FEATURES OF THE MOTION OF SMALL METEORIC BODIES

Astronomy

1965

SovietRxiv

Abstract

Full Text

UDC 523.531

Astronomy

B. L. KASHCHEEV, V. N. LEBEDINETS, M. F. LAGUTIN

FEATURES OF THE MOTION OF SMALL METEORIC BODIES

(Presented by Academician V. G. Fesenkov, 13 III 1965)

From November 1959 to December 1960, at the Kharkov Polytechnic Institute, a year-long cycle of radar measurements of individual meteor radiants and velocities was carried out. The velocity measurements were made by the pulse-diffraction method (ˆ1), and the radiant-coordinate measurements by the method of separated reception of radio waves scattered by the forming meteor trail (ˆ2). A radar station (RLS) with wavelength $\lambda = 8$ m was used. The apparatus and the method for processing the observations are described in (^{3},4). The root-mean-square error of a single velocity measurement was ±2 km/sec, and that of the radiant coordinates $\pm 2^\circ.5$. The orbits of 12,500 meteoric bodies producing meteors brighter than approximately $+7^m$ were computed. The calculations were performed on an electronic computer.

Similar measurements had previously been made only by Davies and Gill (ˆ5), who obtained 2474 orbits for meteors of $+5 \div +7$ magnitude. The orbits of such small meteoric bodies differ substantially from the orbits of large meteoric bodies producing bright photographic meteors (brighter than approximately 0 magnitude). These discrepancies may be explained both by real differences in the character of the motion in the solar system of meteoric bodies of different sizes, and by the different selectivity of radar and photographic methods of observation. In processing the observational material obtained by us, the main attention was paid to taking account of the selectivity effect of the radar method of observation. In order to pass from the measured distribution of orbits to the true one it is necessary to take into account the following factors: a) the "geometrical factor" $1/P_1$, which characterizes the relative detectability of meteors with different radiant declinations, determined by the geometry of reflection of radio waves from ionized meteor trails and by the directional diagram of the antenna system; b) the "physical factor" $1/P_2$, which characterizes the relative detectability of meteors with different velocities, determined by the dependence of the ionization coefficient β, the evaporation height h, and the distribution of the linear electron density α along the meteor trail on the initial mass M_0 and velocity v_0 of the meteoric body, as well as by the dependence of the initial radius of the ionized trail r_0 on v_0 and h; c) the "astronomical factor" $1/P_3$, which characterizes the dependence of the probability of encounter with the Earth on the parameters of the particle orbit.

The astronomical factor affects in the same way the results of ground-based meteor observations by any method. The quantity P_3 was calculated by Öpik (˜6)

$$P_3 = \frac{v_g \sin i}{v_0^2} \left[2 - \frac{1}{a} - a(1 - e^2)\right]^{1/2}, \tag{1}$$

where v_g is the geocentric velocity of the meteor; i is the inclination of the orbit; a is the semimajor axis; e is the eccentricity.

The method for calculating the geometrical factor was described in (˜7). The quantity P_1 depends mainly on the declination of the meteor radiant δ and more weakly on v_0. Table 1 gives the values of $P_1(\delta, v_0)$ for the radar station used at the Kharkov Polytechnic Institute, for an orienta-

···of the antenna system toward the east for meteors with velocities $v_0 = 40$ km/sec.

Table 1

δ	$-20°$	$0°$	$+20°$	$+40°$	$+60°$	$+80°$
$1/P_1(\delta, v_0)$	0.3	0.6	0.9	1.6	2.5	3.4

The maximum value of the power of the signal scattered by a meteor trail with $\alpha < 10^{12}$ el/cm (^{3}) is

$$P_r = \frac{P_t G^2 \lambda^3 \alpha_{\text{eff}}^2}{32\pi^2 R^3} \left(\frac{e^2}{mc^2}\right)^2, \tag{2}$$

where

$$\alpha_{\text{eff}} = \alpha e^{-(2\pi r_0/\lambda)^2} \frac{1 - e^{-\Delta\sqrt{2}}}{\Delta\sqrt{2}}; \qquad \Delta = \frac{8\pi^2 D\sqrt{R}}{v_0 \lambda^{3/2}}; \tag{3}$$

P_t is the transmitter power; G is the directivity coefficient of the antenna system; e, m are the charge and mass of the electron; c is the speed of light; D is the coefficient of ambipolar diffusion; R is the range. The effective sensitivity of the radar, characterized by the minimum value of α_{eff} of trails that can be detected in the direction of maximum radiation, was in our case $\alpha_{\text{eff}}^{\min} = 2 \cdot 10^{10}$ el/cm.

