

Model Radiants of the Geminid Meteor Shower

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Abstract This paper describes the final stage of the study of the Geminid meteoroid stream formation and evolution using the nested polynomials method reported by Ryabova (in: Warmbein (ed.) *Meteoroids 2001*, Proc. of the Internat. Conf., Kiruna, Sweden, 6–10 August 2001; *MNRAS* 375:1371–1380, 2007). In the previous work we discussed possibility to calibrate the model using the shape of the model activity profiles and configuration of orbital parameters. Here we show that the radiant structure also could be utilized for this purpose, since the model radiant structure has a very specific pattern. Model area of radiation does not have a “classical” prolate linear shape, and the configuration of activity centers has a “V” shape. During one night of simulated observations several activity centers could be observed. The model produced maps of the velocity distribution in the radiant area.

Keywords Meteoroids · Methods: numerical

1 Introduction

Ryabova (2007) presented a qualitative model of the Geminid meteoroid stream from the Geminid’s parent body (asteroid (3200) Phaethon) in order to study the main features of its structure and explain the processes which are responsible for that structure. It was shown that the structure of a model stream of collisional (Ryabova 1989), or eruptive (Bel’kovich and Ryabova 1989) origins does not agree with the observations of this meteor shower. The activity profile for the Geminid shower has the specific bimodal shape, which is expected by a cometary model of the stream generation (Ryabova 2001). So there are strong grounds to believe that the stream has a cometary origin. Its formation probably occurred during a relatively short time of one or several cometary revolutions (Lebedinets 1985). The very stable shape of the shower activity profile during last 60 years (Rendtel 2004) could be

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indirect evidence of that. The age of the stream was previously estimated at $2,000 \pm 1,000$ years (Ryabova 1999). The uncertainty of the stream's age gives rise to a peculiar problem, which is that the location of the model cross-section on the ecliptic could be shifted from the location of the real stream.

Ryabova (2007) described how the observed shapes of the flux density and mass index s profiles and the configurations of the shower orbital elements, can help in the calibration of the model. In this paper we concentrate on the model radiant structure.

2 Model

The methodology applied in this work is fairly simple and is regularly used (see for e.g. Fox et al. 1983; Brown and Jones 1998; Vaubaillon et al. 2005). For a given parent body orbit we choose points of ejection according to chosen scheme of the meteoroid stream generation (collisional, eruptive, cometary etc.). Then the ejection velocity vector is obtained for every model meteoroid, and the meteoroid orbit is calculated. Evolution of the orbit is calculated from the moment of ejection till the present.

For this work we used Whipple (1951) formula to calculate the ejection velocity value, while the directions of ejections were assumed to be distributed uniformly in the sunlit hemisphere. The ejection points were distributed uniformly around the parent body orbit, that fits reasonably well to dust production rate proportional to r^{-4} , where r is heliocentric distance. Assuming the age of the stream 2,000 years (Ryabova 1999), the orbit of asteroid (3200) Phaethon calculated for the epoch JD1721206.3 (0.407 AD) has been used as the reference orbit. Meteoroid ejections were modeled for two streams of spherical particles (density 1 g cm^{-3}) with masses of $m_3 = 2.14 \times 10^{-3} \text{ g}$ and $m_4 = 2.14 \times 10^{-4} \text{ g}$. For short we will refer to these streams and their showers as “stream m_3 ” or “shower m_4 ”. The evolution of the test particle orbits was calculated using nested polynomials. In detail the method and model used was described in Ryabova (2007).

To explain how we use a radiant structure to calibrate the model, we should consider the Geminid model cross-section in the ecliptic plane. Figure 1 illustrates that the shower activity profiles and the profiles of the mass index s will be strongly dependent on the location where the Earth crosses the stream (shown as lines A , B , C , D and E in Fig. 1, A being along the Earth orbit). It was shown earlier that the Geminid meteoroid stream consists two layers (Ryabova 2001, 2007). The origin of the layers is that the orbital characteristics of the particles ejected from the parent comet are different for when the comet approaches perihelion and when it moves away from perihelion. In the small panel designated “Stream m_3 ” (Fig. 1), which displays the cross-section of the corresponding model stream, the pre-perihelion layer is shown by gray color, and the post-perihelion layer by black color. The layers cross approximately along the mean orbit of the model stream. The Earth's orbit thus intersects two different dust layers resulting in two different shower activity maxima. If we consider only differential¹ showers, the first maximum of each consists mainly of pre-perihelion meteoroids, the second maximum will be mainly post-perihelion meteoroids. The distance between the first and the second maxima depends on the mass of meteoroids (see small panels in Fig. 1), because the ejection velocity is larger

¹ The differential shower/stream is defined as a shower/stream of particles with a definite meteoroid mass, for example m_3 or m_4 . The cumulative shower/stream consists of particles having masses larger than some minimal mass.

