78. ORBITAL EVOLUTION OF THE α VIRGINID AND α CAPRICORNID METEOR STREAMS

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Abstract. The motions of two typical meteor streams of the Jupiter family, the α Virginids and the α Capricornids, were considered over the interval 1902–2003, perturbations by Venus to Neptune being taken into account. The substantial transformations of their orbits in Jupiter's sphere of action and its neighbourhood were studied. Conclusions are made concerning the role of large perturbations by Jupiter in dispersing meteor streams and altering the visibility conditions of meteor showers.

1. Introduction

It is well known that at the present time several hundred meteor streams exist in the solar system, the majority of them belonging to the Jupiter family. The purpose of this investigation is to study the evolution of the orbits of typical meteor streams of the Jupiter family and to examine the great transformations of their orbits under the influence of strong perturbations by Jupiter.

Two streams have been selected: the α Virginids and the α Capricornids. They are sufficiently intense, act for prolonged periods of time (more than 20 days), contain large bolides and have been under observation for not less than a hundred years.

Analysis of photographic and visual observations (Terent'eva, 1966) reveals that the α Virginid system is very dispersed, and that it is best represented by separate small streams acting for not less than two months. Among those small streams it is most advisable to select stream No. 48, whose aphelion is located in the immediate vicinity of Jupiter's orbit. For the investigation of the α Virginids we have used the orbit of meteor No. 7333, which is included in the catalogue of 413 exact orbits derived by Jacchia and Whipple (1961) from observations made in the U.S.A. during 1951–1954. The initial system of elements is as follows:

$$
\begin{array}{rl}
\text{Epoch} = & \text{1953 April 15.28 UT} \\
M_0 = & 351^{\circ}\!.035 \\
\omega = & \left.\begin{array}{r} 289.0 \\ 25.0 \\ 2.3 \\ 314.0 \end{array}\right\} 1950.0 \\
\Omega = & \\
i = & \\
\pi = & \\
n = & 0^{\circ}\!.211835
\end{array}
\qquad
\begin{array}{l}
a = 2.787\ \text{AU} \\
e = 0.861 \\
q = 0.388\ \text{AU} \\
Q = 5.186\ \text{AU} \\
P = 4.653\ \text{yr.}
\end{array}
\qquad (1)
$$

Wright *et al.* (1956) have made a special study of the α Capricornid stream, investigating the radiants and orbits of 12 double-station and 50 single-station photographs

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obtained by the Harvard Observatory during 1899–1953. They concluded either that the α Capricornids are a single, continuous stream from July 16 to August 22, or that they consist of double (or multiple) independent streams occurring during July 17–August 1 and August 1–22, respectively (see Figure 1). The authors consider the second suggestion more probable, and they also believe that the stream may be associated with P/Honda-Mrkos-Pajdušáková. For the purpose of our investigation the orbit of meteor No. 3567 has been selected. It belongs to the August α Capricornids, and in Figure 1 its orbit is designated as A 15. The initial system of elements is:

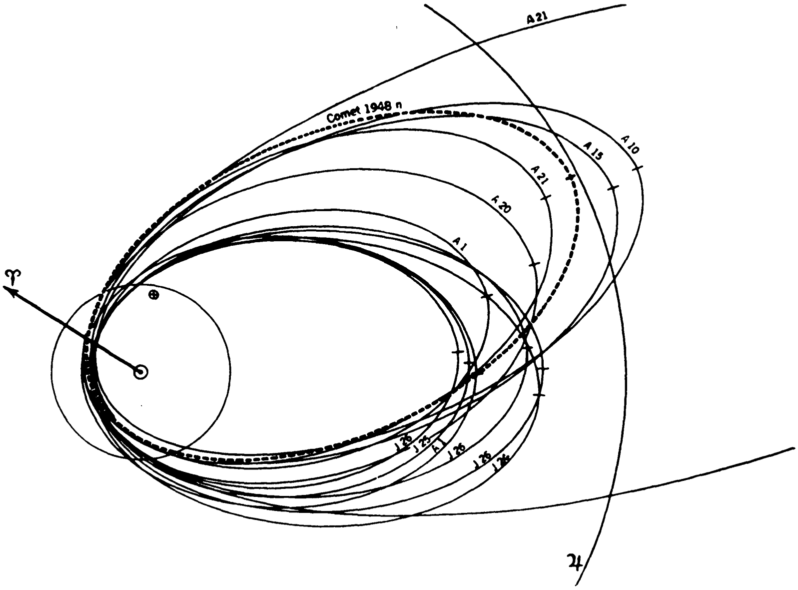

Fig. 1. Orbits of α Capricornids and Comet 1948n P/Honda-Mrkos-Pajdušáková (from Wright *et al.*, 1956).

