Watec 902H2 with 12 mm $f/0.8$ Panasonic lens. Detlef Koschny operated his new image-intensified camera Icc7 with 25 mm $f/0.85$ Fujinon lens for testing at his Dutch home. Meanwhile the camera has arrived in Tenerife, where regular observation shall start soon. Javor Kac has equaled Antal Igaz by bringing a fifth camera into operation. Cvetka consist of a Mintron camera with 3.8 mm $f/0.8$ Computar lens. Since September, Zoltan Zelko has been operating a second camera Huvcse03 at his balcony in Budapest. Last but not least the Belgian team of video observers grew thanks to Tom Roelands. Tom's camera Kempen is installed in Oostmalle and consists of a Watec 902H2 camera with a $f/0.95$ zoom lens.

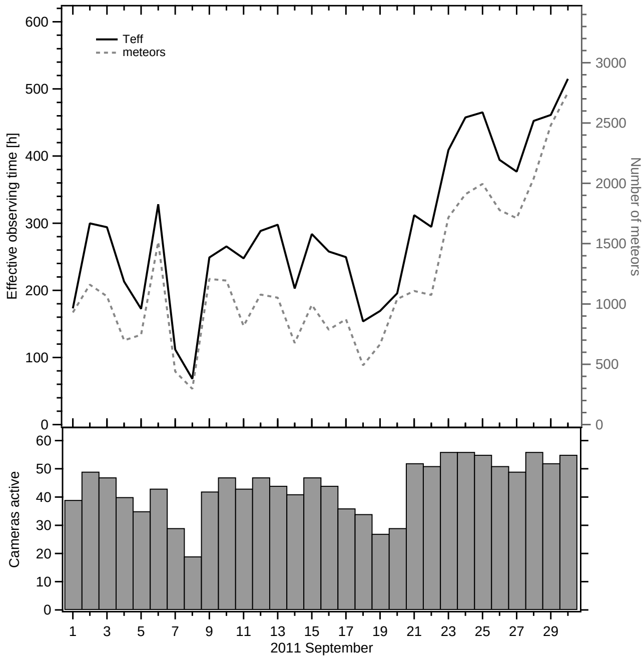

Figure 1 – Monthly summary for the effective observing time (solid black line), number of meteors (dashed gray line) and number of cameras active (bars) in 2011 September.

2 Sporadic activity in September

As September offers no major showers to us, we now will have another look at the sporadic activity. Our May 2011 analysis had shown that their activity profile is not uniform, but contains a clear increase towards the (local) morning hours (Molau et al., 2011b). Consequently the modeling was changed such that sporadic meteors are now considered as a "weighted mix" of different radiation areas (Apex/Antapex, Helion, N/S Torodial). The comparison with the September data (Figure 2) shows that the systematic variations did not fully disappear, but got significantly smaller. Furthermore it is no longer a continuous increase towards dawn: In some cases the flux density is approximately constant,

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NASA-ADS bibcode 2011JIMO...39..193M

in some cases it is raising or falling, and in some cases the activity even seem to peak at midnight.

The observations and analyses of the previous months allowed another insight to mature. Be it the unknown population index of a shower, the possible zenith exponent, the effective collection area of a camera or the loss in limiting meteor magnitude by the angular velocity of meteors – all these effects are secondary. Prime factors for the determination of the flux density are the effective observing time per minute and the stellar limiting magnitude. Only these two parameters are directly estimated during the observation and cannot be corrected. All other factors may be analyzed and possibly adjusted later on.

The effective observing time can be measured easily – a robust estimation of the limiting magnitude is not trivial, however. This summer Sirko Molau spent some time to improve the procedure, and now we learn the first fruits of this work. To demonstrate the problems we have to deal with, let us discuss some aspects of the algorithm in more detail now.

2.1 Estimation of the limiting magnitude

First we will recapitulate how the lm estimation works in principle. At first, all pixels are segmented from an averaged and nearly noise-free image, which are by a certain amount brighter than their neighborhood (Figure 3, left). Based on a star catalog and the plate constants it is calculated in parallel which star should be visible at what position in the field of view at the given point in time (Figure 3, right). In the end it is checked, which segmented pixel fit to what catalog star based only on their position. The identified stars are counted and transformed in a similar fashion to visual star field counts into an (average) limiting magnitude in the field of view.

