SESSION 5

Chairman: B. Ju. Levin

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24. RADAR METEOR ORBITS

(Survey Paper)

V. N. LEBEDINEC

(Astronomical Council, Academy of Sciences of the U.S.S.R., Moscow)

Regular and numerous measurements of individual radiants and velocities of meteors were carried out in Jodrell Bank (Davies and Gill, 1960), Kharkov (Kaščeev *et al.*, 1960; Kaščeev and Lebedinec, 1961), Adelaide (Nilsson, 1964) and as part of the Harvard Radio Meteor Project in U.S.A. (Hawkins, 1962). Observed distributions of radar meteor orbits obtained from a great number of systematic observations have been published up to now only at Jodrell Bank (Davies and Gill, 1960) and Kharkov (Kaščeev *et al.*, 1960; Lebedinec and Kaščeev, 1966). 2474 orbits for meteors about $+5^m$ to $+7^m$ have been obtained in Jodrell Bank, 12500 orbits for meteors brighter than about $+7^m$ have been obtained in Kharkov.

The observed distributions of elements of radar-meteor orbits obtained in Jodrell Bank and Kharkov are in satisfactory agreement (Figure 1). The observed distribution of radar meteor orbits is distorted by selectivity of the radar method just as results of photographic observations are distorted by selectivity of the photographic method, therefore they cannot be directly compared. A correction of the observational results obtained in Jodrell Bank for selectivity of the radar method was made by Davies and Gill (1960) leaving out of account two important factors: the dependence of ionization probability β on velocity (β is the average number of free electrons formed by one evaporated meteor atom) and the effect of an initial radius of ionized meteor trails. Since Davies and Gill's catalogue of orbits was not published, there was no possibility of correcting this drawback. Observation results obtained in Kharkov were corrected for selectivity of the radar method taking into account these factors. The method of taking the selectivity of radar observations into account is given by Lebedinec (1963) and Kaščeev *et al.* (1967). The corrected distribution of radar meteor orbits refers to a complex of meteoroids with masses greater than some minimum value M_0^*, which move in orbits with the perihelion distance $q \leqslant 1$ AU and the aphelion distance $q \geqslant 1$ AU. For observations in Kharkov $M_0^* \approx 2 \times 10^{-4}$ g on the scale of radar meteor masses, in which a meteoroid with the mass $M_0 = 8 \times 10^{-4}$ g moving vertically with a velocity (v_0) of 40 km/sec at an altitude of maximum evaporation produces an ionized trail with a linear electron density $\alpha = 10^{12}$ cm^{-1}. (It is assumed that $\beta \sim v^{7/2}$.)

Figures 2–5 show the corrected distribution of 12500 radar-meteor orbits over semi-major axes a, eccentricities e, perihelion distances q and inclinations i. For comparison the corrected distribution of the same elements is given for orbits of

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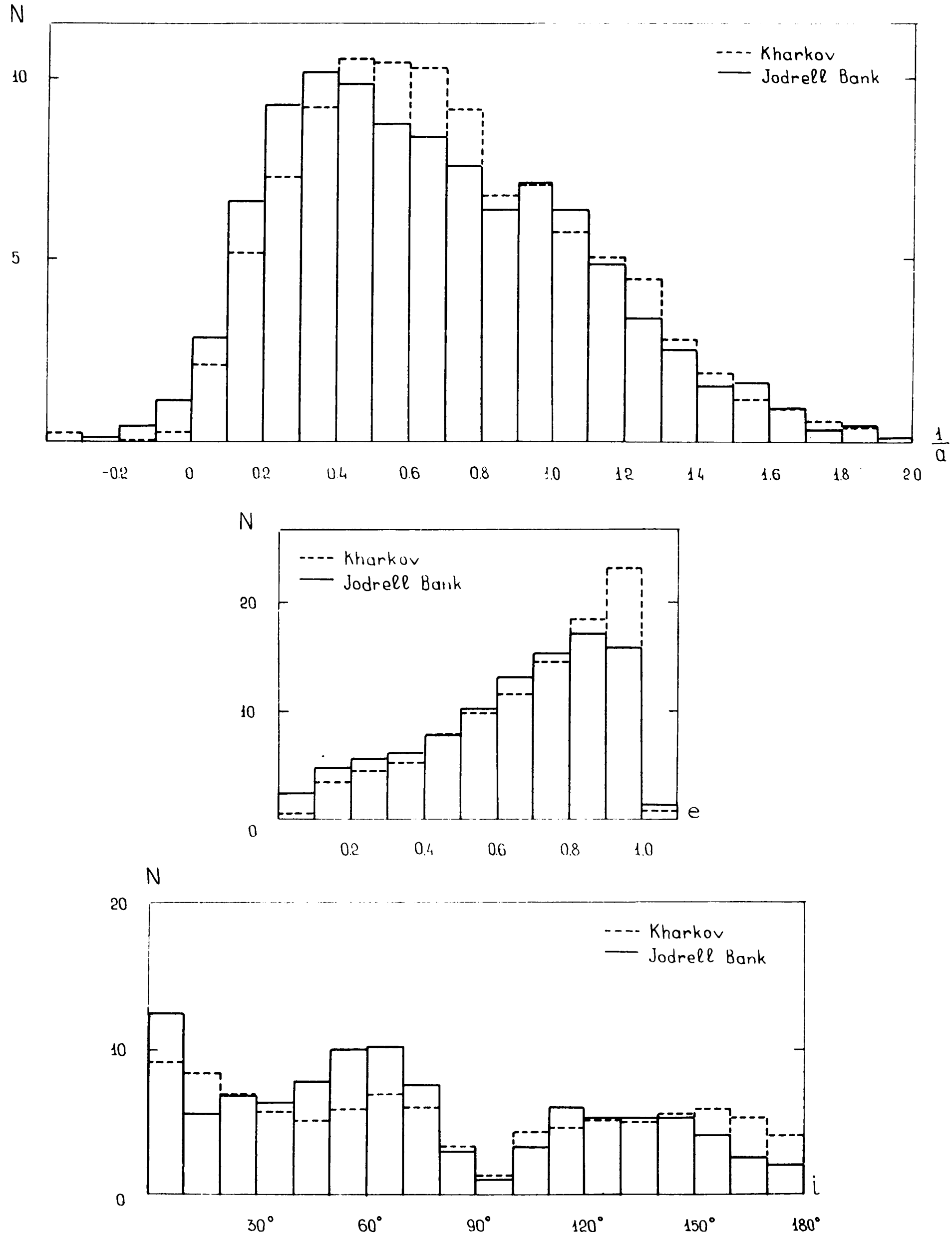

FIG. 1. *Observed distributions, obtained in Kharkov and Jodrell Bank, of the semi-major axes, eccentricities and inclinations of radar meteor orbits.*

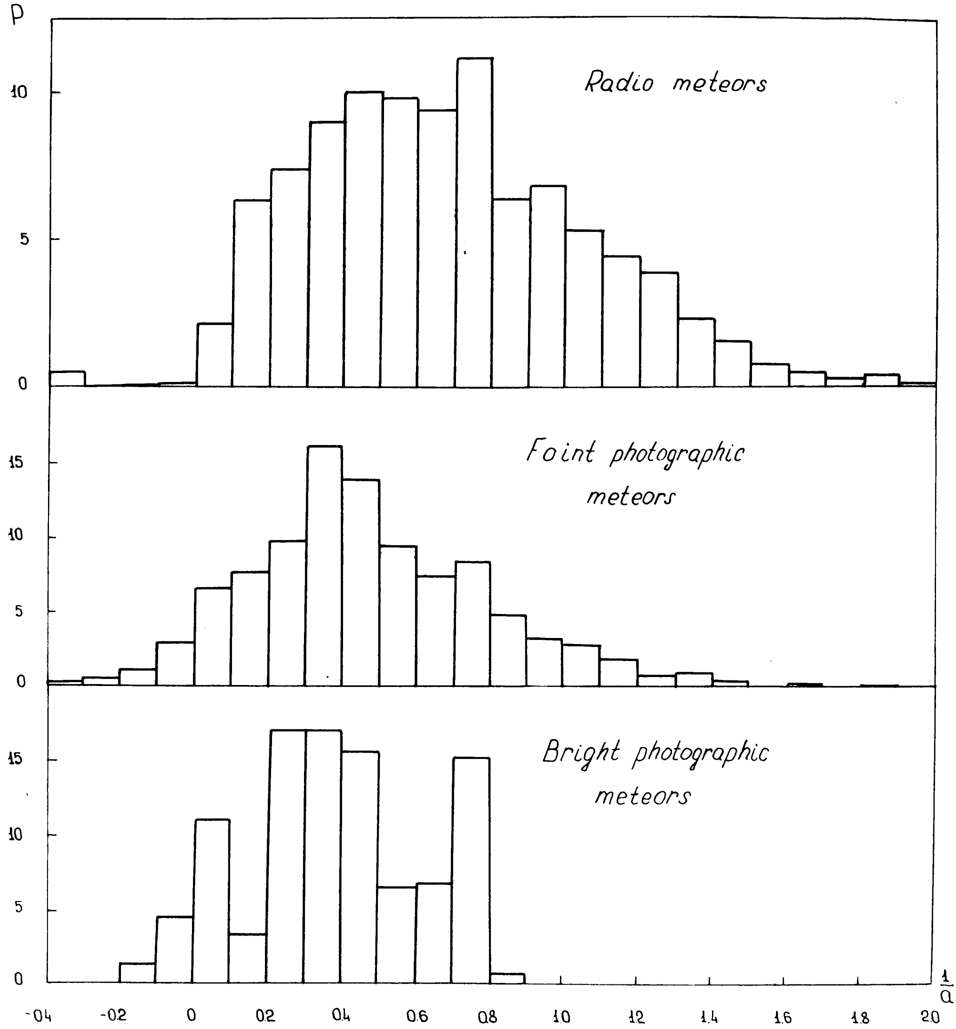

FIG. 2. *Distribution of semi-major axes of radar and photographic meteor orbits.*

2529 faint photographic meteors according to McCrosky and Posen (1961) and for 144 bright photographic meteors according to Whipple (1954). The observed two-dimensional distributions of radar meteor and photographic meteor orbits over a, i; e, i and q, i are given in Figures 6–8. The areas of the circles in Figures 6–8 are proportionate to the number of orbits falling into the corresponding intervals of a, e, q and i values.

