Mass segregation in the Geminid meteoroid stream as seen from recent photographic and video observations

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Summary

On December 13/14 1996, observers from the Dutch Meteor Society carried out photographic and video double station observations of the Geminid shower, resulting in 80 and 102 high precision orbits respectively. Combining these two samples, a specific feature of the Geminid meteoroid stream as earlier reported by Spurný, is confirmed. It is shown that there is a dependence between particle size and orbit size within the stream, such that smaller particles have smaller orbits. It is shown for the first time that this effect also occurs in the visual magnitude range from +1 to +6, where the corresponding particles are disturbed more strongly by radiative effects. Also dependences between meteoroid size and eccentricity and inclination are observable. Up to the present these effects have not been taken into account as a boundary condition for model based estimates of the age of the Geminid stream. The present observations suggest once more that this would be a useful exercise.

Introduction

Because of its small orbit, which is restricted to the area of the inner planets, the Geminid meteoroid stream has a number of outstanding characteristics. Its orbital evolution is such that the stream was not known before the 18th century [1]. The supposed parent body of the Geminids, 3200 Phaeton, appears to be an asteroid but may well be an extinct comet or a remnant of a past larger comet. The Geminids' orbit has a perihelion very close to the Sun and as a result the Geminid particles are completely outgassed and have a relatively high density producing meteors without flares. The activity profile of the Geminid meteor shower is such that it rises slower than it ceases and that the maximum for larger particles occurs later than that of smaller particles. Recently, it was also reported that orbits obtained from photographic data show that there is a dependence between particle size and orbit size such that smaller Earth-crossing particles move in smaller, less eccentric orbits [2].

It is the latter less known feature of the Geminids that is focussed on in the remainder of this paper. Recently, new Geminid orbits obtained from double-station photographic and video observations were published [3,4]. These orbits are from meteoroids covering a much larger magnitude range than available before and are therefore ideally suited to verify this feature.

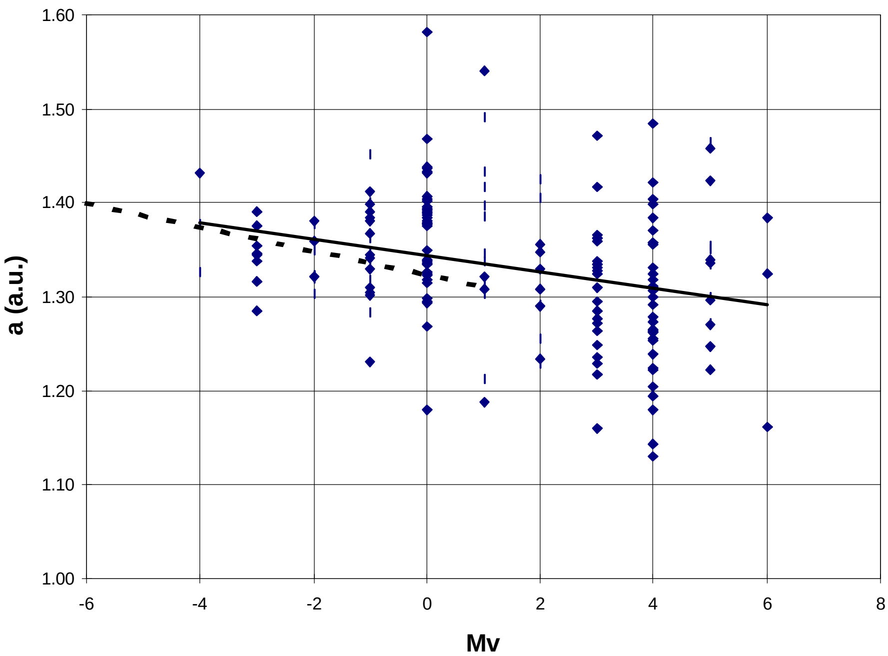

Figure 1. *Dependence of the Geminid orbit size (semi-major axis a) on particle size (absolute visual magnitude M_v). The solid line is a trend line from the current observations. The dotted line is a trend line from [2].*

The observations

On December 13/14 1996, observers from the Dutch Meteor Society carried out photographic and video double station observations of the Geminid shower, resulting in 80 and 102 high precision orbits respectively. Raw data, covering the solar longitude

Table 1. *Dependence on magnitude of the various orbital elements (2000.0) of the Geminid meteoroid stream.*

orb. elem	average M=0	dx/dM [DMS]	dx/dM [2]
a	1.345 ±0.07	–0.0087 ±0.0021	–0.011
e	0.894 ±0.009	–0.0016 ±0.0003	–0.0011
q	0.142 ±0.008	+0.0011 ±0.0002	Non Signif.
i	23.42 ±2.0	–0.0087 ±0.0021	Sign-ificant
ω	324.44 ±1.1	(–0.07) (±0.03)	Non Signif.
Ω	262.37 ±0.09	(–0.005) (±0.003)	Non Signif.

interval of 262.18-262.61 (2000.0), were presented earlier in [3,4]. Figure 1 shows the data in the terms of interest of this paper, namely the semi-major axis as a function of the absolute visual magnitude. The photographic and video samples fit nicely together as the former covers the magnitude range from -4 to +1 whereas the majority of video meteors falls in the range from +2 to +6. The samples together nicely confirm the trend of decreasing semi-major axis with increasing visual magnitude as first noted in [2]. As listed in Table 1, also the actual decrease rates as found in [2] and in Figure 1 agree well, within the limits of uncertainty. Table 1 also shows that the eccentricity *e*, the perihelion distance *q* and the inclination *i* significantly change when traversing the magnitude range from -4 to +6. Changes in the argument of perihelion ω and the solar longitude Ω are not significant, though. Also this is in agreement with [2], with the exception of the perihelion distance for which no significant change was found in [2].

