Short paper

Geminids 2012–2015: multi-year meteor videography

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NEMETODE, a network of low-light video cameras in and around the British Isles, operated in conjunction with the BAA Meteor Section and other groups, monitors the activity of meteors, enabling the precise measurement of radiant positions, of the altitudes and geocentric velocities of meteoroids and the determination of their former solar system orbits. The results from multi-year observations of the Geminid meteor shower are presented and discussed.

Equipment and methods

The NEMETODE team employed the equipment and methods described in previous papers[1,2] and on their website.[3] These included Genwac, KPF and Watec video cameras equipped with fixed and variable focal length lenses ranging from 2.6mm semi fish-eye models to 12mm narrow field systems.

The Geminid meteor stream

The Geminids (IAU MDC 004 GEM) are relatively slow meteors with geocentric velocities of 34 km/s, about half the speed of Perseids and Leonids. Although only apparent to visual observers for about 10 days in December, Geminids can be identified via imaging and triangulation from late November to early January. They are currently the most active and reliable annual shower, producing a ZHR of ~120 at maximum at solar longitude 262° (2016 December 13/14)[4] with a FWHM (full width half maximum) period of about a day.[5]

Table 1. The video observers, their locations and 4-year Geminids totals

Observer	*Location*	*No. Geminids*
David Anderson	Low Craighead, Scotland	454
Steve & Peta Bosley	Clanfield, England	9
Denis Buczynski	Tarbatness, Scotland	627
Allan Carter	Basingstoke, England	858
David Dunn	Lisores, France	40
Mike Foylan	Rathmolyon, Ireland	42
Nick James	Chelmsford, England	452
Frank Johns	Newquay, England	25
Steve Johnston	Warrington, England	8
Michael Morris	Worcester, England	140
Michael O'Connell	Monasterevin, Ireland	233
Alex Pratt	Leeds, England	1324
Nick Quinn	Steyning, England	20
Gordon Reinicke	Newbridge, Ireland	149
Graham Roche	Dublin, Ireland	160
Jeremy Shears	Bunbury, England	69
William Stewart	Ravensmoor, England	1616
Ray Taylor	Skirlaugh, England	29
	Total	6255

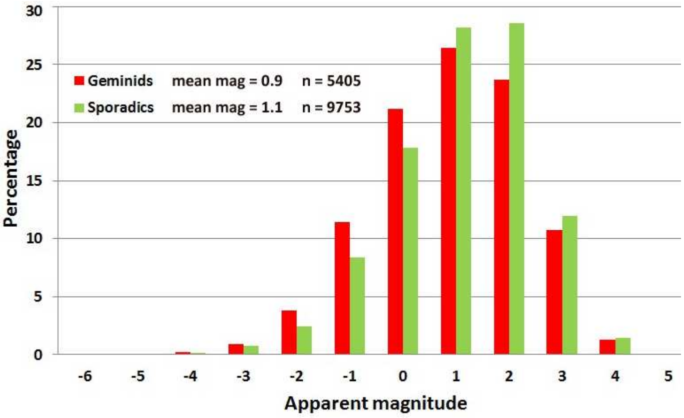

Figure 1. Magnitude distribution of the 2012–2015 Geminid meteors and contemporaneous sporadics.

Whereas most meteor showers originate from comets, the Geminid parent body is the Apollo asteroid (3200) Phaethon.

Results

The NEMETODE dataset contains 6255 single-station Geminids recorded by the observers listed in Table 1. *UFO Analyser* assigns meteors to a stream category. The normal Geminid shower limits are solar longitude 245°.6 to 279°.4 (Nov 27 to Dec 31 in 2016)[6] but, by default, *UFO Analyser* extends the *multi-station* search window to 10 days before and after these normal shower limits. As a result, the earliest probable Geminid from the four years under discussion was assigned on November 18 (Ravensmoor, in 2012) and the latest on January 10 (Skirlaugh, in 2016); a solar longitude range of 235°.936 to 289°.208. However, to reduce the probability of a random multi-capture outlier being inadvertently classified as a Geminid, we have used a search window extension of 0 days in this paper.