3500 radar meteors out of 12500 refer to 195 meteor showers and associations. Two-dimensional distributions of orbits of these 3500 meteors over e, i and q, i are given in Figures 9 and 10. Observed distributions of orbits over *a*, *e*, *q* and *i* for sporadic radar meteors and radar meteor showers are compared in Figures 11–14.

Figures 2–8 show that distributions of radar meteor orbits and photographic meteor orbits differ greatly. Comparison of these distributions reveals some peculiarities in the movement of meteoroids of various sizes in the solar system, and enables us to draw some conclusions concerning the origin of meteor matter.

Various authors consider three main sources of meteor matter: disintegration of comets, breaking up of asteroids in collisions, and penetration of solid particles from the remote regions of the solar system into the central area through the Poynting-Robertson effect.

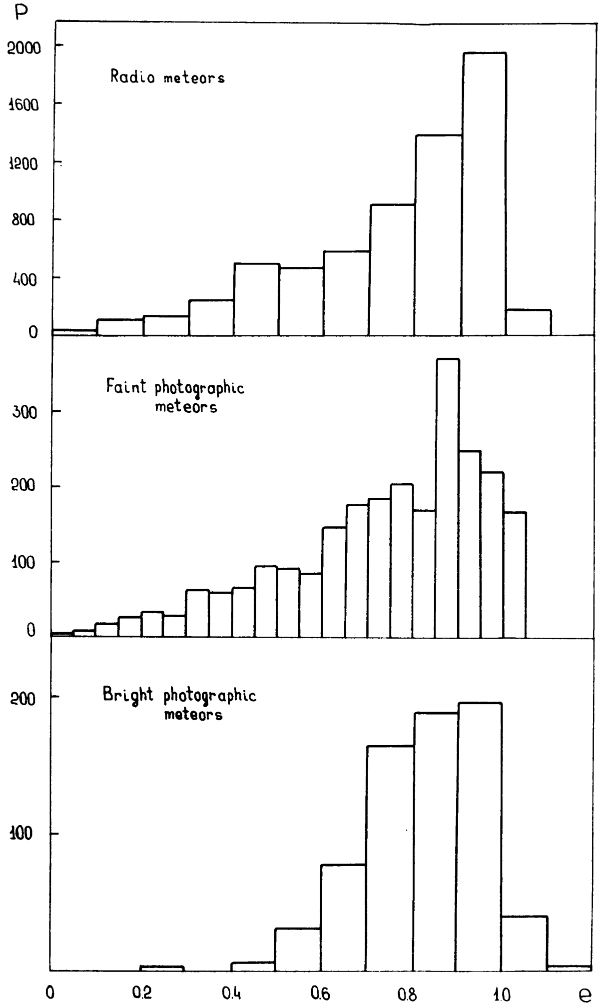

FIG. 3. *Distribution of orbital eccentricities of radar meteors and photographic meteors.*

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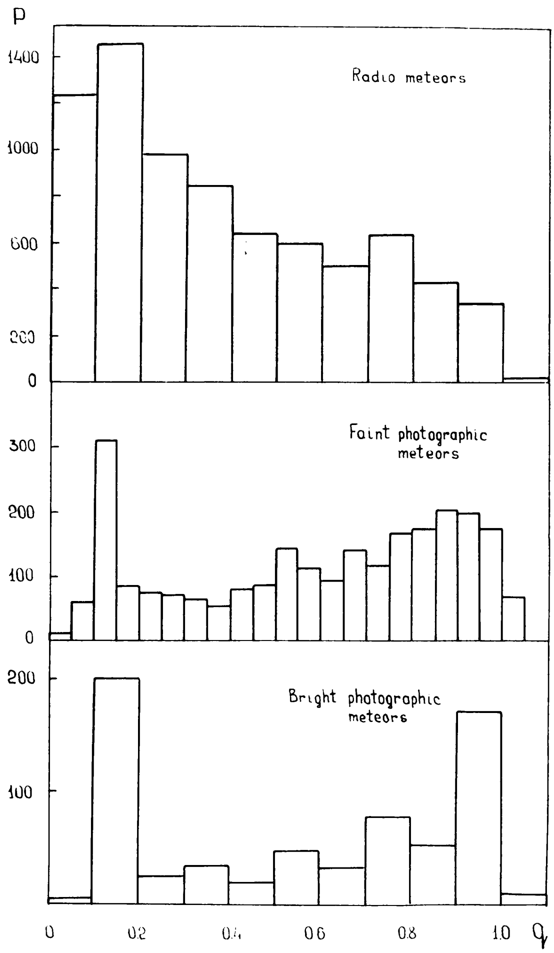

FIG. 4. *Distribution of orbital perihelion distances of radar meteors and photographic meteors.*

Analysing his catalogue of 144 orbits of bright photographic meteors, Whipple (1954) found that 90% of the orbits corresponded to two main types: (a) orbits similar to those of long-period comets (their characteristic features – large dimensions, eccentricities close to 1, and random inclinations); (b) orbits similar to those of short-period comets (characterized by comparatively small dimensions, $a \lesssim 5$ AU, small inclinations, $i < 35°$, and rather large eccentricities, $e \gtrsim 0{\cdot}7$). Large meteoroids have about 4 times as many orbits of type (b) than of type (a). About 10% of the meteors have orbits of an asteroidal type. Hence Whipple arrived at the conclusion that the main source of large meteoroids giving rise to bright photographic meteors was disintegration of short-period comets. Long-period comets contribute approximately one-quarter of this amount, and the contribution from asteroids is still less.

Results of observations carried out with the help of Super-Schmidt cameras (McCrosky and Posen, 1961) show a somewhat greater variety of orbits of faint photographic meteors in comparison to bright ones. Nevertheless, in this case as well, the majority of orbits refers to the above two types of comet orbits (a) and (b), type (b) orbits being more frequent than type (a) orbits.

Radar meteor observations (Davies and Gill, 1960; Kaščeev and Lebedinec, 1961) reveal a great number of orbits with large inclinations $30° < i < 165°$, and small eccentricities $e < 0{\cdot}7$. Such orbits represent about 30% of radar meteors, less than 10% of faint photographic meteors, and about 1% of bright photographic meteors. To explain the large percentage of such orbits for radar meteors Davies and Gill (1960) suggested that at a great distance from the Sun there existed a dust cloud, in which particles move in orbits with random inclinations. Most orbits are situated beyond Jupiter's orbit. Because of the Poynting-Robertson effect, dimensions and eccen-

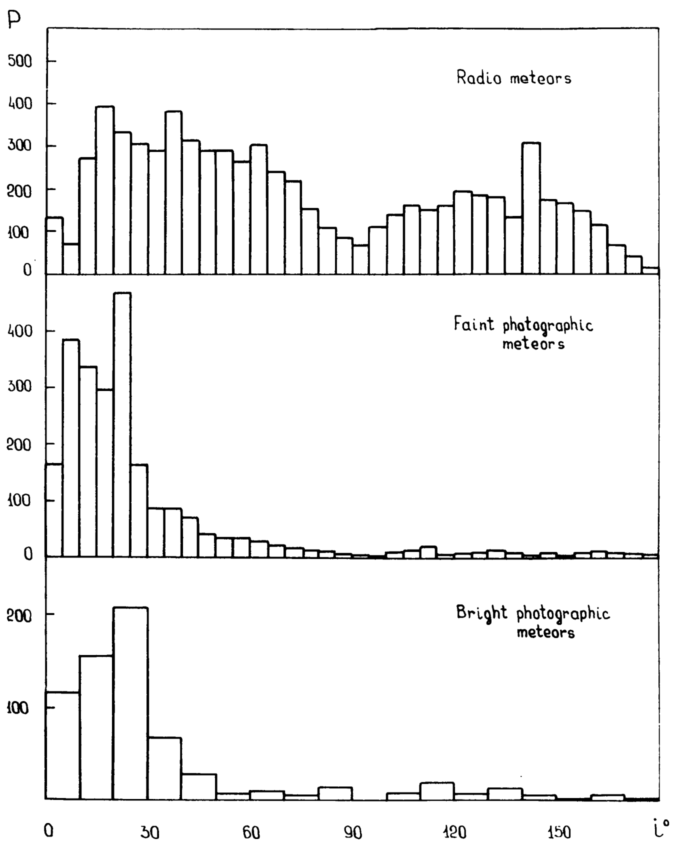

FIG. 5. *Distribution of orbital inclinations of radar meteors and photographic meteors.*

