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VARIATION OF A METEOR SPECTRUM DURING THE TIME OF FLIGHT

by

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The character of the dependence of a meteor's color on its brightness is determined on the basis of a spectrophotometric investigation of 40 meteor spectrograms. The mode of the change of a meteor spectrum along its trajectory in the atmosphere is compared with experimental data on collisions between nitrogen atoms and meteoric gases.

Study of meteor spectrograms has shown that the character of the spectra undergoes changes while the meteorite traverses the atmosphere[1-3]. Investigations of the color indices of various meteors have revealed that these are dependent on the meteor brightness. Since the brightness of any meteor may change sharply during the time of flight, it is natural to expect an analogous dependence for individual meteors. L.Yakkiya explained this phenomenon by the Purkinje effect[4]. In 1959, Z. Ceplecha used a panchromatic emulsion to photograph meteors. The dependence of the color indices on the

brightness obtained by the latter author proved to be different from the dependence obtained by Yakkiya and by J. Davis, who used an emulsion sensitive to blue light. This showed that the meteors' color does in reality change with the brightness[5]. It was found that the fainter meteors are relatively redder than bright ones. The same dependence is observed during the time of flight of one and the same meteor.

The use of photoelectric photometers has made it possible to exclude the subjectivity of visual estimates of meteor magnitudes while retaining an observation efficency close to the visual one[6]. As is well known, in visual observations, the brightness of a moving meteor is compared with the brightness of fixed stars. Owing to a physiological effect the estimate of the brightness, of the moving source, is low, and this introduces a systematic error[7]. A low value for the brightness of visual meteors is also obtained because the radiation of bright meteors (for example the H and K lines of CaII) lies beyond the short-wave limit of twilight vision.

The fainter sections of the meteor trajectories thus appear more red. As has been shown by the observations reported by Z. Ceplecha and

his associates[8], the reddening of meteors with decreasing brightness is also found for telescopic meteors.

Study of meteor spectrograms with identified lines confirms the above data. The present authors examined approximately 40 spectrograms obtained at Odessa, Ashkhabad (A.P. Savrukhin, K.A. Lyubarskii), and Simferopol (V.V. Martynenko, L.A. Pushnoi). All the spectra were photographed on panchromatic aerial photography emulsions with the aid of short-focus prism spectrographs (using mainly NAFA 3S/25 cameras). The angles between the flight direction and the dispersion varied from 30 to 90°. The dispersion of the spectrograms is 200-700 Å/mm. Transverse photometric sections of the spectrograms were carried out on an MF-2 microphotometer, moving the slit along the dispersion direction. Measurements were also conducted on individual lines along the meteor's trajectory. Readings were taken every 0.01 - 0.05 mm.

In the case of 60-70% of the total number of meteor spectrograms considered in the present work the brightness can be seen to undergo sharp changes along the trajectory. In flare-ups the brightness increases

by several stellar magnitudes, and this is in most instances accompanied by a sharp rise in the intensity of radiation in the blue-violet region of the spectrum (in about 50% of the spectrograms). About 20% of the meteors end in a single flare producing radiation in the range of 4400-3900 Å. In the cases indicated the type of the meteor spectrum changes from X to Y (refs. 9 and 10).

About 20% is accounted for by faint meteors (0^m, -1^m), emitting mainly in the red part of the spectrum, and 5% by bright "pulsating" meteorites, most often of Millman's type Z. The spectrum of the several flare-ups in these meteors changes along the trajectory in exactly the same way at all wavelengths, but the red part of the spectrum flares up before the other lines. It seems that the different modes of the change in the type of the meteor spectrum with brightness are due to differences in the meteor structure.

Photometry of meteor spectrograms makes it possible to determine the color indices using the formula:

$$CI = -2.5 \lg \frac{\int_0^\infty E_\downarrow QTP\,d\lambda \int_0^\infty E_* VP\,d\lambda}{\int_0^\infty E_* QTP\,d\lambda \int_0^\infty E_\downarrow PV\,d\lambda}, \qquad (1)$$

in which $E_\downarrow$ is the energy distribution in the meteor spectrum, E_* is the energy distribution in the spectrum of an A0 star, V is the spectral sensitivity of twilight vision, Q is the spectral sensitivity of the photographic emulsion used, T is the spectral transmission of the aerial camera optics, and P is the spectral transmission of the atmosphere[11]. The formula given by (1) is valid if the $E_\downarrow$ values have been corrected for the spectral properties of the photographic system (atmosphere, optics, photosensitive emulsion). If the $E_\downarrow$ values have not been corrected in this way, the formula may be written as follows:

$$CI = -2.5 \lg \frac{\int_0^\infty E_\downarrow d\lambda \int_0^\infty E_* PV\,d\lambda}{\int_0^\infty E_* QTP\,d\lambda \int_0^\infty \frac{E_\downarrow V}{QT}\,d\lambda}. \qquad (2)$$

