IL NUOVO CIMENTO Vol. 27 C, N. 4 Luglio-Agosto 2004
NOTE BREVI
DOI 10.1393/ncc/i2004-10034-x

The orbit and evolution of the Geminid meteoroid stream

V. Porubčan(1)(2), L. Kornoš(1), G. Cevolani(3) and G. Pupillo(3)(4)(5)

(1) *Department of Astronomy, Physics of the Earth and Meteorology FMPI Comenius University - 842 48 Bratislava, Slovakia*
(2) *Astronomical Institute of the Slovak Academy of Sciences - 845 04 Bratislava, Slovakia*
(3) *CNR-ISAC - Via Gobetti 101, 40129 Bologna, Italy*
(4) *DET, Università di Firenze - 50139 Firenze, Italy*
(5) *Osservatorio di Campi Salentina - 73012 Campi Salentina (Lecce), Italy*

(ricevuto l'11 Novembre 2004; approvato il 24 Novembre 2004)

Summary. — The orbit and radiant of the Geminid meteoroid stream based on an analysis of the current version of the IAU MDC catalogue of photographic meteors are studied and discussed. The mean orbit, shape, size and ephemeris of the radiant are derived. The radiant area of the central part of the stream is more concentrated with the densest part of the size of $2^\circ \times 2^\circ$. The orbital evolution of the stream is investigated and compared with the evolution of its potential parent asteroid 3200 Phaethon.

PACS 96.50.Kr – Meteors, meteoroids, and meteor streams.
PACS 95.85.Bh – Radio, microwave (> 1 mm).
PACS 96.30.Ys – Asteroids (minor planets).

1. – Introduction

The Geminid meteor shower active for about two weeks in the beginning of December has been known since the second half of the 19th century [1]. The shower maximum with the visual peak rate of about 100 meteors per hour appears at the solar longitude of 262°. The Geminids rank among the most concentrated meteor showers with the activity corresponding to the half maximum rate lasting for about two-three days (December 12-14). Among all the known regular meteoroid streams the Geminids move on the smallest and at the same time the best-defined orbit [2] with the period of revolution of only 1.6 years. After recognition that the stream may be associated with asteroid 3200 Phaethon by Whipple in 1983 [3], the shower is studied more intensively.

The present paper presents a study of the radiant and orbit of the Geminid meteoroid stream based on the precise photographic orbits available from the current catalogue of the IAU Meteor Data Center—version 2003 [4] and analysis of the orbital evolution of the stream as well as of the asteriod 3200 Phaethon considered for its parent body.

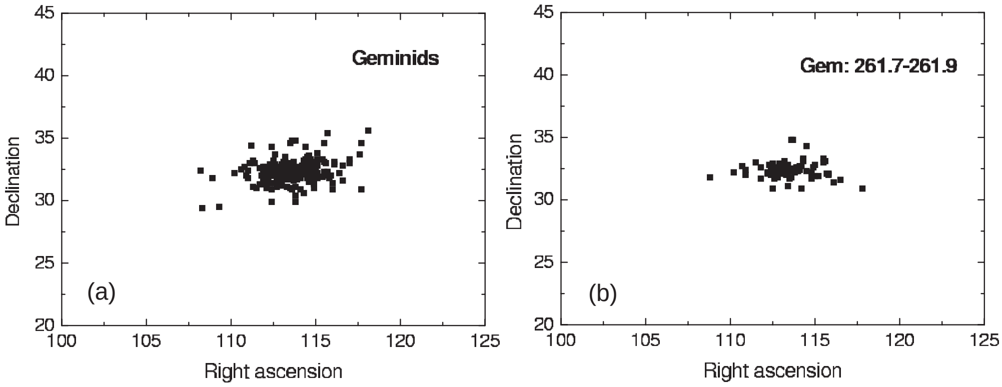

Fig. 1. – Photographic radiants (α, δ) of the Geminid meteor shower reduced to the common solar longitude (261.8°): a) from all the period of activity—385 meteors, b) from the peak of activity (261.7°–261.9°, 106 meteors).

2. – The radiant and mean orbit of the Geminids

Phographic observations provide the most precise orbital and geophysical parameters of meteors. The Geminids are after the Perseids the second best-represented meteor shower in the photographic catalogues and thus a reliable orbit and radiant for the stream can be acquired. The shower is rich also in bright meteors and statistics of the shower members in the photographic catalogues is steadily increasing. Kresák and Porubčan [5] for their analysis of the shower radiant and orbit in 1970 had at disposal 81 Geminids, Williams and Wu in 1993 [6] have derived the mean stream orbit from 100 meteors, Porubčan and Cevolani [7] have found from all available catalogues already 191 Geminids.

