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# Geminid meteor shower of 1996-2007: Global activity from forward-scatter observations

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**Summary.** — Activity and mass distribution of the Geminid meteor shower of 1996-2007 from observations by a forward-scatter radio system operating along Bologna-Modra baseline are analyzed and discussed. Global activity curve for overdense echoes of durations $\geq 1$ s and $\geq 8$ s depicts two distinct peaks at solar longitudes 261.7°, 262.3° and 261.9°, 262.3°, respectively. Larger particles are concentrated more to the centre of the stream and slightly shifted towards the descending branch of the stream activity. The mean mass exponent of the Geminids is 1.73.

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PACS 96.30.Ys – Asteroids, meteoroids.
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PACS 95.85.Bh – Radio, microwave ($> 1$ mm).

## 1. – Introduction

The Geminid meteor shower with a visual zenithal hourly rate over one hundred meteors active for about two weeks with a maximum at solar longitude of 262° (December 13-14) is one of the most striking meteor showers. The stream is moving in a very short period orbit with a period of revolution of only 1.57 year and therefore its parent body was for a long time a puzzle. After discovery by Whipple [1] that the stream is probably associated with asteroid 3200 Phaethon, the stream is attracting more intensive attention of researchers.

From a longer series of visual observations a double maximum on the activity curve of the stream has been disclosed [2]. The longest series of radio observation of the Geminids covering 35 returns were performed by a back-scatter meteor radar at Ondřejov Observatory (Czech Republik) in 1957-1997 [3]. In 1996, regular radio observations of the stream also by a new forward-scatter system operating along two almost rectangular baselines Bologna-Lecce and Bologna-Modra with the transmitter located at Budrio near

 

Bologna (44.6°N; 11.5°E, Italy), the receivers at Lecce (40.3°N; 18.2°E, Italy) and Modra (48.4°N; 17.3°E, Slovakia) has been started. The first observations of the Geminids by the equipment (BLM forward scatter) were performed already in 1995, however over the baseline Bologna-Lecce only [4]. Results of a longer series of observations by the BLM system over a period of 1996-2003 were published by Pupillo *et al.* [5].

In the present paper a global analysis of the activity of the Geminid meteor stream based on observations in 1996-2007 obtained over the baseline Bologna-Modra, taking into account an observability function constructed for the BLM system is performed and discussed.

## 2. – Observations of the Geminids in 1996-2007

The BLM system [6] was designed for a systematic monitoring of meteor activity in selected shower and sporadic periods. The equipment is operating along both baselines each month for about two weeks. Standardly a meteor shower activity is obtained by subtracting sporadic background echoes from all echo counts in corresponding time intervals. For sporadic background echoes are normally taken periods of two-three days prior to or after a shower activity, or by a combination of both periods. The present day data obtained by the BLM forward scatter cover a series of observations of the Geminids for eleven years, 1996-2007.

A similar previous analysis of the Geminids observations by the BLM in 1996-2003 [5] was based on a standard procedure utilizing, besides subtraction of the sporadic background from all echo counts, also a correction for the zenithal distance of the shower radiant. However, the procedure did not take into account also a directional sensibility and corresponding contours at the meteor zone of the transmitting and receiving antennas, which may to a rather large extent influence final results concerning a meteor shower activity and its flux reduced from observations. Therefore, for the present analysis a correction for observability function of the BLM system was developed [7] and applied to the observations obtained over the baseline Bologna-Modra. The derivation of the function was based on the ellipsoidal theory presented by Hines [8]. The observability is strongly dependent on the geometry of the forward-scatter baseline and the shower radiant. Only periods when the observability function was greater than 0.3 were taken into analysis.

Over the eleven years, the Geminids were almost regularly monitored in the period of December 8-19 in which occasionally some short-term interruptions caused by various reasons appeared. Only the data from 2001 and 2003 due to a malfunction of the transmitter are missing completely.

## 3. – Activity and mass distribution

The activity for overdense echoes of durations $t \geq 1\,\mathrm{s}$ and $t \geq 8\,\mathrm{s}$ was obtained by subtracting the corresponding sporadic background from all-echo hourly rates.

An inspection of the activity reveals a multiple-peak appearance and at least two peaks in each year can be disclosed. A similar double-peak activity presented Rendtel and Brown [2] from a series of visual observations in 1988-1997. They analysed data obtained in an observational campaign organized by the International Meteor Organization in which 500 observers recorded over 110000 Geminids.