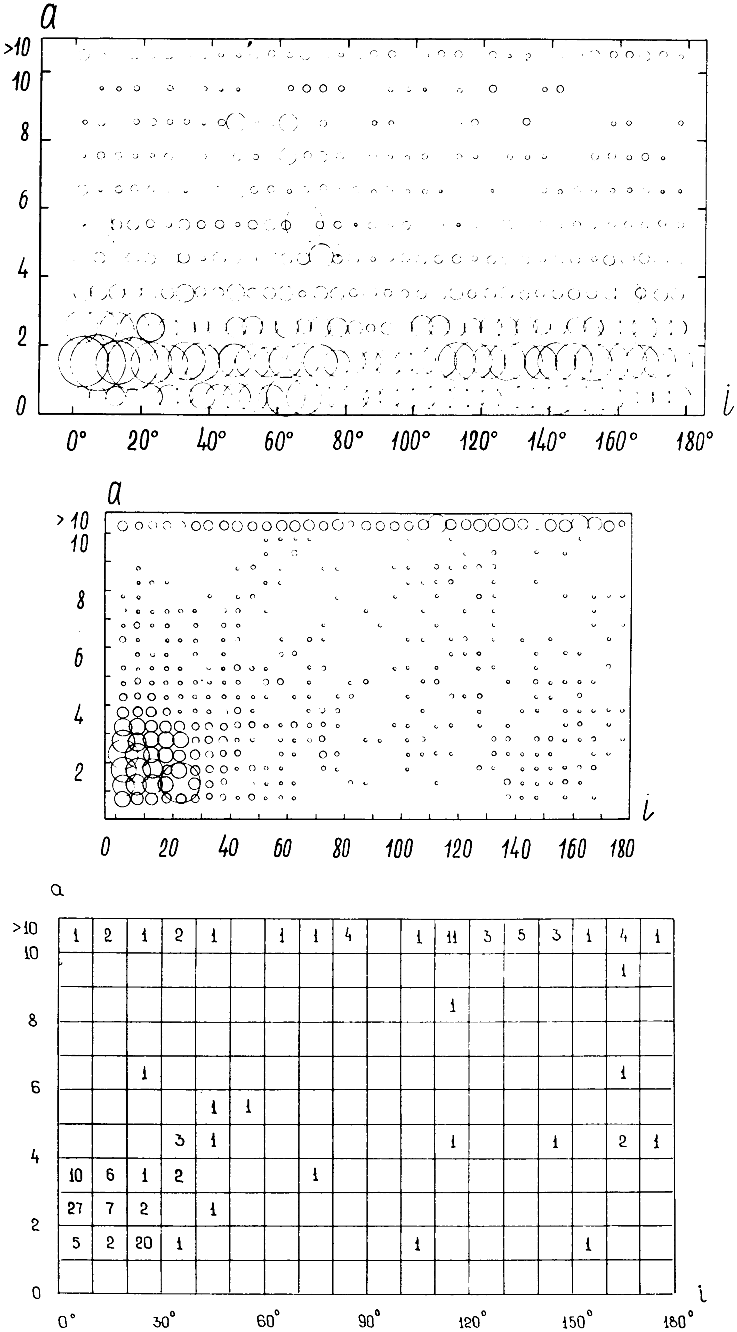

FIG. 6. *Distribution chart of orbital semi-major axes and inclinations for radar meteors, faint photographic meteors and bright photographic meteors, respectively.*

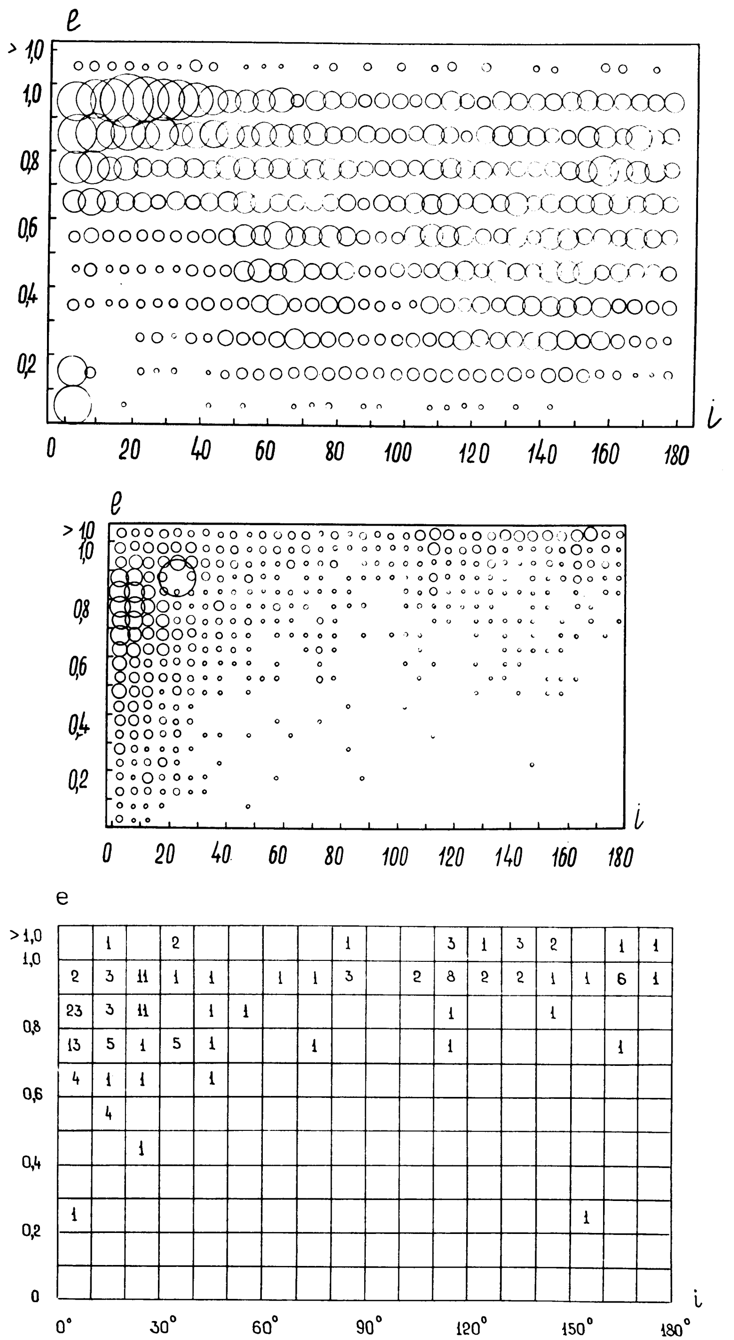

FIG. 7. *Distribution chart of orbital eccentricities and inclinations for radar meteors, faint photographic meteors and bright photographic meteors, respectively.*

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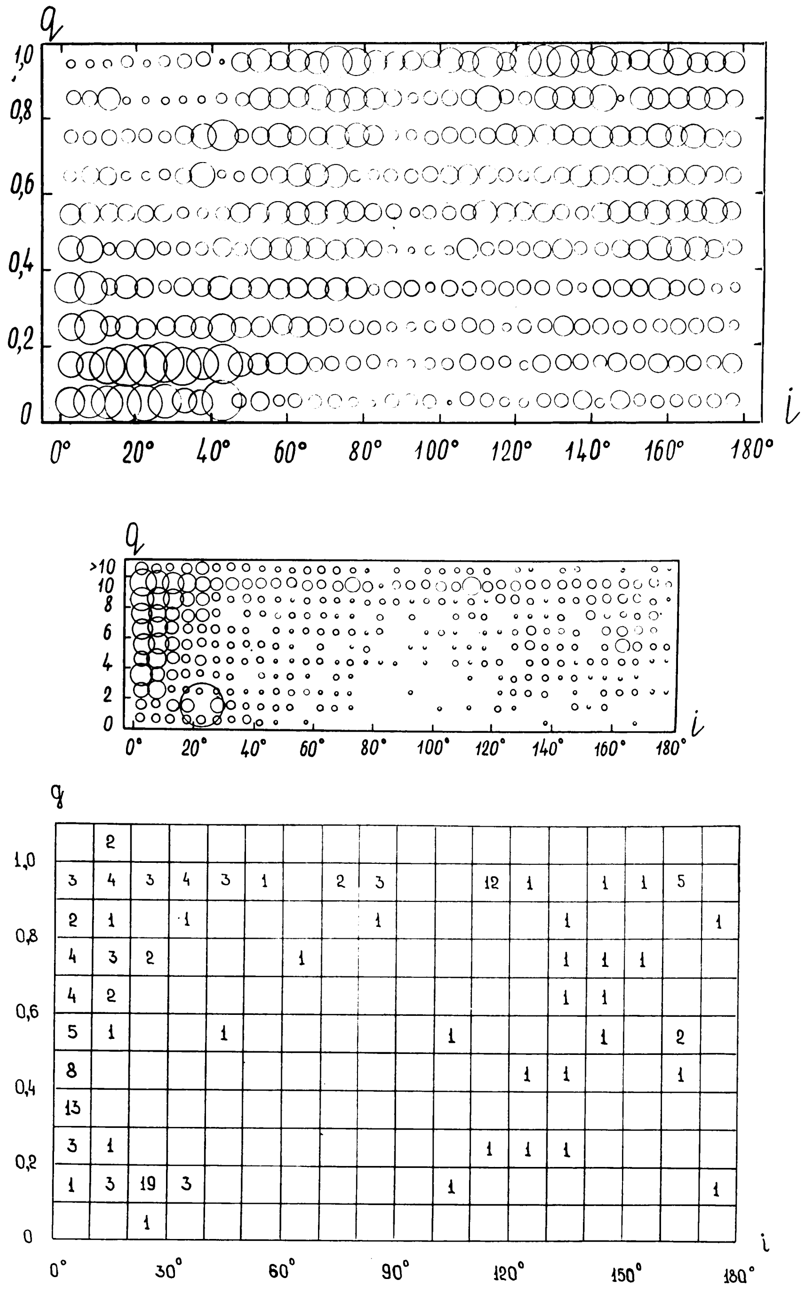

