

The Distribution of the Orbits in the Geminid Meteoroid Stream Based on the Dispersion of their Periods

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Abstract Geminid meteoroids, selected from a large set of precisely-reduced meteor orbits from the photographic and radar catalogues of the IAU Meteor Data Center (Lindblad et al. 2003), and from the Japanese TV meteor shower catalogue (SonotaCo 2010), have been analyzed with the aim of determining the orbits' distribution in the stream, based on the dispersion of their periods P . The values of the reciprocal semi-major axis $1/a$ in the stream showed small errors in the velocity measurements. Thus, it was statistically possible to also determine the relation between the observed and the real dispersion of the Geminids.

Keywords meteoroid · meteor showers · meteoroid streams

1 Introduction

One of the most intense annual meteor showers, Geminids are produced by a meteoroid stream unusual in having small orbits with aphelia well inside the orbit of Jupiter and perihelia close to the Sun. The Geminid's parent body, asteroid (3200) Phaethon, with a perihelion distance of only 0.14 AU and semi-major axis 1.27 AU, appears to be an inactive cometary nucleus (Gustafson 1989, Beech et al. 2003). The Phaethon's active period was determined by Gustafson (1989) as not more than 2000 years ago. This is in agreement with the age of the meteoroid stream, calculated dynamically, and which corresponds to a few thousand years (Ryabova 1999, Beech et al. 2002). The model for the formation of the Geminid meteor stream was developed by Fox and Williams (1982). Later, Williams and Wu (1993) produced a theoretical model showing that meteoroids ejected from Phaethon could have evolved, under the influence of planetary perturbations and radiation pressure, into Earth crossing orbits. The orbits of the Geminid meteoroids with aphelia far inside the orbit of Jupiter lead to the fact that the gravitational effects of the other outer planets are negligible. Furthermore, there have not been any close encounters significantly affecting their orbits during at least the last ten thousand years (Ryabova 2007). Thus, the orbital elements of most stream meteoroids vary little; furthermore, the spread in these elements is approximately invariant with the passage of time (Jones and Hawkes, 1986). Therefore, the structure of the Geminid meteoroid stream is dominated by the initial spread of meteoroid orbits. Ryabova (2001, 2007) developed a model explaining the two branches of the stream as being formed by the disintegration of the parent body, due to differences in orbital parameters of the individual particles ejected from the parent body before and after perihelion. The small perihelion distance may cause an intense thermal processing, which affects the physical properties of the meteoroids (Beech et al. 2003) and the higher density of Geminids, in comparison with other meteoroids (Babadzhanov and Konovalova, 2004).

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The present paper, based on a statistical analysis of a large set of precisely-reduced meteor orbits, shows the dispersion in the orbital elements of Geminid meteoroids for different mass ranges of the particles. For the analysis, data from the photographic and radar catalogues of the IAU Meteor Data Center (Lindblad et al. 2003) were used. Among the 4,581 photographic orbits, 385 meteoroids belonging to the Geminid meteor shower were identified using Southworth-Hawkins D -Criterion for orbital similarity (Southworth and Hawkins, 1963) and fulfilling the condition $D_{SH} \leq 0.20$. Similarly, we applied a limiting value of $D_{SH} = 0.25$ to 62,906 radar orbits and obtained 887 Geminids. The photographic data in the MDC catalogues are limited to the mass range of 10^{-4} kg (3^m) and radar data to 10^{-7} kg (5^m); for more powerful radars to 10^{-9} kg (15^m). To cover a broad mass range of the particles, quality orbits from the reduced database of 8,890 meteoroid orbits (Vereš and Tóth, 2010) of the Japanese TV meteor shower catalogue (SonotaCo 2009) were also used, giving 1,442 Geminids for the limiting value of $D_{SH} = 0.20$, detected mostly up to +2 magnitude.

2 Observed Dispersion of Orbital Elements

It is obvious that examination of the structure of meteoroid streams by means of the period of the individual particles is possible only for the short period meteoroid streams. The meteoroid streams with long periods of several decades to centuries, e.g. Lyrids, Perseids, Orionids, Leonids and Eta Aquarids, have heliocentric velocities close to the parabolic limit. The observational errors of those meteor streams greatly exceed the real deviations from the parent comet's orbit. Given that errors in the heliocentric velocity are a significant source of uncertainty in semi-major axes determination, it should be mentioned that errors in velocity determination in the IAU MDC can reach the value $v_H \sim 10 \text{ km s}^{-1}$. The errors differ both for individual catalogues and for individual meteor showers. The largest spread was found for the Perseids from the catalogues with a lower precision, reaching values of $10 - 15 \text{ km s}^{-1}$ (Hajduková 1993, 2007). But this is certainly not the case with the Geminids, the mean heliocentric velocity of which is only 36.6 km s^{-1} . The values of the reciprocal semi-major axis in this stream show small errors in the velocity measurements. The different precision of measurements, depending on the observation technique as well as on the quality of observations, causes a natural spread in the orbital elements. Figure 1 shows the dispersion in eccentricities, perihelion distances and semi-major axes. For the sake of comparison, we also plotted the orbital element of Geminid's parent body, which was obtained using the computer program Dosmeth (Neslušan et al. 1998).