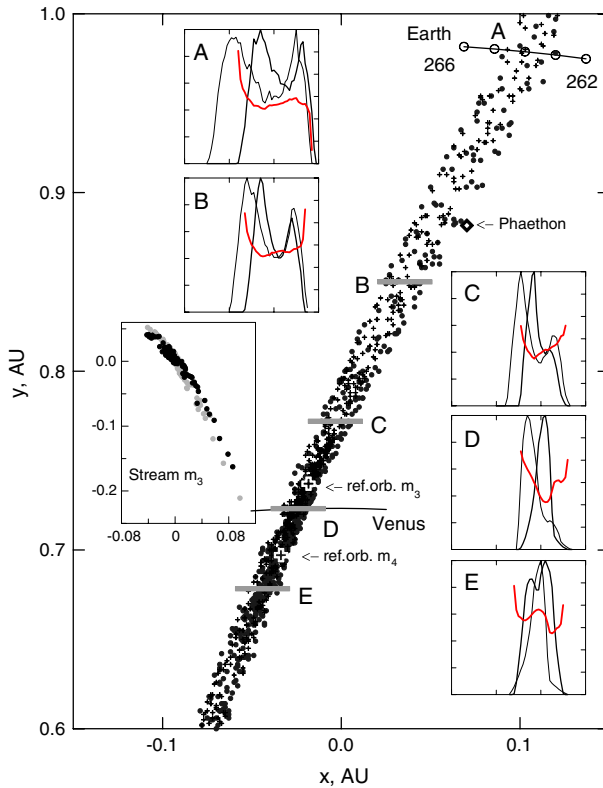


Fig. 1 Geminid’s model cross-section in the ecliptic plane for orbits of particles with masses m_3 (+) and m_4 (•). A designates the Earth’s orbit in the interval 262° – 266° in solar longitudes. Other sections are designated by B–E. In the small panels, designated by A–E, activity profiles, i.e. flux density variations along the Earth’s orbit, for particle masses m_3 (thick line) and m_4 (thin line), and a profile for mass index s (thickest line) are shown. The distance between the tick marks on the abscissa-axes of small panels is equal to 1° . The profiles are calculated along the corresponding sections. The small panel designated by “Stream m_3 ” demonstrates pre- and post-perihelion layers (see text) in the cross-section of the model stream m_3 at the descending node of its mean orbit, designated “ref. orb. m_3 ”. The plane of the plot is normal to velocity vector of the orbit in the node. The abscissa-axis is directed away from the Sun, the scales on both axes are in AU. Figure 1 was modified after Ryabova (2007, Fig. 5) and Ryabova (2006, Fig. 1)

for smaller particles. In the cumulative shower the separation of pre- and post-perihelion meteoroids is not so distinct.

The location of stream in the model presented here is shifted from in the real stream because (1) the exact age of the stream is unknown, (2) we used polynomial approximations instead of a precise method of numerical integration (Ryabova 2007). However, the dependence of the shower activity profiles, the profiles of the mass index and radiant patterns on the location could help us to fit the model. For example, if we were to find that the observed radiant pattern fits the model pattern for section C and differs from all others, we could then suggest that the Earth should cross the stream near the section C. To put it differently, we should move the model in such a way that the section C coincided with the real shower activity area on the Earth’s orbit. It is obvious that the task is unrealizable if the patterns are similar each other.

3 Discussion

Let us consider the radiant areas corresponding to sections A and C in Fig. 1. Figure 2 shows the geocentric equatorial coordinates (α , δ) of the radiants used in our model stream. In this figure and all other figures presenting model radiants, the axes scales are not shown because the model stream is not yet calibrated. The model streams m_3 and m_4 are quite similar in structure, apart from dispersion in the stream m_4 is larger, because ejection velocities for smaller particles are larger. So we may consider a radiant structure pattern for any of the model streams, m_3 or m_4 .

