EVOLUTION OF METEOROID ORBITS OVER MILLENIA

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The evolution of meteorid orbits over long time periods has been studied using the Gauss-Halphen-Gorjatschew method taking into account perturbations from the outer four planets (Galibina 1970). As initial elements, 15 different meteor orbits were taken from photographic observations (McCrosky 1968). Calculations were carried out from the modern epoch back in time for intervals of 10000 to 100000 years. Initial elements and the time intervals are given in Table 1.

Table 1
Initial Systems of Elements for Meteoroid Orbits

No	Meteor no.	Date yr	mo	da	P yr	a AU	e	q AU	q' AU	ω	Ω	i	Time k yr
1	38469	1964	3	15.293	8.242	4.08	0.90	0.39	7.76	105.4	174.6	12.3	10
2	39240	1966	4	25.372	2.935	2.05	0.53	0.96	3.14	209.6	34.5	16.8	10
3	39625	1967	5	15.180	3.626	2.36	0.83	0.38	4.34	111.7	233.4	6.3	29
4	39276	1966	5	31.318	5.119	2.97	0.79	0.60	5.34	264.7	69.2	9.3	10.5
5	38548	1964	6	2.197	2.914	2.04	0.52	0.96	3.11	150.4	71.5	4.1	30
6	39296	1966	6	20.183	4.486	2.72	0.78	0.57	4.86	269.2	88.2	2.0	26
7	39313	1966	7	7.142	6.351	3.43	0.93	0.21	6.64	308.5	104.4	16.1	9.2
8	39681	1967	7	10.291	2.681	1.93	0.63	0.70	3.16	78.0	287.1	6.6	10
9	39317	1966	7	11.312	1.692	1.42	0.51	0.68	2.15	87.4	288.3	1.4	100
10	39320	1966	7	14.173	2.957	2.06	0.57	0.87	3.24	128.4	111.1	3.5	10
11	39373	1966	9	5.127	1.516	1.32	0.27	0.95	1.69	219.9	161.9	22.4	10
12	39043	1965	10	10.101	6.436	3.46	0.71	0.99	5.94	170.6	196.4	32.1	10
13	39434	1966	11	5.446	0.598	0.71	0.43	0.40	1.02	197.2	42.3	3.3	10
14	39078	1965	11	14.296	1.015	1.01	0.02	0.98	1.04	12.3	51.5	0.1	20
15	39116	1965	12	22.437	15.62	6.25	0.84	0.94	11.6	204.6	270.2	52.3	10

Two classes of orbits result: 1) orbits of the Jupiter group, which suffer large perturbations and are unstable; and 2) orbits of the Asteroid and Earth groups, for which the effects of planetary perturbations

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 145–148.

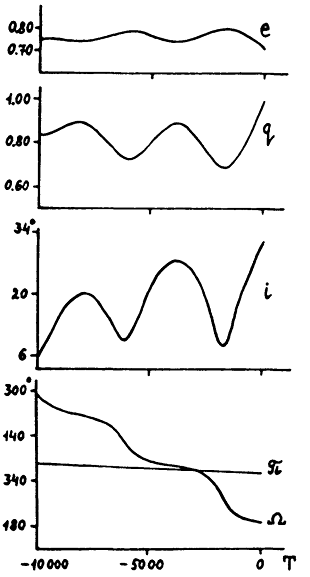

Fig. 1. Evolution of the orbital elements of a meteoroid of the Jupiter group (No. 12).

are small and the orbits are stable. Evolution of the elements of the Jupiter group are typified by those of No. 12 shown in Figure 1. The two outstanding features are: a periodicity of about 3500 years in e, q, i, and Ω, and a very slow rate of change in the direction of the line of apsides. The latter effect for orbits Nos. 4 and 7 is $\Delta\pi=+14°$ over 10500 yr and $\Delta\pi=-8°$ over 9200 yr respectively. The meteor orbit plane oscillates symmetrically relative to the ecliptic plane with gradually growing amplitude. During the evolution of the orbit there are times when the longitude of the ascending node has changed by 180° but differences in the other elements lie within the spread usually observed in meteor streams. For meteor orbit No. 4 we have

