On asteroidal meteoroid streams detection

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Abstract. In this paper a possibility of detection of asteroidal meteoroid streams is discussed. The relation between the geocentric velocity of meteoroids and observed hourly rates of meteors is studied provided that

(a) the meteor luminosity and velocity are related as $I \approx v^5$,

(b) the structure of a meteoroid stream is similar to the Geminid meteoroid stream.

From this viewpoint the most promissing candidates for associations between AAA asteroids and meteoroid streams should be 5496 1973 NA, 2102 Tantalus and 1996 BT.

Key words: asteroid, meteor stream, parent body

1. Introduction

Possible asteroidal origin of some meteor showers was suggested already by Hoffmeister (1948) and thus this problem has been discussed for several decades. There are many studies in which the authors suggest possible associations of meteor streams with the AAA asteroids on the basis of orbital similarities (Sekanina 1973, 1976; Olsson-Steel 1987,1988; Babadzhanov et al. 1990; Obrubov 1991; Porubčan et al. 1992, Štohl and Porubčan 1993; Babadzhanov 1995, etc.). However, there is known only one a rather real association so far, the association between the Geminids and 3200 Phaethon suggested by Whipple (1983). The problem is that asteroids as potential parent bodies of meteor streams are moving in direct orbits at low geocentric velocities and observation or detection of their meteor streams is strongly influenced by several selection effects. In general, selection effects influencing detection of meteor streams were discussed more detailed by Kresák (1968) and Hughes (1993).

In the present paper the detection of meteoroid streams in the orbits of AAA asteroids taking into account their geocentric velocity acting as one very effective selection effect is analyzed and discussed.

2. Relation between the velocity of meteoroids and meteor detection

According to the classical luminous equation the meteoroid mass loss and meteor luminosity I are related as

$$I = \frac{\tau \Lambda A}{4Q} M^{2/3} \rho^{-2/3} \rho_a v^5 \ , \tag{1}$$

where τ is the luminous efficiency, Λ is the heat transfer coefficient, A is the shape factor, Q is the heat of vaporization, M is the mass of meteoroid, ρ is the density of meteoroid, ρ_a is the density of the atmosphere and v is the meteoroid velocity.

In order to solve the stated problem the Geminid meteoroid stream moving in an orbit identical with that of 3200 Phaethon can be considered for a prototype of asteroidal meteoroid streams. Therefore, we have chosen this stream and studied dependence of its magnitude distribution on velocity. The relation between the meteor luminosity I and its brightness m is described by Pogson's equation and, followingly, a relation between the meteor brightness m and its velocity v can be derived.

Let a Geminid meteoroid velocity is v_G, the intensity of its trail I_G and the brightness m_G. If it would enter the atmosphere at another velocity ($v_G \rightarrow v$) the intensity of its trail will also change ($I_G \rightarrow I$) and followingly its brightness m defined by Pogson's equation will be

$$m - m_G = -2.5 \log \frac{I}{I_G} = -2.5 \log \frac{v^5}{v_G^5} \tag{2}$$

Taking for v_G the outside atmospheric velocity of the Geminids $v_\infty = 36.7$ km/s (Porubčan, Štohl 1979) we get

$$m = m_G - 12.5 \log (v) + 19.55 \tag{3}$$

The equation (3) shows theoretical relation between the brightness of the Geminid meteors m_G and velocity v. The limiting magnitude of the Geminids is shifting with the decreasing velocity towards to brighter meteors rather quickly and this fact influences the observed hourly rates very strongly. Substituting for m the limiting visual magnitude of a standard observer ($m = +6$) into equation (3), theoretical relation between the limiting brightness of the Geminid meteors corresponding to the visual limit and various velocities v with which the Geminid meteoroids would enter the atmosphere is shown in Fig.1 and given as

$$m_G = 12.5 \log (v) - 13.55 \tag{4}$$

A meteoroid observed as a meteor of $m = +6$, with physical parameters of the Geminid meteoroids, entering the atmosphere at a velocity of 25 km/s, 20 km/s and 15 km/s will actually correspond to a Geminid (v_G = 36.7 km/s) of the brightness $m_G \doteq 3.9$, 2.7 and 1.2, respectively. This clearly demonstrates the problem of detection of meteoroid streams moving at lower geocentric velocities. In a meteoroid stream of the same spatial density as that of the Geminid meteoroid stream, however, entering in the atmosphere e.g. at 15 km/s, visual observer will observe only meteors which correspond to the Geminids of $m_G < 1.2$. How strongly this fact influences the observed hourly rates is discussed in the next sections.