The comparisons of the modeled results with observations qualitative only. Each of the sections in Fig. 2 show very specific and different patterns for the modeled Geminid radiant structure for the various possible ways of the Earth's orbit crossing through the stream. For an interval of observations, which is less than the full length of the shower, the pattern inevitably changes, because the stream structure (both for a model or a real stream) changes along the Earth's orbit. For example for only one night of observations or 0.5° in solar longitude the radiant structure is shown in Fig. 3; the pattern in Fig. 3 consists of the radiants from the left panel of Fig. 2 related to the selected interval. When selected observation time were to be around the first activity of the maximum, the model predicts that we would observe pre-perihelion meteoroids (Ryabova 2007, Fig. 13), and indeed overwhelming majority of radiants we see in Fig. 3 are from pre-perihelion orbits.

We found that the model radiant area has two centers of activity that correspond to the two maxima of the activity curves as shown in Fig. 2. The location of the activity centers for the model showers m_3 and m_4 (Fig. 4) has a V-shape. But we should take into consideration the following. Firstly, the right center is more intensive than the left one for both showers (Fig. 4). Secondly, the maps for streams m_3 and m_4 contain 5,000 radiants each, while for a real meteor shower flux density for particles with masses m_4 should be 10^5

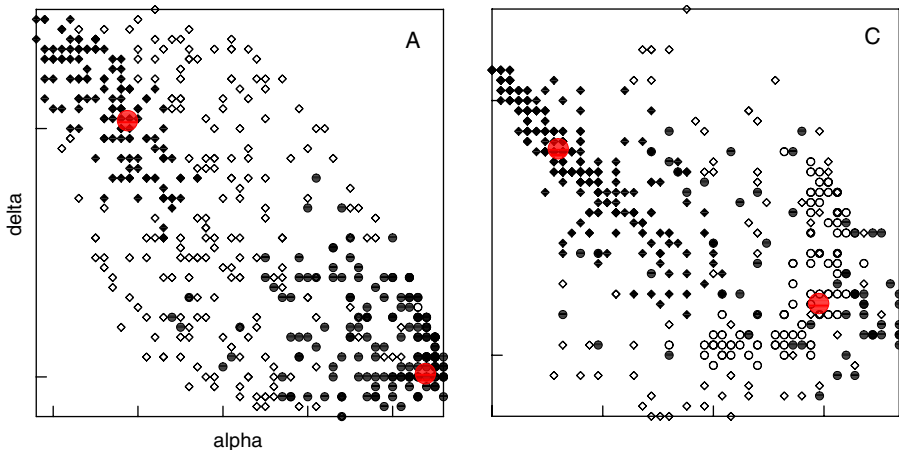


Fig. 2 Geocentric equatorial coordinates for the 500 random model particles forming the activity profiles of the stream m_4 in sections A (Ryabova 2007; Fig. 12, reproduced by courtesy of MNRAS) and C. Two large circles mark the first and the second maxima of activity. The distance between the tick marks on the axes is equal to 0.5° . Cells are designated depending on the true anomaly of ejection point v_e on the cometary orbit: (black diamonds) $180^\circ < v_e < 270^\circ$, i.e. nucleus moving from aphelion; (empty diamonds) $270^\circ < v_e < 360^\circ$, i.e. approaching to perihelion; (black circles) $0^\circ < v_e < 90^\circ$, passed perihelion; (empty circles) $90^\circ < v_e < 180^\circ$, moving to aphelion

Fig. 3 The same, as in Fig. 2, but positions only for meteoroids observed during the first maximum of the shower m_4

