LUMINESCENCE AND IONIZATION OF METEORS

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Abstract

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LUMINESCENCE AND IONIZATION OF METEORS

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Since the autumn of 1966, parallel photographic and radar observations of meteors have been carried out in Dushanbe in order to study the interrelation between the processes of their luminescence and ionization. By the present time, simultaneous radio echoes and baseline photographs have been obtained for 7 meteors, of which 2 (Nos. 661345a and 661345b) belong to the Leonid stream, and the remaining 5 to the Perseid stream. Basic information on the atmospheric trajectories of these meteors is given in Table 1, which contains the coordinates of the apparent radiant

Table 1

Meteor No.	Date	Radiant (1950.0), α	Radiant (1950.0), δ	v_∞, km/sec	$\cos Z_R$	H_B, km	$H_{\max}$, km	H_E, km	$M_{\max}$
661345a	17 XI 1966	152.80	21.68	71.5	0.510	118.4	88.0	84.8	<–7
661345b	17 XI 1966	152.84	21.87	71.6	0.581	114.8	102.1	94.8	–5.3
670805	11 VIII 1967	44.50	58.28	60.1	0.386	108.6	90.7	90.0	–2.4
670821	11 VIII 1967	43.25	57.92	60.5	0.672	114.1	83.8	83.0	–3.8
670866	12 VIII 1967	42.97	56.40	61.7	0.588	107.8	100.5	93.6	–4.3
670931	13 VIII 1967	48.55	59.05	61.0	0.807	111.8	93.4	84.1	–5.8

Meteor No.	Date	Radiant (1950.0), α	Radiant (1950.0), δ	v_∞, km/sec	$\cos Z_R$	H_B, km	$H_{\max}$, km	H_E, km	$M_{\max}$
670954	14 VIII 1967	46.99	56.66	60.8	0.687	113.1	97.2	86.6	–5.0

(α and δ), the extra-atmospheric velocity v_∞, the cosine of the zenith distance $\cos Z_R$, the heights of appearance H_B, maximum brightness $H_{\max}$, and disappearance H_E, and the absolute photographic stellar magnitude $M_{\max}$ at the point of maximum brightness of the meteor.

Complete data on the apparatus and methodology of the photographic and radar observations have been published earlier ([11,12]). We note that for photographic observations NAFA 3s/25 cameras were used ($F = 250$ mm, $D = 100$ mm). For radar observations a radar station was used, operating at a wavelength of 8 m with a pulse power of 65 kW, a repetition frequency of 500 pulses/sec, and a pulse duration of 6.5 μsec. The radar-observation method made it possible to determine the meteor range with an accuracy of ±0.1 km.

The initial data for solving the problem posed are the absolute stellar magnitude and the initial linear electron density of the reflecting point of the meteor.

The absolute stellar magnitude M of a meteor, determined from photographic observations, is related to the luminous intensity I_p (erg/sec) by the relation

$$M = 24.3 - 2.5 \lg I_p. \tag{1}$$

Radar observations make it possible to determine the initial linear electron density q of the meteor trail from the duration of the radio echo T_D

$$q = \frac{mc^2}{e^2} \left(\frac{4\pi^2 D}{\lambda^2} \right) T_D, \tag{2}$$

where e and m are, respectively, the charge and rest mass of the electron; c is the velocity

light; D is the ambipolar diffusion coefficient and λ is the wavelength of the radar. Formula (2) is valid for $q > 10^{12}$ el/cm and when only ambipolar diffusion is present. In the case of saturated meteor trails (which occurred in our observations of bright meteors) and low altitudes, the processes of electron attachment and turbulent vortices play a significant role, which somewhat changes the duration of the radio echo. In the presence of diffusion, attachment, and turbulent vortices ([3]), the duration T of the radio echo is determined by the formula

$$T = \left[\frac{3D}{\omega}\left(T_D e^{-kT} - t\right)\right]^{1/3} + t, \tag{3}$$

where ω is the specific energy dissipation of turbulent vortices; t is the time constant of small-scale vortices and k is the attachment rate.

From (2) and (3) we obtain a formula for determining the linear electron density of the reflecting region of the meteor trail

$$q = \frac{1}{A\lambda^2}\left[\frac{\omega}{3}(T-t)^3 + Dt\right]e^{kT}, \tag{4}$$

where $A = e^2/4\pi^2 mc^2 = 7.1 \cdot 10^{-15}$ cm.

The values of D and k for the reflecting point of the meteor trail can be determined from the relations $\lg D = 0.067h - 5.6$ m^2/sec (4) and $\lg k = 4.99 - 0.07h$ sec^{-1} (5), where h is the height of the reflecting point of the meteor trail in

Table 2

Meteor No.	Height of reflecting point h, km	M	T, sec	q, cm^{-1}	$\lg I_p/q$
661345a	97.8	−6.3	86.5	$8.57 \cdot 10^{15}$	−3.69
661345b	97.3	−4.4	41.3	$1.55 \cdot 10^{15}$	−3.71
670805	98.2	−2.1	18.1	$2.66 \cdot 10^{14}$	−3.87
670821	99.0	−2.9	61.5	$1.90 \cdot 10^{15}$	−4.40
670866	107.5	−3.0	42.0	$3.17 \cdot 10^{15}$	−4.58
670931	95.0	−5.8	63.7	$5.39 \cdot 10^{16}$	−4.69
670954	93.6	−4.8	25.8	$9.20 \cdot 10^{14}$	−3.32

kilometers, and the parameters ω and t are as in (6–8). Formula (4) was applied to specular radio reflections. When observing non-specular trails, where reflection of the signal begins not from the moment of the meteor' s flight but after some time ΔT, a correction ΔT, determined according to (9) by the formula, was added to T in formula (4)

$$\Delta T = 11.1 \sin v, \tag{5}$$

where v is the angle between the axis of the trail and the plane normal to the line of sight of the radar.

