Geminids: 30 years of observations (1980–2009)

Koen Miskotte[1], *Carl Johannink*[2], *Michel Vandeputte*[3] *and Peter Bus*

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?

[1]De la Reystraat 92, 3851 BK Ermelo, Netherlands. Email: k.miskotte@upcmail.nl

[2]Schiefestr. 36, 48599 Gronau, Germany. Email: c.johannink@t-online.de

[3]Cachette Pierrette 78, 9600 Ronse, Belgium. Email: michelvandeputte@hotmail.com

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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

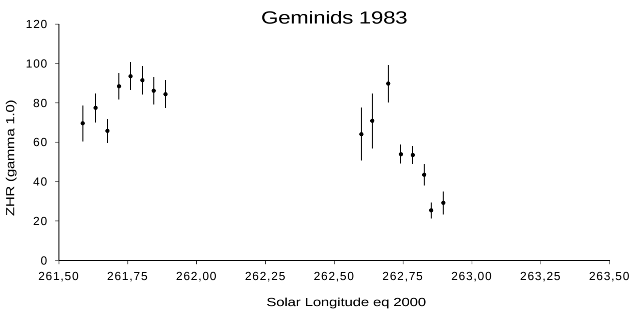

Figure 2 – Geminids 1983 based on data for 1659 Geminids observed by BREHA, JOBKL, JOHCA, MISKO, NIJJO and RISBA.

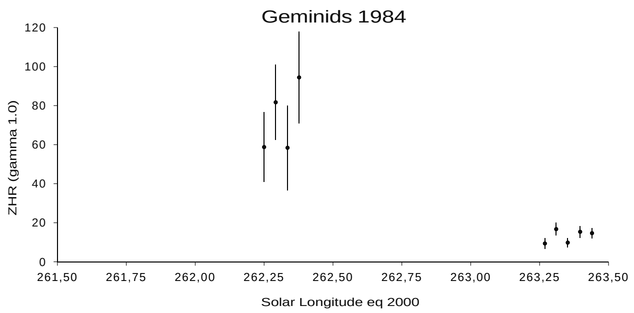

Figure 3 – Geminids 1984 after correction of the original limiting magnitudes. Based on data for 310 Geminids observed by GRIAR, HAARO, JOBKL, KELER, MISKO and RISBA.

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 $01^{\mathrm{h}}00$ 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.

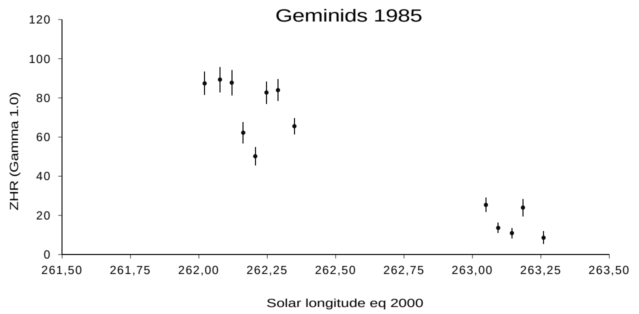

Figure 5 – Geminids 1985 based on data for 1660 Geminids observed by JOBKL and ROGPA.

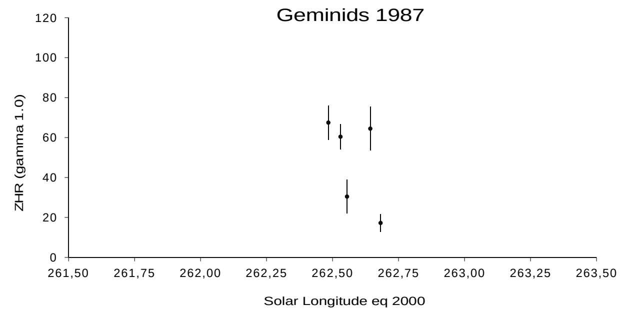

Figure 6 – Geminids 1987 based on data for 217 Geminids observed by RISBA and ROGPA.

