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A preliminary numerical model of the Geminid meteoroid stream

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ABSTRACT

A pilot numerical model of the Geminid meteoroid stream is presented. This model implies cometary origin of the stream. Ejection of relatively small amount of particles (90 000 test meteoroids with masses 0.02, 0.003 and 0.0003 g) from the asteroid (3200) Phaethon (the parent body) was simulated, and their evolution was followed till the present time. The particles close to the Earth orbit were considered as the 'shower'. It was found that the width of the model shower is at least twice less comparatively the real shower. The maximum activity of the model shower is dislocated and occurs about one day late. The most probable reason for both discrepancies is the drastic transformation of the parent body orbit during rapid release of the volatiles in the process of the stream initial formation. The dispersion of the model stream was evaluated in terms of the Southworth–Hawkins *D*-criterion.

Key words: methods: numerical – meteorites, meteors, meteoroids – minor planets, asteroids: individual: (3200) Phaethon.

1 INTRODUCTION

The Geminids is the meteoroid stream producing a major annual meteor shower in December. It is one of the most studied streams, and mathematical modelling of the stream has a long history (see reviews by Ryabova 2006, 2014 and the references cited therein). Relatively recently a Geminid model was published explaining the Geminid's structure (Ryabova 2007, 2008). Let us for brevity in future references call it Model I. The model summed up results of almost twenty years of research and explained the Geminid's structure: the absence of the nodal shift with time, the density distribution across and along the orbit, the mass distribution, several activity 'spots' in the radiant area, etc. The main discovery was that the stream has two layers, and the peculiar bimodal shape of the observed activity profile conforms to cometary scenario of the stream origin. To calculate orbital evolution of meteoroids, Ryabova (2007, 2008) used the method of nested polynomials, which is about 10^6 times faster than numerical integration, so it was possible to use statistically rich models in 10 millions of meteoroid orbits.

However, the use of approximations has some shortcomings, considered in detail by Ryabova (2007). In the result the model stream turned out to be shifted in space and more compact relatively the real stream. These factors are not very important for a *qualitative* model, but when we evaluate the meteoroid matter distribution in space, we should use a more precise *quantitative* model. Numerical integration is expensive: to calculate a frugal model in 30 000 particles a usual desktop computer has to make calculations about one month; therefore it is reasonable to begin with a preliminary model.

The parent body of the stream is the asteroid (3200) Phaethon (Fig. 1). This Apollo-type asteroid has very elongated orbit located far inside Jupiter's orbit. Its origin is not quite clear. Since its discovery in 1983 Phaethon has never shown any trace of activity. But in 2009 June its brightness increased sharply for a short time. The same phenomenon was observed in 2012 (Li & Jewitt 2013). In both years its activity started at perihelion (with ~0.5 d lag) and lasted for approximately two days. Jewitt & Li (2010) preferred explanation is that the brightening occurs as a result of dust produced. Later a comet-like tail was discovered on the asteroid images both in 2009 and 2012 (Jewitt, Li & Agarwal 2013). Nevertheless it was not comet-like sublimation. The most probable mechanism for dust release is thermal fracture and/or thermal decomposition of surface minerals when near perihelion (Li & Jewitt 2013). The observed recurrent activity seems to suggest the Geminid stream replenishment during very long time. It is possible, but hardly could be the main mechanism for the stream formation. A paper discussing why it is so is under preparation (Ryabova 2015).

The several models in 30 000 particles, which we discuss in this work, are statistically pure to study the stream fine structure, but we use them with the other purpose, namely to discuss the details of the modelling method, and to analyse quantitative differences of the models (Model I and the new preliminary one have no qualitative differences) and observations. This is the aim of the presented study. We use only one structural parameter, namely the activity profile of the meteor shower, to make the comparison with results of visual and radar observations.

This numerical model was used also for an earlier study of the 'survivability' of the initial structure introduced in the stream by the ejection process (Williams & Ryabova 2011). It was found that for the Geminid meteoroid stream the main elements of the original

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structure are preserved in the model, while for the other considered streams it is not so.

2 METHOD AND MODELS

2.1 Method

The method of a stream model construction is quite common and was reported many times (e.g. Ryabova 1989; Brown & Jones 1998; Vaubaillon, Colas & Jorda 2005). Briefly it can be described as follows. A point where particle(s) is/are ejected is chosen on the parent body orbit. Based on certain assumptions on the ejection scheme, the velocity vectors of ejected particles are obtained using a generator of pseudo-random numbers, and the particle orbital elements are calculated. The orbital evolution of the test particles is calculated.

