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A PROCESSING METHOD AND RESULTS OF METEOR SHOWER RADAR OBSERVATIONS

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Studies of meteor showers permit to solve some principal problems of meteor astronomy:

- to obtain the structure of a stream in cross-section and along its orbits;

- to retrace the evolution of particle orbits of the stream taking into account gravitational and non-gravitational forces and to discover the orbital elements of its parent body;

- to find out the total mass of solid particles ejected from the parent body taking into account physical and chemical evolution of meteor bodies;

- to use meteor streams as "natural probes" for investigation of the average characteristics of the meteor complex in the solar system.

Many works in meteor astronomy are confined only to the analyses of recorded meteor rates and very often are not made thoroughly enough. We believe the preliminary analysis must contain the following stages: a) estimation of equipment sensitivity and instability; b) reduction of the recorded number of meteors to meteor rates; c) separation of shower rates from the sporadic background. After that one can draw the shower activity curve i.e., shower meteor rates as a function of the solar longitude, the meteor rates being taken from the same hour of every day of observations (for showers lasting several days), or hourly meteor rates being reduced to some reference hour (BELKOVICH, et al., 1984). This procedure eliminates the diurnal variation of shower rates due to the diurnal shift of the stream radiant in relation to the aerial beam.

Analysis of the activity curve can give only qualitative characteristics of a stream - the shape of the curve, its variations from year to year and positions of maxima of the shower activity for different detection levels.

A much wider scope of problems can be solved if flux densities $Q(m)$ of meteor bodies with masses greater than some mass m and the mass exponent s are known to be functions of the solar longitude λ_o.

A simple and effective method of determining the flux density and s parameter has been worked out at the Engelhardt Astronomical Observatory. The main idea of the method is that two modes of detection are chosen for a average sensitivity radar. The first mode is an amplitude one. The meteor echo rate N_o is counted at this threshold level. The rate N_o corresponds to all meteor trails which have their electron line densities α at maximum ionization greater than α_o, i.e., minimum electron line density detected by the radar in a given direction. Meteor echoes with durations greater than T are related to the second mode, that of duration. Selection is restricted to echoes from overdense trails only where maximum electron line density is greater than α_T.

Let the shower radiant position on the celestial sphere be such that the echo plane intersects an aerial beam in the direction of its maximum sensitivity. Then the incident flux densities of meteor bodies $Q(\alpha_o)$ and $Q(\alpha_T)$ generating trails with $\alpha > \alpha_o$ and $\alpha > \alpha_T$ respectively are

$$Q(\alpha_o) = \frac{N_o}{\Sigma_o}, \qquad Q(\alpha_T) = \frac{N_T}{\Sigma_T}$$

where Σ_o and Σ_T are the corresponding effective collecting areas on the echo plane of the radar. The values of Σ_o and Σ_T depend on the mass exponent s only in this particular case. Then one can determine the value of s by solving the equation

$$\frac{N_o}{\Sigma_o(s)} = \left(\frac{\alpha_T}{\alpha_o}\right)^{s-1} \cdot \frac{N_T}{\Sigma_T(s)} \tag{1}$$

using iteration. An equation similar to (1) can be written for any position of the shower radiant in relation to the aerial beam direction. The method for computing the effective collecting areas Σ_o and Σ_T is considered in the papers of BELKOVICH and TOKHTASJEV (1971, 1974).

This method of meteor flux density determination has a number of advantages. On the one hand, different models of radio wave reflection from meteor trails (underdense and overdense ones) can be used which carry out an internal verification of the method. On the other hand, the parameters Q and S are determined in a rather wide mass interval (2-3 orders of magnitude). The method is very sensitive to the choice of physical parameters such as the value of the meteor trail initial radius, ambipolar diffusion coefficient and ionization coefficient as functions of the height and velocity. But the dependence of evaporation heights of meteor bodies on the velocities and masses is the most vulnerable. The first application of the method to the Quadrantids meteor shower has shown a complete failure of the classical theory, which in turn led to development of a new theory. Its difference from the classical one is independence of ionization height on meteor body masses that are less than a certain threshold value (BELKOVICH and TOKHTASJEV, 1974). The modified theory was confirmed recently by experimental data obtained from TV observations (SARMA and JONES, 1985).