The values entering into equations (1) and (2) may be expressed in relative units. This is particularly important in the determinations of E values*, since special photometric standards modeling meteor exposures are

* Translator's note: Sic. This should presumably be "$E_\downarrow$ "

required[12] to obtain absolute $E_\downarrow$ values. In relative photometry of meteor images it is necessary to determine as precisely as possible the contrast coefficient of the characteristic curve. For this purpose we used experimentally determined contrast coefficients in dependence on exposure in the meteor exposure range[12].

V.I. Ivanikov[13] used formula (1) to determine the panchromatic color index for one meteor; this proved to be equal to +0.2.

The described method of determining color indices was used by the present authors to determine the meteor brightness dependence of the color indices on the basis of spectrophotometric data. The color indices obtained by equation (1) or (2) are special and express the difference between the stellar magnitudes of meteors in spectral systems k and l, where k is the photographic system used and l is the visual system.

The quantities appearing in formula (2) were determined as follows: The energy distribution in the spectrum of αLyr was found from the data reported in ref. 14. The sensitivity curve of the eye for twilight vision was obtained from ref. 11. The spectral sensitivity of

panchromatic emulsion and the transmission of the aerial camera optics (in relative units) were determined from the results of laboratory investigations[15]. In ref. 15 the authors also gave curves characterizing in relative units the spectral properties of the entire photographic system used, as well as the spectral transmission of the atmosphere.

The method described in ref. 12 was used in the processing of 12 spectra obtained by V.A. Smirnov at the Odessa Observatory. When processing the spectra obtained at Simferopol and Ashkhabad use was made of stellar images in view of the absence of laboratory standards, for the construction of characteristic curves.

As is well known, a parallel shift of the characteristic curve with respect to the intensity coordinate does not affect the relative intensities. During the determination in relative units of the intensity distribution in meteor spectra it is not necessary to find the systematic error on account of the difference between the exposures of the meteor and the star. In the indicated method of measurement an error may only arise

owing to a difference in the contrast coefficients of the characteristic curves obtained during meteor and stellar exposures[12].

The brightness at selected points along the meteor's trajectories was determined as follows: Intensity distribution curves were constructed in the same scale along the dispersion of selected sections of meteor spectrograms. These curves were then corrected on the basis of data on the spectral properties of the photographic system in question. Numerical integration was next used to find the integral intensities of certain spectral intervals of the selected sections on the meteor spectrograms, and their summation gave the meteor's brightness.

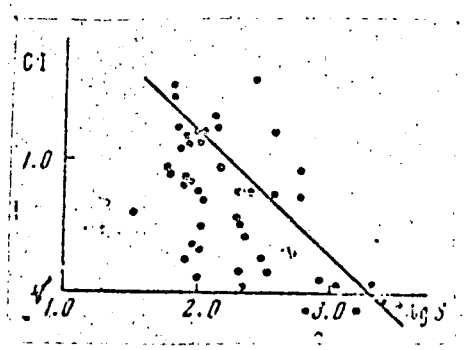

Figure 1.

Dependence of the color index CI on the logarithm of meteor brightness S

Figure 1 shows the values of CI in dependence on log S, where S is the meteor brightness. As follows from the described method of treatment, the values of S are proportional to the absolute exposure. From Figure 1 it may be seen that the points tend to form a linear dependence. This

behavior may be explained as follows: The change in CI with variation of the meteor brightness is given by the logarithm of the ratio

$$\frac{\int E_\lambda \, d\lambda}{\int \frac{E_\lambda V}{QT} \, d\lambda} \qquad (3)$$

The maximum of the $V(\lambda)$ curve is known to lie at 5100 Å. At the same time, the maximum of the energy distribution in the spectra of meteors is in the regions of 3900-4400 Å and 5800-6300 Å. Therefore, the numerator in (3) is as a rule greater than the denominator, and the brighter the meteor the greater does this difference become. If the sign in front of (3) is taken into account, it is clear that brighter meteors have smaller values of CI.