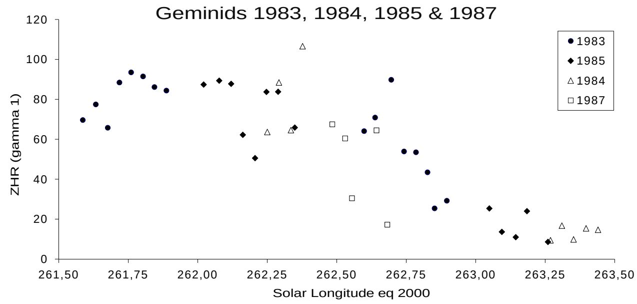

Figure 7 – Combined ZHR curves for 1983, 1984, 1985 and 1987.

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 $23^{\mathrm{h}}00^{\mathrm{m}}$ and $02^{\mathrm{h}}00^{\mathrm{m}}$ 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

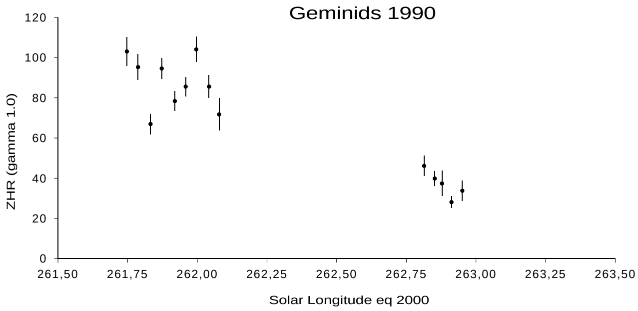

Figure 8 – Geminids 1990 based on data for 2483 Geminids observed by JENPE, JOBKL, LIGMA and ROGPA.

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.

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

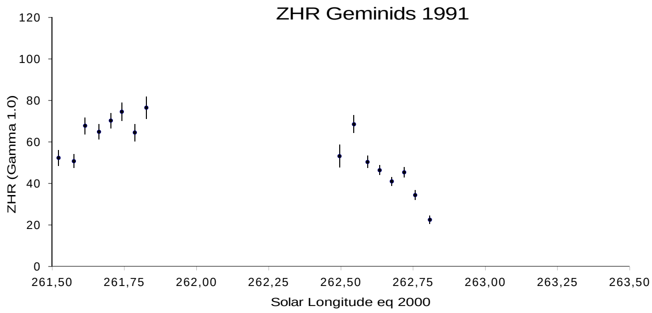

Figure 10 – Geminids 1991 based on data for 4194 Geminids observed by BENPA, HAARO, JENPE, JOBKL, JOHCA, KELER, LANMA, LEVJA, LIGMA, MISKO, RISBA, ROGPA and SCHAL.

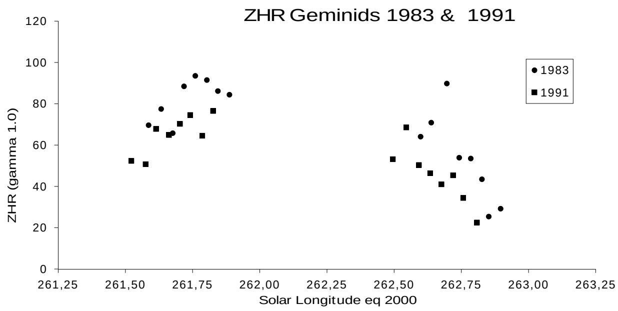

Figure 11 – Geminid curves for 1983 and 1991 in the same graph show clearly the much lower ZHR in 1991.

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

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

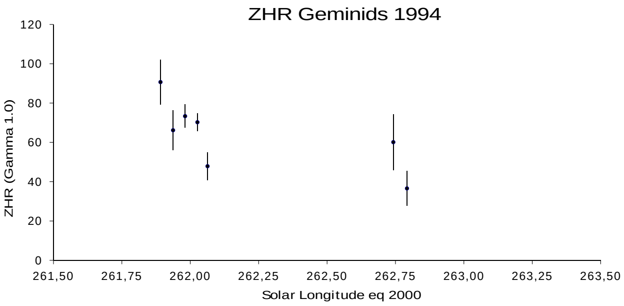

Figure 12 – Geminids 1994 based on data for 603 Geminids observed by BETHA, HAARO, JOBKL, LANMA, MISKO and SCHAL.