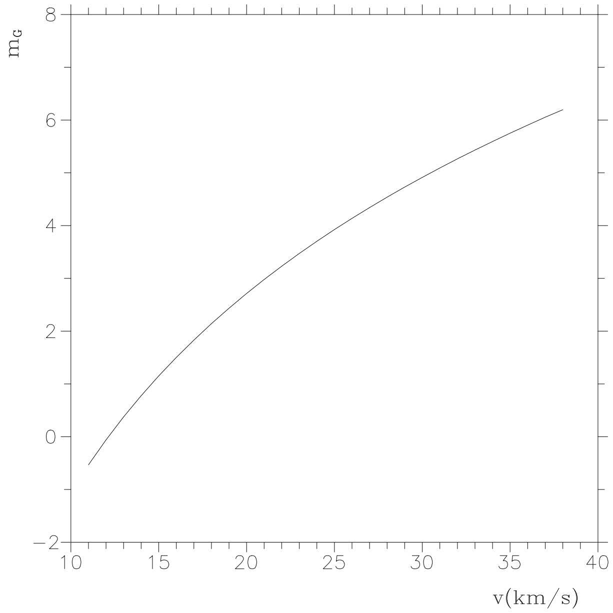

Figure 1. Theoretical relation between the limiting brightness of the Geminid meteors m_G corresponding to the visual limit ($m = +6$) and the velocity v.

3. Transformation of the observed meteor rates

The problem of detection of asteroidal meteoroid streams can be investigated as a problem of the detection of Geminids moving in the orbits of other AAA asteroids as possible parent bodies of meteoroid streams.

Due to a change of the velocity of meteoroids in the atmosphere ($v_G \rightarrow v$) a change in meteor rates must be observed. Further we will discuss the changes in

(a) the rate of meteors of the apparent brightness m observed by one observer $- f(m)$;

(b) the rate of meteors of the zenith brightness m_z observed in the

whole sky above horizon $-$ $F(m_z)$;
Let us consider that the radiant of a theoretical meteor stream is located in the zenith.

When $v_G \to v$, the transformation of (a) and (b) can be presented as follows

$$f(m, v_G) \xrightarrow{T_1} F(m_z, v_G) \xrightarrow{T_2} F(m_z, v) \xrightarrow{T_3} f(m_z, v) \ ,$$

where $f(m, v_G)$ and $F(m_z, v_G)$ are (a) and (b) when the meteor velocity is v_G and $f(m, v)$ and $F(m_z, v)$ are (a) and (b) when the velocity is v.

3.1. Transformations $\mathbf{T_1}$ and $\mathbf{T_3}$

Transformations T_1 and T_3 are defined by a relation between $F(m_z)$ and $f(m)$ as (Porubčan, Štohl 1979)

$$F(m_z = m) = 0.188\ f(m)\ p(m)^{-1} + 0.278\ f(m+1)\ p(m+1)^{-1} \ , \qquad (5)$$

where $0.188\ f(m)\ p(m)^{-1}$ is the contribution of that part of the sky, where no correction to the zenith brightness is necessary to make (it is the part of the sky with the zenith distance $0° < z < 35.7°$ $-$ about 18.8 % of the sky above horizon), $0.278\ f(m+1)\ p(m+1)^{-1}$ is the contribution of that part of the sky, where the zenith brightness correction is -1^m (it is the part of the sky with the zenith distance $35.7° < z < 57.7°$ $-$ about 27.8 % of the sky above horizon), $f(m)$ is the corrected zenithal rate of meteors of the apparent magnitude m and $p(m)$ are coefficients computed by Kresáková (1966) which represent the probability of detection of a meteor of magnitude m (see Tab.1).

Transformation T_1 is realized when $F(m_z)$ are computed from the known $f(m)$ and transformation T_3 is realized when $f(m)$ are computed from the known $F(m_z)$.

Table 1. Coefficients $p(m)$ computed by Kresáková (1966)

m	−4	−3	−2	−1	0
p(m)	0.94	0.92	0.79	0.61	0.435
m	+1	+2	+3	+4	+5
p(m)	0.352	0.339	0.215	0.060	0.0075

3.2. Transformation $\mathbf{T_2}$

Transformation T_2 consists of the three following steps:
1)

$$F(m_z{'}, v) = \frac{v_g}{35}\ F(m_z, v_G = 36.7\ \text{km/s}) \qquad (6)$$

Provided that the spatial density and structure of a theoretical meteoroid stream in space is the same as that of the Geminids, the amount of meteoroids entering the Earth's atmosphere per hour should be proportional to the geocentric velocity of their parent body v_g (the geocentric velocity of the Geminids is 35 km/s (Porubčan, Štohl 1979)).
2)

$$m_z{}' = m_z - 12.5 \log{(v)} + 19.55 \tag{7}$$

This is an analogy with eq.(3), since if $v_G \rightarrow v$ then the change of meteor brightness is described by this equation;
3)

