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Abstract

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Astronomy

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ON THE STRUCTURE OF A METEOR

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In paper ⁽¹⁾ preliminary results were given of the study of meteor photographs obtained by the instantaneous-exposure method; an estimate was made of the dimensions of the simultaneously luminous volume, and the afterglow time of a meteor at a fixed point of its path was calculated. A more detailed study of the meteor photographs obtained in Dushanbe and Odessa makes it possible to elucidate structural features responsible for the luminosity, observed on ordinary obturator photographs, in the intervals between the dashes. In sufficiently bright meteors, instantaneous photographs reveal a bright head part and a weak luminosity of the tail. In places not coinciding with a sharp increase in brightness, the tail almost does not change its length, which corresponds to the phenomenon of a short-lived trail (wake—W) on ordinary photographs ⁽²⁾. During a sharp increase in brightness the length of the tails increases, and during a sharp decrease in brightness it decreases. The tail length may become greater than the intervals between individual instantaneous images; the intervals become blurred, which corresponds to the phenomenon of terminal blending (B in ⁽²⁾).

In Fig. 1, I, the solid line shows the distribution of the intensity of meteor No. 31 (Table 1). Such a distribution is observed for most of the instantaneous images of this meteor. The tail length almost does not change and, consequently, the tail can be assigned to type W. In ⁽¹⁾ it was shown that the luminosity in tails of this type cannot be explained by the radiation of excited atoms evaporated directly from the surface of the meteoric body ⁽³⁾. We attempted to apply to meteor No. 31 the theory developed by McCrosky ⁽⁴⁾. According to this theory, the luminosity in tails of type W is associated with the radiation of excited atoms evaporated from the surfaces of dust particles which, in turn, are continuously torn away by the air stream from the surface of the so-called parent meteoric body (quasi-continuous fragmentation according to B. Yu. Levin ⁽⁵⁾). The displacement of the dust particles relative to the parent body is determined by the formula

$$s = v_0 t - \frac{H^*}{\cos z} \ln \left\{ \frac{\text{Ei} \left(\frac{\sigma}{6} v_0^2 \right) - \text{Ei} \left(\frac{\sigma}{6} v^2 \right)}{2\Gamma A \delta^{-2/3} H^* \rho_0 \exp \left(\frac{\sigma}{6} v_0^2 \right)} m_0^{1/3} \cos z + 1 \right\}, \quad (1)$$

Fig. 1

Figure 1: Fig. 1

where v_0 is the velocity of the meteoric body at the moment of fragmentation; m_0 is the mass of the fragment at the moment it is torn from the surface of the meteoric body; σ is the coefficient

Table 1

Meteor No.	Date	Radiant coordinates (1950.0), α	Radiant coordinates (1950.0), δ	Velocity, km/sec	Height of the measured instantaneous image, km	Radiation intensity in the head part of the instantaneous image, erg/sec
13	1964 VIII 8	284.1	45.6	24.6	80.3	$1.15 \cdot 10^{12}$
31	1964 VIII 10	305.7	74.5	34.2	87.7	$2.70 \cdot 10^{11}$
39	1964 VIII 12	283.9	46.2	24.6	84.4	$1.12 \cdot 10^{12}$

ablation

$$\sigma = \Lambda/2\Gamma Q; \quad (2)$$

Λ, Γ are the coefficients of heat transfer and resistance; Q is the heat of evaporation; A and δ are the shape coefficient and density of the fragment; z is the zenith distance of the radiant; H^* and ρ_0 are the scale height and the atmospheric density at the fragmentation height (it is assumed that the corresponding atmospheric layer is isothermal); t is the lag time (the corresponding change in the velocity of the dust particles from v_0 to the fixed value v).

Fig. 1. I –luminous intensity in the trail of meteor No. 31 (10 VIII 1964); II –linear intensity in the trail of meteor No. 39 (12 VIII 1964); s –distance from the meteor head; the solid curve is the observation; a –theory for $m_0 = 10^{-6}$ g; b –theory for $m_0 = 10^{-3}$ g.

Fig. 2. Photograph of meteor No. 39. Each image was obtained with an exposure of 1/1800 sec.

Figure 2: Fig. 2. Photograph of meteor No. 39. Each image was obtained with an exposure of 1/1800 sec.

It follows from (1) that, as m_0 decreases, the displacement of the dust particles (and, consequently, the length of the trail) increases.

The total luminous intensity of the dust particles (erg/sec) in the meteor trail is determined by the formula

$$I = \frac{1}{2} \tau_0 \nu \Gamma A \delta^{-2/3} \sigma m_0^{2/3} \rho \int_{\Delta s} \frac{v^6 \exp[-\frac{1}{3} \sigma (v_0^2 + v^2)]}{v_0 - v} ds. \quad (3)$$

Here ν is the rate of dusting of the meteor (the number of particles torn from the surface of the meteoroid per unit time); τ_0 is the luminous-efficiency coefficient; ρ is the atmospheric density at the height where the trail is observed; Δs is the integration interval, measured from the fixed s , and corresponds to the exposure time Δt (for the apparatus we used, $\Delta t = 1/1800$ sec.).

