DYNAMICS AND SPATIAL SHAPE OF SHORT-PERIOD METEOROID STREAMS

P.B.Babadzhanov and Yu.V.Obrubov
Astrophysical Institute of the Academy
of Sciences of Tajik SSR,
Dushanbe, 734670, USSR

ABSTRACT. At the early stage of evolution the meteoroid streams may be considered as elliptical rings of relatively small thickness. The influence of planetary perturbations can essentially increase the stream width and its thickness. As a result one stream may produce several couples of meteor showers active in different seasons of the year. 22 short-period meteoroid streams under review may theoretically produce 104 meteor showers. The existence of 67 is confirmed by observations.

1. INTRODUCTION.

The overwhelming majority of meteor streams are generally assumed to be formed by the process of cometary decay.The most effective process for the release of solid particles from a cometary nucleus is their ejection by sublimating gases when comets approach the Sun. Some asteroids may also be progenitors of meteoroid streams if we assume these asteroids to form numerous small fragments during mutual collisions. Irrespective of the source of meteoroid streams, the ejection velocities of particles from a parent body seem to be relatively small - from several m/s to 1 km/s. The ejection velocity of particles depends on the size of the cometary nucleus, its physical-chemical properties and on the distance from the Sun at ejection. The ejection velocity also depends on various meteoroid properties. Immediately after release the meteoroids are subjected to light pressure.

The effect of ejection velocity and light pressure produces the initial dispersion of orbital elements of meteoroids. In this case the semimajor axes and, perhaps, the eccentricities of meteoroids' orbits differ strongly. The difference in orbital orientation of meteoroids and parent body is negligible. So, at the initial stage of evolution a meteoroid stream is very flat, narrow at perihelion and broad at aphelion.

Planetary perturbations, in the general case, change all the orbital elements of meteoroids. Till the recent time when studing meteoroid stream evolution the orbital elements of all meteoroids were assumed to change in the same manner as those of the mean stream orbit. Such an approach caused the stream shape (or the initial dispersion of meteoroid orbits) to be independent of time. However, planetary perturbations may

D. McNally (ed.), Highlights of Astronomy, Vol. 8, 287–293.

essentially increase the dispersion of the orbital elements of meteoroids and, eventually, change the stream shape (Babadzhanov, Obrubov 1985, 1986, 1987 c).

In this paper we will show that the increase in dispersion of orbital elements of short-period meteoroid streams leads to the activity of several meteor showers produced by each stream.

2. DYNAMICS OF SHORT PERIOD METEOROID STREAMS.

In previous papers (Babadzhanov, Obrubov 1986,1987c) we showed that due to gravitation of large planets the long-period variations in orbital elements of asteroid Phaethon (a possible remnant of the Geminids' progenitor) and of stream meteoroids with semimajor axes from 1 to 1,7 AU are satisfactorily described by the following integrals of motion (Moiseev 1945; Lidov 1961):

$$(1-e^2)\cdot\cos^2 i = C1 = \text{const.}, \qquad (1)$$

$$e^2(0.4 - \sin^2 i\cdot\sin^2 W) = C2 = \text{const.}, \qquad (2)$$

where **e** is eccentricity, **i** is inclination and **W** is the argument of perihelion. **C1** and **C2** are constants which may be determined by the observed orbital elements at a given time. For example, for Phaethon C1=0.18 and C2=0.27.

If we add the condition of intersection of the meteoroid's orbit with the Earth's orbit:

$$a(1-e^2) \approx 1 \pm e\cdot\cos W \qquad (3)$$

to the formulae (1,2), then, from numerous orbits determined by **a**, C1, and C2 one may now identify the Earth-crossing orbits (Babadzhanov, Obrubov 1987 b,c). When the stream orbit lies in the ecliptic plane the stream may produce two showers if perihelion distance $q<1$ AU and only one shower if $q \approx 1$ AU. If $i=0$ and a combined solution of equations (1-3) gives only one value of **e** which the orbit may have during its evolution, then orbit may cross the Earth's one at four values of W.

2.1. Geminid stream.

Fig.1 presents secular variations of **e, i** and radii-vectors at the ascending **(Ra)** and descending **(Rd)** orbital nodes of Phaethon versus **W**. As follows from equations (1-3) and Fig.1 Phaethon's orbits, at which intersection with Earth's orbit occurs,have approximately similar inclinations and eccentricities. However their positions in space differ essentially. Each intersection may produce a stream radiant which differs essentially from the other ones.