First we learned that estimating the limiting magnitude requires a precise astrometry. If the camera deviates only slightly from its original position or if the plate constants are only roughly estimated due to lack of reference stars, some of the segmented stars cannot be identified anymore. Consequently, together with the number of identified stars the limiting magnitude is decreasing, and the calculated flux density is increasing.

A simple solution would be to allow for larger tolerances when the stars are identified. However, the procedure must be compatible with a large variety of cameras and observing conditions. It must cover from an aging Mintron cameras with wide angle lenses that show more hot pixels than stars, to an image-intensified cameras with 500 stars or more in a small compass (Figure 4). If the allowed tolerances are increased there will be a catalog star fit to most pixels, no matter whether it is a real star or just noise.

The members of the IMO network soon realized that the highest precision is required when measuring the reference stars. A nice by-product is the improved accuracy of the calculated meteor positions.

Beside the tolerance range there are two thresholds that have a particular impact on the lm determination. On the one hand, there is the threshold to determine when a pixel rises above the background and is segmented. This threshold was fixed in the first implementation, and it was determined during measurement of the reference image. Later we saw that this threshold may vary with the observing conditions. Due to (automatic) gain control, the noise of the camera significantly increases when skies are fully dark, whereas the noise level reduces at dawn or when bright clouds are present. In addition, the ideal threshold depends on the (unknown) limiting magnitude of the camera. The better the limiting magnitude, the more stars do we expect (under clear skies). And here is the problem: If the threshold is lowered to segment sufficient stars, more stars will automatically be identified (partly also noise), which will further increase the limiting magnitude. That yields the next reduction of the threshold, etc. So we have to cope with a feedback loop that has to be damped such that the threshold and the limiting magnitude will converge to stable values even under most variable conditions.

The second threshold determines up to which magnitude stars from the catalog are taken to identify the segmented pixels. Also here the threshold should only slightly be higher than the real lm. If it is too low, 100% of the stars will be identified and you get exactly the limiting magnitude that you defined before as threshold. If it is too big, however, the number of catalog stars grows exponentially and the probability is increasing that for each segmented pixel (star or noise) some catalog star fits. Thus, the limiting magnitude is overestimated and the threshold is further growing in the next step. So here we have another feedback loop.

The current implementation is roughly as follows: The threshold for segmenting pixels is adjusted according to the number of identified stars in the previous minute. If no star was found it is updated such that about 30 pixels are segmented. If n stars were identified, then the threshold is adjusted such that about $n + x$ pixels are segmented. At first, the extra x is 100% of n. With growing number of stars, the extra x is decreasing in percentages. At 500 stars, the extra is only 10% (all values set empirically). That accounts for the fact that the star density in the field of view and thereby the probability of a chance alignment between segmented noise and weak catalog star is growing.

In parallel, the limiting magnitude for catalog stars is determined from the stellar lm in the previous minute plus an extra one magnitude. A smaller extra was not possible, because in case of image-intensified cameras, uneven cloudiness, moon twilight etc. the lm varies significantly in the field of view. The faintest visible stars are clearly fainter than the average limiting magnitude of the field of view. In addition, there are upper and lower limits based on the best limiting magnitude of the camera.