The method was applied by us for a number of years during Geminids and Quadrantids observations (BELKOVICH et al., 1982; BELKOVICH et al., 1984). The main structural parameters were obtained for both the showers: the flux density $Q(10^{-3}$ g) of meteor bodies with masses over 10^{-3} g and the mass exponent s as functions of the solar longitude λ_o. Comparison of the results has been carried out for different years of observations. It was found that the shapes of the curves are rather stable and the relative flux density fluctuations in the shower maxima do not exceed 15 per cent. Then we combined the results obtained in different years to form average curves of $Q(10^{-3}$ g) and s. The assumption that the value of s does not depend on the mass of meteor bodies makes it possible to determine the change of the flux density of particles with masses greater than the threshold mass.

This is necessary for comparison of observational results obtained by different methods.

Logarithms of the Geminids flux densities for different minimum masses normalized to the maximum are shown in Fig. 1. The peculiarities of the curves are their significant asymmetry and the linear variation of the logarithm of the flux density vs the solar longitude on both sides of the maximum. This means the flux density Q(m) is an exponential function of λ_o. It must be noted that the exponent index of the left branch of the curves and the flux maximum position both depend on the mass m.

The variations of logarithm of the flux density $Q(10^{-3}$ g) obtained from radar observations of the Quadrantids (solid line) and the logarithm of the visual meteor rates (dashed line) versus solar longitude are shown in Fig. 2. One can see more symmetrical shapes of the curves than for the Geminids and a sharp change of the slopes in both left and right wings of the curves.

The maximum flux densities as function of the minimum mass are shown in Fig. 3a and b from radar and visual observations of the Geminids and Quadrantids showers. All the results are presented on a comparable mass scale. Good agreement can be noted between our results and those derived from visual observations. Differences between the results of radar observations obtained by different authors can be explained by differences in processing methods and the physical parameters used.

It has been shown for the Geminids that the exponent index of the left wing of the activity curve is similar to that of the flux density curve. The following equation was found:

$$m_o = [(0.5\ \tau_o*)^8 - 0.04]^{-1} \tag{2}$$

where m_o is the minimum detected mass and

$$\tau_o* = \Delta\lambda_o / \Delta \ell nQ$$

This equation can be used to determine the m_o for any kind of observation (radar, photographic, visual, TV).

A mathematical model of the flux density through the plane normal to the velocity vector and crossing the descending node was derived on the basis of the flux and s variations along the solar longitude in the form

$$Q \cdot pm(x, y) \cdot p(m) \cdot$$

Here Q is the total flux through the plane;

$$Q = 1.24 \cdot 10^{18}\ g{\cdot}s^{-1}\ , \ p(m) = m_{min} \cdot m^{-2}$$

(where m_{min} is the minimum mass of the shower particles in grams),

$$pm(x, y) = \frac{p(1 - \beta^2\tau^2)}{2\pi\tau^2} \cdot \exp\ - \frac{\sqrt{(x-r_x)^2 + p^2y^2}}{\tau} - \beta\ (x - r_x) \tag{3}$$

$$p = 1.86,\ \tau = 0.52^{-0.12}\ ,\ \ \beta = 1.47\ m^{0.12}\ ,\ \ r_x = -\ 0.116\ m^{-1/3}.$$

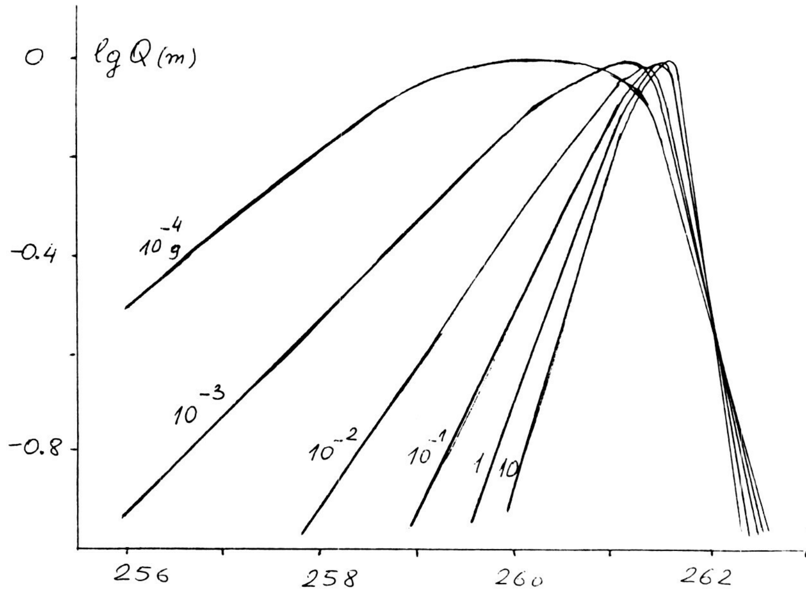

Fig. 1 The Geminids flux density variations of solar longitude for different minimal masses.