It was assumed that Phaethon lost its volatiles during one revolution (Lebedinets 1985). Period of the Phaethon's orbit is very short: now it is 1.6 yr, and 2000 yr ago it was 1.4 yr. Considering that accuracy of the stream age determination is within thousands of years, we may assume that our reference orbit does not change during one orbital revolution. The orbital elements of the asteroid (3200) Phaethon were taken from Dr Edward Bowell's Asteroid Orbital Element Database (ftp://ftp.lowell.edu/pub/elgb/astrorb.html) and integrated back to starting epoch $t_0 =$ JD 1720165.2248 (perihelion passage), since the stream's age was estimated in approximately 2000 yr (Ryabova 1999). The final epoch for the model was taken JD 2453363.5 = 2004 December 24.

We use cometary scenario of ejection, because the observed structure of the Geminid shower seems to agree with it (Ryabova 2007). The distribution of meteoroid production with true anomaly is taken to be proportional to r^{-4}, where r is the heliocentric distance. A dust production rate like this was characteristic for Halley comet during its 1986 apparition (see review in Ryabova 1997). In reality we know nothing about the Geminid's comet production rate as well as the Comet Halley production rate, say, 3000 yr ago. In the review of de Almeida et al. (2007) related to seven comets – possible target comets to space missions – it is indicated that the exponent in the function of dust production varies from −2.3 till −6.0, so our value is quite plausible.

The ejection velocities were calculated using Whipple (1951) formula, and their directions were distributed uniformly in the sunward hemisphere of the nucleus. The ratios of the dust particle's cross-section to its mass A/m were taken 4.45, 8.38 and 18.06. For spherical particles having densities 1 g cm^{-3} that corresponds to masses $m_2 = 2 \times 10^{-2}$ g, $m_3 = 3 \times 10^{-3}$ g and $m_4 = 3 \times 10^{-4}$ g. It worth to notice that the initial model parameters are essentially the same as in Ryabova (2007). We only appended the 'visual' mass m_2.

The resulting model stream, i.e. 30 000 orbits of meteoroids with a fixed mass (m_2, m_3 or m_4),[1] allows us to find the following structural parameters: the activity profile, theoretical radiants, the distribution of meteoroids around the stream. If we have model streams for two meteoroid's masses, we can find also the mass distribution exponent s. In this work, we are discussing only the first parameter – the activity profile.

The equations of motion of the meteoroids were integrated using the Everhart 19th-order procedure with variable step size. Planetary positions were taken from the JPL Planetary Development Ephemeris – DE406. Gravitational perturbations from all planets, the Moon and Pluto were taken into account as well as the radiation pressure and the Poynting–Robertson effect. To calculate the corpuscular part of the Poynting–Robertson effect, the formulae given by Ryabova (2005) were used. During integration encounters of particles with the Earth on the distance ≤0.01 au were tracked, and that explains why the end-epoch is December 24 and not, say, December 14. We consider all period of the Geminid shower activity and over it.

[1] For short we will refer to such a stream as 'stream m_2' instead of 'the stream with meteoroid masses m_2'. And similarly 'm_3-shower' or 'm_4-meteoroid'.

2.2 Activity profile

We define the activity profile of a meteor shower as the number of particles registered at the Earth as a function of time (or solar longitude $\lambda_\odot$). Certainly, if we consider as 'registered' only meteoroids really intersecting with the Earth, the number of modelled meteoroids should be comparable with the real number of meteoroids in the stream. In practice meteoroids having nodes on the distance Δ within the Earth's orbit (or the Earth itself) are referred to as Earth-intersecting (e.g. Brown & Jones 1998; Ryabova 2001a,b; Vaubaillon et al. 2005; Wiegert & Brown 2005). Value of Δ depends on the stream and the aim of modelling. For the Geminids the situation is the following.

Let us consider a model for meteoroids having masses m_2 most typical for visual observations. For this model only eight meteoroids from 30 000 approached the Earth on the distance less than 0.01 au (but more than 0.005 au) in 2004. Ryabova (2007, 3.2) has shown that for the Geminid stream we may count not particles, but orbits, which nodes approach the Earth orbit on the distance $<\Delta$. In our model we have 895 such orbits out of 30 000, if $\Delta = 0.01$ au. Fig. 2 shows a sample of 'registered' nodes. Their positions correspond to the final data of the integration. Theoretically speaking we should re-calculate them from the final epoch of integration to the dates corresponding to the solar longitude of each node. The check has shown that we may neglect the nodes motion on this time interval.