The evaporation height and the distribution of ionization along the trails of meteors produced by meteoroid bodies with various masses and velocities were considered by V. N. Lebedinets (7). The initial radius of ionized meteor trails was obtained in (3).

Taking into account the random position of the specular-reflection point on the trail, the probability of detecting a trail formed by a meteoroid body with given M_0, v_0, and zenith distance of the radiant z, is proportional to the length of the segment of the trail $l(M_0, v_0, z)$ on which $\alpha_{\text{eff}} > \alpha_{\text{eff}}^{\text{min}}$. The relative observability of meteors with different v_0 and z is

$$\frac{1}{P_2} = \int_0^\infty l(M_0, v_0, z) n(M_0)\, dM_0, \tag{4}$$

where $n(M_0) = M_0^{-s}$ is the mass distribution of meteoroid bodies. Table 2 gives the values of $P_2(v_0)$ for $\cos z = 2/3$, $\alpha_{\text{eff}}^{\text{min}} = 2 \cdot 10^{10}$ el/cm, $\lambda = 8$ m, and $s = 2$.

Table 2

v_0, km/sec	15	20	30	40	50	60	70
$1/P_2(v_0)$	0.06	0.40	1.10	1.00	0.68	0.36	0.20

Assigning to each meteor a “cosmic weight” $P = P_1 \cdot P_2 \cdot P_3$, one can pass from the measured distribution of orbits to the distribution for the entire population of meteoroid bodies with masses greater than some minimum value, whose orbits have perihelion distances $q \leq 1$ AU and aphelion distances $q' \geq 1$ AU.

Figure 1 shows the distribution, obtained by the authors, of the orbital elements of small meteoroid bodies. For comparison we shall use photographic determinations of the orbits of 2500 meteors brighter than +3 magnitude (8) and 144 meteors brighter than 0 magnitude (9).

Semimajor axis. Among large meteoroid bodies producing meteors brighter than 0 magnitude, the most frequently encountered values of a are of the order of 5 AU. A large number of orbits are close to parabolic. There is not a single orbit with $a \leq 1$ AU. Among meteors of 0-3 magnitude, orbits with $a \approx 3$ AU are most often encountered. Orbits close to parabolic occur somewhat less frequently. About 6% of the orbits have $a < 1$ AU. For meteors of +5 to +7 magnitude, the maximum of the distribution of orbits in $1/a$ shifts into the region of still smaller values, $a \approx 2$ AU. About 20% of the orbits have $a < 1$ AU. The number of orbits close to parabolic is considerably smaller than in the case of photographic meteors. Thus,

with decreasing mass of meteoroid bodies there is a systematic decrease in the mean sizes of their orbits.

Eccentricity. Photographic and radar measurements give approximately the same distribution of the eccentricities of the orbits of meteoroid bodies of various sizes.

Figure 1

Figure 1: Figure 1

Perihelion distance. For small meteoroid bodies the distribution function increases almost monotonically as q decreases from 1.0 to 0.05 AU. In the case of larger particles, which produce photographic meteors, as q decreases from 1 to 0 there is an almost monotonic decrease of the distribution function. The mean perihelion distance of the orbits of small meteoroid bodies producing meteors of $+5^m$ to $+7^m$ proves to be almost 2 times smaller than for larger meteoroid bodies producing meteors of 0^m to 3^m.

Inclination of orbits. Radar observations give an almost uniform distribution of the orbits of small meteoroid bodies with respect to i. There are two broad maxima at $15^\circ < i < 65^\circ$ and $120^\circ < i < 160^\circ$, and a minimum at $i \approx 90^\circ$. In the case of photographic meteors, most orbits have small inclinations $i < 30^\circ$. A minimum of the distribution function is observed for i close to 90°, and a certain increase at $110^\circ < i < 150^\circ$.