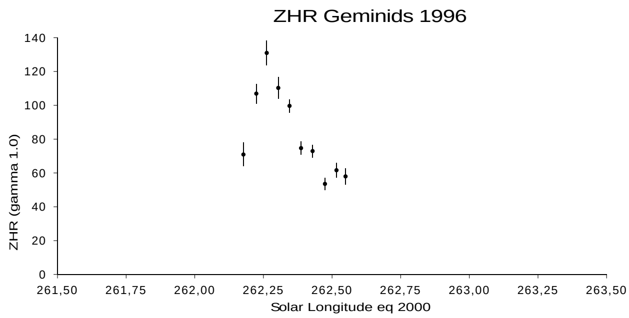

Figure 13 – Geminids 1996 based on data for 2995 Geminids observed by JOHCA, LANMA, LEVJA, MILOL, MISKO and NIJJO.

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."

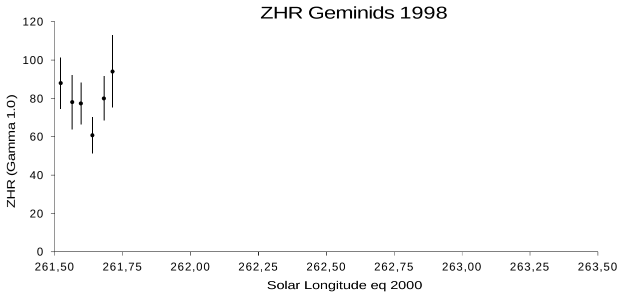

Figure 15 – Geminids 1998 based on data for 238 Geminids observed by SCHAL.

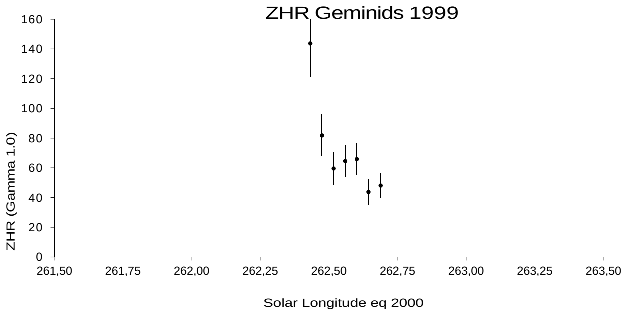

Figure 16 – Geminids 1999 based on data for 239 Geminids observed by VANMC.

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.

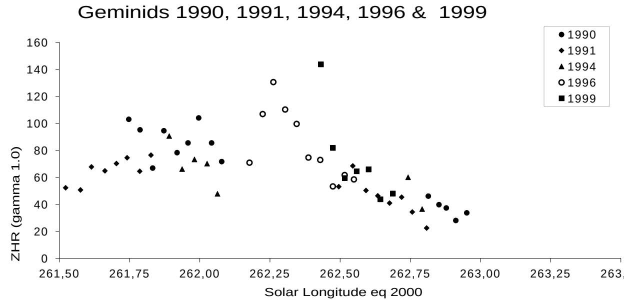

Figure 17 – Combined ZHR curves for 1990, 1991, 1994, 1996 and 1999.

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

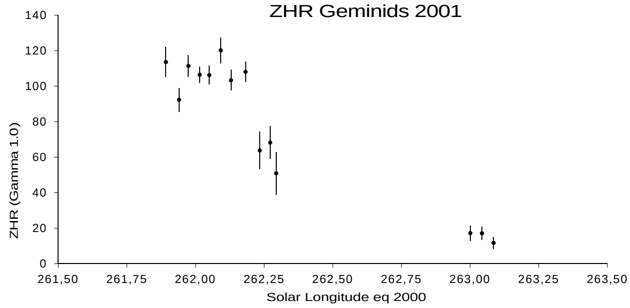

Figure 18 – Geminids 2001 based on data for 2739 Geminids observed by DIJSI, JOHCA, LANMA, MISKO, OSVDA, SCHAL, VANMC, VANSI and VERRI.