The final equations for the noise level and limiting magnitude are as follows:

$$r = n/(n + x)$$
$$t = \log(n + x - 30)/\log(1000 - 30)$$

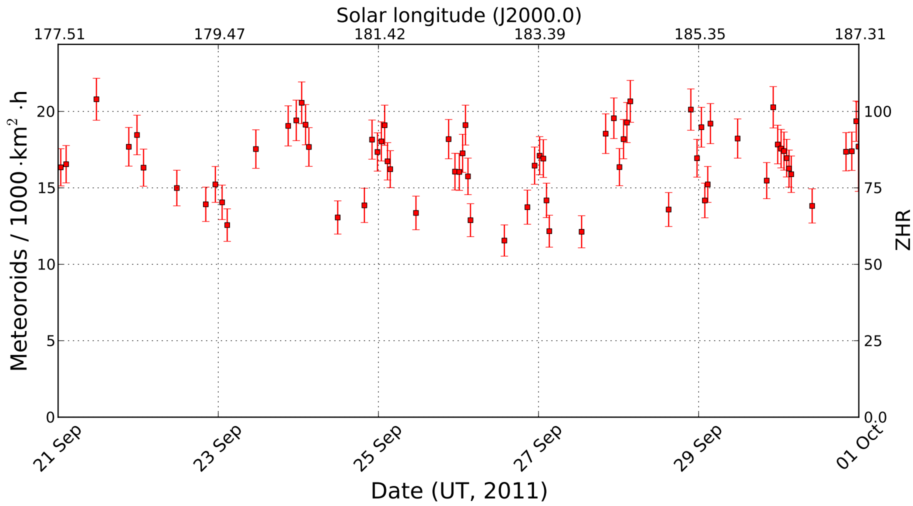

Figure 2 – Flux density of the sporadic meteors in the last third of September 2011, derived from observation of the IMO Video Network.

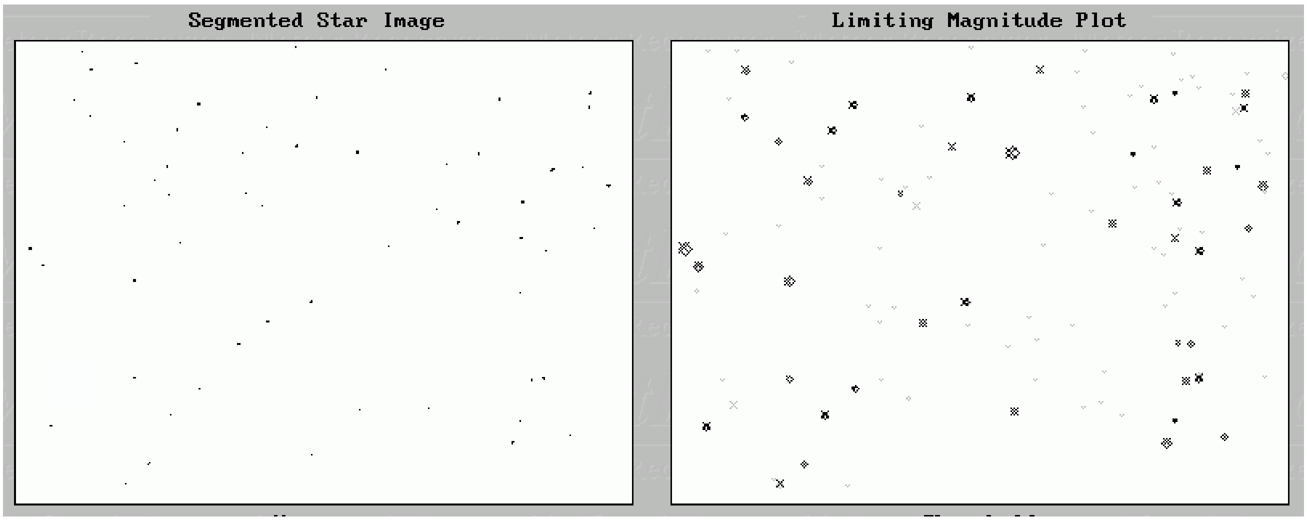

Figure 3 – Limiting magnitude estimation for Mincam1: On the left side, all pixels are marked that are a certain amount brighter than their neighborhood. On the right side the corresponding section of the star catalog is shown. All stars that fit are marked in bold (approx. 50).

