79. THEORETICAL COMETARY RADIANTS AND THE STRUCTURE OF METEOR STREAMS

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Abstract. Observational data on radiants of meteor showers and the structure of meteor streams may be used as an indirect source of information about the evolution of cometary and meteor orbits. Investigation of the structure of some meteor streams provides evidence for comparatively high velocities of ejection of meteoroids from cometary nuclei. Further evolution of the streams is determined by planetary perturbations and other factors, the influence of which depends on the size and composition of the meteoroids.

1. Introduction

The physical properties of comets and meteors seem to confirm their common origin. The relationship between young streams and individual comets is established in a straightforward way. In the long run, a meteor stream gradually dissipates, the comet and the meteoric particles are diverted into new orbits by planetary perturbations, and the link between the stream and the parent comet becomes less obvious. While the effect of dispersive forces leads to the complete destruction of the meteor stream, even before this ultimate result the orbital elements of individual meteoroids have changed so much that it is difficult to see anything in common with those of the comet. It is therefore reasonable to investigate, not the relationship between individual meteors and comets, but rather the link between meteor streams (or associations) and comets.

The cometary radiant method consists of the computation, using cometary orbital elements, of the direction and velocity of meteoric particles during the time the observer is passing by the hypothetical streams; the computational data are then compared with the observational results. When the observer meets the stream in the ecliptic plane the theoretical radiant is characterized by the following parameters:

(1) the ecliptic longitude of the cometary orbit's intersection with the ecliptic plane;

(2) the heliocentric distance of the intersection; and

(3) the orthogonal coordinates of the reversed heliocentric velocity vector.

For terrestrial observations the following theoretical radiant parameters are usually calculated:

(1) the time of closest approach of the Earth to the cometary orbit;

(2) the right ascension and declination of the hypothetical meteor radiant; and

(3) the heliocentric meteor velocity.

Detailed catalogues have been established for theoretical cometary radiants (Pokrovskij and Shajn, 1918; Porter, 1949; Kramer, 1953; Hasegawa, 1958; Zentsev, 1970). Many of these theoretical radiants have been identified with observed meteor

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data. Table I lists the theoretical radiants for comets observed between 1950 and 1961 (Zentsev, 1970). For some of them the corresponding observed radiants of meteor streams are also given.

TABLE I

Some cometary and meteor radiants

Comet/shower	Date	α	δ	v_g (km s^{-1})	Δ (AU)	Ref.
{1951 II	Aug. 3	22	−37	50	0.06	
{Sculptorids	Aug. 4	21	−39			Astapovich (1962)
1951 IV	Mar. 6	138	−27	12	0.22	
1953 II	Mar. 3	229	+20	51	0.22	
1953 VII	Nov. 8	248	−13	9	0.15	
{1954 VII	Dec. 10	198	+68	45	0.12	
{κ Draconids	Dec. 18–28	194	+67			Astapovich (1962)
{195	Dec. 7	190	+75	34		Kashcheev *et al.* (1967)
{1954 X	Mar. 22	254	+57	34	0.02	
{ε Draconids	Mar. 12–31	257	+62			Astapovich (1962)
{1954 XII	June 6	299	+20	49	0.18	
{Sagittids	June 1–13	294	+13			Astapovich (1962)
1955 V	Sept. 2	78	−20	58	0.12	
1955 VII	Nov. 26	297	+32	12	0.16	
1957 IX	Apr. 20	332	−23	67	0.05	
1959 III	July 7	228	+34	11	0.25	
1959 VIII	Oct. 9	267	+52	21	0.06	
1960 VIII	Nov. 4	243	−32	11	0.18	
{1961 II	Sept. 19	101	+39	70	0.06	
{155	Sept. 24–27	100	+31	68		Kashcheev *et al.* (1967)

In addition to identifying the parental relationship between comets and meteor streams it is possible, on the basis of the relatively rich photographic and other observational data, to investigate the structure of individual meteor showers. The best known of the great showers are the Perseids and the Geminids. There are more than 320 photographs available for the former shower, and rather more than 130 photographs and over a thousand radio observations for the latter. The relationship between the Perseids and comet 1862 III was established by Schiaparelli soon after that comet was observed. The parent comet of the Geminids is unknown.