UFO Orbit supports three built-in quality assurance criteria:

Q1 – minimum criteria for radiant computation
Q2 – standard criteria for radiant and velocity computation
Q3 – criteria for high precision computation

The apparent magnitude distribution (measured by *UFO Analyser*) of the Q1-quality Geminids and contemporaneous sporadics is presented in Figure 1. It illustrates that the Geminids are relatively

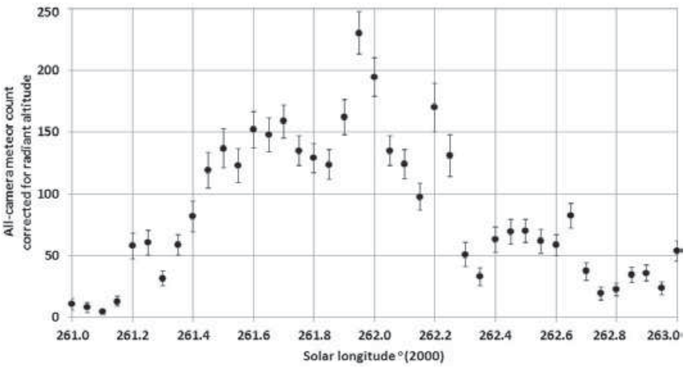

Figure 2. Peak activity profile of the 2012–2015 Geminids.

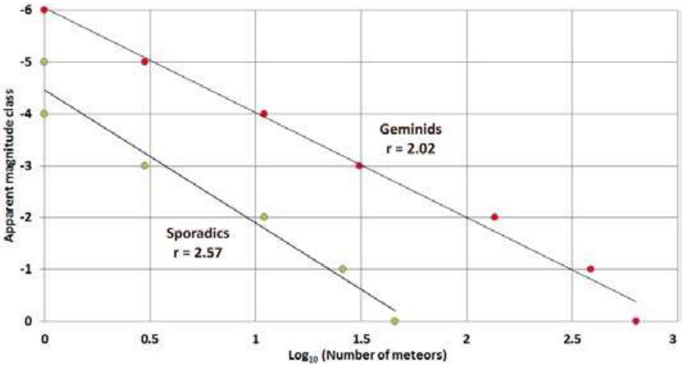

Figure 3. Peak activity population index of the 2012–2015 Geminids and contemporaneous sporadics.

rich in bright meteors but deficient in fainter meteors compared with the sporadic background.

To build a multi-year profile of peak activity, 2585 Q1-quality Geminids between solar longitudes 261° and 263° were corrected for radiant altitude and grouped into 0°.05 (~1.2 hour) bands (Figure 2). The plot suggests maximum rates occurred at solar longitude 261°.95 with a FWHM duration of 0.8 days, from 261°.45 to 262°.25.

Lesser peaks and troughs could be caused by data noise in solar longitude bands where stations had clear skies and good meteor rates or conversely, bad weather. Shower activity varies in detail every year and in future years when we have more data we will see if these features become more or less distinct.

The population index, r, of a meteor shower is the ratio of the number of meteors in adjacent magnitude classes. Most meteor showers have a population index between 2.1 and 3.0. Values of r lower than 2.5 indicate an older meteor stream that is depleted of smaller, fainter meteoroids. If n is the number of meteors with apparent magnitude m, the population index can be estimated from the linear relationship between $\log_{10} n$ and m.[7] This is presented in Figure 3, and is derived using the data from Figure 2 for Geminids in the apparent magnitude range −6 to 0 and for sporadic meteors during the same interval, giving a population index of 2.02 and a correlation coefficient of 0.995 (sporadics, 2.57 and 0.981).

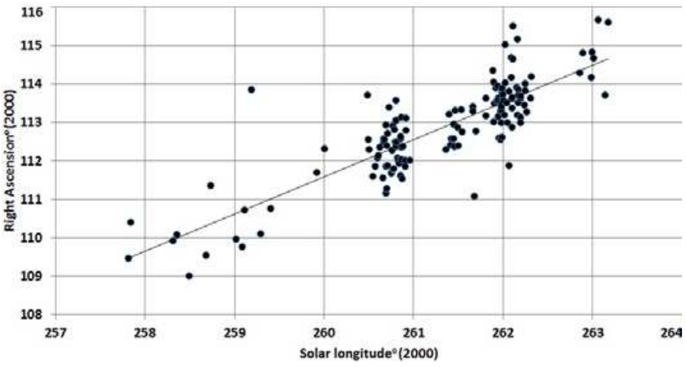

Figure 4. 2012–2015 Geminids radiant drift in Right Ascension.