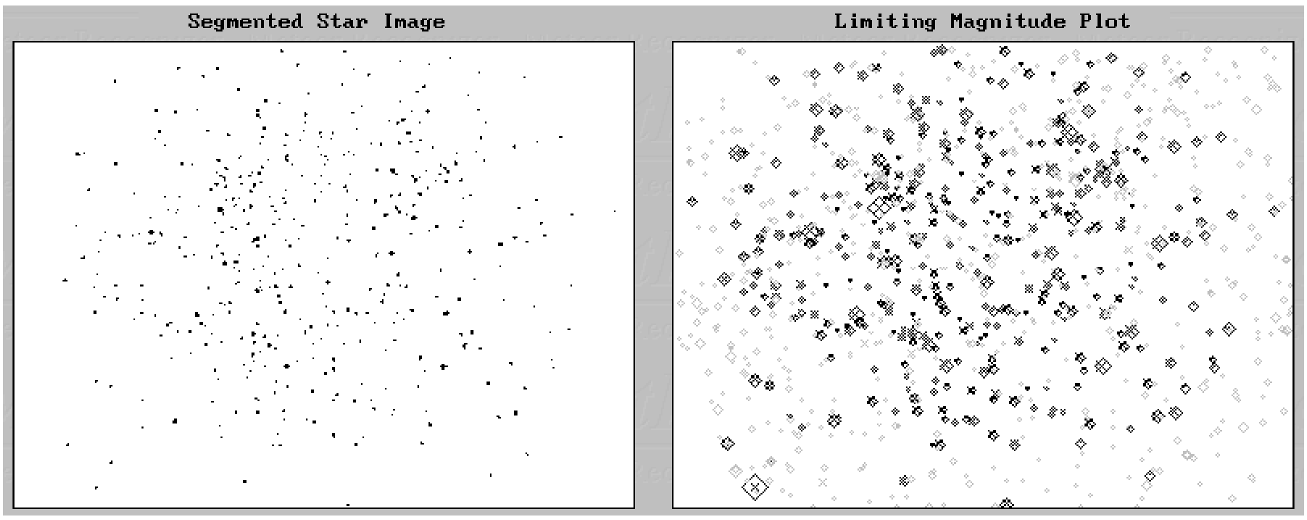

Figure 4 – Limiting magnitude determination for the image-intensified camera Avis2. Due to the tremendous sensitivity, a few hundred stars can be identified in the center. Towards the edges the sensitivity is significantly decreasing, though.

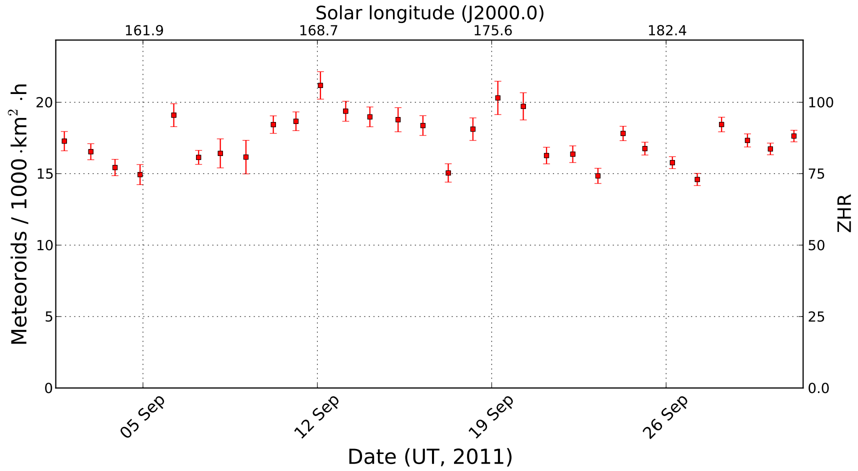

Figure 5 – Flux density profile of the sporadic meteors in September 2011 from data of the IMO Video Network.