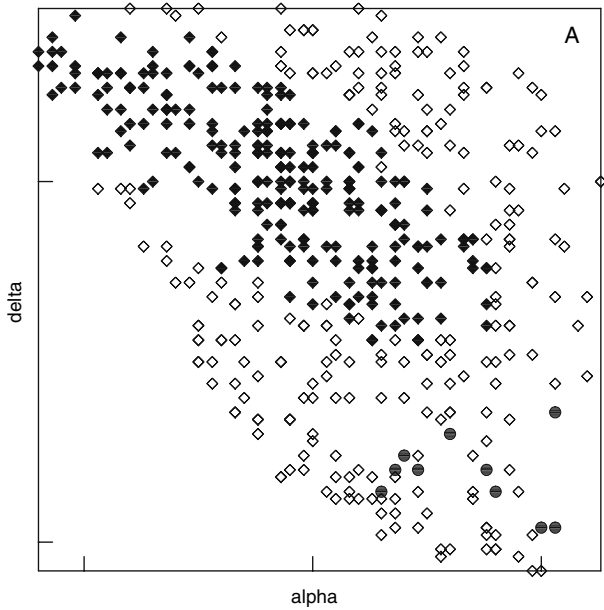
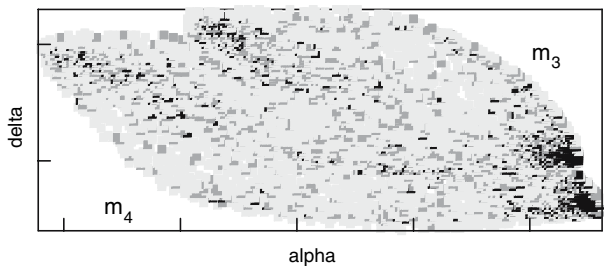


Fig. 4 The superimposed maps of radiant activity for showers m_3 and m_4 . Section A. Highest activity is designated by black color. The distance between the tick marks on the axes is equal to 0.5°



times of flux density for particles with masses m_3 . Finally, we usually do not observe 10 thousand radiants in the Geminid meteor shower. So the left side of “V” can stay unnoticed in the real shower.

Figure 5 shows how the model predicts that we may observe several activity centers during one night of Geminid shower observation. This resulting radiant activity is based on 10,934 radiants in Fig. 5a and 2,373 in Fig. 5b. The amount of test particles for model streams m_3 and m_4 is 10 million for each.

According to data of radar observations (Sidorov and Kalabanov 2001, 2002; Kalabanov et al. 2002) several activity spots were found in the area of Geminids radiation; the authors interpreted them as microshowers of unknown origin. But statistics of their data is rather insufficient to make any conclusions. The lack of observational data is a persistent problem. One of the best samples² of radiants (and orbits) we managed find so far are video

² Another good sample obtained by video observation of meteors at the Ondřejov observatory could be found in Koten et al. (2003). We did not use it here because too small number of meteors with estimated photometric masses $\sim 10^{-4}$ g ($N = 6$) does not allow to compare this subsample with the subsample for meteors with estimated photometric masses $\sim 10^{-3}$ g ($N = 41$).

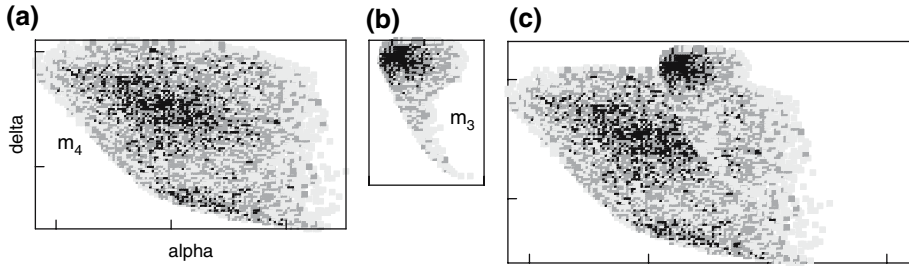


Fig. 5 The map of radiant activity for meteoroids with mass m_4 (a), m_3 (b), and combined (c). Period of “observation” is 0.5° in solar longitude around the first maximum of the activity curve for the shower m_4 , section A. Gradations of gray shows the density of radiants (black is the highest). The distance between the tick marks on the axes is equal to 0.5° in (a) and (c). The sides of the panel in (b) embracing square are equal approximately 0.4° . Unmarked axes are for the same (α , δ) parameters