2. The Perseid Stream Structure

For investigating the structure of the Perseid stream data have been used relating to 320 Perseids, photographs of which had been taken in Odessa (Kramer *et al.*, 1963; Babadzhanov and Kramer, 1963; Kramer and Markina, 1965), Dushanbe (Katasev, 1957; Babadzhanov, 1958; Babadzhanov and Kramer, 1965; Babadzhanov and Sosnova, 1960), Massachusetts and New Mexico (Wright and Whipple, 1953; Whipple, 1954; Jacchia and Whipple, 1961; McCrosky and Posen, 1961), and Ondřejov (Ceplecha *et al.*, 1964; Ceplecha, 1958). The average elements of the stream are given in Table II.

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TABLE II

Orbital elements of the Perseid stream

	a(AU)	e	q(AU)	P(yr)	i	ω	Ω
Comet 1862 III	24.28	0.960	0.963	119.6	113°.6	153°	139°
Perseids (Harvard)	21.56	0.956	0.946	100.1	113.2	150	138
Perseids (320 meteors)	33.56	0.974	0.948	194	113.0	150	138

Figure 1a shows the distribution of Perseids with solar longitude $\lambda_{\odot} = \Omega$ (around the ascending node). The shower activity slowly increases from the last days of July, reaches a sharp peak on August 10–11 and rapidly diminishes in only two days. If one ignores the displacement of the radiant caused by the orbital motion of the Earth, the remaining distribution of meteor velocities and the coordinates of the radiant may be explained, either by measurement errors or by the natural scatter of individual meteor orbits. In general, the instrumental measurement errors are two or three times

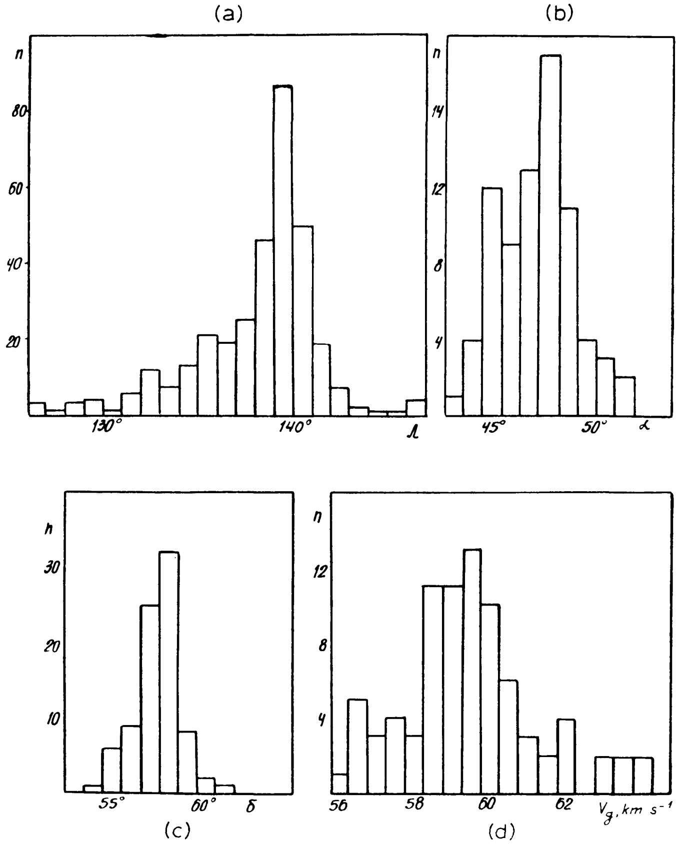

Fig. 1. Distribution of Perseids in (a) Ω, (b) α, (c) δ, and (d) v_g.