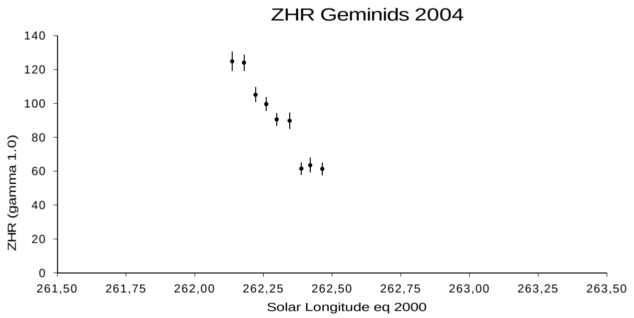

Figure 19 – Geminids 2004 based on data for 4088 Geminids observed by BIEJE, DIJSI, JOHCA, KEERO, MISKO, TUKAR, VANMC and VERRI.

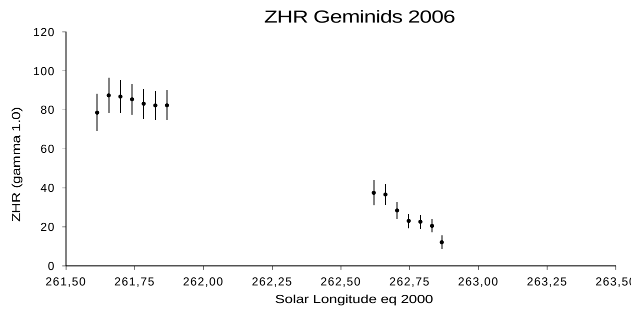

Figure 20 – Geminids 2006 based on data for 1009 Geminids observed by VANMC.

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

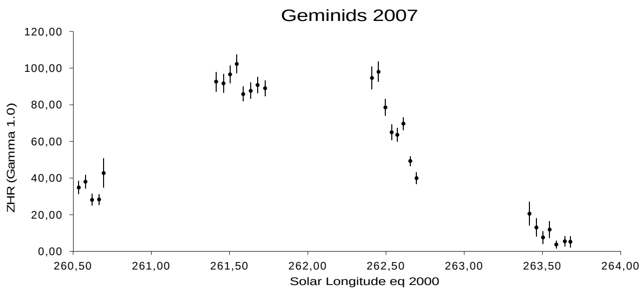

Figure 21 – Geminids 2007 based on data for 5807 Geminids observed by BETFE, DIJSI, JOHCA, LEUPE, MISKO, NIJJO, VANMC and VANSI.

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

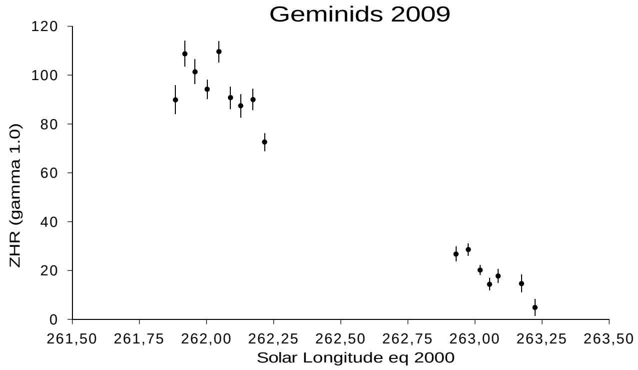

Figure 23 – Geminids 2009 based on data for 4185 Geminids observed by BETFE, BETHA, BIEJE, DIJSI, JOHCA, KEERO, LEUPE, MISKO, NIJJO, SCHAL and VANMC.

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°90 and 262°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).

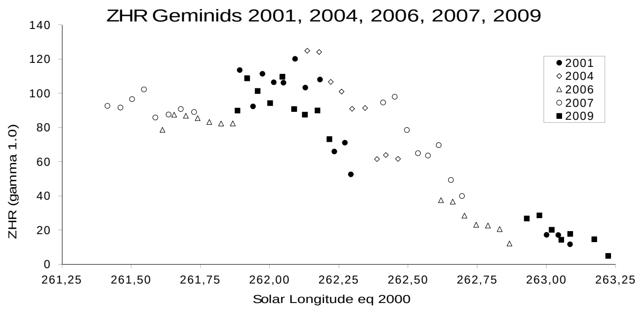

Figure 25 – Combined ZHR curves of the Geminids 2001, 2004, 2006, 2007 and 2009.