In the case of large meteoroid bodies the distribution with respect to i differs for orbits with large and small eccentricities. For $e > 0.8$ the orbits are distributed almost uniformly in i over the interval $30^\circ < i < 180^\circ$. For $e < 0.7$ almost all orbits have small inclinations $i < 30^\circ$. Such an increase in concentration toward the ecliptic with decreasing eccentricity is especially characteristic of the orbits of the largest meteoroid bodies, which produce meteors brighter than magnitude 0. Of the 144 orbits listed in Whipple's catalogue (^{9}), only one falls in the region $e < 0.7$ and $30^\circ < i < 150^\circ$. Among meteors brighter than magnitude +3, such orbits account for less than 10%. For meteors brighter than magnitude +7, such orbits account for more than 30%.

Fig. 1. a—distribution of the semimajor axes of meteoroid-body orbits; —distribution of the eccentricities of meteoroid-body orbits; —distribution of the perihelion distances of meteoroid-body orbits; —distribution of the inclinations of meteoroid-body orbits. The observed distribution is shown by the solid line; the distribution corrected for observational selectivity is shown by the dashed line.

From photographic observations, two main types of orbits of large meteoroid bodies were known: a) similar to the orbits of short-period comets (for them relatively small dimensions $a \lesssim 5$ AU and small inclinations $i < 30^\circ$ are characteristic); b) similar to the orbits of long-period comets (for them large dimensions and arbitrary inclinations are characteristic). Baseline radar observations of meteors revealed two more main types of orbits characteristic of small meteoroid bodies: c) orbits with $e < 0.7$ and $30^\circ < i < 165^\circ$; d) the main mass of small meteoroid bodies moves along elongated orbits with $e > 0.7$, which in shape are close to the orbits of short-period comets, but differ from them by substantially smaller perihelion distances and sizes ($a < 3$ AU). From photographic observations such orbits were obtained for several meteor streams (the Geminids, δ Aquariids, etc.), for which no parent comets were discovered.

The discovery of two new types of orbits of small meteoroid bodies, c) and d), is of great importance for studying the origin and evolution of meteoric matter. The two groups of cometary orbits are related to one another, since perturbations by Jupiter can transfer comets from type b) orbits to type a) orbits. Orbits of types c) and d) are almost never encountered among the known larger bodies of the solar system and are not derivatives of type a) orbits or asteroid orbits.

Apparently, a substantial fraction of small meteoroid bodies is formed in orbits of very large dimensions. Under the action of braking forces (the Poynting–Robertson effect, resistance of the interplanetary medium, etc.), the semimajor axes and eccentricities of the orbits gradually decrease, the more rapidly the smaller the mass of the meteoroid body. As Öpik showed (6), at small i meteoroid bodies producing meteors brighter than magnitude $+9$ will then be captured by Jupiter. At large i, meteoroid bodies with somewhat larger masses will also be able to pass through the "Jupiter barrier." This mechanism can explain the presence of type c) orbits among meteoroid bodies producing meteors of magnitude $+5 \div +7$, and their absence among large meteoroid bodies.

The presence of a large number of meteor streams with type d) orbits shows that a large number of short-period comets with orbits of this type must appear in the solar system. Owing to their proximity to the Sun at perihelion, the lifetime of comets in type d) orbits is very short. Apparently, it is considerably shorter than the lifetime of the meteor streams produced by such comets.

Kharkov Polytechnic Institute
named after V. I. Lenin

Received
13 III 1965

CITED LITERATURE

1. J. G. Davies, C. D. Ellyett, *Nature*, **161**, 596 (1948).
2. J. C. Gill, J. G. Davies, *Monthly Not. Roy. Astron. Soc.*, **116**, 92 (1956).
3. B. L. Kashcheev, V. N. Lebedinets, *Radar Studies of Meteor Phenomena*, USSR Academy of Sciences Press, 1961.
4. B. L. Kashcheev, V. N. Lebedinets, M. F. Lagutin. *Astr. Zh.*, **38**, 681 (1961).
5. J. G. Davies, J. C. Gill, *Monthly Not. Roy. Astron. Soc.*, **121**, 32 (1961).

6. E. J. Öpik, *Proc. Roy. Irish Acad.*, **54A**, 165 (1951).
7. V. N. Lebedinets, *Astr. Zh.*, **40**, 719 (1963).
8. R. E. McCrosky, A. Posen, *Smithsonian Contr. Astrophys.*, **4**, 15 (1961).
9. F. L. Whipple, *Astron. J.*, **59**, 201 (1954).

Note: Figure translations are in progress. See original paper for figures.