FIG. 8. *Distribution chart of orbital perihelion distances and inclinations for radar meteors, faint photographic meteors and bright photographic meteors, respectively.*

tricities of orbits gradually decrease, and orbits can approach the Earth's orbit. As this takes place, large particles giving rise to photographic meteors are captured by Jupiter or are subject to strong perturbations. According to Davies and Gill's estimates smaller particles giving rise to radar meteors can pass 'Jupiter's barrier' if they move in orbits having large inclinations.

Thus, according to Davies and Gill's hypothesis, a considerable portion of the

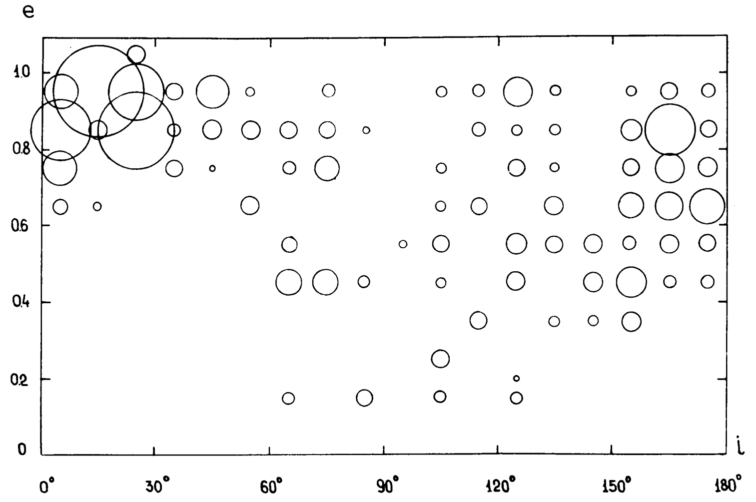

FIG. 9. *Distribution chart of inclinations and eccentricities for radar shower meteors.*

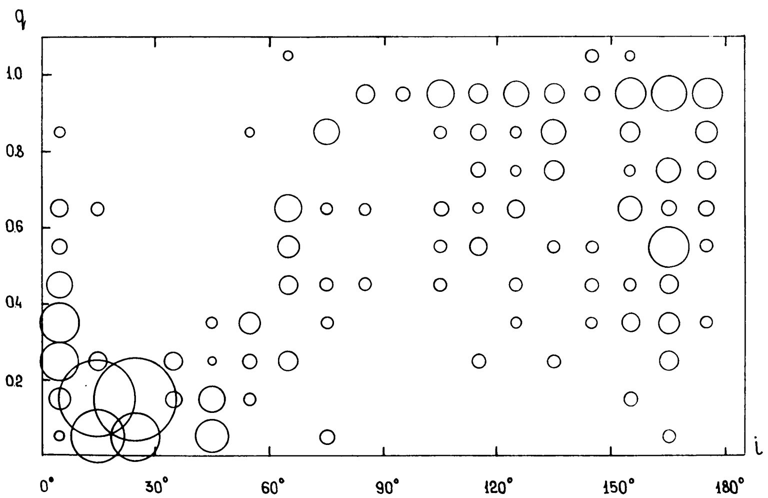

FIG. 10. *Distribution chart of inclinations and perihelion distances for radar shower meteors.*

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small meteoroids giving rise to radar meteors approach the Earth's orbit, as a result of the Poynting-Robertson effect from the dust cloud situated beyond Jupiter's orbit. As this takes place, meteoroids do not experience significant perturbations on the part of Jupiter and other planets.

Let us consider in detail the change of meteoroid orbits as a result of the Poynting-Robertson effect. Robertson (1937) obtained the following formulas for a and e change with the time as a consequence of radiative deceleration:

$$\frac{da}{dt} = -\frac{\alpha(2+3e^2)}{a(1-e^2)^{3/2}}, \quad \frac{de}{dt} = -\frac{5\alpha e}{2a^2(1-e^2)^{1/2}}, \quad \alpha = \frac{3Er_0^2}{4r\delta c^2}, \tag{1}$$

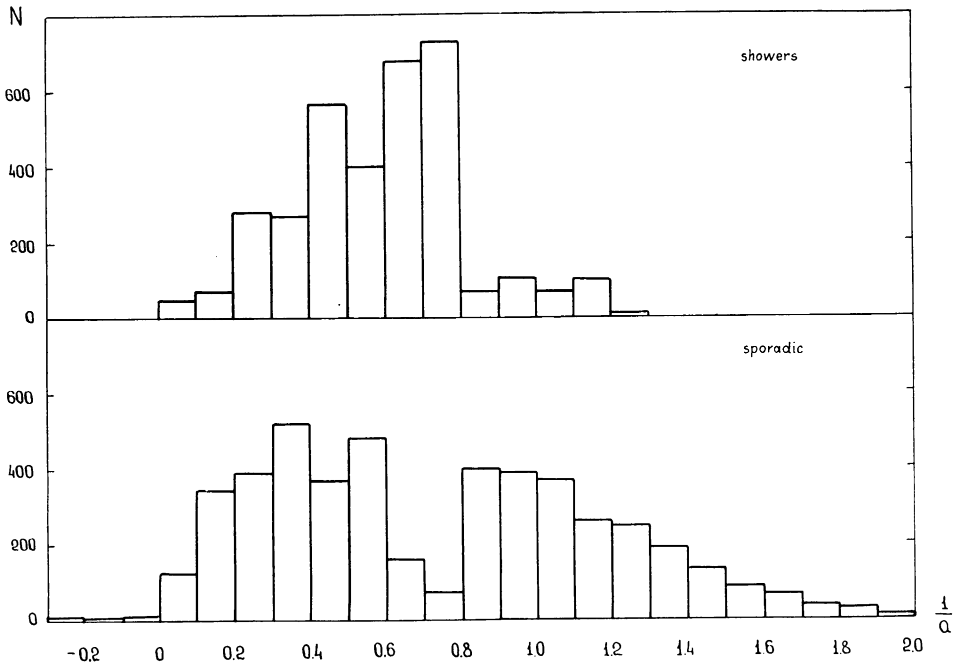

FIG. 11. *Distribution of semi-major axes for shower and sporadic radar meteors.*

where E is the solar constant, r_0 is the distance from the Earth to the Sun, r is meteoroid radius, δ is meteoroid density, c is light velocity.

Wyatt and Whipple (1950) obtained the relation for $e \neq 0$ from (1)

$$\frac{e^{4/5}}{a(1-e^2)} = \frac{e_0^{4/5}}{a_0(1-e_0^2)} = \frac{1}{C}, \tag{2}$$

where a_0, e_0 are initial values of a and e; C is a constant.