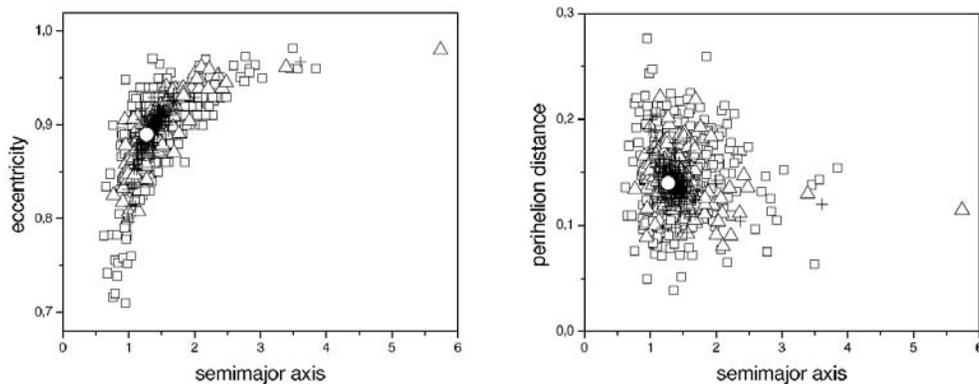


Figure 1. Observed spread in the orbital elements of the 835 photographic (+) and 887 radar (□) Geminids of the IAU MDC, and of the 1442 TV Geminids from the Japanese meteor shower catalogue (Δ). For the sake of comparison, we also plotted the orbital elements of the Geminid's parent body (○).

The observed dispersion of the orbit periods is shown in Figure 2 (left), separately for all three investigated data, obtained by different techniques. The mean period of the Geminids was found to be 1.59 and 1.48 years, derived from the photographic and video orbits, with a standard deviation of 0.37 and 0.24 respectively. The mean period of the fainter particles from the radar observation is 1.69 years, but the period determination from individual orbits varies from 0.53 to 7.54. It is clear that we are not dealing with a stream all of whose meteors have exactly the same period, but obviously the last observed spread in the values exceeds the real deviations.