Table I lists the shower maxima (for equinox 2000.0) derived from the present forward-scatter observations analysis, compared to the previous results obtained by Pupillo *et al.* [5] and visual observations taken from published analyses and IMO pages. In a global

TABLE I. – *Solar longitudes of the Geminid meteor shower maxima derived from forward-scatter observations on Bologna-Modra baseline and their comparison with other analyses (equinox 2000.0).*

| | This analysis | | Pupillo *et al.* [5] | Visual [2] | |
|---|---|---|---|---|---|
| Year | Max. 1. (°) | Max. 2. (°) | (°) | Max.1 (°) | Max.2 (°) |
| 1996 | 262.1 | 262.5 | 262.63 | 262.1–262.2 | 262.4–262.5 |
| 1997 | 262.0 | 262.4 | 262.41 | – | – |
| 1998 | 262.0 | 262.2 | 262.1 | – | – |
| 1999 | 261.5 | 262.5 | (261.83) | 261.6–261.9 | 262.1–262.3 |
| 2000 | 261.2 | 262.5 | 262.62 | 262.1–262.4 | – |
| 2002 | 261.7 | 262.0 | 262.1 | – | – |
| 2004 | 261.5 | 262.2 | – | 262.1–262.2 | 262.2–262.3 |
| 2005 | 262.2 | – | – | – | – |
| 2006 | 261.7 | 261.9 | – | 261.7–261.8 | 262.2 |
| 2007 | 261.6 | 262.6 | – | – | – |

analysis of the Geminids 1996 Rendtel and Arlt [9] found a single maximum at 262.15°. Besides the first peak Bone [10] found another one in the interval of 262.4°–262.5°. In 1999 (`http://www.meteorobs.org/maillist/msg16809.html`), two higher activity periods between 261.6°–261.9° and 262.1°–262.3° were observed. The observations in 2000 presented on IMO page `http://www.imo.net.node/177` are not complete and indicate the shower maximum between 262.1°–262.4°. The 2004 Geminids analysis based on global visual observations [11] exhibits two close peaks at 262.16° and 262.23°. Visual observations of the Geminids in 2006 (`http://www.imo.net/live/geminids2006/`) indicate also the existence of two peaks at 261.7°–261.8° and about 262.2°.

Combining the data from all years a global activity of the shower in 1996-2007 was derived. Figure 1 shows the activity curves for two overdense echo duration groups, $t \geq 1\,\mathrm{s}$ and $t \geq 8\,\mathrm{s}$, derived as the average values from the rates in the bins of solar longitude of a length of 0.2°. This interval was chosen as the most suitable one for proper data occurrence in given bins, preserving the main trends of the global activity curve. If the interval is narrower, the global activity curve is distorted due to gaps in the data where the observability function is less than 0.3. The activity curves for both echo duration groups show a maximum consisting of two peaks: for echoes of duration $\geq 1\,\mathrm{s}$ at solar longitude of 261.7° and 262.3°; for echoes of duration $\geq 8\,\mathrm{s}$ at solar longitude of 261.9° and 262.3°. A slower increase up to the maximum followed by a steeper decrease after maximum on both activity curves is observed. This feature in the variation of the Geminid shower activity is known also from visual and previous radio observations. The width of the shower defined by a rate limit of the half-maximum activity is 1.9° and 1.5° for the echo duration group of $t \geq 1\,\mathrm{s}$ and $t \geq 8\,\mathrm{s}$, respectively. This documents that larger particles are less dispersed in the stream and are concentrated more to its centre. As evident from the curve of activity (fig. 1), larger particles are at the same time slightly shifted towards the descending branch of activity.

The mass exponent $s$ providing information on size distribution of particles in the stream was found from the cumulative numbers of echo duration considering diffusion for a dominant process of an echo decay in the form published by Kaiser [12]. The cumulative numbers from intervals of 3 hours of echo duration $t \geq 1, 1.5, 2, 3, 4, 5, 7, 8, 10\,\mathrm{s}$ were taken