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Let us rewrite (2), using the relation $q=a(1-e)$:

$$\frac{e^{4/5}}{q(1+e)}=\frac{e_0^{4/5}}{q_0(1+e_0)}=\frac{1}{C}. \tag{3}$$

From (3) it is easy to find that for $q_0>5$ AU, $e_0 \leqslant 1$ and for $q \leqslant 1$ AU, $e<0{\cdot}06$. According to results of radar observations in Kharkov (Kaščeev *et al.*, 1960; Lebedinec and Kaščeev, 1966) and Jodrell Bank (Davies and Gill, 1960) orbits with $e<0{\cdot}06$ represent less than 1% of radar meteors. Thus, if particles from the dust cloud

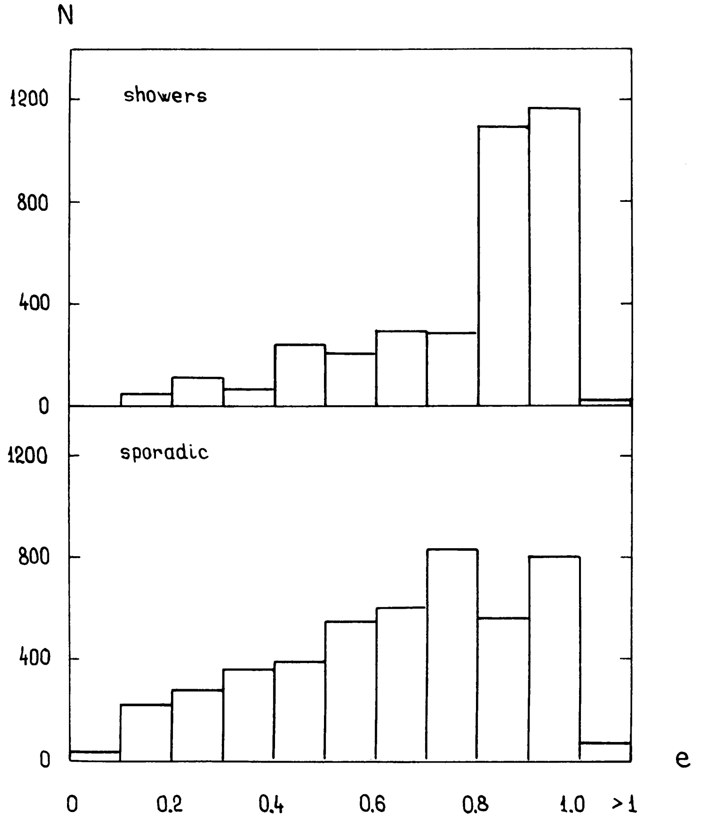

FIG. 12. *Distribution of eccentricities for shower and sporadic radar meteors.*

situated beyond Jupiter's orbit penetrate into the inner regions of the solar system under the action of radiative deceleration, and if in doing so they are not subject to significant perturbation on the part of Jupiter, these particles constitute a negligible portion of the meteoroids producing radar meteors. Therefore, the origin of small meteoroids giving rise to radar meteors which move in short-period orbits with large inclinations, apparently cannot be explained in accordance with the mechanism proposed by Davies and Gill.

As is seen from Figures 2–14, a complex of small meteoroid orbits obtained from radar observations can be presented in the form of the superposition of two components: (c) orbits with random inclination, their number decreases appreciably for $i<30°$ and $i>165°$, they are distributed over q approximately uniformly, the number of orbits systematically increases with the increase of e from 0·1 to 1; (d) orbits with

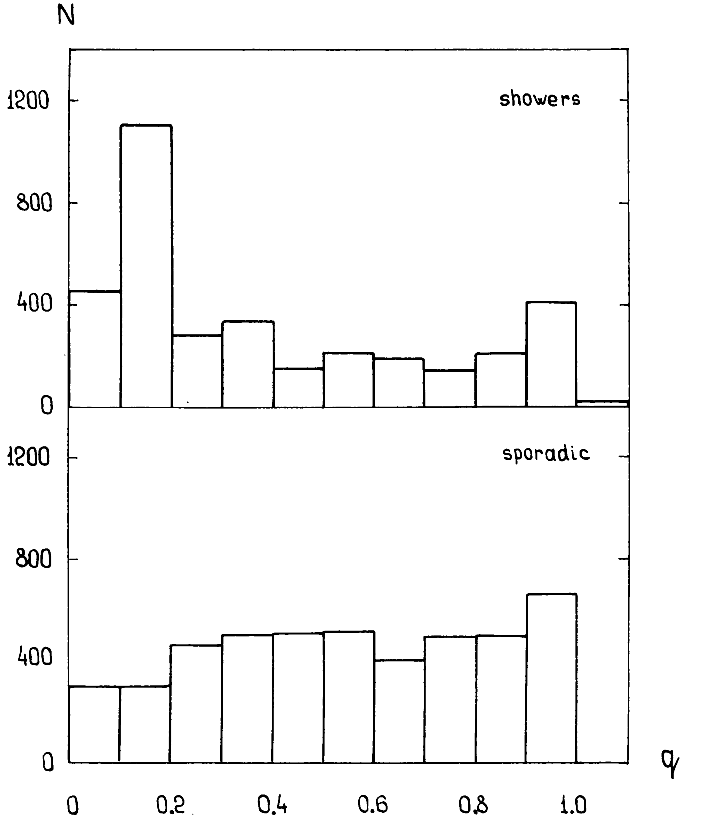

FIG. 13. *Distribution of perihelion distances for shower and sporadic radar meteors.*

small inclination, they have mainly small dimensions $a \lesssim 3$ AU, small perihelion distances $q \lesssim 0{\cdot}3$ AU, and large eccentricities $e \gtrsim 0{\cdot}7$. The majority of sporadic meteors, and a comparatively small number of shower meteors, have orbits of type (c). The majority of shower meteors, and a comparatively small number of sporadic meteors, have type (d) orbits.

Of all the large bodies of the solar system known at present (planets and their

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satellites, asteroids and comets) only long-period comets move in orbits with random inclinations. Only some orbits of short-period comets are similar to orbits of type (d). In this connection it is quite natural to suppose that small meteoroids giving rise to radar meteors are formed mainly as a result of comet disintegration.

In Porter's catalogue (1961) there are orbits of 566 comets which had been observed to the end of 1960: 94 short-period comets with the period $T < 200$ years ($a < 34$ AU), 117 elliptical orbits of long-period comets, 290 parabolic orbits, and 65 hyperbolic ones. Distributions of orbits of short-period and long-period comets over a, e, q and i are presented in Figures 15–18. Figures 19–21 show two-dimensional distributions of short-period comet orbits over i, a; i, e and i, q.

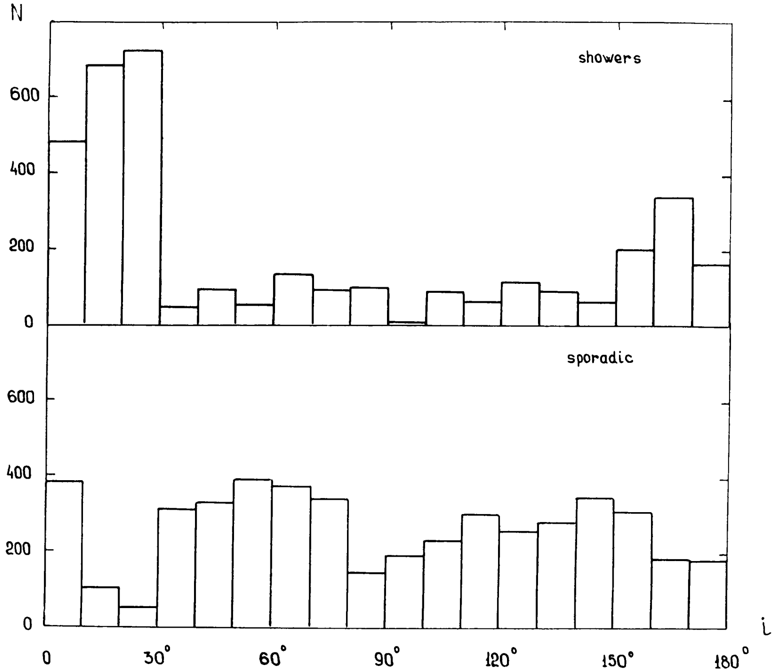

FIG. 14. *Distribution of inclinations for shower and sporadic radar meteors.*

The distribution of orbit inclinations of long-period comets satisfactorily agrees with that of group (c) radar meteors. Let us assume that almost all the meteoroids moving in orbits with large inclinations originate as a result of long-period comet disintegration. They initially move in orbits close to comet orbits. Dimensions and eccentricities of orbits gradually decrease because of the Poynting-Robertson effect, and finally the meteoroids fall into the Sun. Let us assume that during rather a long period of time the rate of meteoroid injection remains practically constant, and

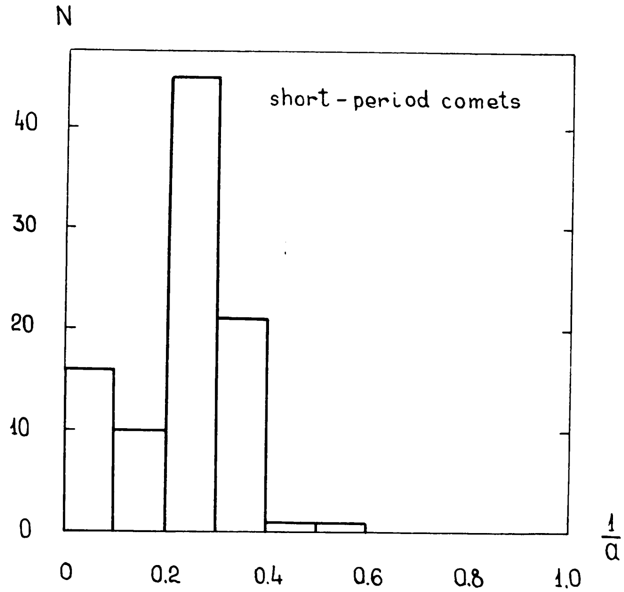

FIG. 15. *Distribution of semi-major axes of short-period comet orbits.*

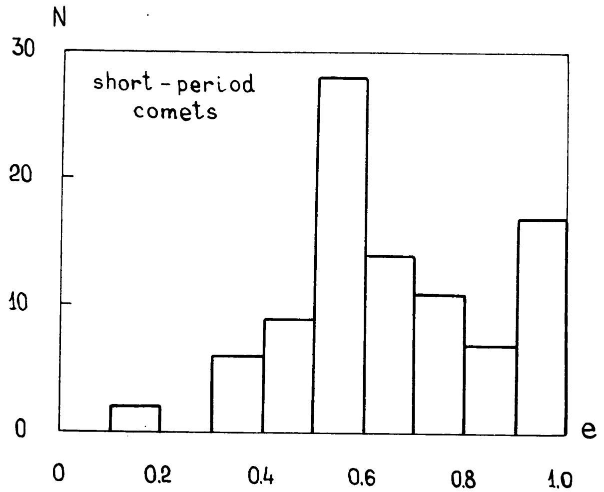

FIG. 16. *Distribution of eccentricities of short-period comets.*

that a stationary distribution of the dimensions and forms of orbits is established.