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

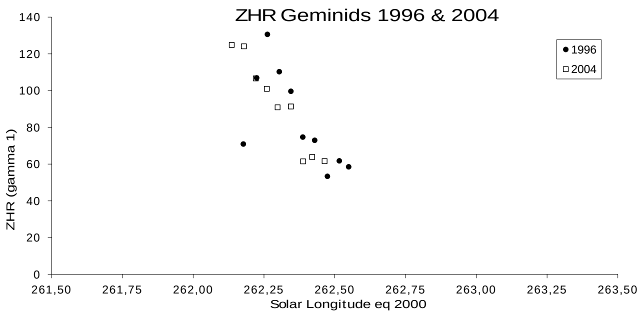

Figure 26 – Geminids 1996 and 2004.

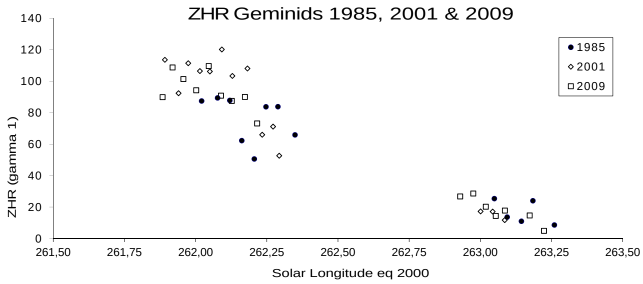

Figure 27 – Geminids 1985, 2001 and 2009.

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 $261^\circ\!.01 \pm 0^\circ\!.02$ and solar longitude $262^\circ\!.34 \pm 0^\circ\!.01$. IMO (period 1988 to 1997) found solar longitude $262^\circ\!.12 \pm 0^\circ\!.02$ (ZHR 140) and solar longitude $262^\circ\!.33 \pm 0^\circ\!.02$ (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.
<u>1988</u>: Unfortunately no data for this return.
<u>1996</u>: A very high and rather sharp maximum appears around solar longitude $262^\circ\!.25 - 262^\circ\!.30$. 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.
<u>2004</u>: 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 $262^\circ\!.35$. 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.

<u>2012</u>: 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 $262^\circ\!.0 - 262^\circ\!.1$ 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.
<u>1985</u>: Main peak around solar longitude $262^\circ\!.0 - 262^\circ\!.1$ followed by a significant dip (be it perhaps slightly influenced by the passage of some cirrus cloud) with a second peak at solar longitude $262^\circ\!.3$ (second main peak). The ZHR values agree with the literature for that period (ZHR 88 ± 4 in the period 1981–1991).
<u>1993</u>: Unfortunately no data.
<u>2001</u>: Maximum ZHR 120 at solar longitude $262^\circ\!.1$. A very deep dip at solar longitude $262^\circ\!.2$ 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.
<u>2009</u>: Peak between $261^\circ\!.9$ and $262^\circ\!.1$. The typical 'little maximum dip'; and then a modest revival around $262^\circ\!.2$. However, at the end of the night a sharp de-

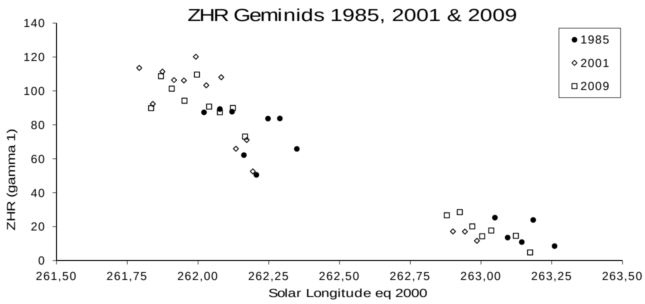

Figure 28 – The same profile as in Figure 27, but with the solar longitude shifted forward by $0\overset{\circ}{.}1$ for 2001 and by $0\overset{\circ}{.}05$ for 2009. It is remarkable that the profiles become exactly identical in shape with just a differences in ZHR level.

crease: is this the beginning of the same dip as seen in 1985 and 2001? Shifting the solar longitudes of 2009 $0\overset{\circ}{.}05$ (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 $261\overset{\circ}{.}6 - 261\overset{\circ}{.}9$). 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.

