STATISTICAL PROPERTIES OF THE HELIUM EMISSION

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ABSTRACT: Statistical anlayses of the data from observations of helium emission show considerable variations in the ultraviolet radiation of the Sun during a solar cycle, and with the period of 27 days. It was established that the electron fluxes with energies of about 25 eV depend on the magnetic activity.

The discovery of the helium emission 10,830 Å in the radiation of the upper atmosphere provided for determining its properties at altitudes greater than 300 km with the aid of optical observations from the surface of the Earth. It is well known that helium emission is caused by the fluorescence of metastable helium atoms in the solar radiation. The appearance of such atoms can occur by several processes [1-4]. However, the most effective process is that of excitation by electrons with energies of about 25 eV. The existence of electrons with energies of several tens of electron-volts in the atmosphere irradiated by the Sun was found indirectly by observations of the helium emission, and was shown directly with the aid of the satellites "Cosmos-3" and "Cosmos-5" [5-10]. Theoretical calculations of the percentage of such electrons in the upper atmosphere, and of their behavior, were made in a number of studies [11, 12]. These electrons are fresh photoelectrons formed as a result of photoionization of the atmospheric atoms and molecules by the hard ultraviolet radiation of the Sun with $\lambda \leq$ 370 Å. But, in addition to such a "stationary" process for the appearance of the electrons, it is also possible that there are eruptive appearances of electrons with energies of several tens of electron-volts as a result of the intrusion into the upper atmosphere of corpuscular streams. /64

The intensity of the helium emission is directly proportional to the flux of the electrons with energies greater than 20 eV, the value of which, in turn, depends on the intensity of the ultraviolet radiation and the flux of the primary electrons with energies of several kiloelectron-volts.

Regular observations of radiation from the upper atmosphere in the region around 11,000 Å, i.e., the OH bands and the helium emissions, were conducted at Zvenigorod, starting at the end of 1959. Some results have already been published [13]. Since the observations were conducted by photographic methods, the intensity of the emission 10,830 Å, which changes as a result of a change in the conditions for irradiation of the Earth's atmosphere, was averaged during the time of the exposure. Moreover, we should keep in mind a number of complicating circumstances in subtracting the helium emission. First of all, the helium emission is blended with the *Q*-branch of the OH band (5.2). Secondly, there are a large number of absorption lines (caused, in particular, by water vapors) in the spectrum for the scattering of the solar light. Although there is no real absorption for the principal lines of the OH band (5.2) and the helium line 10,830 Å, the effect of the absorption lines is seen as the consequence of their blurring in the scattered solar light with the lines of the radiation, because of the relatively large width of the instrumental contour. The deduction of the intensity of the *Q*-branch in the OH band (5.2), which is blended with the helium emission, was made in correspondence to the intensities of the lines in the *P*-branch and to the rotational temperature determined according to them. These causes limit the accuracy /65

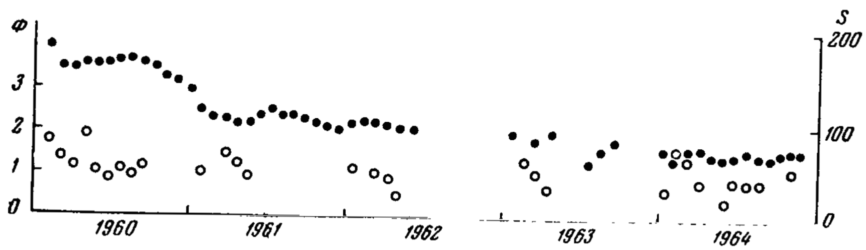

Fig. 1. Comparison Between the Average Flux of the Ultraviolet Radiation of the Sun, Calculated by the Helium Emission (Φ) (Circles), and the Observed Average Flux of the Radio Emission of the Sun (*S*) (Points).