$$v = v_\infty = \sqrt{v_g{}^2 + \frac{2\kappa M_Z}{r_{RA}}}\ , \tag{8}$$

where $\kappa = 6.672 \times 10^{-11}$ Nm^{2}kg^{-2}, $M_Z = 5.976 \times 10^{24}$ kg (mass of the Earth) and r_{RA} is the distance from the centre of the Earth where the process of meteoroid radiation begins (we consider 6473 km, $\approx$ 95 km above the Earth's surface (Porubčan, Štohl 1979)). Equation (8) (Abalakin *et al.*, 1976) shows that each meteoroid with the geocentric velocity v_g is before entering the atmosphere speeded up and enters the atmosphere with the velocity v_∞. If we want to investigate the meteor luminosity just after the meteoroid enters the atmosphere we can take $v = v_\infty$. Another consequence of eq.(8) is the fact that for each meteoroid entering the Earth's atmosphere we have $v = v_\infty \gtrapprox 11.2$ km/s, where 11.2 km/s is the approximate escape velocity at a distance r_{RA} from the Earth's centre. Hence, the velocity v presented on x-axis in Fig.1 is greater than 11 km/s.

4. Results

As mentioned above, in order to verify the approach and results, the Geminid meteoroid stream was used as a prototype of the asteroidal meteoroid streams and a change of the observed meteor rates at various geocentric velocities was investigated. For the analysis, the observations of the Geminids carried out at the Skalnaté Pleso Observatory on December 14, 1974 (Porubčan and Štohl 1979) at the shower maximum, were applied. Resulting meteor counts $f(m, v_G)$ presented in Table 2 were corrected for the cloudiness, personal coefficients of the observers and reduced to the hourly rates. The corresponding $F(m_z, v_G)$ were reduced to the radiant in the zenith considering also a correction of the apparent magnitude to the zenith magnitude m_z.

Using transformations T_1, T_2, T_3, theoretical values of $F(m_z, v)$ and $f(m, v)$ for the geocentric velocities v_g = 10 km/s, 15 km/s, 20 km/s and 25 km/s were computed. These are typical geocentrical velocities of the Amor-Apollo-Aten asteroids in the region of their closest approach to the Earth (Drummond 1982). The corresponding velocities outside the atmosphere are $v = v_\infty$ = 15 km/s, 18.7 km/s, 22.8 km/s and 27.3 km/s, respectively. The computed values

Table 2. $f(m, v_G)$ and $F(m_z, v_G)$ of the Geminids observed at the Skalnaté Pleso Observatory on Dec.14, 1974

m	$f(m, v_G)$	m_z	$F(m_z, v_G)$
-4	$-$	-4	0.08
-3	0.3	-3	0.09
-2	0.1	-2	0.27
-1	0.5	-1	1.50
0	2.2	0	5.35
$+1$	6.4	$+1$	16.90
$+2$	16.4	$+2$	42.90
$+3$	26.6	$+3$	83.40
$+4$	13.4	$+4$	187.10
$+5$	4.0	$+5$	$-$
Total	69.9		337.60

of $F(m_z, v)$ and $f(m, v)$ for each v_g are presented in Tab.3, Tab.4 and Fig.2, Fig.3.

It can be concluded that there is a small chance to detect a meteoroid stream having even the same spatial structure as is that of the Geminids for the geocentric velocity $v_g < 20$ km/s. As the average rate of the sporadic background meteors is about 10 meteors per hour (Williams 1995), the meteoroid streams having the hourly rates lower than is the standard rate of the sporadic background meteors are difficult to distinguish. Moreover, there is parallelly acting another selection effect hampering detection of these streams. Namely, with the decreasing v_g the radiant area of the stream is increasing and this makes a detection of a meteoroid stream still more problematic.

This is a significant conclusion because (a) the Geminids rank among the most significant annual meteor showers. Hence, even a not very populated meteoroid stream is difficult to recognize from the sporadic background also for $v_g > 20$ km/s. (b) Moreover, up to the present time (October 16, 1997) there are known 423 AAA objects to which 289 theoretical asteroidal meteoroid streams may be associated. For each of these streams the distance between the Earth and the asteroid's orbit in the moment of the closest approach is less than 0.1 AU. More than 81% of them (236) have $v_g < 20$ km/s and more than 92% of them (267) have $v_g < 25$ km/s. Only 18 of them have v_g in the interval 25 km/s $< v_g < 30$ km/s.

Only 4 of these streams have $v_g > 30$ km/s and it is interesting to note that only one of them - the Geminids is known so far (the geocentric velocity of its potential parent 3200 Phaethon is $v_g = 33.76$ km/s).