To obtain the activity curve of the model shower the nodes should be projected on the Earth orbit. The most simple (and seems to be logical) way of projection is the normal projection, practically coinciding with the projection along the position vector (line a in Fig. 2). From Fig. 2 it is obvious that a model activity profile will be the more distorted the wider is the registration band if we use the normal projection. Fig. 3 demonstrates how the activity profile for the stream m_2 changes with the band narrowing. Shape of the curve holds, but its width decreases on about 0°.3. Two alternatives exist to deal with the problem: (1) to obtain an optimal width of the band Δ experimentally, i.e. to find a reasonable balance between statistical stability of the activity profile and the distortion because of too wide Δ; the more meteoroids in the model the better is the profile, and the large is calculation time; (2) to project nodes on the Earth orbit along the general path of the node's secular motion in the ecliptic, i.e. along the stream section (line b in Fig. 2). The second technique being more logical than the normal projection is much more complicated in realization.

2.3 Width of the shower

The width of the shower is about 2°.5, 2°.1 and 1°.7 in $\lambda_\odot$ for m_4-, m_3- and m_2- showers correspondingly (see Fig. 3). Although Phaethon's orbit is a very 'unpertubed' one (Ryabova 2007, Fig. 2) and although the initial features of the Geminid stream structure are quite recognizable even after 2000 yr of evolution (Williams & Ryabova

Table 1. Amount (in per cents) of the model stream meteoroids with $D > D_t$.

D_t	Meteoroid mass		
	m_2	m_3	m_4
0.20	–	1	1
0.15	1	5	14
0.10	6	17	37

2011), we hoped that the model shower width will increase, but it was not the case, it is the same as in Model I. It has to be admitted that dispersion of the stream due to encounters with planets is not high.

2.4 Profile dependence on the meteoroid mass

The less is the model meteoroid's mass the wider is the model shower (Fig. 2). The reason is the cometary scenario of ejection, when the ejection velocity is higher for smaller meteoroids. Observations show the same picture (Ryabova 2001a, fig. 5). The stream m_4 is more dispersed, so the activity of its shower is about four times less than for the stream m_2. We see that the shape of activity profile for the shower m_4 is rather chaotic because of statistic fluctuations. So in this case 30 thousand particles model is too pure.

2.5 How many particles escaped from the stream?

What is the meteoroid stream? We could define it as the population of meteoroids having a common origin and similarity in orbits. Due to perturbations, both gravitational and non-gravitational, the stream meteoroid orbits evolve and some of them lose their similarity with the parent body orbit (or with the mean orbit of the stream, this is under discussion). These meteoroids replenish the sporadic meteoroid population. To evaluate how many particles leaved a stream we need (1) a measure of orbital similarity and (2) the threshold, separating stream and non-stream meteoroids. There are a number of such measures elaborated for meteoroid stream identification and for determining the parent of a meteoroid (see for example, articles by Valsecchi, Jopek & Froeschlé 1999, Jopek, Valsecchi & Froeschlé 2003, Jopek & Williams 2013 and references herein). We should realize, however, that the threshold values obtained in these studies are based on terrestrial observations, so they are related to substreams, and not to streams as a whole.

Any meteoroid stream has its own natural dispersion conditioned by a history of its life: a scenario of generation, the subsequent evolution governed by gravitational and non-gravitational perturbations, its age, encounters with planets, etc. Let us take a closer look at the Geminid model stream dispersion. As a measure of orbital similarity we applied commonly used D-criterion of Southworth & Hawkins (1963). We obtained the phase distance D between the asteroid Phaethon orbit and the model meteoroid orbits for the final epoch and calculated amount of the meteoroid orbits whose phase distance exceeds a definite threshold value D_t. From the Table 1, we see that even after two thousand years of evolution all m_2-meteoroid orbits are still within the distance 0.2 from their parent body orbit. The stream m_4 is much more dispersed, and the reason is explained in the Section 2.3. For this model stream 37 per cents of meteoroids are deflected on the distance 0.1 from the parent body orbit, comparatively with only 6 per cents for the stream m_2. This is the