T(kyr)	-10.4	-7.4	-3.5	0
e	0.88	0.86	0.82	0.79
q(AU)	0.32	0.40	0.52	0.60
ω	71°	253°	77°	265°
Ω	249°	69°	249°	69°
i	5°	8°	9°	9°
π	320°	322°	326°	334°
ΔΩ(AU)	-0.52	+0.009	-0.19	+0.18
Δ☋(AU)	-0.14	-0.39	+0.18	+0.02
L_E=69°	N	S	N	S
L_E=249°	S	N	S	N

Here ΔΩ and Δ☋ are distances in the plane of the ecliptic between the Earth and the meteor orbit at the ascending and descending nodes respectively, and L_E is the longitude of the Earth. The radiant of the meteor stream (at L_E=69°) alternates from north (N) to south (S). Since in this case ω is near 90° or 270°, the meteor stream could be observed also at L_E=249°.

Orbit No. 12 behaves similarly

T(kyr)	-7.25	-3.2	0
e	0.76	0.75	0.71
q(AU)	0.82	0.84	0.99
ω	200°	6°	171°
Ω	196°	16°	196°
i	18°	26°	32°
π	36°	22°	7°
$\Delta\Omega$(AU)	+4.06	-0.14	+4.68
$\Delta_{\mho}$(AU)	-0.14	+4.80	+0.01
L_E=16°	N	S	N

except that the change in longitude of perihelion is greater and the shower could be observed at only one node L_E=16°.

Since a real meteor stream is an aggregate of orbits, each one evolving with a somewhat different period, there will be times when both branches, N and S, (and perhaps an ecliptic branch Q) can be observed simultaneously. The branch activity will depend on the inner redistribution of evolving orbits.

Among the prominent meteor showers this structure is observed in the delta-Aquarids and the Taurids. About 5% of small meteor streams (13 out of 249, Terentjeva 1966, 1968) show north and south branches. For the 15 orbits studied here, formation of branches in the time intervals considered is possible for Nos. 1, 4, 7, and 12.

Evolution of the elements of orbits of the Asteroid group is typified by No. 9 shown in Figure 2. Small variations with a period of about 20 kyr are superimposed on larger variations of period 58 kyr for i and about 100 kyr for q and e.

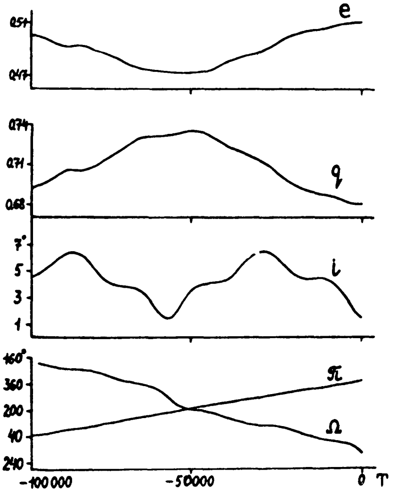

Fig. 2. Evolution of the orbital elements of a meteoroid of the asteroid group (No. 9).

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In the Earth group of meteoroids are two subclasses: "Cyclids" having orbits similar to the Earth, and a group with eccentric orbits lying almost wholly inside the Earth's orbit, which we call "Eccentrids". Perturbations to the elements are small as shown in Table 2.

Table 2
Perturbations to Cyclids and Eccentrids

Type		Δe	Δq (AU)	Δi°	$\Delta\Omega^\circ$	$\Delta\pi^\circ$	T kyr
Cyclid	No. 14	-0.005	0.005	-1.3	-21	26	20
Eccentrid	No. 13	0.002	-0.001	-0.7	- 8	11	10

The following conclusions can be drawn.

1) Branches will develop in a meteor stream when Jupiter exerts strong perturbations and where either the direction of the line of apsides is stable or there is a certain commensurability in the motion of the lines of nodes and apsides.
2) The age of meteor streams having branches is not less than 3000 to 4000 years.
3) The motion of meteoroids with aphelion distances less than values typical of the asteroid belt is stable over time intervals of from 10000 to 100000 years with respect to perturbations from the outer planets.

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