Only one of the above expected theoretical asteroidal meteoroid streams (parent body is 5496 1973 NA) has v_g higher than is that of 3200 Phaethon, i.e. 33.76 km/s (37.39 km/s). There are two probable additional theoretical

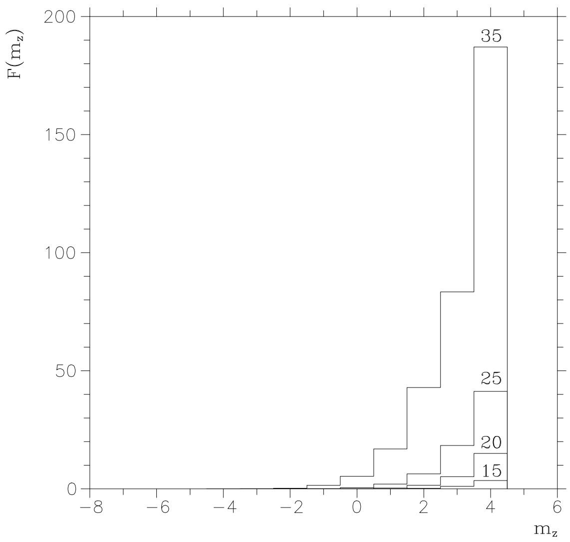

Figure 2. The hourly rates of the zenith magnitudes $F(m_z)$ of the Geminids ($v_g = 35$ km/s) observed at the Skalnaté Pleso Observatory in 1974 and corresponding theoretical rates computed for the geocentric velocities $v_g = 15$, 20 and 25 km/s.

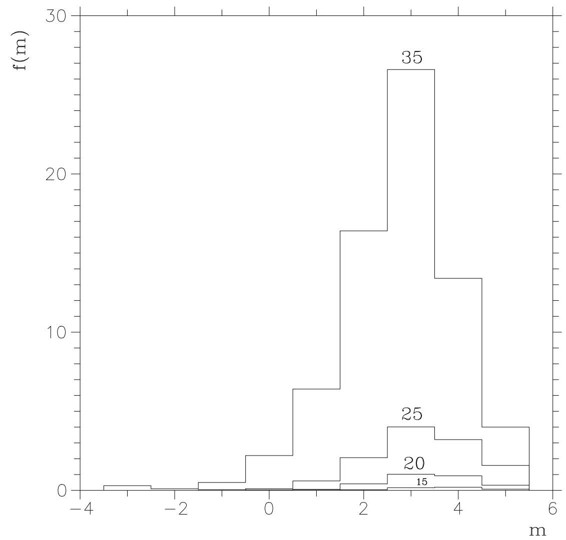

Figure 3. The magnitude distribution of the Geminids observed at the Skalnaté Pleso Observatory in 1974 ($v_g = 35$ km/s) and theoretical distributions corresponding to the geocentric velocities $v_g = 15$, 20 and 25 km/s.

asteroidal streams with the geocentric velocity $v_g > 30$ km/s which may be associated with 2102 Tantalus ($v_g = 33.48$ km/s) and 1996 BT ($v_g = 30.02$ km/s). These three theoretical meteoroid streams have the best chances for detection. The stream associated with 5496 1973 NA should have its maximum activity on about June 29 ($L_\odot \doteq 100°$, the geocentric radiant: $\alpha = 16.2°$; $\delta = +66.9°$), the second stream associated with 2102 Tantalus should have its maximum of activity on about Dec.26 ($L_\odot \doteq 275°$, the geocentric radiant: $\alpha = 135.5°$; $\delta = -44.5°$) and the third one associated with 1996 BT should have the maximum of activity on Jan.26 ($L_\odot \doteq 306°$, the geocentric radiant: $\alpha = 154.5°$; $\delta = +16.5°$).

Table 3. Computed values of $F(m_z, v)$ for individual geocentrical velocity v_g

m_z	$v_g = 10$ km/s	$v_g = 15$ km/s	$v_g = 20$ km/s	$v_g = 25$ km/s
−2				0.06
−1			0.05	0.11
0		0.03	0.09	0.52
+1	0.02	0.06	0.37	2.02
+2	0.03	0.24	1.55	6.34
+3	0.11	1.07	5.15	18.36
+4	0.53	3.55	15.00	41.27
Total	0.69	4.95	22.21	68.68

Table 4. Computed values of $f(m, v)$ for individual geocentrical velocity v_g

m	$v_g = 10$ km/s	$v_g = 15$ km/s	$v_g = 20$ km/s	$v_g = 25$ km/s
−1				0.05
0			0.03	0.11
+1		0.02	0.07	0.60
+2	0.01	0.04	0.41	2.07
+3	0.02	0.17	1.02	4.01
+4	0.02	0.20	0.92	3.21
+5	0.01	0.08	0.33	1.58
Total	0.06	0.51	2.78	11.63

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