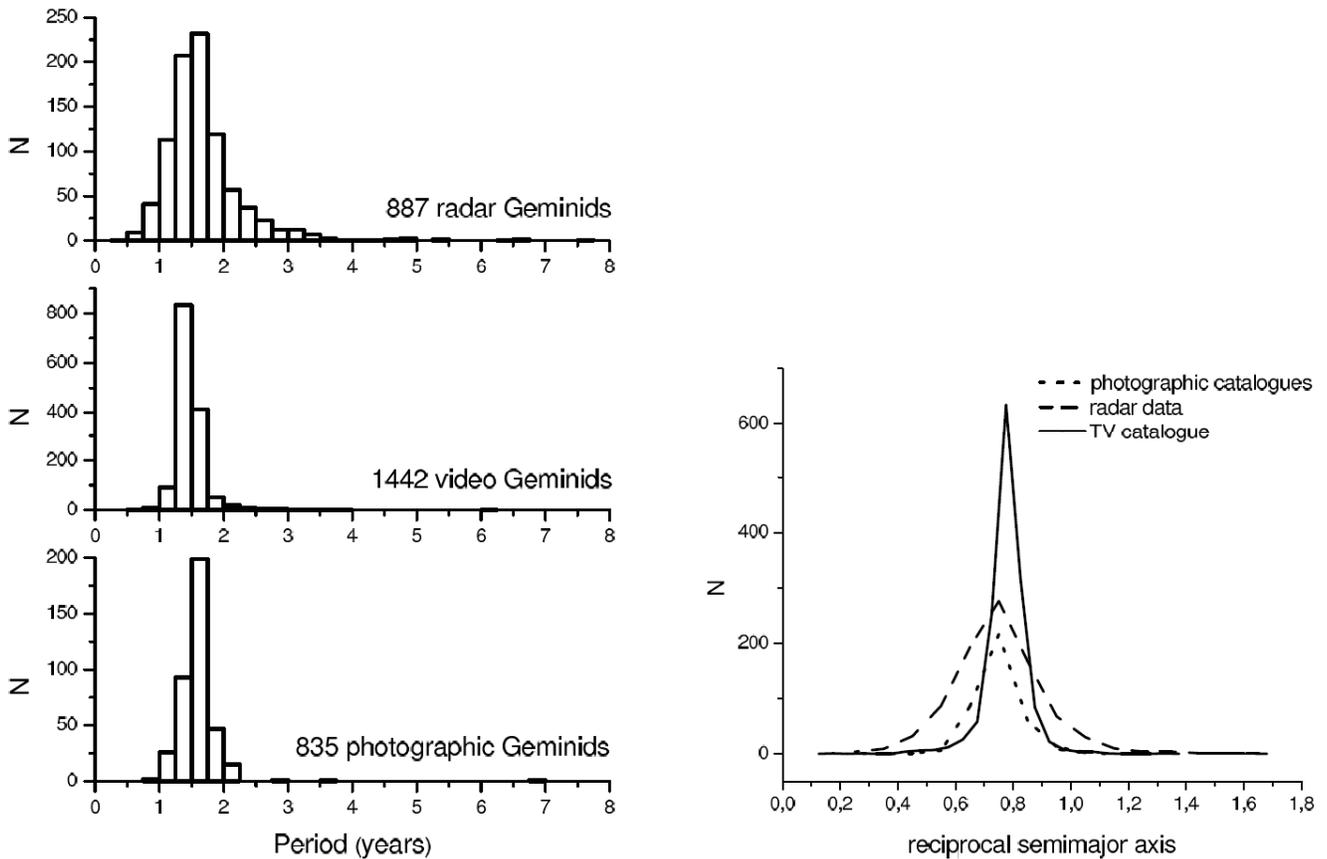


Figure 2. Comparison of observed dispersion of the period of revolution (left) and of the reciprocal semimajor axes (right) of Geminids from three different sets of data in term of mass particles, obtained using different techniques and different measurement methods. The observed dispersion is greater for radar Geminids in comparison with both other sets of data.

A complete study about the real dispersion of orbital periods in meteor streams was made by Kresák (1974), which showed that the observed dispersion of the semi-major axes involves the real orbital dispersion plus errors, which are greater by a factor of 10^4 for the orbits of the meteoroids than in the case of well-determined cometary orbits. Porubčan (1984), in his study of the dispersion of the orbital elements of meteor orbits, analyzing 153 photographic Geminids determined the mean orbital period at 1.66 years. The widely-observed dispersion is also seen in distributions of the reciprocal semi-major axes (Figure 2 right). The radar data in general are of a lower precision, which is obvious from the greater spread in the values of the semi-major axes in comparison with both other catalogues, in which the precision is comparable. The observed dispersion of the semi-major axis, defined by the standard

deviation, is 0.079 for the photographic and 0.158 for the radar Geminids from the IAU MDC. The smallest standard deviation of 0.071 was derived from the Japanese video data, probably because we used a strict selection (Vereš and Tóth, 2010) of high quality video meteor orbits.

3 The Accuracy of the Semi-major Axes and their Dispersion

We tried to estimate the real dispersion of the semi-major axis within the meteor stream by comparing the observed dispersions in different catalogues of orbits, where the observational errors are different. However, for each observation technique, there are different sources of errors, which produce the observed dispersion in semi-major axis determination. On the basis of this fact, we chose in our analysis the median a_M as the most representative value of semi-major axis a , because the arithmetic mean value a is strongly affected by extreme deviations caused by gross errors. It was shown (Kresáková 1974) that the medians of $(1/a)_M$ in several major meteor showers do not differ from those of their parent comets beyond the limits of statistical uncertainty. The dispersion of the semi-major axis within the meteor stream is described by the median absolute deviation Δ_M in term of $1/a$: $\Delta_M(1/a) = |(1/a)_{1/2} - (1/a)_M|$, where $(1/a)_{1/2}$ are limiting values of the interval, which includes 50 percent of all orbits. The probable range of uncertainty is determined by $\pm n^{-1/2} \Delta_M(1/a)$, where n is the number of the meteor orbits used for the median determination $(1/a)_M$. For the sake of comparison, we also derived the deviation of the median $1/a$ from the parent body: $\Delta(1/a)_{Ph} = |(1/a)_M - (1/a)_{Ph}|$, where the $(1/a)_{Ph}$ is the reciprocal semi-major axis of Geminid's parent body Phaethon.

The results of our analysis are shown in Table 1 as in Figure 3. Table 1 summarizes the numerical results obtained separately for the three different sets of Geminids. The mean value, the standard deviations and the median semi-major axis a are listed in the first part of the Table. The second part contains the mean value, the standard deviations and the median reciprocal semi-major axis $1/a$. The median absolute deviation Δ_M in term of $1/a$, and the deviation of the median $1/a$ from the parent body, are listed in the last part of the Table. For comparison, we also list the chosen orbital elements from 3200 Phaethon.