For Ω the absence of a change seems to contradict the earlier mentioned Geminid characteristic of a later maximum with increasing particle size. It should be noted, however, that the observations were restricted to only a small part of the entire activity profile, in which such a change is not expected to be observable. Also extending the observation sample with DMS photographic observations from 1990-1994 did not change that, because for that sample the covered magnitude range is too small. Also, adding this sample did not alter the other results of Figure1 and Table 1 very much, so it was decided to leave these observations out and stick to the well-determined 1996 sample, which was obtained using the same equipment during the entire, though restricted, observation period.

Age of the Geminid stream

In the literature there is no agreement on the age of the Geminid stream. In his review in [5], Olsson-Steel lists ages ranging from 500 to 10.000 years. There *is* agreement, though, that radiative effects, i.e. the effect of the light of the Sun on the motion of the meteoroids, have played an important role in creating the current characteristics of the Geminid stream.

There are three main radiative effects. The first one is the *radiation pressure*. Meteoroids only absorb and retransmit light at the face that is turned towards the Sun. In this way the light pushes very, very softly against the meteoroid away from the Sun, slightly counteracting the gravity pull. As the distance dependence of the radiation pressure and gravity are equal, this effect does not change the *shape* of the orbit (it remains elliptical), but only its *size*: it becomes bigger. The effect is well known from the dust tail of a comet: the freshly ejected dust moves in an orbit slightly wider than the comet itself, because of the radiation pressure, and as a result the dust moves a little slower and lags behind the comet. Figure 2A shows in an exaggerated way the orbit of the comet, the orbits of freshly ejected large dust particles outside of that and even farther outside the orbits of small dust particles. However, for meteoroids in the visible range, the change in semi-major axis of the orbit due to radiation pressure amounts to no more than a few hundredth of a percent, which would be invisible in Figure 2A.

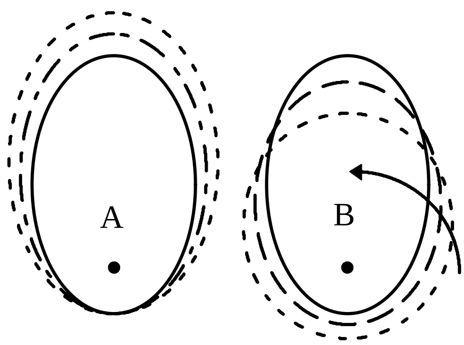

Figure 2. *Orbits of a comet (solid), small (short dashes) and large particles (long dashes) shortly after ejection (A) and after long influence of the Poynting-Robertson effect (B).*

A second well-known radiative effect is the Poynting-Robertson effect. While light is absorbed almost perpendicular to the motion of the meteoroid, the light is re-emitted in directions covering half a sphere. Due to the relativistic Doppler effect, light emitted in the forward direction (relative to the meteoroid's motion) gets a slight blue-shift and light sent in the backward direction a slight red-shift. As blue light has a higher energy (momentum), the meteroid is slowed down as a result. The effect is very small, but after thousands of years it makes the orbit significantly smaller and less eccentric. As for radiation pressure, the effect is stronger for small particles because for these the surface, which determines the amount of light gathered, is relatively large in relation to the mass, which determines the effect of the encountered forces. Figure 2B shows the effect of the Poynting-Robertson effect after thousands of years of evolution, starting from the situation of 2A.

Figure 2B also shows how the Earth moves through the stream. It shows nicely how it first encounters the smaller particles and then the larger particles, in agreement with visual observations. What the new observations add to this picture is that we now not only know that the Earth encounters the larger particles later, but also that the larger particles move in larger orbits.

There is also a third radiative effect, the Yarkovskii-Radzievskii effect. This effect takes into account that a particle emits radiation most strongly at the side where it is hottest. Normally, the hottest side is the side where the particle is irradiated by the Sun. However, when particles spin very fast (>10.000 rad/s, [5]) such equilibrium is no longer present and the Y-R effect takes off. In contrast to the Poynting-Robertson effect, the Y-R effect does not have an average effect on the stream's orbit but only tends to diffuse the stream. This does not affect the picture described earlier.

Conclusions

The confirmation of the recently found effect that the size of Geminid orbits rather strongly depends on the particle size, is a nice example how video observations are an important complement to photographic observations. The extension of the magnitude range is also an important addition, because the radiative effects are known to be much stronger for the smaller meteoroids and thus the observations put a stronger boundary condition to model calculations. It would be useful to revisit the existing stream models and take into account the current results to arrive at a better age estimate of the Geminid stream.

References

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Vervolg van bladzijde 50

Er kan snel gecontroleerd worden of waarnemingen uit bepaalde nachten aanwezig zijn, welke zwermen zijn waargenomen, onder welke condities en door wie. Voor veel analyses zal het elektronisch archief volstaan. Voor verdere bewerking (magnitudendistributies, intekeningen) kan altijd een aanvraag voor kopieën bij Olga worden ingediend.

Ik hoop het bijwerken van het elektronisch archief op niet al te lange termijn te kunnen voltooien waarna het op de DMS FTP site geplaatst zal worden en daar voor iedereen toegankelijk zal zijn.

Figuur 2 geeft het overzicht van de stand van zaken tot en met 1997. De gegevens van 1991, 1994 en 1995 zijn pas voor de helft ingevoerd, maar toch zijn duidelijk de succesvolle visuele jaren uit de DMS geschiedenis zichtbaar.

1997 slaat in dit verband beslist geen gek figuur.

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