Owing to the differences in the semimajor axes the variation rate in orbital elements of the Geminid meteoroids is different. The dispersion of orbits increases so that, eventually, after 20 000 yr it will embrace all four possible intersections. Thus, if the dispersion in meteoroid orbits is sufficiently large, and the arguments of perihelia of individual orbits cover a range from 0° to 360° then the stream produces four annual meteor showers. The Geminid meteoroid stream produces the nighttime pre-perihelion Geminid and Canis Minorid showers as well as the post-perihelion Daytime Sextantids and δ-Leonids. Among these four showers three are surely observed (Babadzhanov, Obrubov 1985, 1986, 1987 a,c).

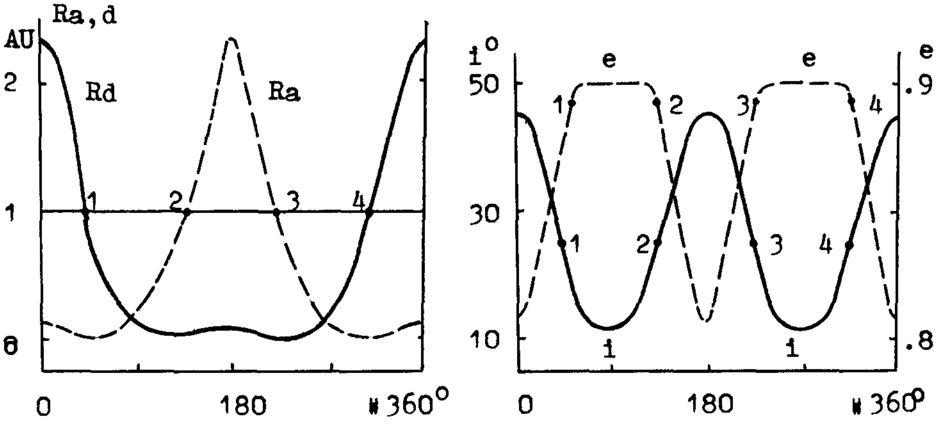

Fig.1 The dependence of the eccentricity, inclination and radii-vectors at the orbital nodes of Phaethon on the argument of perihelion. The intersection 1 corresponds to the δ-Leonids, 2 - Canis Minorids, 3 - Daytime Sextantids and 4 - Geminids.

It should be noted that Geminid stream thickness of about 1 AU in the regions of stream intersections by the Earth is a characteristic feature of this stream.

2.2. Quadrantid stream

Consider now a more interesting case when the combined solution of equations (1-3) gives two values of eccentricity at which a given orbit crosses the Earth's orbit. We have come across this case for the first time when studing the evolution of the Quadrantid stream. Two values of the eccentricities at which the intersection may occur correspond to four pairs of W. Hence, eight meteor showers are theoretically possible. For the Quadrantids this conclusion is confirmed by the calculations of secular perturbations of the mean orbit (Babadzhanov, Obrubov 1987 c) and by calculations of orbital evolution according to Everhart's method.

Fig. 2 shows the dependences of **e**, **i**, **Ra** and **Rd** on the argument of perihelion. These dependences are based on calculations of secular perturbations of the Quadrantid mean orbit by the Halphen-Goryachev method. It is evident that this stream may produce four meteor showers with small inclinations ($i<30°$) and perihelion distances ($q < 0.1$ AU) as well as four showers with large inclinations ($i \approx 70°$) and perihelion distances $q \approx 1$ AU. Qualitatively the same conclusion may be obtained from equations (1-3). These showers are $\varkappa$- Velids, Daytime Arietids, Southern and Northern δ- Aquarids, Quadrantids and Ursids, α- Cetids and Carinids (Table 2). It should be noted that the activities of all these showers (except of the $\varkappa$- Velids and Carinids) are confirmed by observations.