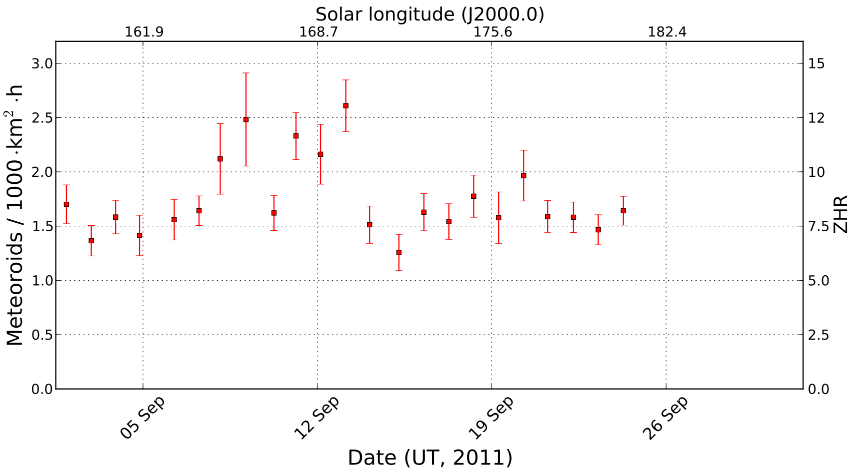

Figure 6 – Flux density profile of the Antihelion source in September 2011 from data of the IMO Video Network.

$$
\begin{array}{lll}
nl_{(t+1)} = nl_{(t)} + 2 & \text{if} & t - r > 0.2 \\
nl_{(t+1)} = nl_{(t)} + 1 & \text{if} & 0.2 > t - r \geq 0.1 \\
nl_{(t+1)} = nl_{(t)} + 0 & \text{if} & 0.1 > t - r \geq -0.1 \\
nl_{(t+1)} = nl_{(t)} - 1 & \text{if} & -0.1 > t - r \geq -0.2 \\
nl_{(t+1)} = nl_{(t)} - 2 & \text{if} & -0.2 > t - r
\end{array}
$$
$$lmcs_{(t+1)} = lms_{(t)} + 1$$

where r is the identification ratio, t the target ratio, n the number of identified stars, x the number of unidentified stars, 30 ... 1000 is range of segmented stars, $nl_{(t)}$ is noise level at time t, $nl_{(t+1)}$ is noise level at time $t+1$, $lmcs_{(t+1)}$ is lm for catalog stars at time $t+1$ and $lms_{(t)}$ is stellar lm at time t.

The last few weeks have taught us that despite the risk from the described feedback loops, the procedure yields a robust lm estimation under a large variety of cameras (variable sensitivity, vignetting), fields of view (wide angle or tele lens) and observing conditions (clear skies, fog, clouds, Moon, twilight). In Spring the calculated sporadic flux density easily varied by a factor of ten from one camera to the next. Now we obtain with most cameras a value of roughly 15 meteoroids per 1 000 km^2 per hour with systematic deviations that are rarely larger than a factor of two in either direction. Only some, mostly weak, cameras still yield values beyond 50. Here a further analysis has to show why lm is underestimated and how the algorithm can be optimized further.

As evidence for the consistent limiting magnitude estimation, Figure 5 presents the overall profile of the sporadic flux density in September 2011. It shows that the values are within a small range of 15 to 20 meteoroids per 1 000 km^2 per hour. The differences from one day to the next are typically even smaller.

Finally, Figure 6 shows the same graph for the Antihelion source. Here in particular a rate increase between September 8 and 14 looks interesting, which may point to some sub-structure. After September 24 the shower is not detected anymore because then it merges by definition into the Taurids.

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Molau S., Kac J., Berko E., Crivello S., Stomeo E., Igaz A., and Barentsen G. (2011b). "Results of the IMO Video Meteor Network – May 2011". *WGN, Journal of the IMO*, **39:4**, 105–109.

Handling Editor: Javor Kac

Table 1 – Observers contributing to 2011 September data of the IMO Video Meteor Network. Eff.CA designates the effective collection area and Tot.CA the total collection area.

