35. THE VARIATION OF SPORADIC METEOR RADIANT DENSITY AND THE MASS LAW EXPONENT OVER THE CELESTIAL SPHERE

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1. The Incident Flux

At the Engelgardt Observatory of the V.I. Uljanov-Lenin Kazan State University systematic azimuthal radio echo observations are carried out at a wavelength of 8 m. Simple radio echo equipment is used with a five-element Yagi antenna. The observational program provides for a 30° turn of the antenna in azimuth every 5 min.

The method of using azimuthal observations for the determination of visible radiant-density distribution on the celestial sphere (Pupyšev, 1965, 1966) is based on the fact that with the rotation of the aerial the region of radiants a, a', a'', b, b', b'', registered by the aerial also turns, the same region of the sky A being observed several

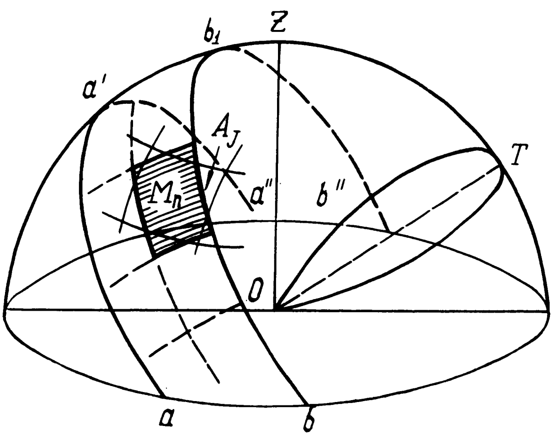

FIG. 1. *Geometry of the problem.*

times at various positions of the a, a'', b, b'' band, although with its different M-regions. If we divide the celestial sphere into roughly equal regions (in our case 105 regions have been taken), and on the band a, a'', b, b'', take n M-regions (in our case $n = 16$), then for each aerial position and observation time we can write a relation between the

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number of a region M_n and an area A_j covered by it. The registered number of meteors from the whole band a, a'', b, b'', $\bar{N}$ is equal to the sum of meteors from each of the M_n regions $\bar{N}=\Sigma N_n$. As for the number of meteors from the M_n regions it can be related to radiant density, making use of the Kaiser formulas (Kaiser, 1960, 1961), and those modified by Belkovič (1966), who introduced a factor for the influence of the initial train radius and meteor velocity on the probability of detection.

A somewhat different method of consideration of the physical factor was suggested by Lebedinec (1963). This dependence has the following form (for equipment of average sensitivity):

$$N_n = Q_{jn}(\alpha_{zo})\, h_0 H y_1 \left(\xi_{jn}^{1-s} + \frac{y_2}{y_1} \right) \approx Q_{jn}(\alpha_{zo})\, K_n \xi_{jn}^{1-s} = X_{jn} K_n, \tag{1}$$

where $Q_{jn}(\alpha_{zo})$=meteor flux from a solid angle of one steradian intersecting a unit plane (1 km^2) per unit of time (1 hour) and creating electronic density in the train greater than α_{zo} ($\alpha_{zo}=0{\cdot}6\times10^{11}$ el/cm). K_n=equipment parameter depending on the size and position of region M_n on the aerial direction diagram, the initial radius, and the exponent s. This parameter can be calculated for each region M_n. y_2/y_1=ratio of the number of overdense trains to underdense ones creating a signal amplitude equal to the threshold level.

For meteor flux $\theta(M_0)$ with mass greater than M_0 Equation (1) has the following form:

$$\begin{aligned} N_n &= \theta_{jn}(M_0)\, h_0 H y_1 \left\{ \iint\limits_0^{\infty} \left[\xi_{jn}^{1-s} - \frac{y_2}{y_1} \right]^{-1} v^{n(1-s)} P\left(\frac{v}{L}\right) \mathrm{d}v \right\}^{-1} = \\ &= \theta_{jn}(M_0)\, K_n F_{jn}(v) = Y_{jn} K_n . \end{aligned} \tag{2}$$