From (1) and (3) we find a stationary distribution of orbit eccentricities of meteoroids originating as a result of the disintegration of comets which moved in orbits with the given e_0 and q_0. Differential distributions proportionate to the number of

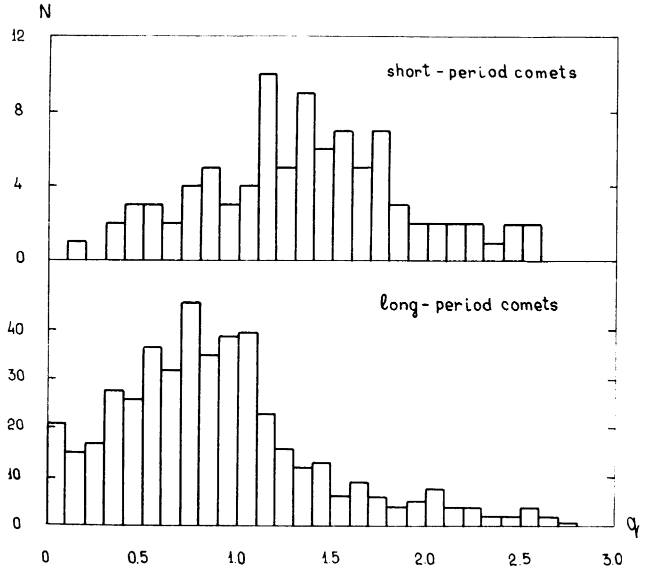

FIG. 17. *Distribution of perihelion distances of comet orbits.*

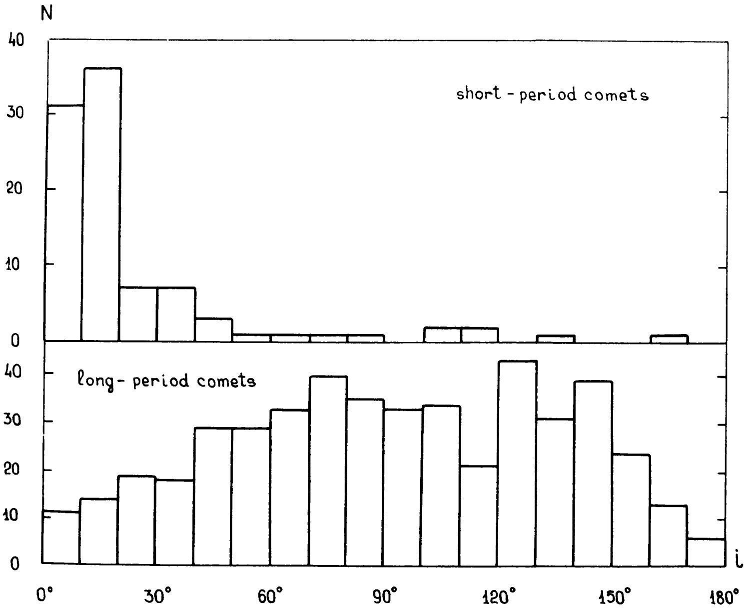

FIG. 18. *Distribution of inclinations of comets.*

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meteoroids that pass perihelion per unit time can be written down in the form

$$\left(\frac{dN}{de}\right)_{e_0,\,q_0} = -A\left(T\,\frac{de}{dt}\right)^{-1}, \tag{4}$$

where T is a period of revolution in orbit with the given e and q; and A is the coefficient characterizing the rate of meteoroid injection into the orbits with the given e_0 and q_0.

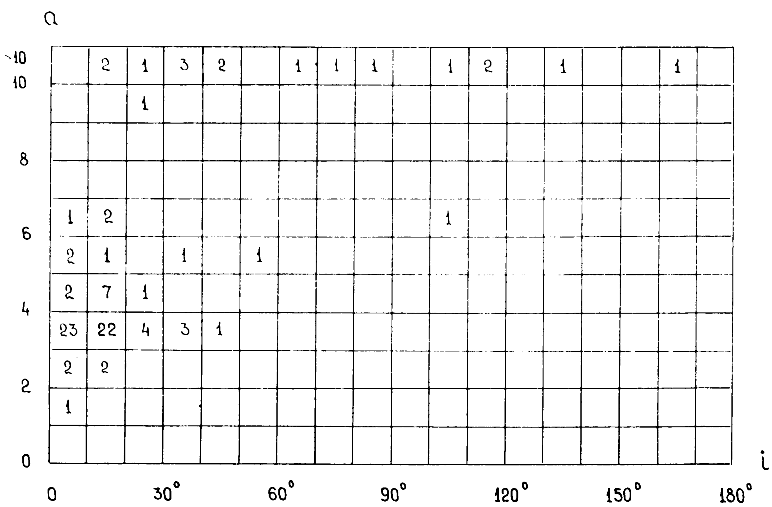

FIG. 19. *Distribution chart of inclinations and semi-major axes for short-period comet orbits.*

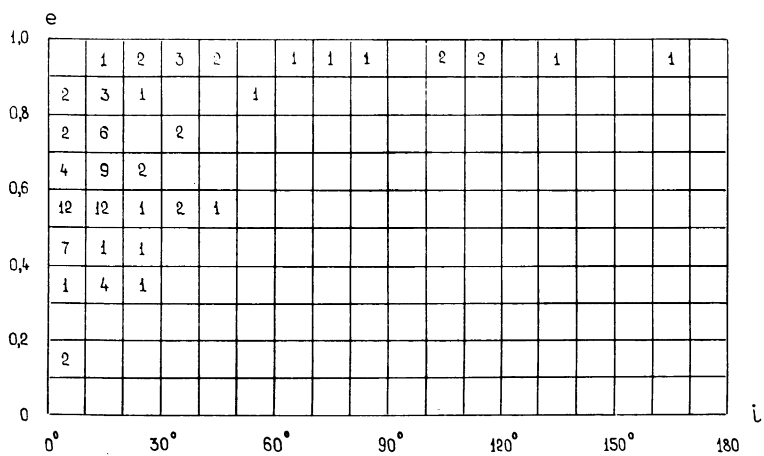

FIG. 20. *Distribution chart of inclinations and eccentricities for short-period comet orbits.*

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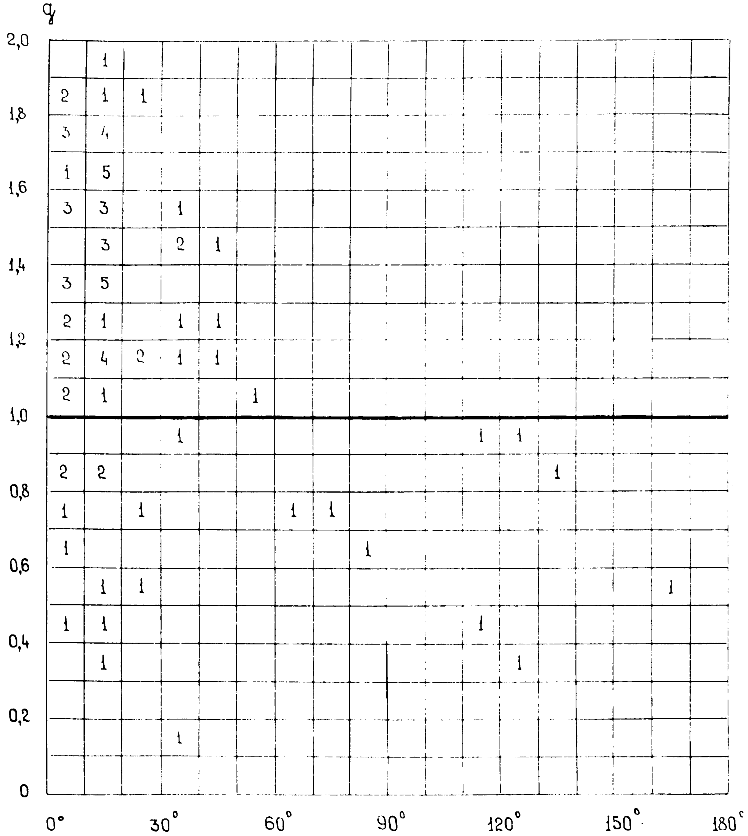