Code	Name	Place	Camera	FOV [°²]	Stellar LM [mag]	Eff.CA [km²]	Nights	Time [h]	Tot.CA [10³km²h]	Meteors
BASLU	Bastiaens	Hove/BE	Urania1 (0.8/3.8)*	4545	2.5	237	12	21.8	13.1	18
BERER	Berko	Ludányhalászi/HU	Hulud1 (0.95/3)	2256	4.8	1540	27	217.9	208.2	1131
			Hulud2 (0.75/6)	4860	3.9	1103	24	191.5	116.6	574
			Hulud3 (0.75/6)	4661	3.9	1052	26	182.7	120.1	390
BREMA	Breukers	Hengelo/NL	Mbb3(0.75/6)	2399	4.2	699	5	45.2	—	139
			Mbb4(0.8/8)	1477	—	—	5	33.1	—	115
BRIBE	Brinkmann	Herne/DE	Hermine (0.8/6)	2374	4.2	678	25	168.1	69.7	574
		Bergisch Gladbach/DE	Klemoi (0.8/6)	2286	4.6	1080	26	142.9	127.4	638
CASFL	Castellani	Monte Baldo/IT	Bmh1 (0.8/6)	2350	—	—	15	75.6	—	230
			Bmh2 (1.5/4.5)*	4243	3.0	371	20	107.0	185.1	383
CRIST	Crivello	Valbrevenna/IT	C3P8 (0.8/3.8)	5455	4.2	1586	25	190.3	221.7	720
			Stg38 (0.8/3.8)	5614	4.4	2007	30	242.7	315.6	1636
CSISZ	Csizmadia	Zalaegerszeg/HU	Huvcse01 (0.95/5)	2423	3.4	361	21	99.2	18.4	283
ELTMA	Eltri	Venezia/IT	Met38 (0.8/3.8)	5631	4.3	2151	24	225.8	178.2	791
GONRU	Goncalves	Tomar/PT	Templar1 (0.8/6)	2179	5.3	1842	27	203.1	250.1	935
			Templar2 (0.8/6)	2080	5.0	1508	27	211.5	137.2	873
			Templar3 (0.8/8)	1438	4.3	571	24	106.7	106.7	565
GOVMI	Govedič	Središče ob Dravi/SI	Orion2 (0.8/8)	1447	5.5	1841	26	157.5	288.1	714
HERCA	Hergenrother	Tucson/US	Salsa3 (1.2/4)*	2198	4.6	894	11	95.9	32.8	360
IGAAN	Igaz	Baja/HU	Hubaj (0.8/3.8)	5552	2.8	403	25	161.2	54.3	577
		Debrecen/HU	Hudeb (0.8/3.8)	5522	3.2	620	30	225.7	116.0	729
		Hódmezővásárhely/HU	Huhod (0.8/3.8)	5502	3.4	764	27	228.6	97.0	652
		Sopron/HU	Husop (0.8/6)	2031	3.8	460	25	164.3	—	737
JONKA	Jonas	Budapest/HU	Husor (0.95/4)	2286	3.9	445	27	193.1	155.5	726
KACJA	Kac	Kostanjevec/SI	Metka (0.8/8)*	1372	4.0	361	19	152.9	43.9	276
		Ljubljana/SI	Orion1 (0.8/8)	1402	3.8	331	27	194.8	87.3	730
		Kamnik/SI	Cvetka (0.8/3.8)	4914	4.3	1842	17	134.7	129.3	807
			Rezika (0.8/6)	2270	4.4	840	17	145.3	214.2	1320
			Stefka (0.8/3.8)	5471	2.8	379	18	154.1	80.5	717
KERST	Kerr	Glenlee/AU	Gocam1 (0.8/3.8)	5189	4.6	2550	23	166.3	407.2	746
KOSDE	Koschny	Noordwijkerhout/NL	Icc7 (0.85/25)	714	5.9	1464	17	66.5	100.0	282
			Lic4 (1.4/50)*	2027	6.0	4509	17	85.3	164.4	360

Table 1 – Observers contributing to 2011 September data of the IMO Video Meteor Network – continued from previous page.