$$\begin{aligned}
&\text{Epoch} = \text{1952 August 15.3216 UT} \\
&M_0 = 352\overset{\circ}{.}046 && a = 3.105\ \text{AU} \\
&\left.\begin{aligned} \omega &= 272.1 \\ \Omega &= 142.34 \\ i &= 0.4 \\ \pi &= 54.4 \end{aligned}\right\} 1950.0 && \begin{aligned} e &= 0.827 \\ q &= 0.538\ \text{AU} \\ Q &= 5.673\ \text{AU} \\ P &= 5.471\ \text{yr.} \end{aligned} \qquad (2) \\
&n = 0\overset{\circ}{.}180141
\end{aligned}$$

In our studies we have for the first time considered the three-dimensional form of a meteor stream. This was accomplished by making suitable variations in some of the initial elements (M_0, a, i). We studied the motion of ten α Virginid particles and five α Capricornid particles.

The integration of the differential equations of motion of those particles has been performed on the electronic computer BESM-4, using both the double-precision

TABLE I

Approaches of the particles of the α Virginid meteor stream to Jupiter

Particle	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)	$T_{\min}$	$\Delta_{\min}$ (AU)
	1908		1931		1955		1967		1979		1991		2002/2003	
I	–	–	Oct. 13	0.497	Sept. 8	0.298	–	–	–	–	Mar. 28	0.316	Dec. 5	0.395
II	–	–	Oct. 11	0.507	Aug. 23	0.175	–	–	May 22	0.145	–	–	–	–
III	–	–	Oct. 16	0.489	Aug. 27	0.178	–	–	June 16	0.131	–	–	Jan. 22	0.373
IV	–	–	Oct. 12	0.536	Oct. 2	0.384	–	–	–	–	June 7	0.592	–	–
V	–	–	Oct. 11	0.489	Aug. 22	0.125	–	–	Apr. 6	0.360	–	–	–	–
VI	Apr. 23	0.509	Dec. 3	0.073	Aug. 14	0.062	Dec. 20	0.934	–	–	–	–	May 31	0.204
VII	–	–	Oct. 15	0.253	Aug. 21	0.112	–	–	Apr. 11	0.869	–	–	–	–
VIII	–	–	Oct. 12	0.606	Aug. 26	0.140	–	–	–	–	–	–	–	–
IX	–	–	Oct. 11	0.509	Aug. 26	0.177	–	–	May 21	0.146	–	–	–	–
X	–	–	Oct. 12	0.520	Aug. 28	0.206	–	–	June 8	0.160	–	–	Jan. 5	0.496

programme by Kazimirchak-Polonskaya (1972) and the single-precision Cowell programme by Belyaev (1972). Perturbations by Venus to Neptune were taken into account, the integration being carried over an interval 50 yr before and 50 yr after the epoch of osculation and using step-sizes from 0.3125 to 20.0 days.

2. The α Virginids

In the case of the α Virginids it was ascertained that the main particle I with the initial orbit (1) and the particles II, III, . . ., X with variant orbits make a succession of approaches to Jupiter. Table I lists the approaches for which $\Delta_{\min} < 1.0$ AU. It is evident that in 1931 and 1955 all ten particles approached Jupiter closely. The values of $\Delta_{\min}$ and $T_{\min}$ varied quite significantly, however, and the evolution of the various orbits before 1931 and after 1955 was quite different.

Table II illustrates the orbital evolution of particle I in the form of orbits averaged over four intervals of time, each being separated by close approaches to Jupiter. It is evident that

(1) the orbital elements that determine the shape and size (a, e) as well as the direction of the line of apsides (π), are exceptionally stable during the 100-yr interval, in spite of close approaches to Jupiter;

(2) By contrast, the elements determining the spatial orientation of the orbit (Ω, i) undergo appreciable changes. The ascending node, for instance, regresses through 86°.4, and this shifts the time of appearance of the shower by about three months.