FIG. 21. *Distribution chart of inclinations and perihelion distances for short-period comet orbits.*

Let us express T in terms of e and C with the help of Kepler's third law,

$$T = a^{3/2} = \frac{C^{3/2} e^{6/5}}{(1 - e^2)^{3/2}}. \tag{5}$$

From (1), (3)–(5) we obtain

$$\left(\frac{\mathrm{d}N}{\mathrm{d}e}\right)_{e_0,\, q_0} = \frac{2AC^{1/2}}{5\alpha e^{3/5}} = \frac{2A}{5\alpha} \frac{q_0^{1/2}(1 + e_0)^{1/2}}{e_0^{2/5}} e^{-3/5}. \tag{6}$$

If initial orbits are almost parabolic, then $e_0 \approx 1$. When e_0 changes from 0·9 to 1·0, the function $(1 - e_0)^{1/2}/e_0^{2/5}$ remains practically constant (it changes from 1·43 to 1·41). Assuming that $e_0 = 1$, we obtain

$$\left(\frac{\mathrm{d}N}{\mathrm{d}e}\right)_{q_0} = \frac{2\sqrt{2}\, A(q_0)}{5\alpha} q_0^{1/2} e^{-3/5}, \tag{7}$$

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where $A(q_0)$ is an initial distribution of perihelion distances of meteoroid orbits. Integrating (7) with respect to q_0, we find the eccentricity distribution of the orbits of all meteoroids which are injected into orbits close to parabolic ones with any q_0,

$$\frac{dN}{de} = \frac{2\sqrt{2}}{5\alpha} e^{-3/5} \int_{q_{01}}^{q_{02}} A(q_0)\, q_0^{1/2}\, dq_0 . \tag{8}$$

We find boundary q_0 values from the conditions $q' = 1$ AU and $q = 1$ AU

$$q_{01} = \frac{e_0^{4/5}}{1 + e_0} \frac{1 - e}{e^{4/5}} \approx \frac{1 - e}{2e^{4/5}}, \quad q_{02} = \frac{e_0^{4/5}}{1 + e_0} \frac{1 + e}{e^{4/5}} \approx \frac{1 + e}{2e^{4/5}} . \tag{9}$$

In a particular case of the initial power distribution of perihelion distances

$$A = A_0 q_0^n \tag{10}$$

we obtain from (8)–(10)

$$\frac{dN}{de} = \frac{2\sqrt{2}\, A_0}{5\alpha} e^{-3/5} \int_{(1-e)/2e^{4/5}}^{(1+e)/2e^{4/5}} q_0^{n+1/2}\, dq . \tag{11}$$

For $n \neq -1{\cdot}5$

$$\frac{dN}{de} = \frac{2^{-n} A_0}{5(n + 1{\cdot}5)\,\alpha} \frac{(1 + e)^{n+1\cdot5} - (1 - e)^{n+1\cdot5}}{e^{(4n+9)/5}} , \tag{12}$$

for $n = -1{\cdot}5$

$$\frac{dN}{de} = \frac{2\sqrt{2}\, A_0}{5\alpha} e^{-3/5} \ln \frac{1 + e}{1 - e} .$$

Equation (2) in the general form cannot be solved with respect to e. In the range $0 < e < e_0$ (for $e_0 \leqslant 1$) the dependence of e on q is well approximated by the equation

$$e = \frac{4q^2}{C^2} = \frac{4e_0^{8/5}}{(1 + e_0)^2 q_0^2} q^2 . \tag{13}$$

From (1) and (13) we obtain

$$\frac{dq}{dt} = \frac{C^2}{8q} \frac{de}{dt} = \frac{5\alpha C^{6/5} (1 - e^2)^{3/2}}{2^{26/5} q^{11/5}} . \tag{14}$$

From (5) and (13) we find

$$T = \frac{2^{12/5} q^{12/5}}{C^{9/10} (1 - e^2)^{3/2}} . \tag{15}$$

From (14) and (15) let us find the stationary perihelion-distance distribution of the orbits of meteoroids which are injected into orbits with the given e_0 and q_0:

$$\left(\frac{dN}{dq}\right)_{e_0, q_0} = -A\left(T \frac{dq}{dt}\right)^{-1} = \frac{2^{14/5} A}{5\alpha C^{3/10} q^{1/5}} . \tag{16}$$

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If $e_0 \approx 1$, $C \approx 2q_0$. Then let us write (16) in the form

$$\left(\frac{dN}{dq}\right)_{q_0} = \frac{2^{5/2} A(q_0)}{5\alpha q_0^{3/10} q^{1/5}}. \tag{17}$$

Integrating (17) with respect to q_0 we obtain

$$\frac{dN}{dq} = \frac{2^{5/2}}{5\alpha q^{1/5}} \int_q^{q\sqrt{(1+q)/(1-q)}} A(q_0)\, q_0^{-3/10}\, dq_0. \tag{18}$$

Boundary q_0 values are found from the conditions: $q_0 = q$ and $q' = 1$ AU.
In the case of the initial power distribution over q_0 we obtain from (10) and (18)

$$\frac{dN}{dq} = \frac{2^{5/2} A_0}{5\alpha q^{1/5}} \int_q^{q\sqrt{(1+q)/(1-q)}} q_0^{n-0\cdot 3}\, dq_0. \tag{19}$$

For $n \neq -0{\cdot}7$

$$\frac{dN}{dq} = \frac{2^{5/2} A_0}{5(n+0{\cdot}7)} q^{n+0\cdot 5} \left[\left(\frac{1+q}{1-q}\right)^{(n+0\cdot 7)/2} - 1\right], \tag{20}$$

for $n = -0{\cdot}7$

$$\frac{dN}{dq} = \frac{2^{5/2} A_0}{5\alpha} q^{-1/5} \ln \sqrt{\frac{1+q}{1-q}}.$$

From (1) and (5) we have

$$\frac{d\left(\frac{1}{a}\right)}{dq} = -\frac{1}{a^2}\frac{da}{dt} = \frac{\alpha(2+3e^2)}{a^3(1-e^2)^{3/2}},$$

$$\left[\frac{dN}{d\left(\frac{1}{a}\right)}\right]_{e_0,\,q_0} = A\left[T\frac{d\left(\frac{1}{a}\right)}{dt}\right]^{-1} = \frac{AC^{3/2}e^{6/5}}{\alpha(2+3e^2)}. \tag{21}$$

In the range $0{\cdot}2 < e \leqslant 1$ the dependence of e and $e^{6/5}/(2+3e^2)$ on a is well approximated by the equations

$$e = \exp\left(-0{\cdot}5\frac{C}{a}\right),$$
$$\frac{e^{6/5}}{2+3e^2} = \frac{0{\cdot}2}{1+0{\cdot}16\left(\frac{C}{a}\right)^2}. \tag{22}$$

From (21) and (22) we obtain

$$\left[\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)}\right]_{e_0,\,q_0} = \frac{0{\cdot}2AC^{3/2}}{\alpha\left[1+0{\cdot}16\left(\frac{C}{a}\right)^2\right]}. \tag{23}$$

For $e_0 \approx 1$, $C \approx 2q_e$, Equation (23) will take the form

$$\left[\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)}\right]_{q_0} = \frac{2^{3/2}A(q_0)\,q_0^{3/2}}{5\alpha\left[1+0{\cdot}64\left(\frac{q_0}{a}\right)^2\right]}. \tag{24}$$

Integrating (24) with respect to q_0, we have

$$\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)} = \frac{2^{3/2}}{5\alpha}\int_0^{-a\ln|1/a-1|}\frac{A(q_0)\,q_0^{3/2}\,\mathrm{d}q_0}{1+0{\cdot}64\left(\frac{q_0}{a}\right)^2}. \tag{25}$$

The integration limits in (25) are determined from conditions: $q=0$ and $q=1$ AU for $a>1$ AU; $q=0$ and $q'=1$ AU for $a<1$ AU.

In the case of the initial power distribution of orbits over q_0 we obtain

$$\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)} = \frac{2^{3/2}A_0}{5\alpha}\int_0^{-a\ln|1/a-1|}\frac{q_0^{n+3/2}\,\mathrm{d}q_0}{1+0{\cdot}64\left(\frac{q_0}{a}\right)^2}. \tag{26}$$

Equations (25) and (26) are applicable in the ranges $0{\cdot}5<a<0{\cdot}8$ AU and $1{\cdot}25<a<\infty$. For $0{\cdot}8<a<1{\cdot}25$ AU Equations (25) and (26) are less exact because of using approximation (22).

Let us find the function of the orbit distribution over $1/a$ for a number of n values.