In the present version of the MDC catalogue of photographic orbits the orbital elements of 4581 meteors are compiled [4]. The catalogue has increased by about one thousand new orbits. This provides a possibility to derive also a more precise mean orbit and radiant of the stream.

In the present analysis the stream members were searched for by a computerized stream search procedure utilizing the Southworth-Hawkins D criterion [8]. For a limiting value of the $D \leq 0.2$, 385 meteors belonging to the Geminids, from the period December 3-16, were found in the catalogue. The orbits are compiled from the period of 55 years (1936-1991) and the stream radiant daily motion and radiant ephemeris derived is

$$\alpha = 113.7° + 0.92(L_\mathrm{s} - 261.8°)\,,$$
$$\delta = 32.2° - 0.12(L_\mathrm{s} - 261.8°)\,.$$

The daily motion in right ascension and declination was found by the least-squares solution and L_s is the solar longitude of the time of observation for equinox 2000.0 and 261.8° is the solar longitude of the maximum of activity.

The size of the radiant area corresponds to the dispersion of the orbits and thus also to the stream structure. To find the size and form of the stream radiant area, individual radiants were reduced to a common solar longitude of the maximum of activity, by allowing for the daily motion of the radiant and are plotted in fig. 1a. The Geminid

TABLE I. – *The mean Geminid meteor stream orbit derived from photographic observations.*

Author	q (AU)	a (AU)	e	$i(°)$	$\omega(°)$	$\Omega\,(°)$	Number
Kresák and Porubčan [5]	0.129	1.38	0.906	24.9	325.8	261.0	81
Williams and Wu [6]	0.141	1.379	0.898	23.6	324.2	260.7	100
Porubčan and Cevolani [7]	0.143	1.333	0.891	23.7	324.7	261.0	191
Present analysis	0.141 $\pm$.013	1.342 $\pm$.079	0.894 $\pm$.019	23.6 $\pm$2.4	324.5 $\pm$1.5	261.8 $\pm$1.3	385
3200 Phaethon	0.1399	1.2714	0.8899	22.16	321.97	265.44	

radiant area is slightly elongated and of the size of approximately 10° × 5°. The densest part is confined to the area of 5° × 3°. In fig. 1b the radiant area for meteors from the central part of the stream activity of the length of 0.3° (solar longitude 261.7°–261.9°, 106 Geminids) is depicted. The radiant area in the central part of the stream is more concentrated and in its densest part reaches a size of 2° × 2°, while in the marginal regions the radiant is more diffuse.

The mean orbit of the Geminids derived from 385 photographic orbits is listed in table I. For comparison the table lists also the orbits derived in previous searches [5, 6] and [7]. The angular elements in table I are referred to equinox 2000.0. The photographic orbits derived by various authors from samples of different sizes show only minor differences, which document that the Geminids are a rather strongly concentrated meteoroid stream.

Porubčan and Cevolani [7] in their analysis of 191 photographic Geminids have shown apparent systematic changes of some orbital elements over a time span of 50 years. The most evident is the change in the semi-major axis exhibiting a steady decrease approximately from 1.46 to 1.28 AU. Extended statistics of the Geminids enlarged by almost 200 additional orbits provided a possibility to verify the conclusion and fig. 2 shows the distribution of the semi-major axis *vs.* individual years (1936-1991). The distribution does not follow a steady decrease of the Geminid semi-major axis and is more consistent with the orbital evolution of the stream presented in fig. 3.

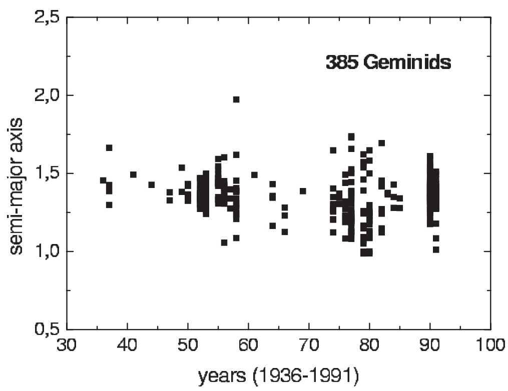

Fig. 2. – Distribution of the semi-major axis of 385 photographic Geminid meteors (from 1936-1991). The years of observation (x-axis) are designated by the two last numbers.