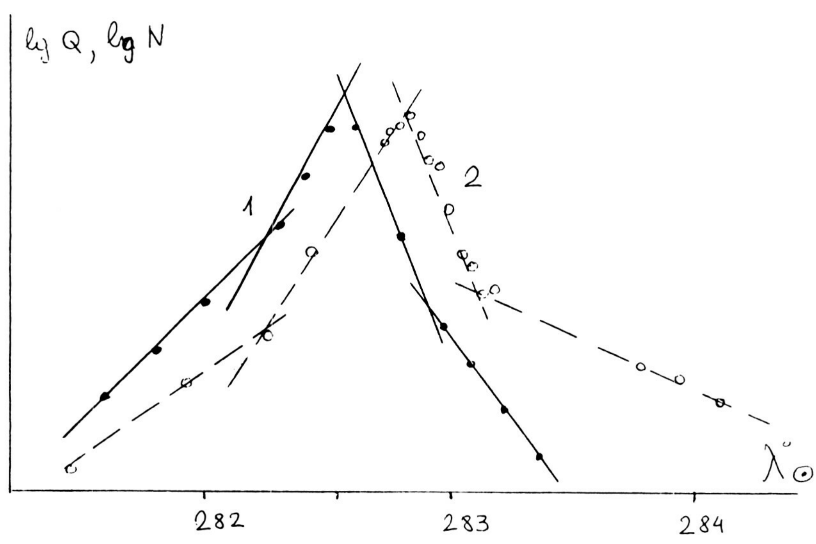

Fig. 2 Flux density logarithm for meteor bodies over 10^{-3}g (1) and the hourly meteor rate logarithm (2) for visual observations (HINDLEY, 1972) of the Quadrantids (in relative units) depending on solar longitude.

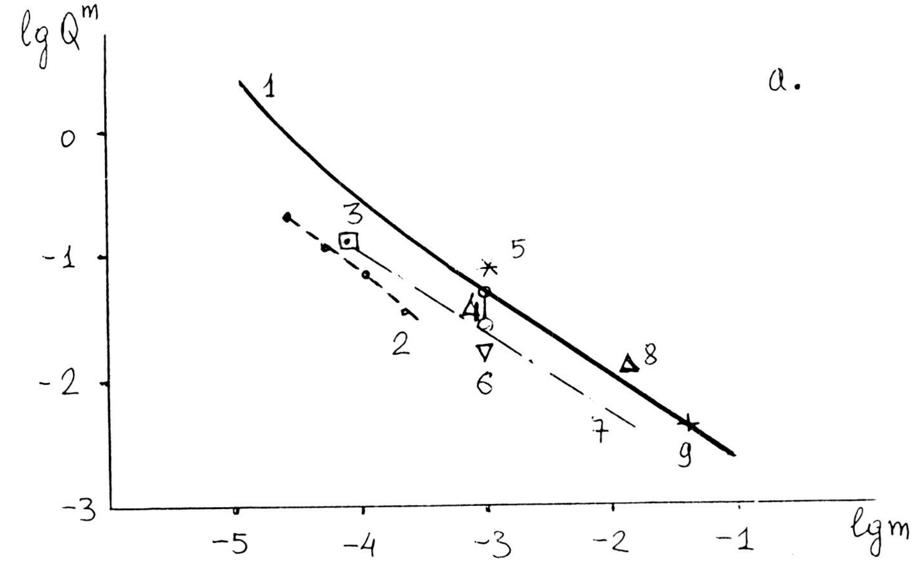

Fig. 3a The Geminids flux density variations in maximum depending on minimal mass: 1-EAO data, 2-HUGHES (1974), 3-LEBEDINETS (1970), 4-KOSTYLEV and SVETASHKOVA (1977), 5-TKACHUK (1982), 6-ANDREEV et al., (1982), 7-ANDREEV and RYABOOVA (1982, 8-LEVIN (1956), 9-PORUBCHAN and STOHL (1979).