For $n=-0{\cdot}5$

$$\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)} = \frac{\sqrt{2}A_0}{3{\cdot}2\alpha}\,a^2\ln\left[1+0{\cdot}64\left(\ln\left|\frac{1}{a}-1\right|\right)^2\right],$$

for $n=-1$

$$\frac{\mathrm{d}N}{\mathrm{d}\left(\frac{1}{a}\right)} = \frac{2A_0}{0{\cdot}8^{3/2}\alpha}\,a^{3/2}$$

$$\times\left[-\ln\frac{1-0{\cdot}8\ln\left|\frac{1}{a}-1\right|+\sqrt{-1{\cdot}6\ln\left|\frac{1}{a}-1\right|}}{\sqrt{1+0{\cdot}64\left(\ln\left|\frac{1}{a}-1\right|\right)^2}}+\operatorname{arctg}\frac{\sqrt{-1{\cdot}6\ln\left|\frac{1}{a}-1\right|}}{1+0{\cdot}8\ln\left|\frac{1}{a}-1\right|}\right], \tag{27}$$

for $n = -1{\cdot}5$

$$\frac{dN}{d\left(\frac{1}{a}\right)} = \frac{2^{3/2}A_0}{4\alpha}\, a \operatorname{arctg}\left(-0{\cdot}8 \ln\left|\frac{1}{a} - 1\right|\right),$$

for $n = -2$

$$\frac{dN}{d\left(\frac{1}{a}\right)} = \frac{2A_0}{\sqrt{0{\cdot}8\alpha}}\, a^{1/2}$$

$$\times \left[\ln \frac{1 - 0{\cdot}8 \ln\left|\frac{1}{a} - 1\right| + \sqrt{-1{\cdot}6 \ln\left|\frac{1}{a} - 1\right|}}{\sqrt{1 + 0{\cdot}64\left(\ln\left|\frac{1}{a} - 1\right|\right)^2}} + \operatorname{arctg} \frac{\sqrt{-1{\cdot}6 \ln\left|\frac{1}{a} - 1\right|}}{1 + 0{\cdot}8 \ln\left|\frac{1}{a} - 1\right|}\right].$$

With the help of Equations (8), (18) and (25) it is possible to obtain stationary distributions of orbits over e, q and a for any distribution of the initial meteoroid orbit perihelion distance $A(q_0)$, if the initial orbits are almost parabolic; with the help of Equations (11), (19) and (26) the stationary distributions can be obtained for a particular case of the power distribution $A(q_0)$. Distribution of orbital eccentricities (11) is most sensitive to change of the power n in (10), distributions of q and a are less sensitive to a change in n. The distribution of e for orbits with great inclinations obtained from radar observations (Kaščeev *et al.*, 1967) agrees satisfactorily with the theoretical distribution for $n = -1{\cdot}0 \sim -1{\cdot}5$. Distributions over q and a are also closest to the theoretical ones for $n = -1{\cdot}0 \sim -1{\cdot}5$.

The values of $n = -1{\cdot}0 \sim -1{\cdot}5$ in the distribution of initial perihelion distances of meteoroid orbits are quite reasonable in a physical sense. On the basis of the icy conglomerate model of comets it is possible to suppose that the loss of comet mass is proportional to the amount of solar radiation absorbed. In the case of orbits close to parabolic the velocity of meteoroids at perihelion $v \sim q^{-1/2}$. If the mass loss occurs mostly in a small section of the orbit near perihelion, it can be expected that the loss of long-period comet mass during one revolution will be proportionate to $q^{-3/2}$. Then the distribution of initial perihelion distances of meteoroid orbits $A(q_0) \sim q_0^{-(1{\cdot}0 \sim 1{\cdot}5)}$ corresponds to the distribution over q of long-period comets $A_k(q_0) \sim q_0^{(0 \sim 0{\cdot}5)}$. Such a theoretical distribution $A_k(q_0)$ agrees qualitatively with the observational one (Figure 17) in the range $0 < q < 1{\cdot}1$ AU. For a more strict comparison, as well as for comparison in the larger range of q_0 values, it is necessary to take into account the dependence of comet detectability on q_0.

Satisfactory agreement of the theoretical distribution of meteoroid orbits over e, q and $1/a$ obtained by us from the results of radar observation, as well as good agreement between the distribution of type (c) radar meteor orbit inclinations and long-period comet orbits, show that the majority of small meteoroids giving rise to radar meteors and moving in orbits with large inclinations, apparently originate as a result of long-period comet disintegration.

From a comparison of Figures 5 and 18 it is seen that the distribution of orbital inclinations, for both bright and faint photographic meteors, agrees well with that of short-period comets. Agreement is much worse in the distributions of semi-major axes, eccentricities and perihelion distances. Orbits of only two comets have $a<2{\cdot}5$ AU, while orbits of more than 40% of bright photographic meteors have $a<2{\cdot}5$ AU. Only one short-period comet with $q<0{\cdot}3$ AU is known. Orbits of about 25% of both bright and faint photographic meteors have such q values. The mean e value for orbits of 94 short-period comets is about 0·6, and for orbits of photographic meteors with $a<34$ AU it is about 0·8. Large meteoroids moving in short-period orbits have large eccentricities ($e>0{\cdot}8$) more often than short-period comets. While it is possible to explain lower a values of meteoroid orbits by action of radiative deceleration, increase in e cannot be explained in this way. It is still more difficult to explain simultaneous decrease in q and increase in e by an action of radiative deceleration. Thus, the observed complex of large meteoroid orbits with small inclinations apparently could not be formed by the disintegration of comets moving in orbits similar to those of short-period comets known at present.

The a, e and q distributions of group (c) radar meteor orbits differ from those of short-period comet orbits still more than in the case of photographic meteor orbits with small inclinations. About $\frac{2}{3}$ of radar meteor orbits with small inclinations have $a<2{\cdot}5$ AU, $e>0{\cdot}8$ and $q<0{\cdot}3$ AU. Such orbits have been obtained for 40 radar meteor streams and associations. Orbits of this kind have the major Geminid and Arietid streams, and also major associations for which parent comets have not been found. At present not even a single comet with such an orbit is known.

As in the case of photographic meteors, a difference between the distribution in a for group (c) radar meteor orbits and for short-period comet orbits, can be partially explained by a gradual decrease of meteoroid orbit dimensions because of the Poynting-Robertson effect. Difference in distributions of eccentricities and perihelion distances can hardly be explained by changes in meteoroid orbits. It points apparently to an essential difference, at the moment of meteoroid origin, between the initial orbits of most of the meteoroids, and the orbits of all the comets known at present, or of any large bodies in the solar system.

Detection of a great number of major meteor streams and associations having orbits with $i<50°$, $a<2{\cdot}5$ AU, $e>0{\cdot}8$ and $q<0{\cdot}3$ AU shows that a great number of comets or other large bodies giving rise to meteor streams, should constantly appear in the solar system with this type of orbit. If we take the icy conglomerate model for comets, then the lifetime of a comet having an orbit with $q<0{\cdot}3$ AU and $a<2{\cdot}5$ AU will be very short, because all the orbit is in the vicinity of the Sun, and it approaches the Sun closely at perihelion. Apparently, these comets should completely disintegrate after several revolutions round the Sun. Assuming that the disintegration time of meteor streams of the Geminid and Arietid type is comparable to the time of fall into the Sun of small meteoroids that give rise to radar meteors, it is possible to estimate roughly the appearance frequency of short-period comets in orbits with very small perihelion distances. To obtain the observed number of radar meteor streams it is necessary that one such comet should appear every 100–1000 years.

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DISCUSSION

Southworth: I am sure that the observations in Kharkov are similar to these by the Harvard-Smithsonian system, but the conclusions are very different, no doubt because of different corrections for observational selection. We have found radar orbits generally similar to photographic orbits, except with smaller average major axes and inclinations. Also, we have not found a larger proportion of small perihelion distances in radar orbits than in photographic orbits.

Lebedinec: The main sources of the selectivity of radar observations are: (1) The dependence of the ionization probability upon velocity. We adopted $\beta \sim v^{3.5}$, which is close to the relation $\beta \sim v^4$ adopted at Harvard. (2) The influence of the initial radius of the trail which makes it difficult to observe faint high-velocity meteors. This factor is not being taken into account at Harvard. In my opinion this is one of the reasons for the discrepancies.

Ceplecha: How do you correct the observed velocity to the no-atmosphere velocity?

Lebedinec: For all meteors of a given velocity we have assumed uniform deceleration corrections, Δv, which have been determined from the theory. The relation $\Delta v \sim 1/v$ was adopted. For medium velocities $\Delta v \approx 1$ km/sec.

McIntosh: During what period of time were the Kharkov observations obtained, and were they uniformly distributed throughout the year?

Lebedinec: The observations were carried out in 1960. The number of orbits is not uniformly distributed in different months.

Babadžanov: Why did you use in determining the distribution of orbital elements of bright meteors only the observations of Whipple? There are a number of observations of bright meteors obtained in Czechoslovakia and USSR.

Lebedinec: We were able to use the data by Whipple only, because only these have been corrected for the sensitivity of the photographic method of the observations.

Babadžanov: The cosmic weights can be very easily determined from the orbital elements.

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