Figure 1 *I* also gives the theoretical curves calculated by the method of McCrosky (allowing for photographic diffusion) for the values $m_0 = 10^{-6}$ g and $m_0 = 10^{-3}$ g. The observations appear to be well satisfied in the case when the mass of the fragments is greater than 10^{-3} g. For comparison it should be noted that McCrosky obtained satisfactory agreement between theory and observations for $m_0 = 10^{-6} - 10^{-4}$ g. However, he pred-

assumed that $\sigma = 10^{-12}$, whereas we used the value $\sigma = 3 \cdot 10^{-12}$. Our choice of σ is determined by equation (2). For the motion of dust particles the heat-transfer coefficient Λ may be taken equal to 1, since in this case it coincides with the accommodation coefficient (6). For the drag coefficient the value $\Gamma = 2$ was adopted. This is probably the maximum possible value of Γ for the motion of dust particles. With $Q = 8 \cdot 10^{-10}$ we obtain $\sigma = 3 \cdot 10^{-12}$. Apparently, this value is

Fig. 2. Photograph of meteor No. 39. Each image was obtained with an exposure of 1/1800 sec.

minimal for the motion of dust particles. With this value of σ , McCrosky would have obtained values of m_0 close to ours, although the initial mass of the meteoroid considered by him is only 0.052 g. Thus, McCrosky's theory requires, in order to explain the luminosity of type-W trails, comparatively large fragment masses, which contradicts the assumption of quasi-continuous fragmentation.

In Fig. 1 *II* are shown the observed curve of the change in linear intensity in the trail of meteor No. 39 and the theoretical curves for $m_s = 10^{-6}$ g and $m_0 = 10^{-3}$ g. The calculations show that for no values of m_0 is it possible

Fig. 3. I –light curve of meteor No. 13 (8 VIII 1964); II –linear sizes s of instantaneous images; H –height above sea level; M –absolute brightness in stellar magnitudes

Figure 3: Fig. 3. I –light curve of meteor No. 13 (8 VIII 1964); II –linear sizes s of instantaneous images; H –height above sea level; M –absolute brightness in stellar magnitudes

to bring McCrosky' s theory into agreement with the observations. It should be noted that in the case of meteor No. 39 we are dealing with a type-B trail. Consequently, the phenomenon of the closing of gaps cannot be explained by fragmentation alone. The latter is confirmed by the following facts.

In Fig. 2 a photograph of meteor No. 39 is given, in which it is seen that the length of the trails increases as the meteor penetrates deeper into the atmosphere, i.e., with decreasing height and increasing air density. This also contradicts the view that the closing of gaps is explained by the lag of the fragmentation products of the meteoroid.

In Fig. 3 I is given the curve of the change in brightness of meteor No. 13 as a function of height, and in Fig. 3 II—the corresponding sizes of the trails of this meteor. The longest trail coincides with the maximum brightness (with the flare). However, it is known that at the moment of fragmentation the intensity of radiation is maximal. Consequently, the longest trail should have been observed below the brightness maximum, where the displacement of the fragments relative to the parent body coincides with the observed trail length. In Fig. 3 there is no shift of the maximum trail sizes relative to the flares in the meteor brightness. Evidently, it fol-

Fig. 3. I –light curve of meteor No. 13 (8 VIII 1964); II –linear sizes s of instantaneous images; H –height above sea level; M –absolute brightness in stellar magnitudes.

should be sought not in a displacement of the luminous fragments relative to the parent body, but in the duration of the meteor' s luminosity at the given point.

Öpik (7) assumes that the luminosity in the tails (wake train) is due in its origin to recombination of ions of meteoric matter. The recombination radiation consists of continuous and discrete components. As Öpik showed, the continuous radiation may be neglected in comparison with the discrete, so that the spectrum of the recombination radiation in photographs differs in principle very little from the spectrum of neutral atoms excited as a result of collisions. The efficiency of the discrete recombination radiation, however, according to Öpik, is for an individual ion several times greater than the collisional radiation of an individual excited atom. Öpik, nevertheless, immediately arrives at the conclusion that the contribution of recombination radiation to the meteor luminosity is small, considering that, first, a neutral atom can be excited and radiate several times

(there are several excitations per ion), second, an insignificant fraction of the ions survives until recombination, and third, recombination proceeds very slowly and its yield is small.

Below we attempt to estimate the contribution of recombination radiation to the luminosity of the meteor tail. The intensity of recombination radiation can be calculated from the formula

$$I_j = \tau_j p_j \alpha^2 / 8\pi D t \text{ erg/cm} \cdot \text{s}, \quad (4)$$

where

$$\alpha = \frac{\beta}{\mu v} \frac{dm}{dt} \text{ electron/cm} \quad (5)$$

is the linear electron density; τ_j is the efficiency of recombination radiation; β and p_j are, respectively, the coefficients of ionization and recombination; D is the diffusion coefficient; μ is the mean mass of the atoms of meteoric matter; dm/dt is the ablation rate; t is the time, counted from some instant corresponding to the initial formation of the trail.

The speed of meteor No. 39 is $v_0 = 24.6$ km/s. Its intensity is $I = 1.12 \cdot 10^{12}$ erg/s. Integrating over the exposure time, we obtain, at $t = 0.012$ s, an intensity of radiation due to recombination $I_t = 1.1 \cdot 10^{10}$ erg/s, which approximately coincides with the intensity measured at this place in the tail (10^{10} erg/s). In the calculations the usual values of the constants were adopted: $\tau_j = 1.5 \cdot 10^{-12}$ erg per recombination; $p_j = 2.6 \cdot 10^{-12}$ cm³/s (7); $\beta = 0.2$; diffusion coefficient $D = 10^5$ cm²/s (8). The last value was chosen taking into account the initial expansion of the trail.

It remains to note that recombination radiation changes comparatively slowly with time. It falls off much more slowly than the observed intensity in the meteor tail. Apparently, the processes of ionization and recombination in meteor phenomena occur much more complexly than is described by equations (4) and (5). To elucidate these processes it is desirable to obtain spectral photographs by the method of instantaneous exposure.

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