The data obtained from the observations carried out for the reflecting point of the meteors are presented in Table 2.

It follows from the data of Table 2 that, at a mean velocity of 64.0 km/sec, the absolute stellar magnitude is on average $M = -4.2 \pm 0.6$, and $\lg I_p/q = -4.04 \pm 0.20$.

From parallel photographic and radar observations of 7 meteors carried out in Manchester, Davis and Hall ⁽¹⁰⁾ found that at $v = 32.2$ km/sec $M = +1.1 \pm 0.7$ and $\lg I_p/q = -3.96 \pm 0.14$. These two series of observations, pertaining to different intervals of stellar magnitudes and meteor velocities, make it possible to find the dependence of the probability and the ionization coefficient on velocity and to refine the stellar-magnitude scale of radio meteors.

The intensity I_p of the meteor' s luminosity is related to the energy carried away by the evaporating molecules by the relation

$$I_p = -{}^1/{}_2 \tau_p v^2 dm/dt, \tag{6}$$

where τ_p is the luminous-efficiency coefficient, characterizing the fraction of the meteor' s total energy radiated in the spectral region 4500–5700 Å, and m is the mass of the meteoric body.

The linear electron density is determined by the expression

$$q = -\frac{\beta}{\mu v}\frac{dm}{dt}, \tag{7}$$

where β is the probability of ionization of an evaporated meteoric atom of mass μ.

From relations (6) and (7) it follows that

$$\frac{I_p}{q} = \frac{\tau_p}{\beta}\frac{\mu}{2}v^3. \tag{8}$$

According to ⁽¹¹⁾, the average mass μ of a meteoric atom is $3.82 \cdot 10^{-23}$ g. On the basis of a statistically large series of photographic observations of meteors and experiments with artificial meteors, it was obtained ⁽¹²⁾

$$\tau_p = 5.25 \cdot 10^{-10} v, \tag{9}$$

where v is expressed in cm/sec.

From parallel photographic and radar observations in Dushanbe and Manchester we obtain, respectively, the following values of the ionization probability

$$\begin{aligned} \beta &= 0.17 \quad \text{at } v = 64.0 \text{ km/sec}, \\ \beta &= 0.010 \quad \text{at } v = 32.2 \text{ km/sec}. \end{aligned} \tag{10}$$

Representing the dependence of the ionization probability on velocity in the form $\beta = \beta_0 v^n$, from (10) we find that

$$\beta = 10^{-28} v^4. \tag{11}$$

The ionization probability and the ionization coefficient τ_q, expressing the fraction of the total energy of the meteor expended on ionization, are related by the relation

$$\tau_q = \frac{2\Phi}{\mu v^2} \beta, \tag{12}$$

where Φ is the mean ionization potential, equal to 7 eV (13). Taking (11) into account, we obtain the following dependence of the ionization coefficient on the velocity of the meteor:

$$\tau_q = 6 \cdot 10^{-17} v^2. \tag{13}$$

From (8), (9), and (11) it follows that the ratio I_p/q is on average equal to 10^{-4} and does not depend on other parameters of the meteor, in particular on its velocity and brightness. Taking into account, in addition, relation (1), we obtain the following dependence between the absolute magnitude and the initial linear electron density of the meteor:

$$M = 34.3 - 2.5 \lg q. \tag{14}$$

Thus, parallel photographic and radar observations of meteors contribute to the solution of a number of questions of meteor physics. The accumulated observational material still covers only comparatively narrow intervals of meteor brightnesses and velocities. Therefore, further development of this method and accumulation of more extensive observational material are highly necessary.

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CITED LITERATURE

[1] P. Babadzhanov, N. N. Suslova, S. A. Karaselenikova, Bull. Inst. Astrophysics, Acad. Sci. Tajik SSR, No. 41–42, 3 (1966). [2] R. Sh. Bibarsov, Sh. Yu. Isamutdinov, R. Sh. Chebotarev, Astr. circular, No. 400, 7 (1967). [3] R. Sh. Bibarsov, Bull. Inst. Astrophysics, Acad. Sci. Tajik SSR, No. 55 (1968). [4] J. S. Greenhow, G. S. Hawkins, J. Atmos. Terr. Phys., 6, 133 (1955). [5] R. Sh. Bibarsov, Astr. circular, No. 458, 7 (1968). [6] H. Teilteilbaum, Space Res., 6, 438 (1966). [7] A. I. Delov, M. F. Lagutin, I. A. Lysenko, Izv. higher educational institutions, Radiophysics, 7, No. 2, 225 (1964). [8] A. P. Savrukhin, Comets and Meteors, No. 14, 11 (1966). [9] L. A. Manning, J. Geophys. Res., 64, No. 10, 1415 (1959). [10] J. Davis, J. E. Hall, Proc. Roy. Soc. A, 271, 120 (1963). [11] E. J. Öpik, *Physics of Meteor Flight in the Atmosphere*, N. Y., 1958. [12] F. Verniani, Smithsonian Astrophys. Obs. Special Report, No. 145 (1964). [13] A. F. Cook, P. M. Millman, Astrophys. J., 121, 250 (1955).

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