Functions ξ_{jn}^{1-s} and $F_{jn}(v)$ determine the dependence of detection probability on velocity, and can be considered functions of radiant region position on the celestial sphere, i.e. during the solution we can consider products $X_{jn}=Q_{jn}\times\xi_{jn}^{1-s}$ and $Y_{jn}=\theta_{jn}\times F_{jn}$. We can derive a system of equations from azimuthal observations,

$$\bar{N} = \Sigma N_n = K_1 X_{j1} + K_2 X_{j2} + \cdots + K_n X_{jn}, \quad X_{jn} = Y_{jn}, \tag{3}$$

for 12 azimuths and for every hour, i.e. 288 equations in all. Attributing density $Q(\alpha_{zo})$ and $\theta(M_0)$ to areas A_j covered by the corresponding regions M_n, and solving the system of Equations (3) we can find the distribution of values X_{jn} or Y_{jn} over the celestial sphere. Dividing them by coefficients ξ_{jn}^{1-s} and F_{jn} we shall obtain the radiant density distribution of sporadic meteors on the celestial sphere.

The following assumptions have been made during the solution of this problem:

(1) A random position of the reflection point on the train;

(2) The dependence of the initial radius on the height is based on the data supplied by Greenhow and Hall (1960);

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(3) Ionization coefficient β is proportional to the velocity to the third power ($\beta \sim V^3$) within the range of 70–15 km/sec;

(4) The mass law exponent s is assumed to be equal to 2·5;

(5) Radiant density within a region on the celestial sphere is even and constant during the period of the averaging of observations (15 days);