Code	Name	Place	Camera	FOV [°2]	Stellar LM [mag]	Eff.CA [km^2]	Nights	Time [h]	Tot.CA [10^3km^{2}h]	Meteors
LERAR	Leroy	Gretz/FR	Saphira (1.2/6)	3260	3.4	301	14	63.4	—	83
MACMA	Maciejewski	Chelm/PL	Pav35 (1.2/4)	4383	2.5	253	25	119.1	—	212
			Pav36 (1.2/4)*	5732	2.2	227	24	130.6	—	180
			Pav43 (0.95/3.75)	2544	2.7	176	25	133.4	31.6	213
MARGR	Maravelias	Lofoupoli-Crete/GR	Loomecon (0.8/12)	738	6.3	2698	5	36.6	37.0	241
MOLSI	Molau	Seysdorf/DE	Avis2 (1.4/50)*	1776	6.1	3817	20	155.8	546.1	2535
			Mincam1 (0.8/8)	1477	4.9	1084	24	171.8	176.8	672
		Ketzür/DE	Remo1 (0.8/3.8)	5600	3.0	486	25	126.6	—	280
			Remo2 (0.8/3.8)	5613	4.0	1186	27	177.7	106.9	475
MORJO	Morvai	Fülöpszállás/HU	Huful (1.4/5)	2522	3.5	532	28	194.6	122.0	571
OTTMI	Otte	Pearl City/US	Orie1 (1.4/5.7)	3837	3.8	460	27	130.7	—	639
PERZS	Perko	Becsehely/HU	Hubec (0.8/3.8)*	5498	2.9	460	25	173.8	100.8	1148
ROETO	Roeland	Oostmalle/BE	Kempen (0.95/8)	1593	4.2	524	10	73.3	—	72
ROTEC	Rothenberg	Berlin/DE	Armefa (0.8/6)	2366	4.5	911	16	80.7	63.0	250
SARAN	Saraiva	Carnaxide/PT	Ro1 (0.75/6)	2362	3.7	381	19	122.4	—	402
			Ro2 (0.75/6)	2381	3.8	459	4	20.6	—	56
SCALE	Scarpa	Alberoni/IT	Leo (1.2/4.5)	4133	—	—	27	206.7	—	689
SCHHA	Schremmer	Niederkrüchten/DE	Doraemon (0.8/3.8)	4900	3.0	409	22	89.1	55.5	338
SLAST	Slavec	Ljubljana/SI	Kayak1 (1.8/28)	588	—	—	25	119.4	—	430
STOEN	Stomeo	Scorze/IT	Min38 (0.8/3.8)	5566	4.8	3270	26	208.2	370.8	1248
			Noa38 (0.8/3.8)	5609	4.2	1911	26	206.8	292.3	988
			Sco38 (0.8/3.8)	5598	4.8	3306	27	210.1	230.3	1440
STRJO	Strunk	Herford/DE	Mincam2 (0.8/6)	2362	4.6	1152	15	75.1	60.6	257
			Mincam3 (0.8/12)	728	5.7	975	22	89.2	46.6	358
			Mincam5 (0.8/6)	2349	5.0	1896	21	105.8	104.2	499
TEPIS	Tepliczky	Budapest/HU	Humob (0.8/6)	2388	4.8	1607	24	191.4	137.8	1013
TRIMI	Triglav	Velenje/SI	Sraka (0.8/6)*	2222	—	—	25	113.8	88.3	310
YRJIL	Yrjölä	Kuusankoski/FI	Finexcam (0.8/6)	2337	5.5	3574	21	99.1	162.2	425
ZELZO	Zelko	Budapest/HU	Huvcse02 (0.95/5)	1606	3.8	390	19	124.1	—	330
			Huvcse03 (1.0/4.5)	2224	4.4	933	8	58.2	48.4	156
						Overall	30	8 659.1	—	36 284