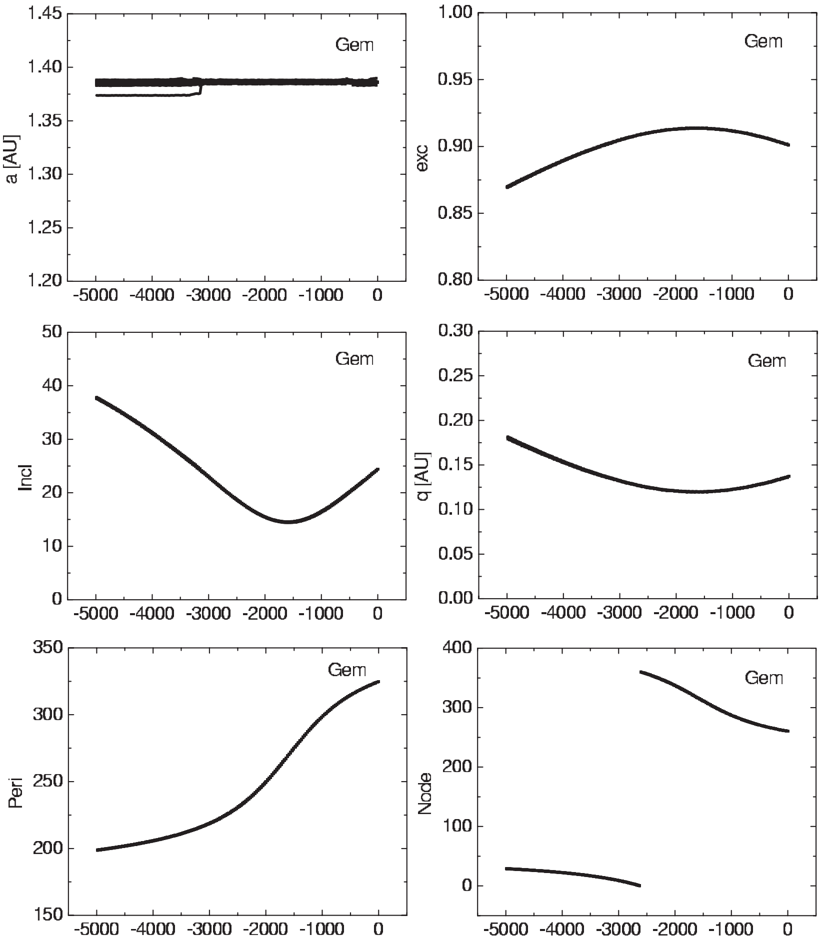

Fig. 3. – Backward integration of the orbital elements of the Geminid meteoroid stream over 5000 years.

3. – The orbital evolution of the Geminids and 3200 Phaethon

In order to study the association between the Geminids and 3200 Phaethon, the orbital evolution of the mean orbit of the stream and the asteroid over 5000 years back was investigated. We have applied for the backward integration of the orbital evolution the DE multistep procedure of Adams-Bashford-Moulton's type up to 12th order, with variable step-width, developed by Shampine and Gordon [9] and the positions of perturbed major planets were obtained from the Planetary and Lunar Ephemerides DE406 prepared by the Jet Propulsion Laboratory [10].

The results of the integration are presented on plots in figs. 3 and 4, where the diagrams depicting the evolution of the orbital elements a, e, i, q, ω and Ω over 5000 years, are shown. The plots of the Geminids are represented by 36 modeled particles distributed equidistantly according to the mean anomaly by 10° along the mean orbit of the stream. Figure 5 shows the evolution of the D criterion describing similarity between the orbits of the Geminids and Phaethon (left plot) and the difference between their