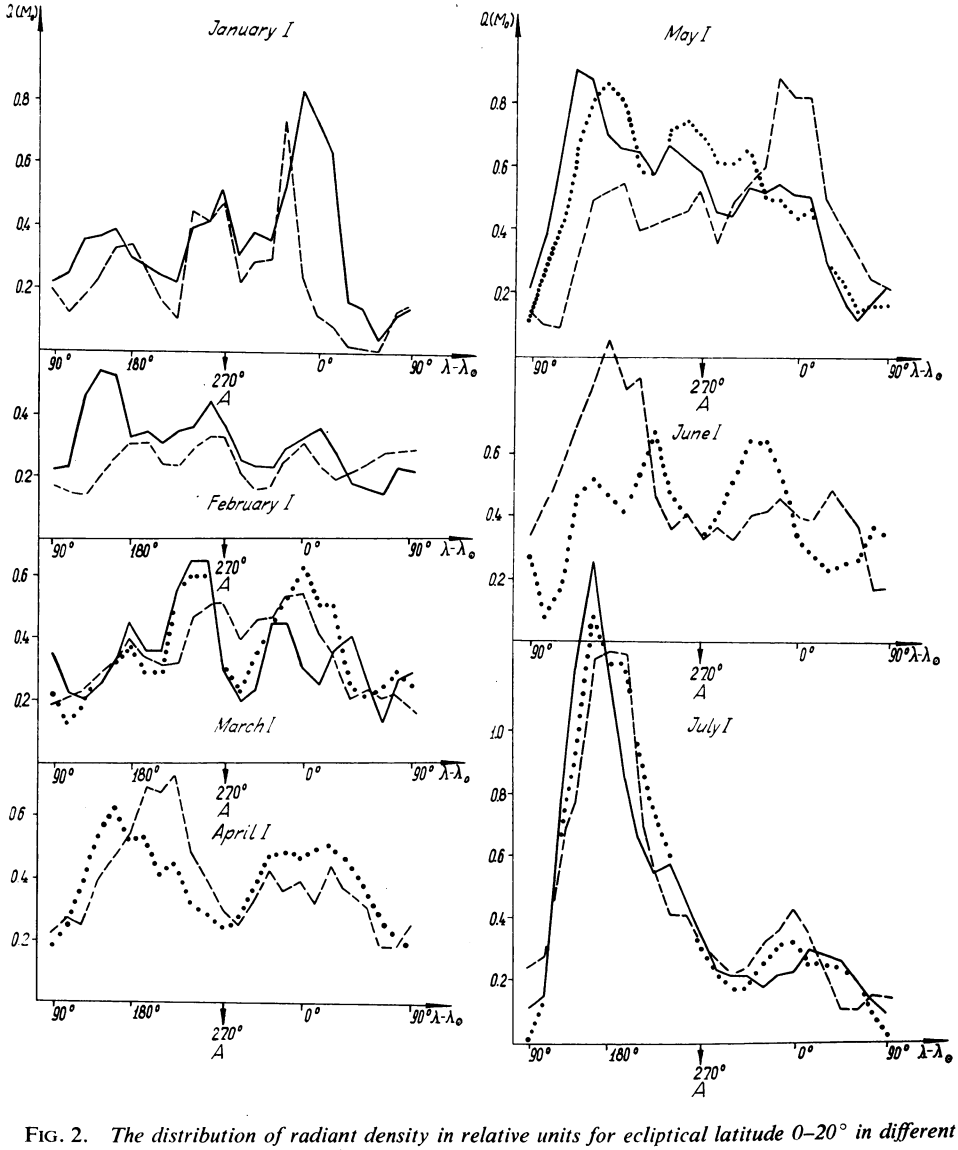

FIG. 2. *The distribution of radiant density in relative units for ecliptical latitude 0–20° in different months. Solid line = 1966, dashed line = 1965, dotted line = 1964.*

(6) The dependence of geocentric meteor velocity on the elongation angle from the apex at a heliocentric velocity of 36 km/sec is assumed.

As a result of 2·5 years observations (2 000 000 meteors during 10000 hours of equipment operation) distributions of radiant density of sporadic meteors for every half month with $M > M_0 = 3 \times 10^{-5}$ g ($\alpha_{zo} = 0{\cdot}6 \times 10^{11}$ el/cm) were obtained.

The main peculiarities of flux distribution $\theta_{jn}(M_0)$ are as follows:

(1) The distribution for ecliptic latitudes greater than $+35°$ is practically even.

(2) The greatest variations are observed in the ecliptic region. In the apex, solar and anti-solar directions the density increases while in the antapex it decreases.

(3) The character of distributions practically does not change from year to year.

(4) Three maxima are observed from November to April; they are approximately equal in intensity and are caused by the Earth's movement and the effect of the physical factor.

In April–May a general increase in radiant density at all latitudes is observed with a maximum in the solar direction. At this period a large number of summer fluxes come into action, hence distribution varies somewhat from year to year.

In June a sharp increase of density in the anti-solar direction and a decrease in the solar direction take place. This is connected with a double intersection (Kaščeev and Lebedinec, 1961) by the Earth of the orbit belt in May and June–July. It is characteristic that this maximum is retained till October. The nature of this maximum variation is in good agreement with the data provided by Nilsson (1964) and Gill and Davies (1956), based on the results of the determination of individual meteor orbits.

(5) It should be noticed that the observed anti-solar maximum is situated more than 90° from the apex, this distance reaching 120° by September. Nilsson has also observed such a displacement. If we neglect the physical factor, the distance from the apex is equal to the usually observed value of 70°–90°.

(6) The amplitude of the seasonal variation is about 1·5. The mean flux is equal to 0·35 steradian^{-1} km^{-2} hour^{-1}. An increase in the density in summer takes place at all latitudes.

(7) The nature of distributions does not depend on the value of s within the range of 2 to 3, only the absolute flux value changing.

(8) Meteor showers, even great ones, are not revealed in the distributions since small samples (5^{m} per hour) and averaging over 15 days are taken.

(9) The mean annual distribution differs considerably from distributions for different months and cannot be utilized for their description.

(10) The half-monthly distributions obtained have standard deviations, 20% in the apex and up to 100% in the antapex, which is determined by the scattering of the observed number of meteors.

(11) One of the drawbacks of the distributions is a shortage of data in the regions lying to the South of the ecliptic. At medium latitudes these regions are observed close to the horizon and a small number of times. The organization of such observations

in the equator region would be of interest. This would afford a full picture of the visible radiant-density distribution in the ecliptic region.

2. Exponents

The mass law exponent s,

$$N \sim \frac{C}{M^s}, \tag{4}$$

defines the structure of meteor flux in the vicinity of the Sun. Since the distribution of radiant density is uneven, it is natural to assume that s is not constant for various regions along the Earth's orbit, where we obtain all the information concerning meteors.