TABLE II

Orbital evolution of particle I of the α Virginid meteor stream

	Ω	π	i	e	a (AU)	P (yr)	q (AU)	Q (AU)
1903–1931	55°.8	313°.3	2°.4	0.87	2.74	4.54	0.35	5.1
1932–1954	25.0	314.0	2.3	0.86	2.78	4.65	0.39	5.2
1955–1990	341.6	314.6	4.6	0.86	2.71	4.46	0.38	5.0
1991–2003	329.4	315.3	7.3	0.85	2.74	4.53	0.41	5.1

Analysis of the results for the α Virginids leads to the following conclusions:

(1) The particles may be divided into two groups according to the character of their approaches to Jupiter. Particles IV and X, whose approaches to that planet are of the same type as those of particle I, exhibit orbital evolutions of a similar character.

(2) On the other hand, the orbits of particles II, III, V, VII, VIII, IX, and especially VI (which penetrated very deeply into Jupiter's sphere of action) are characterized by stability only of the semimajor axis, period and aphelion distance, while all the other elements are subject to rather substantial changes. The regression of the line of nodes is enormous.

Figures 2 and 3 illustrate the evolution of the orientation elements Ω, π, i, eccentricity and perihelion distance for particles III and VI, the differences in evolution rate for which are particularly pronounced. The evolution of the orbital inclination of particle III is of exceptional interest. From the beginning of 1902 to the middle of 1955 the inclination remains invariable at about 2°.3. On 1955 June 22 the particle enters Jupiter's sphere of action, attains its least distance from Jupiter ($\Delta_{\min}=0.178$ AU) on August 27 and leaves the sphere on October 26. During this 4-month period i rises rapidly from 2°.3 to 10°.2, and then maintains the latter value for 24 yr. At the second and even closer approach to Jupiter (to $\Delta_{\min}=0.131$ AU on 1979 June 16) it