Table 1. Numerical data obtained separately for the three different sets of Geminids observed by different techniques. n – number of meteors; \bar{a} , $\bar{1/a}$ – the mean values; σ_a , $\sigma_{1/a}$ – the standard deviations; a_M , $(1/a)_M$ – the median a , $1/a$ respectively; $\Delta_M(1/a)$ – the median absolute deviation; $\Delta(1/a)_{Ph}$ – deviation of the median $1/a$ from the parent body.

	\bar{a}	a_M	σ_a	$\bar{1/a}$	$(1/a)_M$	$\sigma_{1/a}$	$\Delta_M(1/a)$	$\Delta(1/a)_{Ph}$
$n_{phot} = 835$	1.361	1.356	0.180	0.744	0.737	0.079	0.040	0.049
$n_{tv} = 1442$	1.302	1.285	0.185	0.777	0.778	0.071	0.029	0.008
$n_{rad} = 887$	1.402	1.351	0.343	0.749	0.740	0.159	0.081	0.047
Phaethon	1.271			0.787				

The dispersion, described by the median absolute deviation Δ_M in terms of $1/a$ obtained from the photographic, video and radar catalogues, are 0.040, 0.029 and 0.081 AU⁻¹ respectively. This corresponds to a deviation of ± 0.01 years for the Geminid's period obtained from the precise photographic measurements. This is in agreement with a study by Kresáková (1974), which analyzed meteor orbits obtained from the most precise double-station photographic programs; it was shown that the dispersion of the 157 analyzed Geminids is moderate and the period can be put into narrow limits, between 1.62 and 1.64 years.

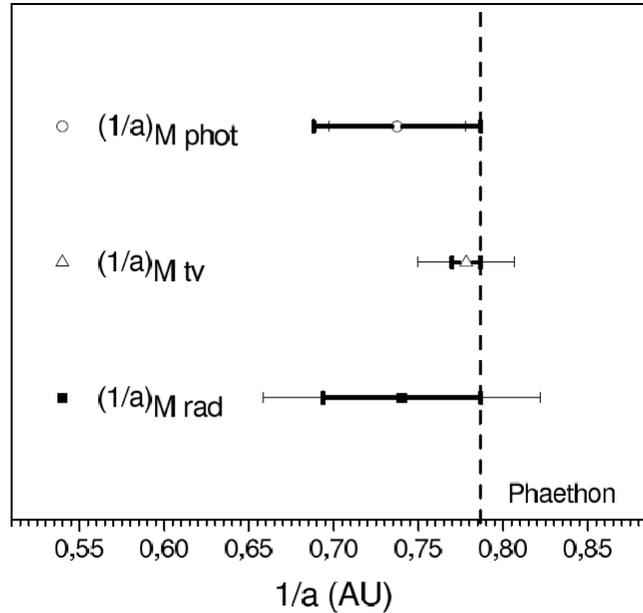


Figure 3. Dispersion in terms of $1/a$ for Geminids observed by three different techniques. Bold line – the deviation of the median $1/a$ from the parent body $\Delta(1/a)_{ph}$; thin line – the absolute median deviation Δ_M in terms of $1/a$; vertical line – Phaethon.

The deviation of the median reciprocal semi-major axis from the parent body, obtained from Japanese video orbits, is only 0.008 AU^{-1} , whereas for the orbits from the IAU MDC catalogues, it is approximately five times greater. For the video and radar orbits, $\Delta(1/a)_{ph}$ is considerably smaller than Δ_M ($1/a$), but for photographic orbits, it is slightly bigger.

4 Conclusions

The analysis of a sufficient number of meteor orbits of chosen catalogues of meteors observed with different techniques allowed us to estimate the dispersion of semi-major axes within the Geminid meteor stream. It was shown that the dispersion differs considerably between the three different sets of data in terms of the different masses of the particles. This may be a consequence of different measurement errors for different observation techniques, as well as of different dispersions in the orbital elements for particles belonging to different mass ranges. The dispersion was found to be higher for small particles obtained by radars in comparison with the results of video and photographic observations of large meteoroid particles. It was found that the real dispersion of the Geminids is at least 2 times smaller than indicated by the observations, based on all three investigated catalogues. The deviations in terms of $1/a$ determined from the investigated catalogues range from ± 0.029 to $\pm 0.081 \text{ AU}^{-1}$. This corresponds to a deviation of ± 0.01 years for the Geminid's period obtained from the precise measurements and of ± 0.02 years using data of lower accuracy.

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