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less than the observed orbital scatter. We may therefore safely ascribe the observed distribution of stream parameters to orbit scatter inside the meteor stream itself. Figures 1b, 1c, and 1d are histograms of the distributions of the Perseids with respect to right ascension α, declination δ and geocentric velocity v_g. In order to exclude the effect of motion of the radiant these histograms were obtained using observations only during the 24 hours for which $139° < \lambda_{\odot} = \Omega < 140°$. The parameters of the distributions are given in Table III.

TABLE III

Distribution parameters for Perseid radiants

	α	δ	v_g (km s^{-1})
Average	47°.8	57°.9	59.7
Variance	4.3	1.6	3.3
No. of meteors	78	84	82

By grouping the observations according to Ω it is easy to compute average values of the orbital elements for separate parts of any cross-section of the meteor stream. We shall consider in some detail the dependence of the orbital inclination i on Ω, for the correlation coefficients between the other elements are very small. Instead of the elements Ω and i it is convenient to introduce the spherical coordinates $\lambda_k = \Omega_k - 90°$ and $\beta_k = 90° - i_k$ of the kth orbital pole. The average weighted values of $\bar{\beta}_k$ for average values $\bar{\lambda}_k$ are given in Figure 2. The nearly straight-line dependence of $\bar{\beta}_k$ on $\bar{\lambda}_k$ shows that the poles of the meteor orbits are approximately located along the arc of a great circle, the pole of which has coordinates λ_p, β_p and is the point of closest approach of all the meteor orbits.

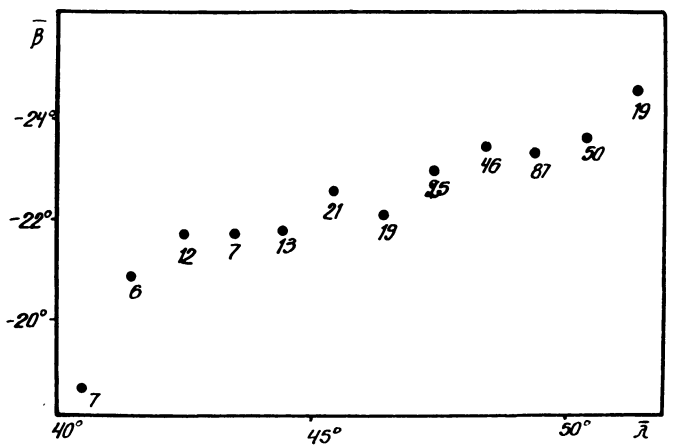

Fig. 2. The $\bar{\beta}$, $\bar{\lambda}$ dependence.

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Solving the system of equations of the type

$$x \cos \lambda_k + y \sin \lambda_k = \tan \beta_k, \qquad k = 1, \ldots, n \tag{1}$$

for

$$x = \cos \lambda_p \cot \beta_p$$
$$y = \sin \lambda_p \cot \beta_p, \tag{2}$$

we obtained for the 320 meteors

$$\lambda_p = 5^h 50^m, \qquad \beta_p = +61°03', \tag{3}$$

to which correspond an average true anomaly of 275°, an average heliocentric distance of 1.55 AU, and an average distance of 1.36 AU above the ecliptic plane.

Guigay (1947, 1948) obtained approximately the same result from visual observations. A detailed analysis of the observations shows that nearly 60% of the meteors pass within 2° of the point λ_p, β_p; more than 50% of the orbits pass within 0.15 AU of the point where the hypothetical decay of the parent comet took place.

3. The Geminid Stream Structure

In comparison with the Perseids the Geminid stream is very small, its semimajor axis not exceeding 1.5 to 1.8 AU and its revolution period being some 2.5 yr. The Geminid meteoroids are nearly uniformly dispersed along the orbit.