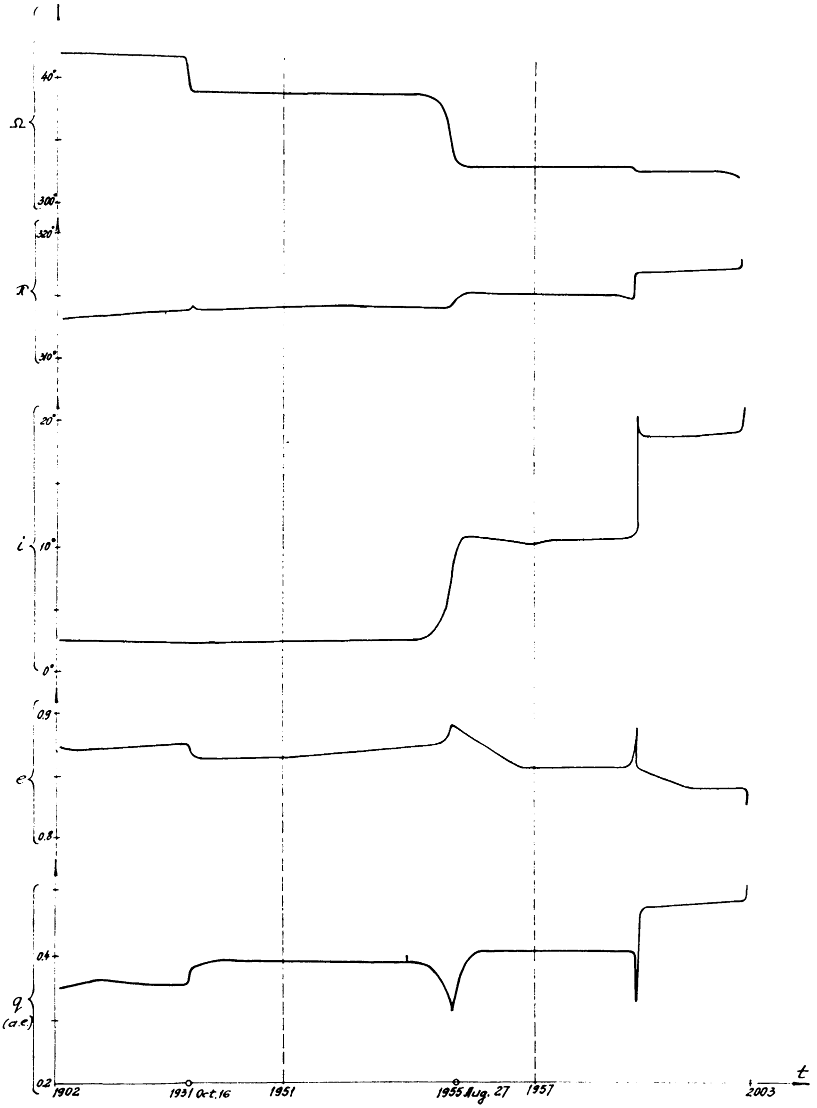

Fig. 2. Evolution of the orbital elements of particle III of the α Virginid stream. Between the vertical broken lines the time scale is expanded.

increases even more sharply, from 10°2 to 19°5 (it remains in Jupiter's sphere of action from April 15 to August 15 of the same year); at the beginning of 1980 it drops slightly, to 18°4, and at the approach to Jupiter in 2003 ($\Delta_{\min}=0.373$ AU) it continues to increase up to 20°3.

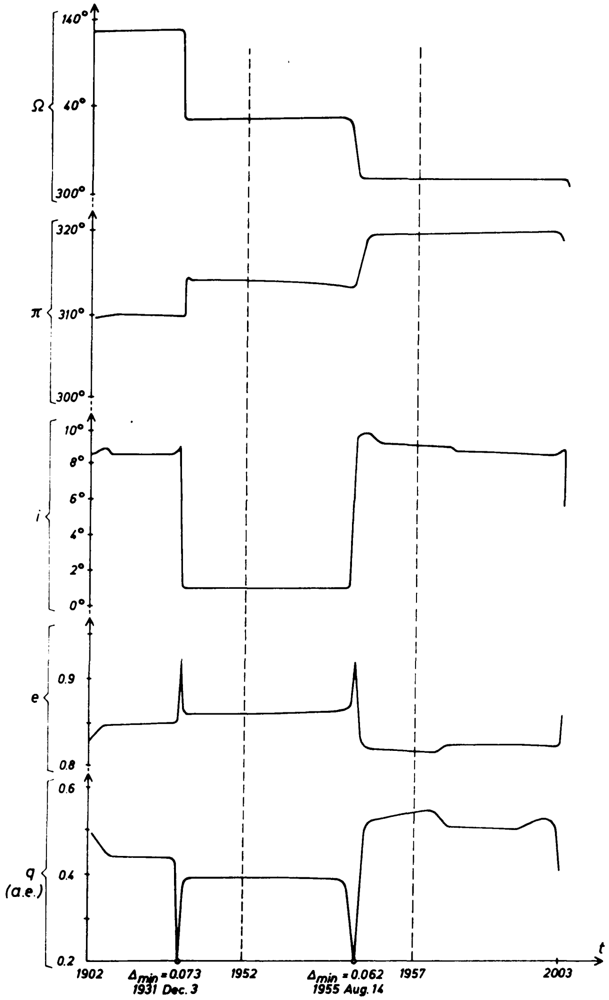

Fig. 3. Evolution of the orbital elements of particle VI of the α Virginid stream. Between the vertical broken lines the time scale is expanded.

The longitude of the ascending node of the orbit of particle VI behaves in a similar way. It is nearly constant (127°4 to 126°6) from 1902 to 1931. On 1931 September 28 particle VI enters Jupiter's sphere of action, has an exceptionally small perijove distance ($\Delta_{\min}=0.0726$ AU on December 3) and leaves the sphere on 1932 February 7. During this interval Ω regresses from 126°6 to 25°3. It then remains invariable until the end of 1954, and during the second, even deeper passage through Jupiter's activity sphere (1955 June 9 to October 23, $\Delta_{\min}=0.0623$ AU on August 14) changes from 25°.0 to 316°.6. The stability of ☊ is then maintained until the 2003 approach. During the period under study (1902–2003) the total change in ☊ is 175°.4 (from 127°.4 to 312°.0).