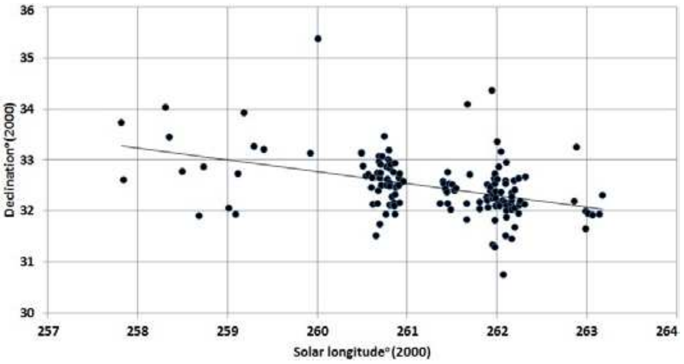

Figure 5. 2012–2015 Geminids radiant drift in Declination.

The IMO *Meteor Shower Calendar*[5] lists an r value of 2.6 for the Geminids. Molau *et al.*[8] demonstrated that this value is not consistent throughout the shower, estimating that the Geminids in 2015 displayed a smaller population index value of 2.2 on their nights of peak activity.

Multi-station Geminids

The dataset contains the following numbers of Geminids concurrently recorded from 2 or more stations, categorised in each quality class:

Q1 585
Q2 228
Q3 157

The Q3-quality data were used in the multi-station analyses.

Radiant drift

UFO Orbit was used to derive the radiant point for each multi-station Geminid, corrected for zenith attraction. These were used to estimate the daily drift of the radiant in Right Ascension and Declination (Figures 4 and 5). The data range was limited to solar longitudes between 257° and 267° to reduce the introduction of non-linear effects to the measurement of the radiant drift.

The method of least squares gives the linear fits:

$$\text{RA} = 0.966 \times (\text{Solar longitude}) - 139.560$$
$$(\text{Correlation coefficient } r = 0.840)$$
$$\text{Dec} = -0.231 \times (\text{Solar longitude}) + 92.812$$
$$(\text{Correlation coefficient } r = 0.419)$$

If we assume that Geminid maximum occurred at solar longitude 261°.95, its estimated RA is 113°.5 (7h 34m) and Declination +32°.3. The average daily motion in RA (dRA) is 0°.97 and in Declination (dDec) is −0°.23. These are presented in Table 2 for comparison with other sources.

Table 2. The position of the Geminid radiant at maximum and its daily motion

	Solar long.	*RA*		*dRA*	*Dec*	*dDec*
NEMETODE	261°.95	113°.5	7h 34m	0°.97	32°.3	−0°.23
HBAA[4]	262°	113	7h 33m	1°.02	32°	−0°.15
Jenniskens *et al.*[9]	262°.0	113°.5	7h 34m	1°.15	32°.3	−0°.16
Molau *et al.*[10]	261°.5	113°.3	7h 33m	1°.07	32°.4	−0°.09
SonotaCo[6]	261°.4	112°.8	7h 31m	0°.90	32°.3	−0°.19

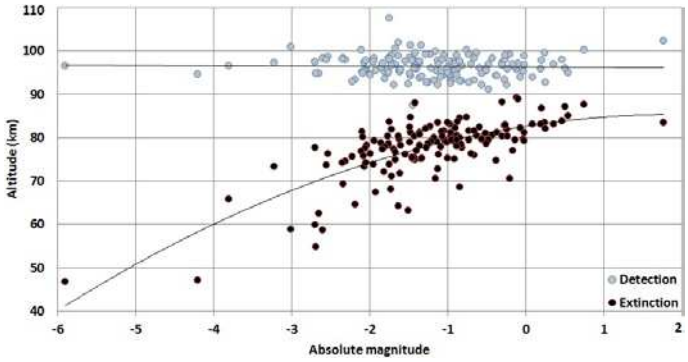

Figure 6. Detection and extinction heights of the 2012–2015 Geminid meteors.