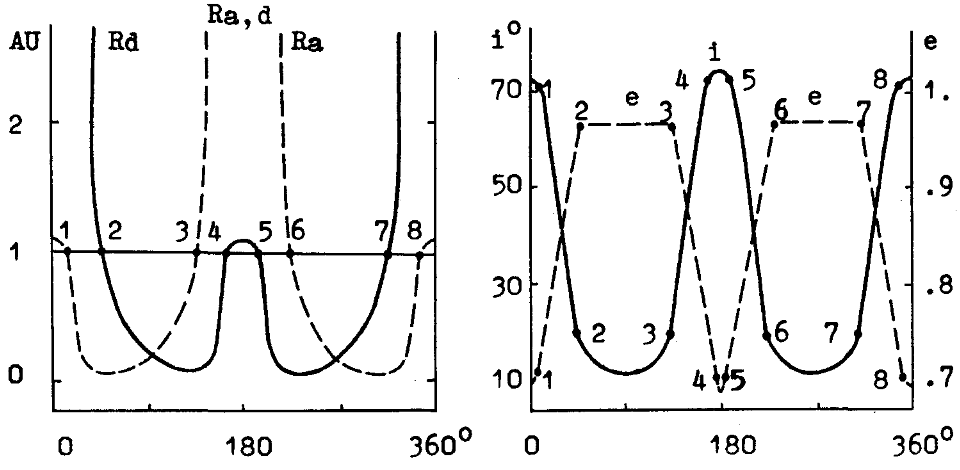

Fig. 2. The dependense of **e, i, Ra** and **Rd** of the Quadrantid orbit on **W**. The intersection 1 corresponds to $\varkappa$-Velids, 2 - Daytime Arietids, 3 - S. δ -Aquarids, 4 - Quadrantids, 5 - Ursids, 6 - Daytime α-Cetids, 7 - N. δ-Aquarids, 8 - Carinids.

In the Geminid stream the dispersion rate of orbits is mainly defined by the initial dispersion in semimajor axes. However, in the Quadrantid stream (because of the encounters of particles with Jupiter) the dispersion rate is defined also by the difference in meteoroid position in the same orbit. This conclusion is well illustrated by the results of Williams et al (1979) and also by our calculation using Everhart's method.

Investigation of the orbital evolution of 36 Quadrantid particles with semimajor axes a ranging from 2.7 to 3.2 AU using Everhart's method shows that the dispersion of meteoroid orbits causing the annual activity of all related meteor showers may be formed over 10-12 millenia.

2.3. Other Meteoroid Streams: The shape and number of meteor showers produced by these streams.

Simulation of the Geminid and Quadrantid stream evolution by the above methods shows that the qualitative features of these streams (the number of meteor showers, approximate orbits of meteoroids responsible for them etc.) may be obtained from equations (1-3). Furthermore, equations (1,2) permit us to estimate the shape which the stream may take under planetary perturbations. We have evaluated, firstly, a possible thickness of some short-period meteoroid streams at perihelion **Hq**,

https://doi.org/10.1017/S1539299600007905 Published online by Cambridge University Press

aphelion **HQ** and middle part **Hm** of their orbits and, secondly, the possible number of meteor showers produced by each stream. These data are given in Table 1. This Table also gives semimajor axes (in AU), maximum and minimum of inclinations and the stream width L (in AU) along the Earth's orbit computed from shower duration according to Cook (1973). **Nsh** - the number of meteor showers which may be produced by the meteoroid stream.

Table 1. Semimajor axes, maximum and minimum of inclinations,thickness and number of possible meteor showers for short-period meteoroid streams