The most significant aspect in the evolution of the α Virginids is shown in Figure 4, where the variations in ☊ are illustrated for all ten particles from 1954 March 15 to 1957 January 2. Initially, all the particles had orbits with ascending nodes at longitudes

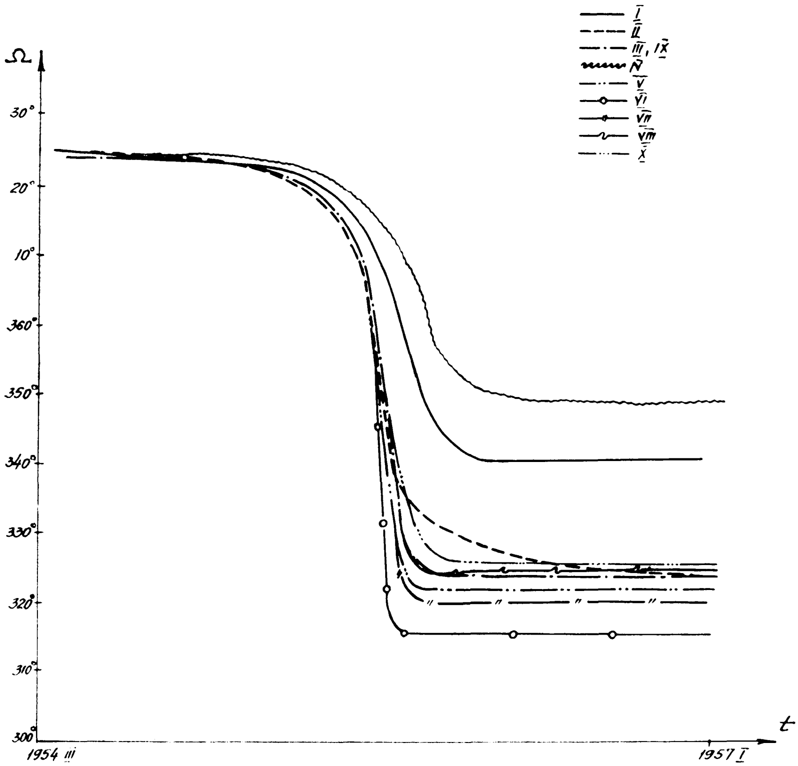

Fig. 4. Perturbations in the longitudes of the ascending node of α Virginid members 1954–1957.

near 25°. Owing to the different conditions of the approaches to Jupiter in 1955, the dispersion in the lines of nodes of the particles increased to 35°. It is evident that this dispersion will increase even more significantly as the different particles continue to make further approaches to Jupiter, not only under different conditions but at different times (see Table I).

3. The α Capricornids

Table III summarizes the circumstances of the approach of the main particle of the α Capricornid stream to Jupiter. Table IV and Figure 5 illustrate the orbital transformations in the form of three averaged orbits.

TABLE III

Approaches of the main particle of the α Capricornid meteor stream to Jupiter

Date	Δ (AU)	
1911 Aug. 24	0.950	
1912 Jan. 6	0.335	Enters sphere of action
Mar. 14	0.0323	$\Delta_{\min}$
May 19	0.326	Leaves sphere of action
Oct. 21	1.043	
1970 June 15	0.954	
Nov. 12	0.311	Enters sphere of action
1971 Jan. 29	0.110	$\Delta_{\min}$
Apr. 5	0.309	Leaves sphere of action
Oct. 2	1.031	

TABLE IV

Orbital evolution of the main particle of the α Capricornid meteor stream

	Ω	π	i	e	a (AU)	P (yr)	q (AU)	Q (AU)
1902–1911	66°	61°	33°.2	0.73	3.14	5.6	0.85	5.4
1912–1970	142	54	0.4	0.83	3.10	5.5	0.54	5.7
1971–2003	228	49	8.2	0.81	3.05	5.3	0.57	5.5

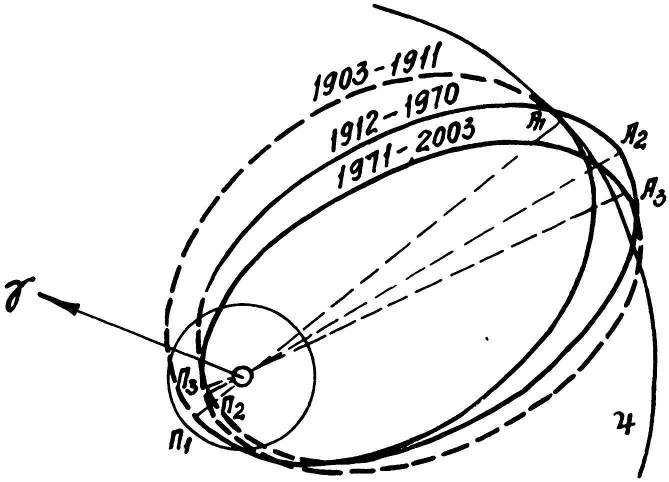

Fig. 5. The orbit of the main particle of the α Capricornid stream.