For our investigation we have used photographic observations of 134 meteors (Whipple, 1947; Ceplecha, 1957). Figure 3 illustrates the average dependence of the

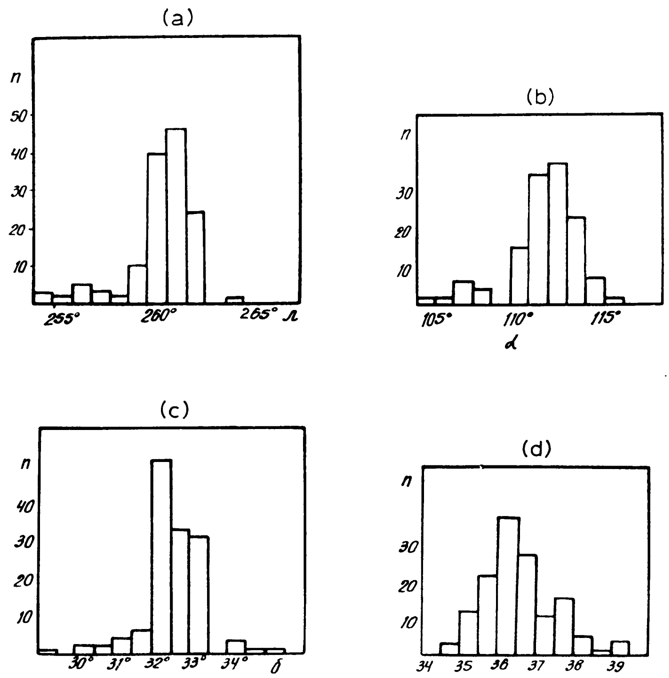

Fig. 3. Distribution of Geminids in (a) ☊, (b) α, (c) δ, and (d) v_g.

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number of photographed meteors on the solar longitude and gives histograms of the distributions in α, δ, and v_g. At solar longitude $\lambda_\odot = 260°$ the stream activity increases sharply, while at $\lambda_\odot = 263°$ the number of meteors is practically zero. The radiant is limited to an area of not more than 12 square degrees, the right ascension varying between 110° and 115° and the declination from 32°.0 to 33°.5. The relative range in geocentric velocity is somewhat greater, from 33 to 38 km s^{-1} with the peak near 36 km s^{-1}.

In the case of the Geminids the dependence of the orbital inclination on the longitude of the ascending node is weak, revealing itself as an increase in i with a decrease in Ω. The point of closest approach of the meteor orbits is located near the ascending node at a heliocentric distance of 0.16 AU.

4. Changes in the Structure of Meteor Streams Due to Gravitational Perturbations

A meteor stream gradually dissipates under the influence of various forces. Particles fine enough are affected by light pressure; while the orbits of all particles change in response to planetary perturbations. It cannot be excluded that the structure of a stream is also determined by other factors; their contribution, however, may be assessed only after one has taken into account all the gravitational forces and the effects related to the absorption and the re-emission of light.

The structure of a stream and its evolution obviously depend on the initial velocity of ejection of particles from the surface of the nucleus of the parent comet. The cometocentric velocity vector is a random quantity, so there is no need to compute the motions of individual particles by the methods applied for the calculation of the perturbations on planets, asteroids, and comets, where the theory of motion involves a large number of exact observational data. As for meteors, the only data available are their coordinates and the velocity at the moment of disappearance, and the most perfect classical theory for the motion of an individual meteoroid would be of no use, since it cannot be verified by observation. We thus conclude that in order to resolve the problems of meteor astronomy we should turn instead to the study of the distribution of random values characterizing the velocity vector and coordinates of a random meteoroid.

When studying relatively large meteoroids, which penetrate the Earth's atmosphere and give rise to relatively bright meteors, we must first find out how the planetary perturbations change the initial distribution of particles in the stream. To this effect, we may operate with some statistical model for the particle distribution.

The meteoroids are constantly under the attraction of the planets. The Perseid meteoroids, however, are generally located far from the planets, and they are subject to large perturbations only when near their nodes. Accordingly, it is convenient to divide the disturbances in the motions of Perseids into two classes: (1) perturbations far from the nodes; and (2) perturbations near the nodes.

The first class of perturbations is generally secular, and they do not reach high values. Moreover, their distribution in absolute value may be considered uniform. The secular

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