Detection and extinction altitudes

UFO Orbit computed the start and end altitudes of the Geminids and their absolute magnitudes (see Figure 6). (Note: Absolute magnitude is the magnitude the meteor would have if it was observed in the zenith, 100km above the observer.)

The method of least squares gives the following linear and polynomial fits:

Detection altitude (km) = –0.08 × (Abs mag) + 96.27
(Correlation coefficient r = 0.03)
Extinction altitude (km) = –0.718 × (Abs mag)^2 + 2.784 ×
(Abs mag) + 82.641 (Correlation coefficient r = 0.75)

The results suggest that, in most cases, for every magnitude increase in brightness the Geminids penetrate about 5km lower into the Earth's atmosphere before burning up. More data on fireball-class Geminids are needed to confirm whether they do in fact reach progressively lower altitudes.

Table 3. Geocentric velocities of Geminid meteors

	Vg (km/s)
NEMETODE	33.6±2.7
Jenniskens *et al.*[9]	33.8
Molau *et al.*[10]	35.5
SonotaCo[6]	33.5

Geocentric velocities

UFO Orbit computed the geocentric velocities (Vg) of the Q3 Geminid meteors, giving an average value of 33.6 ± 2.7 km/s.

This is compared with other sources in Table 3.

Orbits

UFO Orbit computed the orbital elements of 151 Q3 Geminids, presented in Table 4. (6 Geminids were rejected because of poor alignment geometry or short trails, giving large orbital errors). Figure 7 illustrates how the Geminid stream intersects with the Earth's orbit.

Conclusions

Poor weather can prevent a single observer from obtaining good coverage of the peak activity of the Geminid meteor shower because its duration is only about a day. This is mitigated by coordinating a network of observing stations across a wide geographical area. By combining the results from several years it is possible to construct a general profile of their meteor rates.

Data from the NEMETODE dataset for 2012–2015 suggest that Geminid maximum occurred at solar longitude 261°.95 with a radiant at RA 113°.5 (7h 34m), Declination +32°.3.

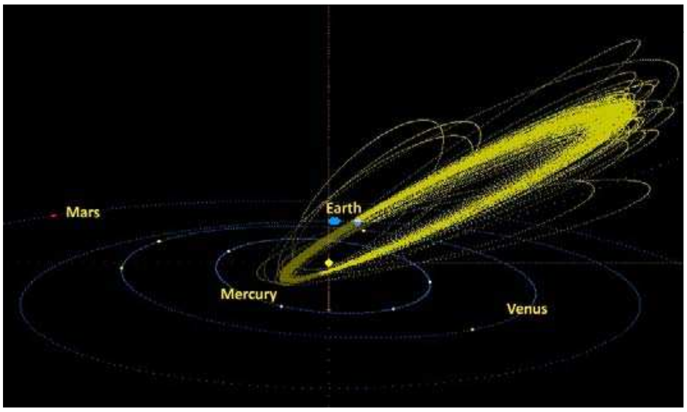

Figure 7. Solar system view of the 157 Q3 Geminid orbits. *(UFO Orbit)*

The Geminid meteor shower is rapidly evolving. The shower's activity level has increased dramatically over the past century and it is now the year's most active and reliable shower. In upcoming decades its orbit may gradually shift away from its intersection with that of the Earth. While the period covered in this paper is too short to show evidence of changes in the activity profile due to this shift, long-term annual monitoring will be invaluable in recording any variability.

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Table 4. Orbital elements of Geminid meteors, IAU MDC data and parent body (3200) Phaethon

	a (au)	*q (au)*	*e*	*p*	*Peri*	*Node*	*Incl*
NEMETODE	1.289±0.105	0.147±0.012	0.886±0.072	1.466±0.119	324.326±26.393	260.969±21.237	22.671±1.845
Jenniskens *et al.*[9]	1.31	0.145	0.889		324.3	261.7	22.9
(3200) Phaethon[11]	1.271	0.140	0.890	1.43	322.154	265.251	22.246