The evolution of this meteor stream is quite different from that of the α Virginid stream. During the interval 1902–2003 the ascending node advances by 162° and the line of apsides regresses through 12°; the inclination varies considerably, first rising from 33°.2 to 45°.8, then falling to only 0°.4 and subsequently rising to 8°.2. The perihelion distance q undergoes appreciable changes during the first approach to Jupiter, starting at 0.85 AU, diminishing to a minimum value of 0.23 AU, and then increasing to 0.54 AU, where it remains, with minor variations, to the end of the period under investigation; the eccentricity also undergoes appreciable perturbations during the first approach to Jupiter. However, as with the α Virginids, the semimajor axis, period and the aphelion distance of the α Capricornids are quite stable. Figure 6 shows the detailed evolution of the orbital elements during the very close approach to Jupiter in 1912.

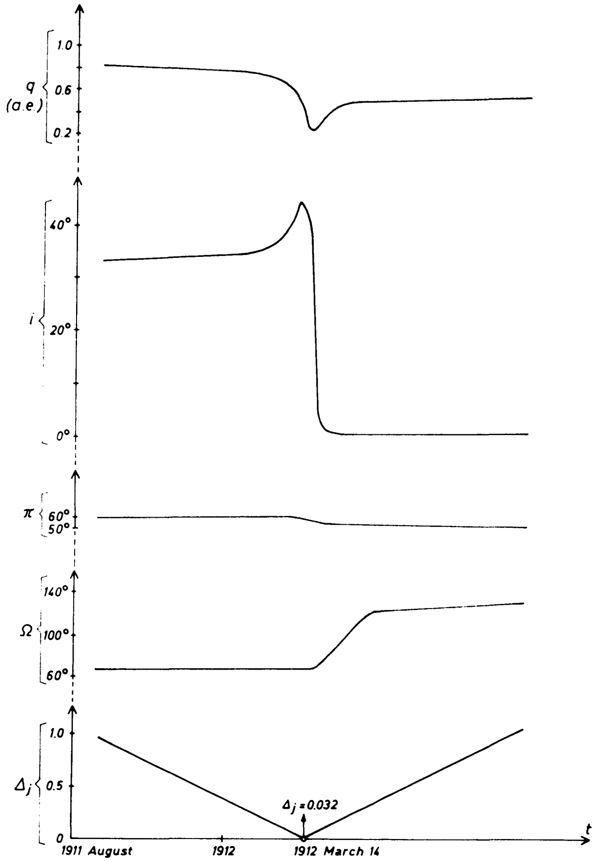

Fig. 6. Evolution of the orbital elements of the main particle of the α Capricornid stream.

Integration of the equations of motion of four other particles in the stream gave results and conclusions similar to those obtained in the case of the α Virginids.

4. Conclusions

On the strength of the foregoing results on the α Virginid and α Capricornid meteor streams the following conclusions may be drawn:

(1) The close approach of individual parts of meteor streams to Jupiter result in the production of systems of related meteor orbits, and in changes in the spatial density and structure of the streams and the conditions of the encounters of those streams with the Earth.

(2) The streams investigated were characterized by stability of the semimajor axes, periods of revolution and aphelion distances, but by considerable variations in the lines of nodes and apsides and in the inclinations.

(3) Consequently, the great perturbations in Jupiter's activity sphere are the main cause of the gradual dispersion of the basic streams and the origin of small meteor streams and sporadic meteors that may be observed at other times of the year and with different radiants.

It is interesting to study the changes in the radiants, for these changes reflect those in the orbital elements. For this purpose Terent'eva has developed algorithms for calculating by electronic computer the following quantities:

(1) the moment of closest approach of the Earth to the orbit of a meteor stream;

(2) the shortest distance between the orbits of the Earth and the meteor stream at that moment;

(3) the coordinates of the geocentric radiant and the geocentric velocity of a meteor shower; and

(4) ephemerides for the radiant of a shower.

Acknowledgment

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