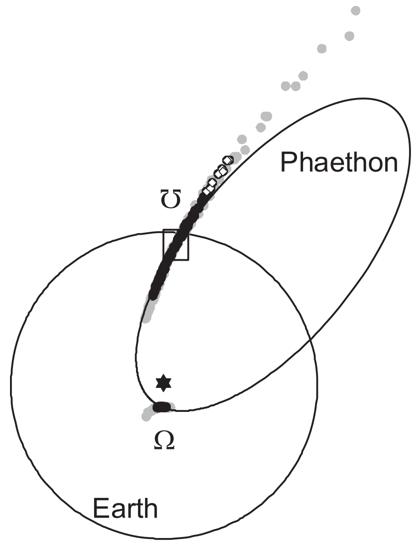

Figure 1. The asteroid Phaethon orbit in projection to the ecliptic plane. The descending (Ω) and ascending nodes of the model Geminid stream (200 particles, the mass = m_2) in the ecliptic plane are designated by black dots, the same for the mass = m_4 is shown by grey dots. White squares designate nodes of m_2-meteoroids with $D > 0.1$ (an explanation see in the Section 2.4). For the rectangle frame an explanation see in the Section 2.5.

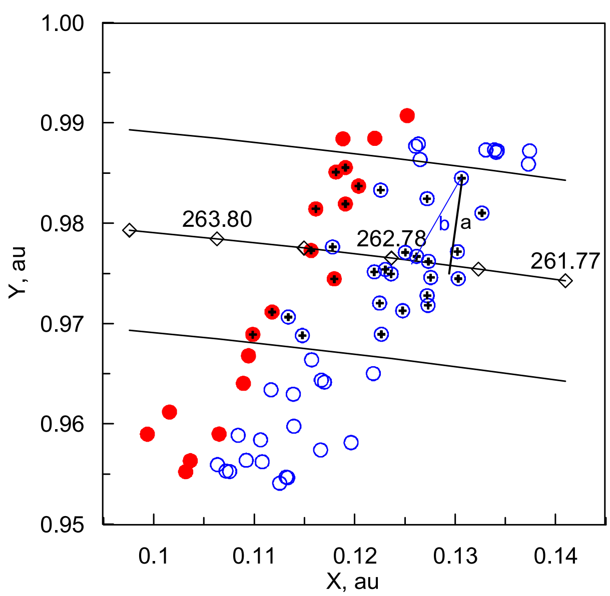

Figure 2. Geminid model cross-section in the ecliptic plane at the descending node for a stream of 1000 orbits of particles with masses m_2. The reference system is standard heliocentric ecliptic one. Ticks (⋄) on the Earth orbit are placed every half a day, and labels mark 12 h of a day (J2000) in solar longitude. Nodes of the orbits of meteoroids ejected (○) before perihelion passage, and (•) after perihelion passage are shown. Crosses mark the nodes of 'registered' 30 meteoroids in the band along the Earth orbit having width $2\Delta = 0.02$ au. Lines a and b show directions of the nodes projection on the Earth orbit: a – the normal projection, b – along the section (also see the text).

'natural' dispersion of the Geminid *model* stream, conditioned by the process of its formation.

Fig. 1 shows the model cross-sections of 200 orbits from the streams m_2 and m_4 by the ecliptic plane. The nodes of meteoroids with $D > 0.1$ for the stream m_2 are shown by white rectangles

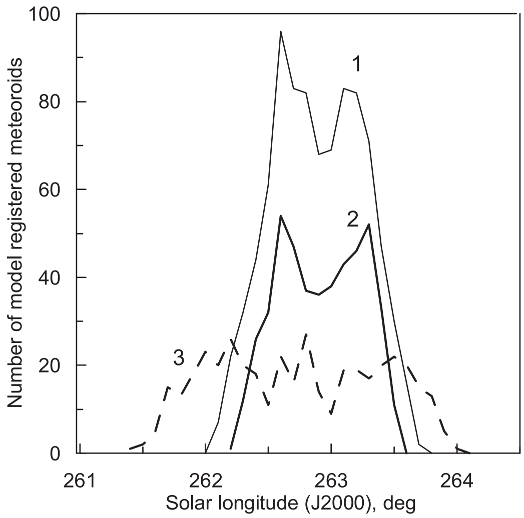

Figure 3. Model activity curves for model streams in 30 thousand particles: the number of registered particles versus solar longitude. (1) The mass of particle is m_2, $\Delta = 0.01$ au (895 nodes). (2) The mass of particle is m_2, $\Delta = 0.005$ au (469 nodes). (3) The mass of particle is m_4, $\Delta = 0.01$ au (411 nodes). Rate (*N*) is in meteors per 0°.1 in solar longitude.