The exponent s can be obtained by means of radio echo studies from the distributions of durations of overdense trains, from height distributions, and echo amplitude distributions.

The suggested method of obtaining the variation of the exponent s over the celestial sphere is based on the s variations in the course of 24 hours during observations at various azimuths, and on the use of the density distributions of sporadic meteor radiants obtained by Pupyšev (1966). From radio-echo amplitude distribution the slope of underdense trains K_1 is defined as

$$K_1 = \frac{\ln N_0 - \ln N}{\ln A - \ln A_0}. \tag{5}$$

N and N_0 = the number of meteors with amplitudes greater than A and A_0 respectively. It is assumed that the equipment is sufficiently sensitive for a reliable determination of K_1 ($\alpha_{zo} = 0{\cdot}6 \times 10^{11}$ el/cm). Belkovič has found that, with taking into account the initial train radius,

$$K_1 = \frac{s - 1}{1 + 0{\cdot}23\,(kr_0)^{1{\cdot}58}}, \tag{6}$$

r_0 = the value of the meteor train initial radius at the characteristic height, k = the wave number. Only K_1 can be obtained from observations. Let us divide the celestial sphere into i regions and assume that each of them has its own K_1, but the meteor mass-distribution law remains the same. During the experiment we get the amplitude distribution and K_1 by the summary meteor number $\bar{N}$ from a certain number n of these i regions, i.e.

$$\bar{N} = \bar{N}_0 \left(\frac{A}{A_0}\right)^{-\bar{K}_1}.$$

Similarly, for each of these regions we can write:

$$N_i = N_{0i}\left(\frac{A}{A_0}\right)^{-K_{1i}}, \quad \sum N_i = \bar{N},$$

$$\bar{N} = \bar{N}_0\left(\frac{A}{A_0}\right)^{-K_1} = \sum_{i=1}^{n} N_i = \sum_{i=1}^{n} N_{0i}\left(\frac{A}{A_0}\right)^{-K_{1i}},$$

$$\bar{N}_0\left(\frac{A}{A_0}\right)^{-\bar{K}_1} = \sum_{i=1}^{n} N_{0i}\left(\frac{A}{A_0}\right)^{-K_{1i}}.$$

The value $(A/A_0)^{-K_{1i}}$ can be expanded into a series

$$\left(\frac{A}{A_0}\right)^{-K_{1i}} = 1 - K_{1i}\ln\frac{A}{A_0}.$$

K_{1i} varies from 1 to 1·5, and if A/A_0 approaches 1 then we can confine ourselves to a linear term, then

$$\bar{N}_0\left(1 - \bar{K}_1\ln\frac{A}{A_0}\right) = \sum_{i=1}^{n} N_{0i}\left(1 - K_{1i}\ln\frac{A}{A_0}\right),$$

$$\bar{N}_0 = \sum_{i=1}^{n} N_{0i}, \quad \bar{N}_0\bar{K}_1 = \sum_{i=1}^{n} N_{0i}K_{1i}. \tag{7}$$

Here N_{0i} = the number of meteors from the i region over the celestial sphere, and if we obtain K_1 and N_0 from observations and get N_{0i} from the radiant-density distribution, then solving this system of equations formed on the basis of azimuthal observations we can arrive at the celestial sphere distribution K_1. In order to proceed to the s values we must take into account the influence of the initial train radius for the meteors of each region. The initial radius is a function of the height, i.e. geocentric velocity. We assume the dependence of geocentric velocity on the elongation angle at a heliocentric velocity of 36 km/sec, which is in good agreement with the results of photographic and radio echo determination of radiants and meteor velocities. The method of the formation and solution of the Equation system (7) is similar to the method of determination of radiant distribution.

To test the method the calculation of s variation over the celestial sphere for October 1964, as well as for January, May and July 1965, was carried out. The celestial sphere was divided into 27 regions, the band of the radiants to be observed into 8 regions ($40^\circ \times 40^\circ$).

Four to six 24-hour observation cycles were processed for each month, and the diurnal variation of K_1 was obtained for four azimuths at 2-hour intervals.

Figure 3 shows the diurnal variations of K_1 at four azimuths for different months. Standard deviations σK_1 are also indicated. These resulted during the treatment of amplitude distribution by the least-squares method. During the determination of K_1

small amplitudes and amplitudes corresponding to the transitional trains were omitted.