No	Stream name	a AU	i max	i min	HQ	Hm	Hq	L	Nsh
1	Quadrantids	2.6-3.2	76	10	4.0	4.8	0.8	0.04	8
	δ -Aquarids							0.6	
2	δ-Cancrids	2.3	0	0	0	0	0	0.1	2
3	Virginids	2.6	10	3	0.5	0.4	0.03	1.2	4
4	δ-Leonids	2.6	12	6	1.0	1.7	0.14	0.7	4
5	Camelopardalids	1.5	8	7	0.5	0.4	0.23	0.4	4
6	σ-Leonids	2.4	2	1	0.1	0.2	0.00	0.9	4
7	δ-Draconids	2.8	38	9	1.6	2.6	0.31	0.4	6
8	μ-Virginids	3.1	24	10	2.0	1.5	0.36	0.7	4
9	α-Scorpiids	2.2	10	3	0.4	0.3	0.02	0.5	4
10	α-Bootids	2.6	30	17	2.6	2.0	0.44	0.5	4
11	Φ-Bootids	1.2	20	18	1.0	0.8	0.58	0.4	4
12	τ-Herculids	2.7	24	8	1.9	1.8	0.31	0.4	4
	Jun.Bootids	3.3							
13	θ Ophiuchids	2.9	10	4	0.7	0.6	0.06	0.1	4
14	α-Capricornids	2.5	15	7	1.1	0.9	0.14	0.3	4
15	ι-Aquarids	1.8-2.4	19	5	1.1	0.9	0.14	1.1	4
16	κ-Cygnids	3.1	41	6	1.6	3.2	0.16	1.0	8
	χ-Scorpiids	3.1							
	Piscids	1.9-2.1							4
17	Taurids	1.9-2.6	16	2	1.0	0.7	0.12	1.8	4
	χ-Orionids	2.2							4
18	κ-Aquarids	3.2	3	1	0.1	0.2	0.01	0.3	4
19	Ann.Andromedids	3.2	22	4	2.1	1.7	0.30	0.8	4
20	Geminids	1.0-1.7	55	12	2.0	1.5	0.05	0.1	4
	D.Sextantids								
21	Dec.Phoenicids	3.0	16	9	1.5	1.2	0.27	1.0	4
22	δ-Arietids	2.1	3	2	0.2	0.2	0.05	0.1	4

https://doi.org/10.1017/S1539299600007905 Published online by Cambridge University Press

Table 1 shows that the overwhelming majority of meteoroid streams can produce four meteor showers each. The investigation of the Encke meteoroid stream shows that eleven observable meteor showers (Table 2) are produced by this stream (Babadzhanov et al. 1987).

In addition to the Quadrantids the ϰ-Cygnids and, perhaps, the δ-Draconids belong to the type of meteoroid streams which can produce eight showers each. This conclusion is confirmed by our calculation of the secular evolution of the mean orbits of these streams by the Halphen-Goryachev method.

Table 2. Theoretical and observed radiants of meteor showers.

	RA	Dec	Vg	Ls	RA	Dec	Vg	Ls	RA	Dec	Vg	Ls	RA	Dec	Vg	Ls
	Quadrantids(4)-.09				Carinids				Ursids(0)-.22				ϰ-Velids			
Rt	227	51	41	282	151	-59	43	278	219	56	41	276	144	-55	43	276
Ro	230	48	41	283	?	?	?	?	223	62	38	281	?	?	?	?
	N.δ-Aquar.(4)-.11				S.δ-Aquar.(4)-.12				D.Arietids(3)-.07				α-Cetids(3)-.12			
Rt	336	-4	41	124	346	-13	40	133	49	24	40	80	49	12	42	76
Ro	337	-5	40	128	333	-16	41	125	43	23	37	77	44	12	39	78
	δ-Leonids(4)				ρ-Leonids(2)-.17				γ-Leonids(2)-.10				Aug.Cancr.(2)-.23			
Rt	159	19	21	338	152	2	21	338	148	23	21	136	142	6	21	136
Ro	159	19	23	338	161	7	21	342	150	20	22	152*	139	12	20	141
	α-Capricornids(4)				χ-Sagit.(2)-.20				ε-Aquar.(2)-.09				χ-Capric.(1)-.26			
Rt	309	-10	23	127	313	-27	23	127	307	-10	23	305	312	-28	23	305
Ro	307	-10	23	127	290	-26	26	100	310	- 7	23	315	314	-24	27	324
	S. ι-Aquarids (4)				N.ι-Aquarids(4)-.18				Ass.30 (3)-.13				Ass.16 (3)-.18			
Rt	335	-14	33	131	332	-7	33	131	16	3	34	35	13	10	34	35
Ro	333	-15	34	131	321	-8	33	120	13	-3	29	29	7	3	29	30
	N.Piscids(1)-.18				S.Piscids(4)-.25				May Ariet.(2)-.14				Ass 41 (3)-.18			
Rt	9	8	32	176	12	1	31	176	40	19	32	58	42	12	32	58
Ro	0	3	27	168	6	0	26	177	36	18	25	54*	33	9	29	52
	N.Taurids(4)-.10				S.Taurids(4)-.15				ζ-Perseids(2)-.13				β-Taurids(4)-.06			
Rt	51	23	32	219	53	15	31	219	86	27	32	101	86	20	32	101
Ro	58	22	29	230	50	14	27	220	84	24	29	102	86	19	30	96
	N.χ-Orion.(4)-.21				S.χ-Orion.(1)-.20				ϰ-Aurig.(2)-.23							
Rt	73	26	32	239	74	19	31	239	109	26	31	121	108	18	32	121
Ro	84	26	25	258	85	16	26	259	94	28	24	102*	?	?	?	?
	Geminids (4)-.05				Canis-Minor.-.04				δ-Leonids				D.Sextan.(4)-.15			
Rt	112	32	34	260	109	12	34	260	169	16	34	194	161	-1	34	194
Ro	112	32	34	261	109	12	39	258	?	?	?	?	154	4	31	189