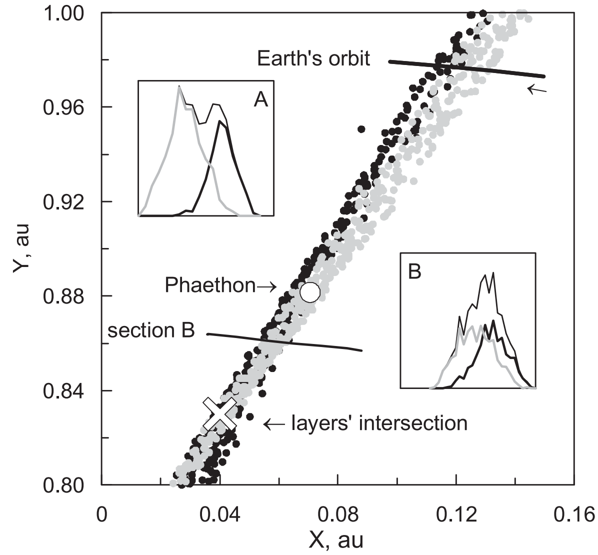

Figure 4. A rectangular cutout from the cross-section in Fig. 1. Stream m_2 descending nodes. The post-perihelion layer is designated by black dots, and the pre-perihelion layer by grey dots. The large cross marks the place of the layers intersection. Approximately this is the densest part of the stream, the stream 'core'. The asteroid Phaethon descending node is shown by large white circle. In the small panel A the activity profile (1) from Fig. 3 (thin black line) is shown. The profile A consists of pre-perihelion meteors (grey line) and post-perihelion meteors (thick black line). The activity profile in the small panel B is calculated along the section B just for an example.

on the plot. It is not surprising to find these orbits on the cross-section's periphery. We see that the stream m_4 seems to enclose the stream m_2. The 3D-shape of the Geminid stream resembles a seashell (Barentsen & Lefevre 2007). Evidently we may expect that far from the Geminid's 'core', which is in the vicinity of the Phaethon orbit, but does not coincide with it, the meteoroid mass distribution is probably very complicated. We may expect also, that the further from the 'core', the smaller is the fraction of large particles in the stream.

It is interesting to note that for 'registered' on the Earth meteoroids of all masses, i.e. for shower meteoroids, the upper limit of *D* is about 0.045.

2.6 Layers in the stream

The activity profiles on Fig. 3 (for m_2-shower) have two peaks. Why it is so was explained in detail by Ryabova (2007; 3.5). In short, the reason is that the initial geometrical difference between orbits of the meteoroids ejected before and after perihelion of the parent comet intensifies with time. The first maximum of the model shower activity curve is generated mainly by pre-perihelion ejecta (Fig. 4), and the second one by post-perihelion ejecta. From comparison with observations (Section 3) we will see that the model stream is shifted in space relative to the real one. The shift implies that the model stream should be intersected by the Earth not along the way shown in Fig. 4, but at some other place. The problem is that we do not know where exactly it should be. Small panels in Fig. 4 show that the shape of model shower activity profiles obviously depends on the location of the intersection. So we have to use observations to fit the model. The reasons of the shift we shell discuss in Section 3.4.

2.7 The stream location and its age

The estimation of the stream age used in our model is based on the review by Ryabova (1999), where it was formulated rather cautiously 'it [the age] does not exceed a few thousand years'. The specific value of 2000 yr have been chosen from consideration that at this time the Phaethon's perihelion distance was minimal over

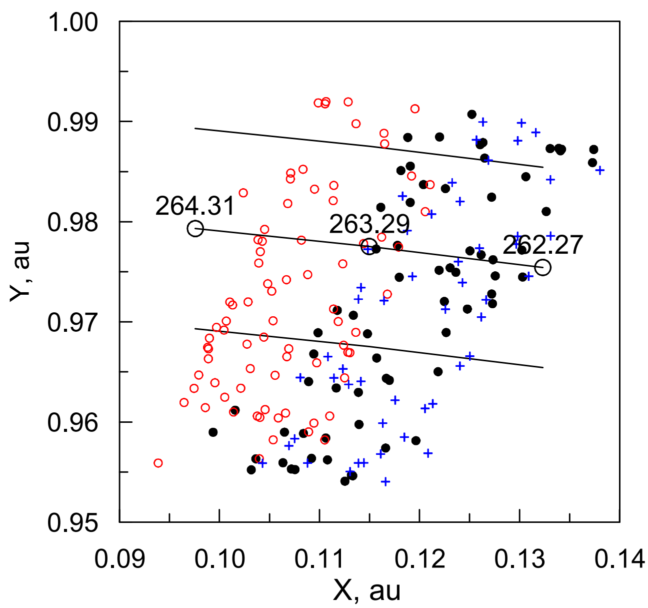

Figure 5. Geminid model cross-section in the ecliptic plane in dependence of the stream age. The mass of particles is m_2. The reference system, the Earth orbit and the band of registration are like in Fig. 2. Ticks and labels on the Earth orbit mark 0 h of a day in solar longitude (J2000). Nodes of the meteoroids ejected in 1537 (perihelion passage) designated by circles (○), in 2 BC by dots (•), and in 1002 BC by crosses (+).