We come to the following conclusions from the study of these curves:

(1) The diurnal changes of K_1 are greater than the possible values of σK_1.

(2) The behaviour of diurnal curves is different for various azimuths and months.

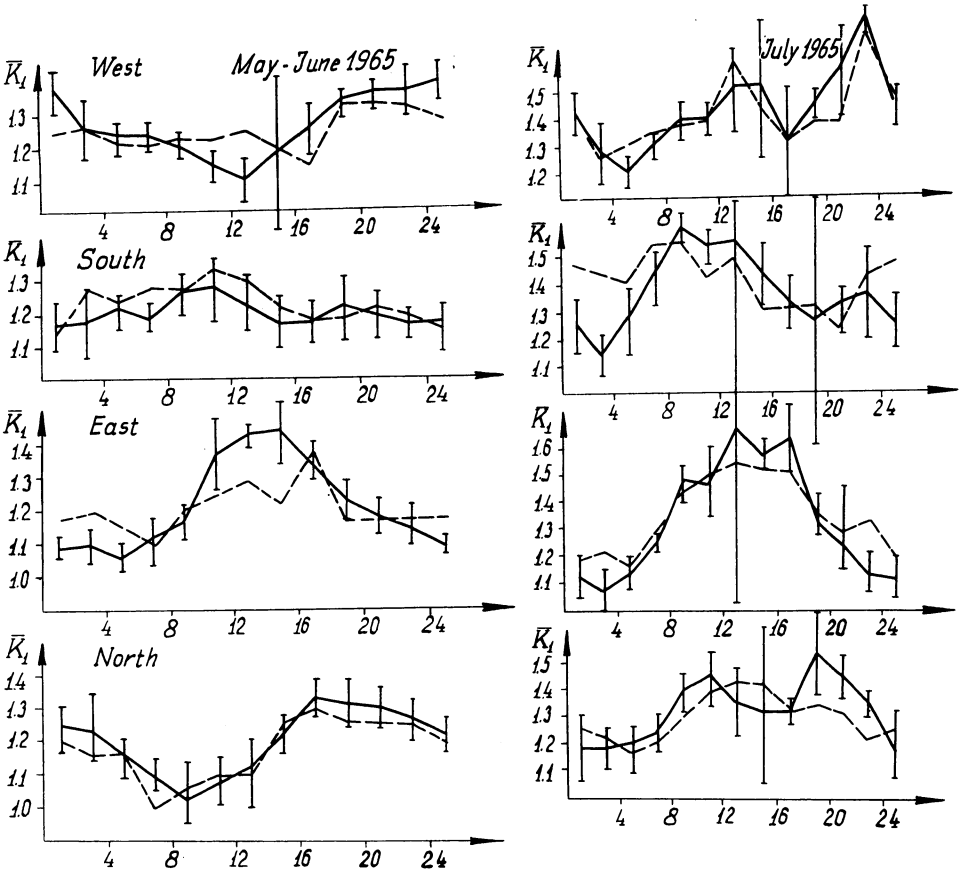

FIG. 3. *The diurnal variations of* K_1 *at four azimuths in different months. Solid line = observed values, dashed line = calculated values. Standard deviations* σK_1 *are indicated by vertical bars.*

The greatest variations of K_1 are observed in May and July, when K_1 changes from 1·1 to 1·6. The distribution of s values over the celestial sphere is shown in Figure 4.

Special notes:

(1) The results obtained are estimates. Apart from much averaging, and the use of speed dependence on the elongation angle, we must also note that radiant-density distribution has been obtained on the assumption that s is constant. The problem should be solved by the iterative method. It is necessary to find radiant distribution