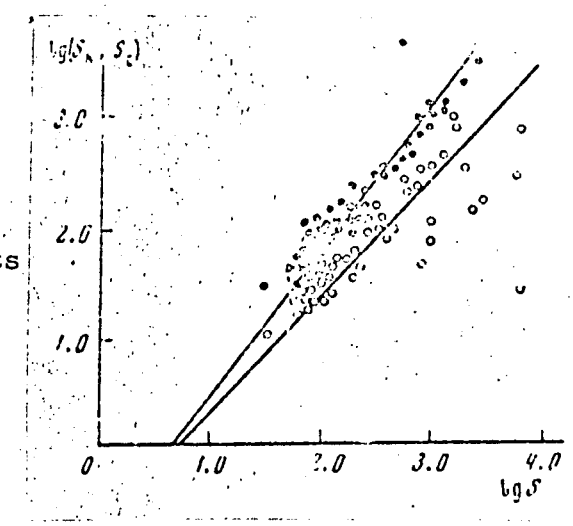

Figure 2.

Dependence of the emission in the red (•) and blue (o) parts of the meteor spectrum on the logarithm of the brightness S

Figure 2 shows the variation of the emission in the "red" and "blue" parts of the spectrum on the logarithm of the brightness. The

emission in the "red" section was obtained by numerical integration in the wavelength interval 6500-5200 Å, and that in the "blue" section between 5200 and 3900 Å. It may be seen from this figure that, at the same emission intensity in the "red" and "blue" parts of the spectrum, the "red" spectrum appears at a lower meteor brightness than the "blue". These results thus confirm once more the fact that the fainter sections of meteor trajectory are usually more red, and the brighter sections are more blue.

An attempt may be made to interpret the changes in the form of the meteor spectra during the time of flight in the atmosphere and the changes in the glow intensity on the basis of experimental data[16-19]. For example, B. Yu. Levin[20] notes that the physical processes occurring while the meteor is moving over the initial part of its trajectory are analogous to the cathodic sputtering of metals bombarded by ions, and the intensive emission of meteors resembles the emission of an iron arc.

Let us consider the experiments that make it possible to estimate indirectly the physical conditions of the excitation of a meteor spectrum, i.e. the spectrum of elements making up the meteorite. Inelastic collisions

of heavy particles are processes accompanied by radiation that are closest to the meteor phenomenon. Experiments of this kind make it possible in principle to model the process of entry of the meteorite into the atmosphere, accompanied by increasing opposing flow of the particles. As a result of such experiments one can determine the excitation functions on the effective atomic cross sections, which have been used in a number of cases to calculate the meteor radiation[21].

The calculations show that the following conditions are necessary in experiments on the bombardment with nitrogen atoms of a gas target corresponding to the model of meteor gas:

1) the current density of the bombarding particles should be of the order of 1 $a.cm^{-2}$;

2) the energy of the particles should be about 200 ev.

In practice it is found that it is very difficult to obtain such conditions. The difficulty lies in the need to produce a high current density at a small potential difference.

In ref. 21 the experiments were conducted at a considerably lower current density and greater particle velocities than in a meteor phenomenon.

Of course, the energy of the individual particles differed in these experiments from the corresponding values of meteoric particles. In spite of this, the values for the particle flux, depending on the product of the density ρ and the velocity v of the particles, are close to those in a meteor phenomenon, and this justifies the application to meteors of the effective excitation sections obtained from Derbeneva's experiments[21].

The experiments quoted make it possible to assess the conditions of meteor radiation. In point of fact, the character of the changes of the effective excitation cross sections determined by experiments corresponds to the change in the radiation of elements as the meteorite penetrates the atmosphere. The curves of the change in the effective cross sections for individual spectral lines reproduce and explain the course of the changes in the intensity of the same lines in meteor spectra. For example, when the energy of the bombarding particles is increased from 400 to 1200 ev (ref. 18), the effective excitation cross section for NaI 5890 Å increases from 2×10^{-18} to 10^{-17} cm^2. Analogous changes occur in the effective cross sections for MgII 4480 Å, MgI 5176 Å, CaI 4226 Å, and so on. As a

rule, the effective cross section increases with increasing energy of the bombarding particles. The lines listed above are relatively the most intense both in meteor and in experimental spectra.

The cross section for CaII 3934 Å has the relatively high value of 2×10^{-17} cm^2 at 600-700 ev. Consequently, this line should appear brightly as soon as the interaction energy reaches the required 600 ev.

As is well known from the practice of spectroscopic analysis, the emission of the spectral lines of a component in a gaseous mixture may affect decisively the emission of the remaining components. The flare up of the lines of one of the elements making up the meteorite may lead to the flare up of the lines of other elements.