last 5000 yr, therefore the ejection velocity had its maximal value. The question is: what will happen with the shower location if we vary the stream age? To answer this question we generated several model streams of 1000 meteoroids by the procedure described in Section 2.1, but with various ages. Fig. 5 shows that showers with the age of 2000 and 3000 yr have coinciding locations, while young 500 yr old shower is shifted about one day later. In all cases the model showers take place after the real shower maximum, which according to IAU Meteor Data Center (Jopek & Jenniskens 2011; Jopek & Kaňuchová 2014) is 262°.1.

3 COMPARISON WITH OBSERVATIONS

The model activity curve calculated here corresponds to the incident flux density curve (Ryabova 2007; 3.2) and should be compared with the flux profile of the observed shower, but not with the zenith hourly rate profile. That is why our selection of data samples for comparison is rather limited, especially for radar observations. Taking into consideration that we intend to compare only two parameters, namely (1) the location of the main shower maximum of activity, and (2) the shower width, a couple of samples both radar and visual ones will suffice.

It is important that the model shower profiles are the differential profiles (for particles with a definite mass), and the observational profiles are the cumulative ones, i.e. for particles with masses larger than the given minimal mass m_0. So to compare the locations of the activity maxima, we have to assume that the observed maximum is produced by the mean mass meteoroids. As to the shower width, we compare the model m_4-profile and the cumulative observational profile ($m > m_4$): it is possible to recalculate the profile for $m_0 = m_4$, if the mass index s is available. The Geminid's observed width depends on m_0: the less is the minimal mass, the wider is the profile (Ryabova 2001a; Fig. 5). That is why the comparison is made for the smallest available mass m_4. The width is compared at the half-maximum level to avoid influences of the observational interval limitation and of the possible wrong separation the stream meteoroids from the sporadic background.

3.1 Visual observations

Analysis of the 2004 Geminid meteor shower from global visual meteor observations was given by Arlt & Rendtel (2006). During 612 h of observations 29 077 Geminid meteors were registered. The incident flux density was calculated by Arlt & Rendtel (2006; fig. 6) for meteors up to magnitude +6.5, i.e. for the masses $\geq m_0 = 4.6\times 10^{-4}$ g according to the authors. The mean shower mass $\bar{m}$ (or mathematical expectation) is approximately equal to 0.08 g (for mass index $s = 1.7$ and the maximal possible mass for meteoroids equal 10^3 g). The observed shower has the double main maximum: two distinct peaks were found at $\lambda_\odot = 262°.16$ and 262°.23. One peak is visible also at 261°.3, i.e. before the main maximum. As it was mentioned above our models are statistically pure to study the stream fine structure, so we can only confirm existence of the double main peak. The observed shower has the total width of 8° in solar longitude (Arlt & Rendtel 2006; fig. 2), but on the level of 50 per cents of activity it is only 1°.4 wide.

Another proper sample for comparison is the 1996 visual Geminids (Brown et al. 1998). The limiting mass was the same as in the 2004 sample. The resolution of the flux curve here is not so high as for the 2004 Geminids, but it is sufficient to estimate maximum activity of the shower (261°.82 ± 0°.2) and the width at the half-maximum level (1°.0 ± 0°.2). A weak secondary maximum is possible at 261°.5. Here $\bar{m} = 0.03$ g ($s = 1.8$).

The limiting mass in the both samples is close to m_4, so for comparison of the shower width we may use the cumulative ($m > m_4$) observational profiles and the model m_4-profile. To compare the locations of the activity maxima the model m_2-profile may be used.