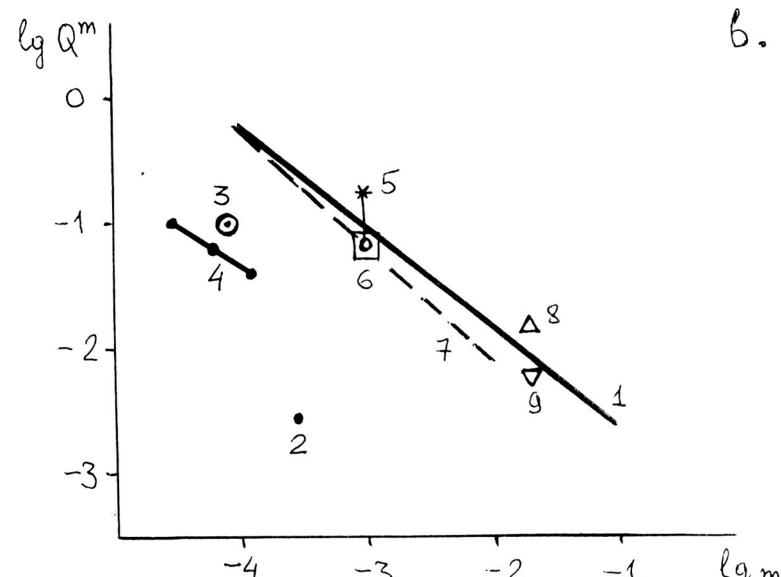

Fig. 3b The Quadrantides flux density variations in its maximum depending on the minimal detected mass: 1-EAO results, 2-WEISS (1957), 3-LEBEDINETS (1970), 4-HUGHES (1974), 5-TKACHUK (1982), 6-ANDREEV et al., (1982), 7-ANDREEV and RYABOVA (1982), 8-PRENTICE (1953), 9-HINDLEY (1972).

The coordinates in the plane are as follow: OX is the line of the normal plane intersection with the plane of the mean stream orbits, the positive direction of the axis is outside the orbit, the coordinate origin corresponds to the point of intersection of the mean orbit of the biggest stream particles with the normal plane. The projection of the Earth's orbit (equinox of 1950.0) on the normal plane is

$$y = -0.50\, x - 0.15$$

The scale is chosen so that one unit equals 1° of the Earth's orbit arc or 0.0158 a.u. It follows from the model that the flux density of meteor bodies with fixed mass decreases exponentially in the normal plane from the maximum point to the periphery.

The following equations for the mean values of the Geminids orbit elements as functions of the mass of meteor bodies have been found from radar and photographic observations (BABADJANOV and KRAMER, 1963; BABADJANOV et al., 1969; KASHCHEEV et al., 1960; WHIPPLE, 1954; CEPLECHA, 1957; JACCHIA and WHIPPLE, 1961; HAWKINS and SOUTHWORTH, 1961):

$$\Omega = 261°593 - 0.0698\ m]-1/3$$

$$a = 1.411 - 0.0146\ m^{-1/3}$$

$$e = 0.9000 - 0.0009\ m^{-1/3}$$

The inclination of the orbit $i = 23°4$ and the argument of the perihelion $\omega = 324°413$ practically do not depend on the mass m.

The values of the node longitude of the flux density maximum Ω, the seminarjor axis a, the eccentricity e, the perihelion and aphelion distances q and q', the period of partial revolution around the orbit T, and the extra atmospheric velocity of the Geminids particles V_∞ are given in the Table as functions of mass.

Table

m(g)	Ω	a(a.u.)	e	q(a.u.)	q'(a.u.)	T(year)	V(km s^{-1})
∞	261.59	1.411	0.900	0.141	2.681	1.676	36.24
1	261.52	1.396	0.899	0.141	2.651	1.649	36.18
10^{-1}	261.44	1.380	0.898	0.141	2.619	1.620	36.08
10^{-2}	261.27	1.343	0.896	0.140	2.546	1.557	35.88
10^{-3}	260.90	1.265	0.891	0.138	2.392	1.422	35.41
10^{-4}	260.09	1.097	0.881	0.131	2.063	1.148	34.20
10^{-5}	258.35	0.733	0.858	0.104	1.362	0.628	29.30

Apparently the mass of particles ~ 10^{05} g is the minimal one in the Geminids because further decrease of mass is accompanied by a sharp decrease of the semi major axes.

Orbital elements of the Geminid's parent body can be found by increasing the mass m to the infinity in the equations (4):

$\Omega = 261°.593$, $a = 1.411$, $e = 0.9000$, $w = 324°.413$, $i = 23°.4$

The total mass of the entire stream can be estimated using this mathematical model. For the Geminid stream, it turned out to be 0.9×10^{15} g. It corresponds to a spherical body 1.2 km in diameter assuming a particles density of 1 g cm^{-3}. Of course, one has to consider these values as minimal because of the disappearance of some particles due to catastrophic collisions and decrease of individual particle masses through loss of volatile elements.

The proposed method was recommended by the IAU Commission 22 (PATRAS, 1982) for the processing of meteor shower observations.

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