In conclusion, we shall mention one other point. Experimental work has not as yet provided sufficient information on the effective excitation cross sections of atoms, whose knowledge is necessary for the determination of the luminous efficiency of the meteor and also of the individual elements making up the meteorite. To a large extent this is caused by the difficulty of the experiments themselves. Attention should

be turned to the possibility of obtaining the effective excitation cross sections directly from meteor spectrograms, using the method of absolute spectrophotometry of meteors[12]. However, preliminary experiments should determine the model of an "artificial meteor" for which calculations could be carried out[19].

The discussed experiments will thus help to clarify the processes that accompany meteor radiation. Interpretation of the meteor spectra and of the radiation intensity is already possible on the basis of existing experimental data.

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REFERENCES

1. S.N. Blazhko, On the spectrum of the meteor of August 12, 1917, Astron. Zh., 9, no. 3-4, (1932) 146-162.

2. A.N. Vyssotsky, A meteor spectrum of high excitation. Astrophys. J., 91, no. 2 (1940) 264-266.

3. P.M. Millman, Meteor news, J.R. Astron. Soc. Canada, 34 (1940) 3.

4. L. Yakkiya, Fragmentation as the cause of anomalies of faint meteors. In "Meteory" [Meteors], Moscow, 1959.

5. Z. Ceplecha, On the color index of meteors, BAC, 10 (1959) 39.

6. J. Davis, Photoelectric meteor observations and the color indices and visual magnitudes of meteors, M.N., 126 (1963) 5.

7. V.I. Ivanikov, Errors in visual brightness estimates and the color index of meteors, Byull. Komissii po kometam i meteoram, no. 10 (1965) 13.

8. Z. Ceplecha, J. Grygař, and L. Kohoutek, Distribution of telescopic meteors, BAC, 16 (1965) 2, 123.

9. V.A. Smirnov, Identification of the spectral lines of meteors with the aid of laboratory dispersion standards, Astron. zh., 44, no.6 (1967) 1316-1324.

10. P.M. Millman, A general survey of meteor spectra. Smithsonian Contributions to Astrophysics, 7 (1963) 119-127.

11. D. Ya. Martynov, Kurs prakticheskoi astrofiziki [Course of Practical Astrophysics], Nauka, Moscow, 1967.

12. V.A. Smirnov, On the photometric standardization and calibration of meteor spectrograms, Astron. vestnik, 3, no. 1 (1969).

13. V.I. Ivanikov, Spectral energy distribution and the color index of one meteor, Byull. In-ta astrofiziki, no. 41-42 (1966) 26.

14. A.V. Kharitonov, Energy distribution in the spectrum of αLyr, Izv. Astrofizicheskogo in-ta, 15 (1962) 52.

15. V.A. Smirnov and Ya. A. Smirnova, Spectrophotometric properties of a system used for the photography of meteors, Inform. byull. "Geofizika i astronomiya", no. 14 (1969).

16. J.M. Sluthers, E. De Haas, and J. Kistemaker, Charge exchange ionization and electron loss cross sections in the energy range 5 to 24 keV, Physica 25 (1959) 1376.

17. J.M. Sluters, and J. Kistemaker, Excitation mechanism of Ar^+ ions in He, Ne, Ar, Kr, and Xe, Physica, 25 (1959) 1389.

18. S.H. Neff, Excitation in atomic collisions related to meteor radiation, Astrophys. J., 140 (1964) 348-360.

19. J.F. Friichtenicht, J.C. Slattery, and E. Tagliaferri, Meteor luminous efficiency, Astrophys. J., 151 (1968) 2, 743-758.

20. B. Yu. Levin, Fizicheskaya teoriya meteorov i meteornoe veshchestvo v Solnechnoi sisteme [Physical Theory of Meteors and Meteorites in the Solar System], Izd-vo AN SSSR, Moscow, 1956.

21. A.D. Derbeneva, Meteor emission coefficient, Astron. zh., 43 (1966) 2.

S u m m a r y

Intensity distributions at various points of a meteor trajectory are constructed from 40 meteor spectra. The dependence of the color indices CI, determined by formulas (1) and (2), on the meteor brightness S is obtained. For equal emission intensity in the "red" and "blue" parts of the spectrum, the "red" spectrum appears at lower meteor magnitudes than the "blue". The variations of the meteor spectra during the motion are interpreted on the basis of experiments involving the bombardment of a gaseous target (meteor gases) with nitrogen atoms.