* active field of view smaller than video frame

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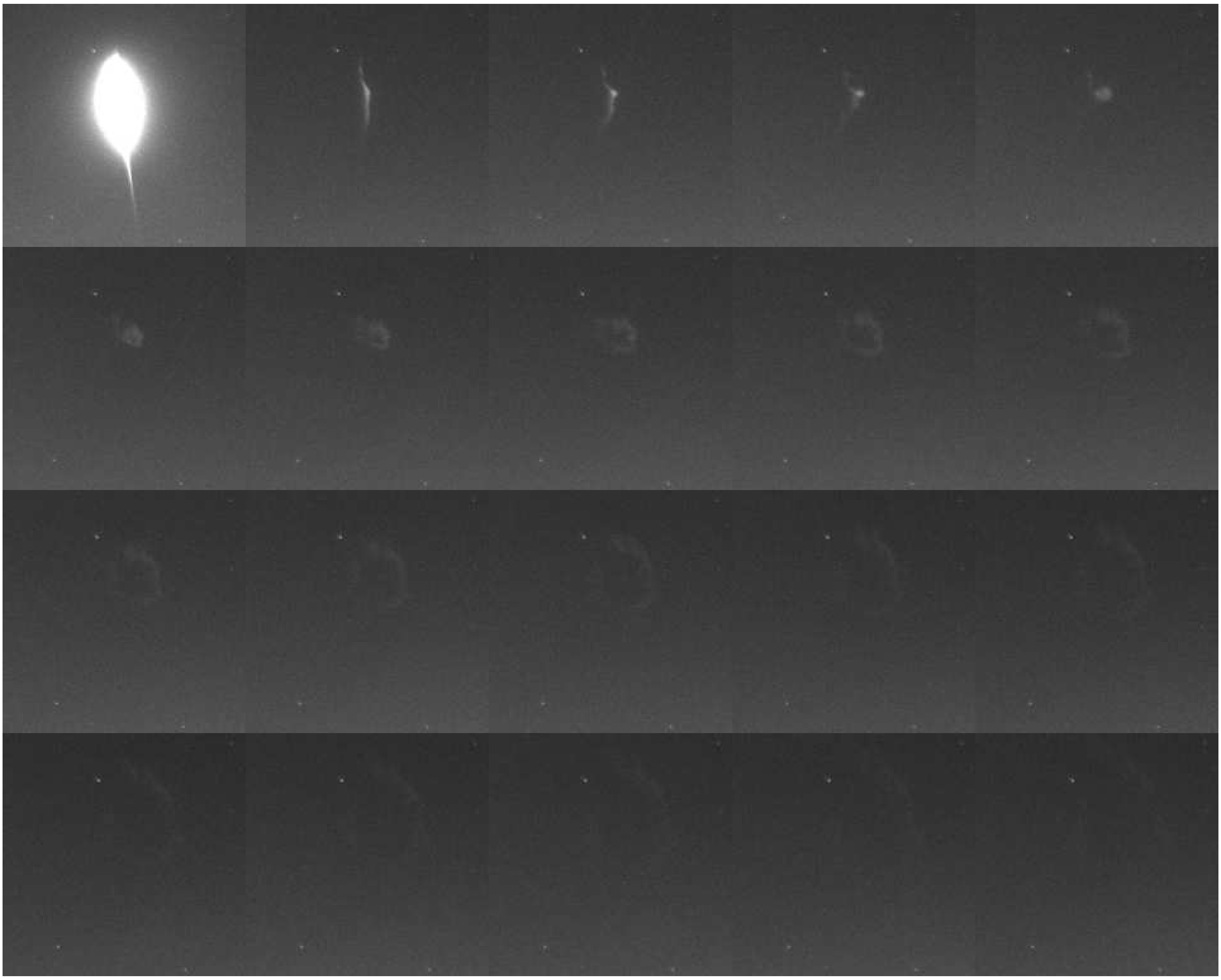
Leonid fireball with persistent train



This bright Leonid fireball was recorded on 2011 November 19 at $04^{h}07^{m}51^{s}$ UT by Peter Meadows from Great Baddow, Chelmsford, Essex, UK. Development of persistent train until $04^{h}10^{m}46^{s}$ UT is shown in this sequence. The images were taken using an Imaging Source monochrome DMK AU03 Camera with Opticstar 2.8–12.0 mm $f/1.4$ Lens. Each exposure was 9.7 s in duration with successive images also taken every 9.7 s. The full frame image of the fireball is shown below – note the bright Moon at the bottom.