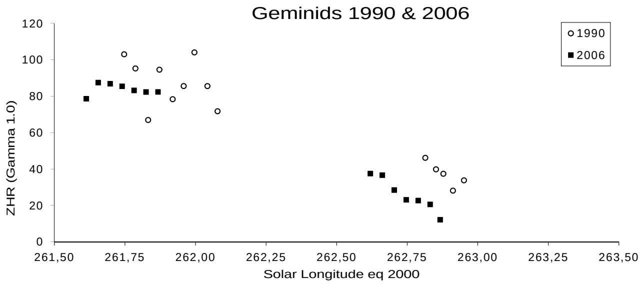

Figure 29 – Geminids 1990 and 2006.

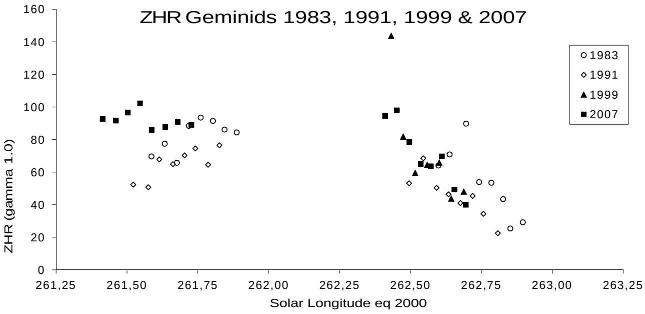

Figure 30 – Geminids 1983, 1991, 1999 and 2007. 2007 has slightly higher ZHRs than in 1983. 1991 is clearly an outlier with considerable lower ZHRs in the night of December 13–14, this effect is less pronounced in the next night. See also part 5.2 for a possible explanation.

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 $261\overset{\circ}{.}2 - 261\overset{\circ}{.}8$. And a fireball parade between solar longitudes $262\overset{\circ}{.}50 - 262\overset{\circ}{.}68$.

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^h00^m and 04^h00^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^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^h – 04^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^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