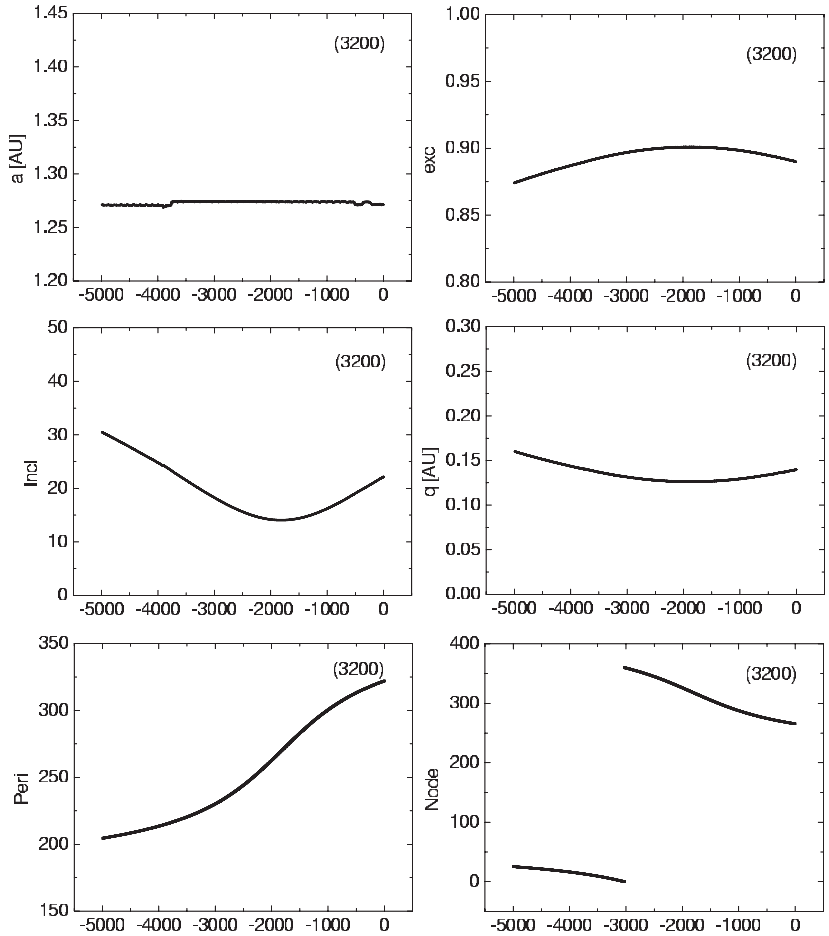

Fig. 4. – Backward integration of the orbital elements of asteroid 3200 Phaethon over 5000 years.

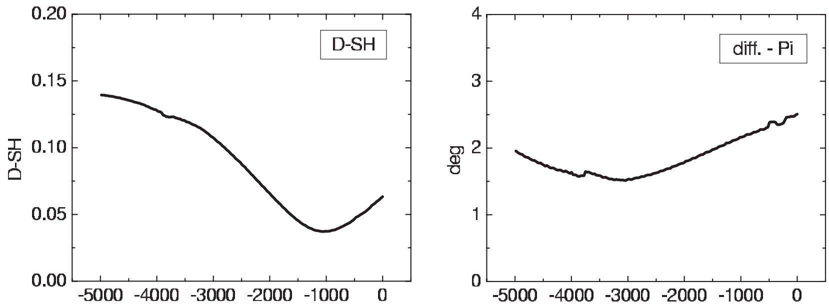

Fig. 5. – Variation of the Southworth-Hawkins D-criterion (left) and difference in the longitudes of perihelia between 3200 Phaethon and Geminid stream (right) over 5000 years.

longitudes of perihelia (right plot).

The association of the Geminids with 3200 Phaethon was first suggested by Whipple [3] and orbital evolution of both the stream and asteroid over 17000 years was investigated by Williams and Wu [6]. The association is very close and the asteroid moves within the stream. However, the Geminids are strongly concentrated and represent a typical cometary meteoroid stream. Thus when 3200 Phaethon is a parent of the Geminids, it has to be at present an inactive cometary nucleus more than an asteroid.

Comparison of the variations of the orbital elements presented in figs. 3, 4 exhibits a very close association between the Geminids and Phaethon. All the elements besides the semi-major axis are practicaly identical over the whole period of integration. From the variation of the D value it is apparent that the orbits were closest, with D below 0.05 (fig. 5, left plot), about one thousand years ago. Similarity of both the orbits is stressed also by a stable and almost identical orientation of the lines of apsides over the whole period of integration of 5000 years, depicted as the difference in the longitudes of perihelia between the stream and Phaethon plotted in fig. 5 (right plot).

* * *

The authors are indebted for the support of the research to VEGA, the Slovak Grant Agency for Science, grant No. 1/0204/03.

REFERENCES

[1] Kronk G. W., *Meteor Showers: A Descriptive Catalogue* (Enslow Publ., Hillside, USA) 1988.
[2] Porubčan V., *Bull. Astron. Inst. Czech.*, **29** (1988) 218.
[3] Whipple F. L., *IAU Circ.* (1983), No. 3881.
[4] Lindblad B. A., Neslušan L., Porubčan V. and Svoreň J., to be published on *Earth, Moon, and Planets*, **94** (2004).
[5] Kresák L. and Porubčan V., *Bull. Astron. Inst. Czech.*, **21** (1970) 153.
[6] Williams I. P. and Wu Z., *Mon. Not. R. Astron. Soc.*, **262** (1993) 231.
[7] Porubčan V. and Cevolani G., *Nuovo Cimento C*, **17** (1994) 243.
[8] Southworth R. B. and Hawkins G. S., *Smithson. Contrib. Astrophys.*, **7** (1963) 261
[9] Shampine L. F. and Gordon M. K, *Computer Solution of Ordinary Differential Equations* (Freeman and Comp., San Francisco) 1975.
[10] Standish E. M, *JPL IOM* (1998), 312.F-98-048.