3.2 Radar observations

3.2.1 Kazan observations (1964–1967, 1969–1971)

Bel'kovich, Sulejmanov & Tokhtas'ev (1982) presented analysis of many years' radar observations in Kazan. The cumulative profile of activity calculated for masses $\geq 10^{-3}$ g has clear shape, but rather low resolution: 0°.5 in $\lambda_\odot$ near the maximum and about 1° on the periphery. The total width of the profile is 10°.8 (Bel'kovich et al. 1982; fig. 1), and the width on the half-maximum level is about 2°.5 (Bel'kovich et al. 1982; fig. 3). The maximum of the flux falls on 262°.06. (All values here are recalculated to epoch J2000.)

The electron line density α in the maximum of ionization of a meteor trail produced by a meteoroid with the mass 10^{-3} g is equal, according to the authors, to 1.62×10^{12} cm^{-1}, while the minimal registered α (mean for all years of observation) is 1.8×10^{11} cm^{-1}. Knowing that α is proportional to the meteoroid mass (Bel'kovich 1971; equation 1.15), we can calculate the minimal registered meteoroid mass as 1.0×10^4 g. The mean mass of shower meteoroids is equal then to 0.03 g ($s = 1.7$). (This estimation is valid only near the maximum of the shower, because s changes from 1.6 to 1.7 in the maximum till 2.2 on the periphery of the shower.) Therefore it is possible to use the model m_2-shower for comparison. The flux profile recalculated to the meteoroid mass m_4 turned out to be 3°.4 wide on the half-maximum level.

3.2.2 CLOVAR observations (1996)

Brown et al. (1998) obtained the flux profiles at three different limiting sensitivities α and the mass index profile for the 1996 Geminid meteor shower using the CLOVAR (Canada London Ontario VHF Atmospheric Radar) radar. These three α-levels are: 8.7×10^{10} (I), 1.6×10^{11}(II) and 2.5×10^{11} (III) cm^{-1}, corresponding to meteor magnitudes +7.7, 7.0 and 6.5, respectively, according to the authors. Resolution of the profiles is about 0°.5 in solar longitude. The shape of the profile III, which is more or less equivalent to the visual limiting magnitude (+6.5), is not clearly pronounced. Nevertheless, it is possible to identify the main maximum near 262° and possibly a secondary maximum near 260°.4. On the half-maximum level the profile is about 2°.5 wide. The total period of the shower activity is about 4°.6. This is a 'truncated' width, because observations began on December 10, where the flux was already 40 per cents of its maximum, i.e. the shower beginning was not observed.

Here the limiting mass is the same as in the visual observations (4.6×10^{-4} g), which means that the cumulative ($m \geq m_0$) observational profile and the model m_4-profile are comparable. The mean mass of the shower meteoroids is equal to 0.014 g ($s = 1.9$), so positions of activity maxima we compare with the model m_2-profile.

3.3 Shower width

In a cometary model of the particle's ejection the dispersion of a model stream (and its shower) depends on meteoroid masses. The width of a model *shower* depends also on the place where the Earth intersects the model *stream* (see small panels A and B in Fig. 4). For comparison with observations we take the largest possible model value: the maximal total width for the m_4-shower is about 2°.7, and the width on the level of 50 per cents of activity is 2°.1. The width of the model m_4-shower is about four times less than the observed one! However on the half-maximum level the situation changes (Fig. 6): the radar profiles are still wider, but the visual profiles become more narrow.

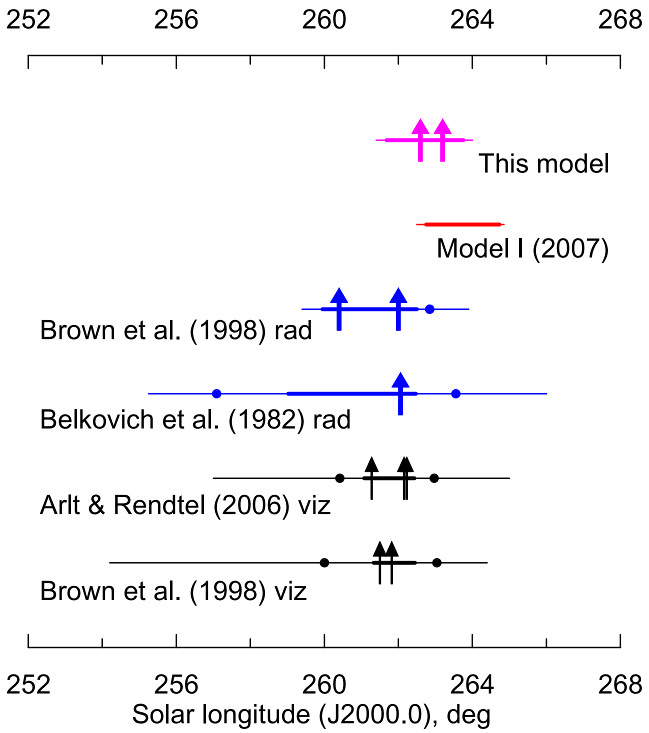

Figure 6. Activity period (i.e. width) and maxima of the Geminid meteor shower on observations and models. The thin line shows the total width, the thick line shows the width on the half-maximum level of activity, large dots point 20 per cent activity level. For the models the maxima correspond to m_2-shower, and the width to m_4-shower. (Model I does not include m_2-meteoroids.) Observational parameters see in the text.