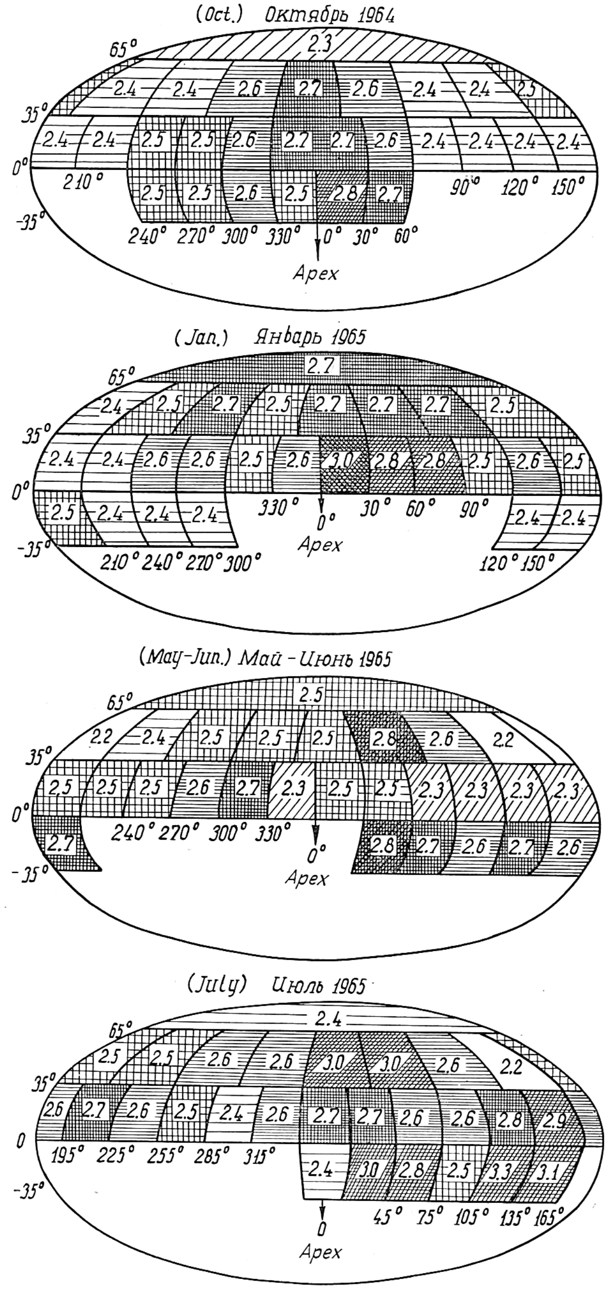

FIG. 4. *The distribution of the mass law exponent s over the celestial sphere in different months.*

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at $s = \text{Const}$, find the distribution of s and then recalculate radiant distribution with a variable s, etc.

(2) For sporadic meteors exponent s in all cases is greater than 2 and changes within the limits from 2 to 3.

(3) The distributions are not the same for different months. The general tendency is the increase of s in the apex direction. This is particularly obvious in October and January. The decrease of s to 2·3 is characteristic of May–June in the solar direction in the ecliptic plane, and in July in the anti-solar. Since at this time the Earth intersects the region of summer streams obviously, for this region, values, of $s \approx 2{\cdot}3$–$2{\cdot}4$, somewhat smaller than for neighbouring regions where $s = 2{\cdot}6$–$2{\cdot}7$, i.e. greater particles predominate. It must be noted that in July a general increase of s to 2·7–2·8 is observed. On the whole the apex increase remains in force.

(4) The increase of s in the apex direction can be determined by the accepted model of the dependence of geocentric speed on the elongation angle. But even if we take into account this distribution of velocities, s will decrease only 0·1.

(5) Knowing the dispersion $\bar{K}_1$ of the observed value of K_1 we can obtain dispersions $D(K_{1i})$ for each region i of the celestial sphere, since

$$\bar{N}_0^2 D(\bar{K}_1) = \sum_{i=1}^{n} N_{0i}^2 D(K_{1i}).$$

Solving this system like the system of main equations we can get $D(K_{1i})$ for each region. The standard deviation $\sigma(s)$ for May–June is 0·1–0·2 which is somewhat less than the s variations over the celestial sphere.

(6) The mean value of s for October equals 2·57, for January 2·56, for May 2·51 and for July 2·70. If we consider s to be constant $\bar{s} \approx 2{\cdot}5$.

(7) The drawback of this experiment is insufficient statistical data (4–6 days a month for 4 months), hence continuation of this kind of processing is desirable for the purpose of obtaining more detailed information on s variations in the course of a year.

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