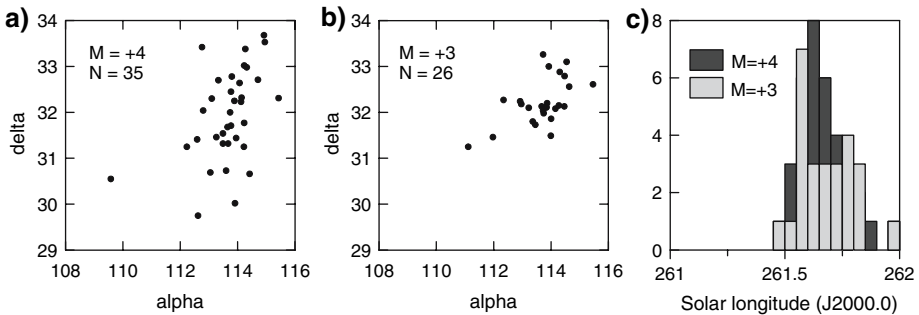


Fig. 6 Radiant positions for DMS video orbits (see text) are shown for Geminid meteors of estimated visual magnitude (a) $M = +4$ and (b) $M = +3$. N is number of radiants for each sample. Distribution of the same orbits in solar longitude is shown in (c)

observations completed by the Dutch Meteor Society³ (Lignie and Betlem 1997; Lignie 1998), is shown in Fig. 6. Taking into account that in the model we considered the differential showers, i.e. with a definite particle mass, we have to make comparison within a narrow mass range. Thus in Fig. 6 the radiant positions (α , δ) are shown Geminid meteors of estimated visual magnitudes⁴ $M = +3$ and $M = +4$. DMS observations are concentrated in a narrow range of solar longitudes (Fig. 6c) between the maxima. This case of observed meteor activity should be compared with the narrow-range patterns obtained by the model that were shown in Figs. 3 and 5. But we cannot make direct comparisons between these structures obtained by the model and from observations because the statistics in case of the observations are poor. Another possible issue could be observational bias although any such selection effects were not studied yet.

Figure 7 displays the geocentric velocity distributions for sections A and C. Section A shows distinct regions occupied by different velocity intervals, but in section C there are no specific intervals. The results in Fig. 7 highlight that when we will have statistically

³ <http://www.dmsweb.org>

⁴ We do not consider still unsolved problem of so called “mass scale”, i.e. correspondence of the meteor mass and magnitude for different methods of observations. So the choice of $M = +3$ and $M = +4$ is rather arbitrary: just faint meteors.

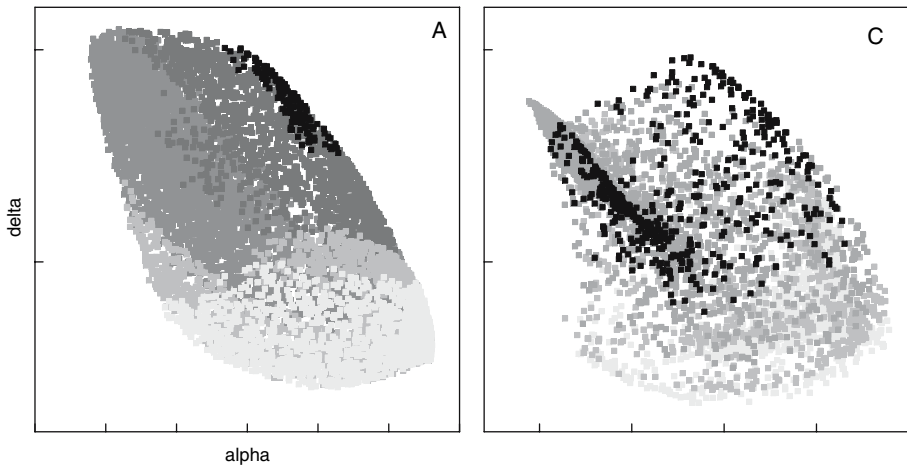


Fig. 7 The maps of geocentric velocity distribution in radiant areas for sections *A* and *C* of the shower m_4 . The darker areas correspond to larger velocity. The distance between the tick marks on the axes is equal to 0.5° . Unmarked axes are for the same (α , δ) parameters

reliable meteor observations that are free of observational selection effects, such as the geometrical one, comparison with the model predictions as were described in this paper can be made successfully. Such systematic comparisons will serve further calibrations of the model to determine the scale of the observed structures found in the radiant distribution of simulated meteors in the model stream. For example, an issue that needs to be resolved concerns the scale of the model radiants in Figs. 2–7 and the precision at which individual meteor radiants can be determined observationally, e.g. Koten et al. (2003) and Campbell-Brown (2007).

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