There are several factors contributing to the stream dispersion. The ejection velocity used in the model is close to the largest possible one, because 2000 yr ago the Phaethon's orbit had the smallest perihelion distance. Gravitational perturbations and encounters with planets as well as solar radiation effects have very temperate influence on the stream width (see Section 2.3). That is why increasing the stream age up to 10 000 yr (only to see what happens, because there are no arguments for such age, see the relevant review by Ryabova 1999), we will get the model shower width 25 per cent *less* than for the age 2000 yr. If the parent body changed its orbit during the stream generation, this could increase the stream width. According to Lebedinets (1985) hypothesis the generation of the stream could be very quick, even during 0.5 orbital revolutions, and rapid release of the volatiles can be responsible for the drastic transformation of the cometary orbit. This could explain the discrepancy in the total shower width between the model and observations.

According to observations the Geminids have rather narrow core and extended low-level activity (Fig. 6). The asymmetry is obvious: the activity grows more slowly, than it falls. It is interesting to look at the relative intervals of the shower's core (half-maximum level) and 20 per cent activity level (Fig. 6). We see that models give another pattern of activity: both peaks are equal, and the broad low-level activity is absent (Figs 3, 6).

In the present model dust production is proportional to r^{-4} and symmetrical with respect to perihelion. All particles are ejected diring one orbital revolution. What changes could be introduced to the model to approximate it to the real stream? One possibility is the mentioned mechanism of the orbital transformation by Lebedinets (1985). Another possibility is that the core of the stream was generated by this catastrophic dust release, and the wide low-level 'tail' by long-term recurrent perihelion activity.

3.4 Why the maximum of activity in the model is later

The same Lebedinets' mechanism is probably responsible for the second discrepancy: the model shower maximum is shifted on a good 1° later! That was the case in Model I, and the reason was hoped to be using approximations instead of a precise method of numerical integration. Now we have to admit that it is not so. Varying the model stream age we also did not get a favourable shift in the shower location (Fig. 5). The present location of the stream depends on the location of the parent orbit during ejection. To calculate our initial orbit, we took into account gravitational perturbations from all planets, the Moon and Pluto, and did not get a satisfactory result. Transformation of the comet orbit by the jet force could explain both discrepancies.

4 SUMMARY

Several years ago the final version of the qualitative model of the Geminid meteoroid stream was published by Ryabova (2007, 2008). This model explains most of the Geminid's structural features, including the shower bimodality, yet it has two serious discrepancies with the real stream. The first is that the location of the stream is not correct, and the second is that the width of the model shower is about half that of the real shower. We had hopes that these disagreements will decrease, if a precise numerical method for calculation of orbital evolution will be used. To obtain the quantitative spatial density distribution of particles we also need a more precise model. The first runs of the numerical model were made, and some preliminary results are presented here.

We found that the stream width increased insignificantly, so gravitational perturbations due to encounters with the planets are not responsible for the mentioned discrepancy. The shower maximum in the numerical model is still one day late. Increasing or decreasing the stream age does not shift the shower into an earlier date. Long-term recurrent dust release at perihelion possibly can justify the stream width, but only in the activity tail area. We again come to the hypothesis that the parent orbit underwent a strong transformation due to jet forces (Lebedinets 1985). Such transformation explains both discrepancies. Unfortunately, it is hardly possible to calculate the initial body orbit, if it is the case.

Nevertheless there is still some hope to obtain a valid Geminid's model. Having measurements of the Geminid's space density (or flux density) far from the Earth orbit, we could apply something like 'free-transform' action in Photoshop to fit the model.

The dispersion of the model stream for three meteoroid masses was evaluated. It was found that for overwhelming majority of the stream meteoroids the phase distance D between meteoroids and the parent body orbit does not exceed 0.2 after 2000 yr of evolution (Table 1). However, we should have in mind that the model stream dispersion (judging by the shower width) is at least twice less than the dispersion of the real stream.

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