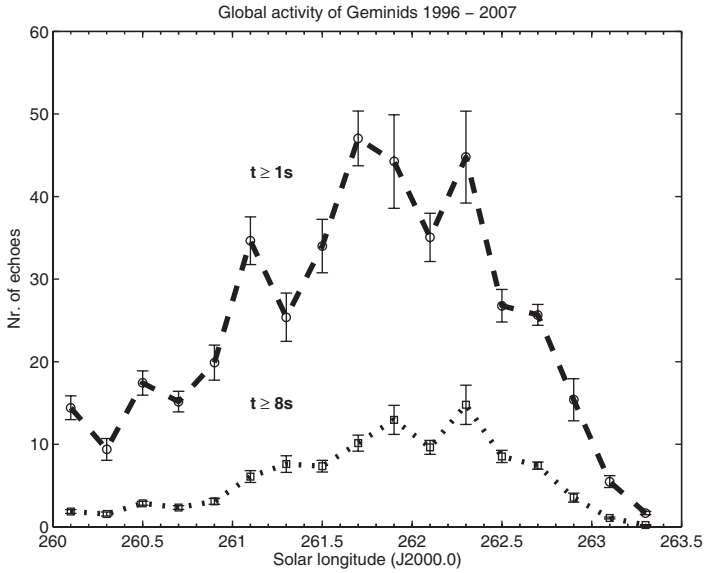


Fig. 1. – Global activity of the Geminids 1996-2007 for overdense echoes of duration $t \geq 1$ s and $t \geq 8$ s.

into computation. Table II lists the mass exponents derived for the shower from periods about the maximum of activity and for the sporadic background in individual years, bounds with the 95% confidence intervals. The mean mass exponent value is $1.73 \pm 0.20$ and without the data from 2004, $1.69 \pm 0.17$.

The mass exponent is indicating a tendency of variation over the observed period with an increase from 1996 up a maximum in 2002-2005 and following by a decrease. However, the data from 2001 and 2003 are missing and the highest value of $s = 2.11$ in 2004 is based on a relatively high activity of the sporadic background in that year, therefore, the variation cannot be considered for conclusive.

TABLE II. – *Mass exponent s of the Geminids 1996-2007 and sporadic background derived from forward-scatter observations on the baseline Bologna-Modra.*

| Year | Geminids | Sporadics |
|---|---|---|
| 1996 | $1.52 \pm 0.11$ | $2.11 \pm 0.11$ |
| 1997 | $1.47 \pm 0.10$ | $2.22 \pm 0.13$ |
| 1998 | $1.61 \pm 0.02$ | $2.21 \pm 0.15$ |
| 1999 | $1.50 \pm 0.10$ | – |
| 2000 | $1.79 \pm 0.21$ | $2.41 \pm 0.14$ |
| 2002 | $1.86 \pm 0.12$ | $2.51 \pm 0.15$ |
| 2004 | $2.11 \pm 0.19$ | $2.53 \pm 0.14$ |
| 2005 | $1.98 \pm 0.19$ | $2.50 \pm 0.14$ |
| 2006 | $1.82 \pm 0.14$ | $2.04 \pm 0.08$ |
| 2007 | $1.65 \pm 0.07$ | $2.21 \pm 0.12$ |

## 4. – Conclusions

An analysis of the activity of the Geminid meteor shower based on observations by the BLM forward-scatter system along the baseline Bologna-Modra in 1996-2007, has revealed a complicated structure of the stream. The shower activity was derived by subtracting the sporadic background echoes from all echo counts and by applying an observability function constructed for the system [7].

From a multiple peak structure of the stream two dominant peaks confirmed also by the corresponding visual observations can be recognized (table I). A global activity curve obtained from eleven years (1996-2007) for echo duration groups of $t \geq 1\,\mathrm{s}$ and $t \geq 8\,\mathrm{s}$ (fig. 1) confirms reality of the double-peak structure of the Geminid maximum. Similar double-peak structure is known also from extended visual observations [2,13] and is expected from theoretical models [14,15].

The positions of the two peaks at solar longitudes 261.7°, 262.3° for echoes of $t \geq 1\,\mathrm{s}$ and at 261.9°, 262.3° for echoes of $t \geq 8\,\mathrm{s}$ are very close. The widths of activity in solar longitude corresponding to a half-strength of the maximum of 1.9° (echoes of $t \geq 1\,\mathrm{s}$) and 1.5° (echoes of $t \geq 8\,\mathrm{s}$) differ by almost half a degree. This means that larger particles are less dispersed and are concentrated more to the centre of the stream. At the same time, larger particles are slightly shifted towards the descending branch of activity. The mean mass exponent $s$ of the Geminids derived from the shower maxima is 1.73 and a possible variation of $s$ over the eleven years of observation indicating a non-uniform distribution of meteoroids according to masses along the orbit of the stream is observed.

The observed variation of the mass exponent $s$ will be the topic of our next analysis in which also data from Bologna-Lecce baseline are going to be included. Consequently, the observed profile of $s$ of the shower will be compared with the published theoretical models of the stream profile.

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