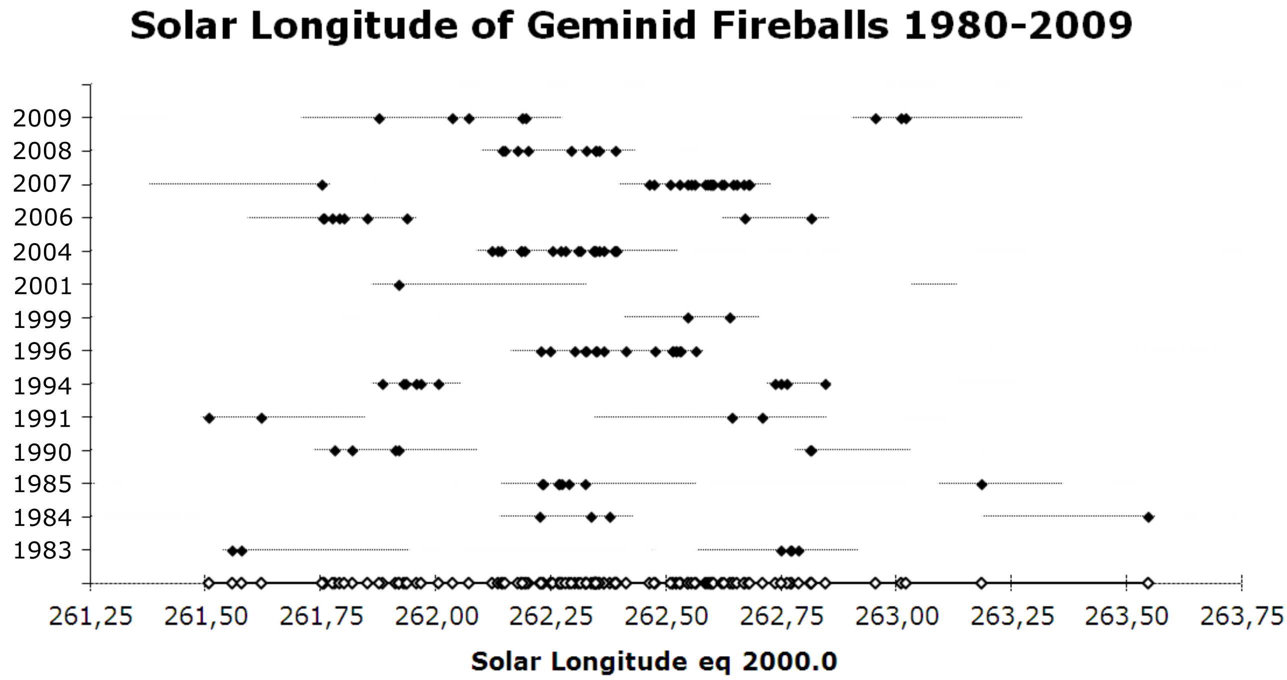

Figure 31 – All Geminid fireballs observed in the period 1980–2009 plotted in function of the solar longitude (eq 2000.0). The bottom line marks all fireballs while the higher lines indicate the fireballs per year in function of the solar longitude.

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.

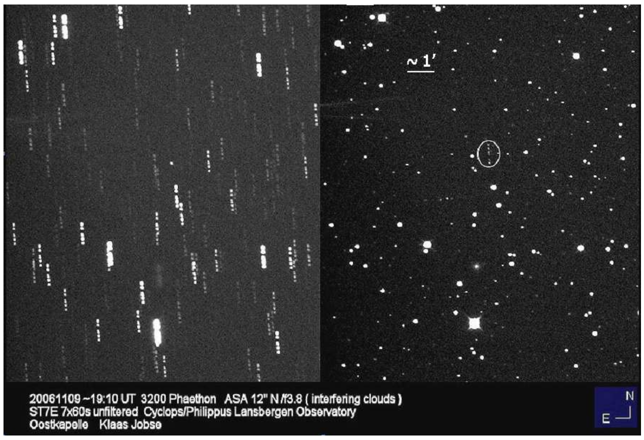

Figure 33 – Images of 3200 Phaethon taken by Klaas Jobse with his ASA 12"N/f 3.8 telescope.

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.

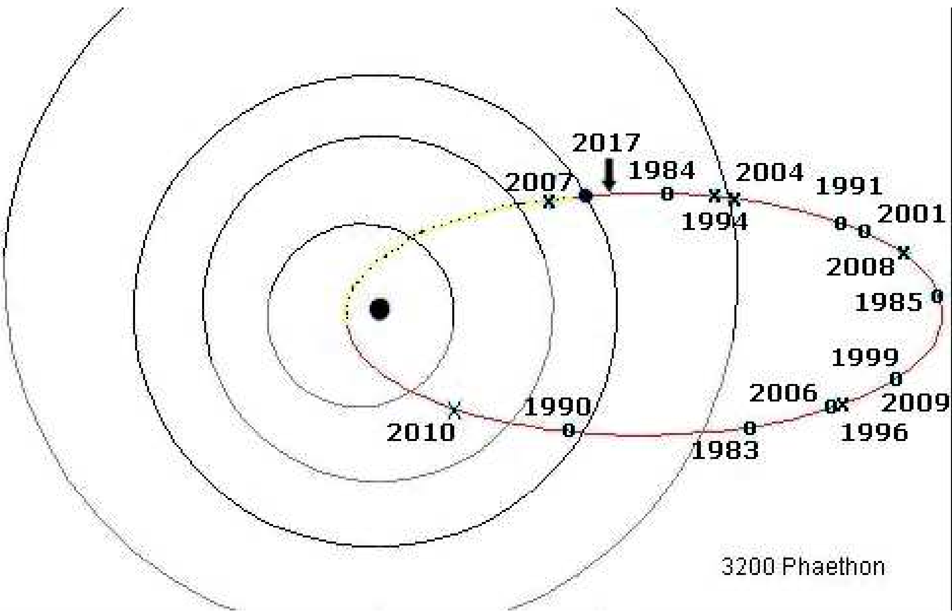

Figure 32 – The positions of 3200 Phaethon are projected on the elliptic orbit for each year when Geminids of −3 or brighter were observed (JPL HORIZONS on-line solar longitude system data and ephemeris computation service. `http://ssd.jpl.nasa.gov/?glossary&term=ephemeris`.), (Orbit Diagram: JPL Small-Body 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 $00^{\mathrm{h}}00^{\mathrm{m}}$ 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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