Summarizing the investigation of the dynamics and shape of short-period meteoroid streams one can say that a phenomenon of the formation of shower branches and twin showers is widely spread. 22 meteoroid streams given in Table 1 can theoretically produce 104 meteor showers. The existence of 67 is confirmed by observations. The results of a search for related meteor showers produced by six well-known short-period meteoroid streams are presented in Table 2.

Theoretical (**Rt**) and observed (**Ro**) coordinates of the geocentric radiant (right ascension **RA** and declination **Dec**), geocentric velocity **Vg** (in km/s) and solar longitude **Ls**, at which the shower activity occurs, are given in Table 2 for each shower. After shower name Table 2 gives the references to the catalogue where the observed orbit was found: (0)- Sekanina (1970), (1) - Sekanina (1973), (2) - Sekanina (1976), (3) - Kascheev et al. (1967), (4) - Cook (1973) and the values of D-criterion between the observed and theoretical orbits. Twin showers, found by Drummond (1982), and confirmed by the results of our investigation, are marked by an asterisk *.

Thus, owing to the differences in the ejection velocities and light pressure the initial dispersion of stream meteoroid orbits is produced. The influence of planetary perturbations can greatly increase the dispersion of orbital elements that causes a meteoroid stream to thicken essentially and leads to the activity of twin showers and northern and southern branches. In conclusion it should be noted that when estimating the volume, density and mass of a meteoroid stream it is necessary to take into account the stream thickness and the activity of all related showers.

REFERENCES

Babadzhanov P.B., Yu.V.Obrubov 1985, Report of Meetings of Comission 22, Transactions of IAU, XIX, p. 195

Babadzhanov P.B., Yu.V.Obrubov 1986, Dokl. AN SSSR, 290, 1, pp 53-57

Babadzhanov P.B., Yu.V.Obrubov 1987a, Handbook for MAP, 25, ed. R.G.Roper, US GPO, pp 2-10

Babadzhanov P.B., Yu.V.Obrubov 1987b, Dokl. AN Taj.SSR, 30, pp 486-491

Babadzhanov P.B., Yu.V.Obrubov 1987c, in Interplanetary Matter, eds. Z.Ceplecha, P.Pecina, Praha, pp141-150

Babadzhanov P.B., Yu.V.Obrubov, N.Makhmudov 1987, Sov. Comet Circular 373, pp 3-4

Cook A.F. 1973, in Evolutionary and Physical Properties of Meteoroids, eds. C.L.Hemenway, P.M.Millman, A.F.Cook, Washington D.C.,pp 183-191

Drummond J.D. 1982, Icarus, 49, pp 135-142

Kascheev B.L., V.N.Lebedinets, M.F.Lagutin 1967, Meteor Phenomena in the Earth's Atmosphere, Nauka, Moscow, 260 p.

Lidov M.L. 1961, Iskusstvennie Sputniki Zemli, 8, pp 5-45

Moiseev N.D. 1945, Trudy Gos. Astron. Inst. Mosk.Univ., 15, pp 75-99

Southworth R.B., G.S.Hawkins 1963, Smith. Contr. Astroph., 7, pp 261-286

Sekanina Z. 1970, Icarus, 13, pp 475-493

Sekanina Z. 1973, Icarus, 18, pp 253-284

Sekanina Z. 1976, Icarus, 27, pp 265-321

Williams I.P., C.D.Murray, D.W.Hughes 1979, Month. Not. R. Astron. Soc., 189, 2, pp 483-492