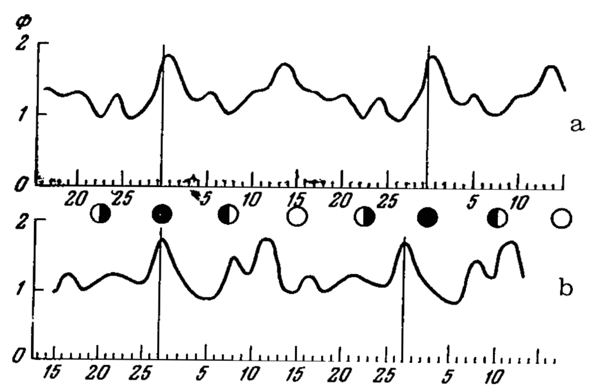

Fig. 2. Average Variations in the Ultraviolet Radiation of the Sun, Calculated for a Wave of 10.7 cm. (a) With a 27-Day Period; (b) With the Period for the Age of the Moon (29.5 Days).

of individual measurements for the intensity of the helium emission. However, it is possible to find the average statistical properties of the 10,830 Å emission.

Figure 1 shows the average change in the flux of the ultraviolet solar radiation, calculated by the helium emission, for 1960-1964. In this case, we used the data on the temperature of the atmosphere according to [14]. We showed simultaneously the change in the flux of the radio emission of the Sun at a wavelength of 10.7 cm, averaged for a 27-day interval.

The relationship between the temperature of the atmosphere and the flux of the radio emission from the Sun has already been found with the aid of satellites [14, 15]. The dependence of the variations in intensity of the ultraviolet radiation was also obtained with a 27-day period [16, 17]. However, the correspondence between the ultraviolet and the radio emission of the Sun, for 10.7 cm, is not completely precise [18]. According to the observations of helium emission, a certain correlation was previoulsy obtained between the ultraviolet radiation of the Sun, calculated by the flux, and the indices of the solar activity [13]. According to the available data, we can also find the existence of a 27-day variation (Fig. 2b). The average position of the maximum, and its value relative to the minimum level (~ 1.3) correspond roughly to the direct observations on satellites for certain periods of time [17]. However, while it is impossible to make a detailed comparison, we will limit ourselves to the average characteristics, since, as has been shown, /66 the measurement accuracy of the intensity is not great. It is well known that helium blends with the *Q*-branch of the OH band (5.2). For this band, there is also found on the average a 27-day periodicity for the variations in intensity and rotational temperature [19]. We can assume that these two phenomena are independent and that they have independent variations with the period of 27 days. This conclusion can be substantiated by the fact that, for the calculated flux of the ultraviolet radiation of the Sun (Φ), on the average there is observed a variation with the lunar period of 29.5 days (Fig. 2a). Actually, this means the presence of lunar tides, the effect of which was not considered in calculating Φ. Obviously, /67 the variations with the lunar period for Φ and the rotational temperature of the OH band (5.2) are independent [19], since these values change in the antiphase, which excludes the possibility of instrumental errors.

The observations in the auroral zone showed an increase in the intensity of the λ 10,830 Å emission with the geomagnetic activity [20]. According to the data of the Zvenigorod station, a comparison was made between the electron flux F with energies of about 25 eV, calculated by the helium emission, and the K-index, local and planetary (Fig. 3). We can see that, when $K < 4$, the electron flux remains, on the average, almost constant. Only when $K \geq 4$ does there begin a sharp increase. Moreover, for the local $\bar{K}$-index, this transition usually occurs more sharply than that for the planetary index. It is possible that this shows the substantial role of the non-uniformities in the planetary distribution of electrons with energies of several tens of electron-volts in the characteristics near the high-latitude zones. In addition to the secondary electrons of such energies, as a result of the intrusion of electrons with energies on the order of several kiloelectron-volts, it is possible that there is a direct intrusion of electrons with energies of several tens of electron-volts [21], including also those from the adjacent region of the southern hemisphere.

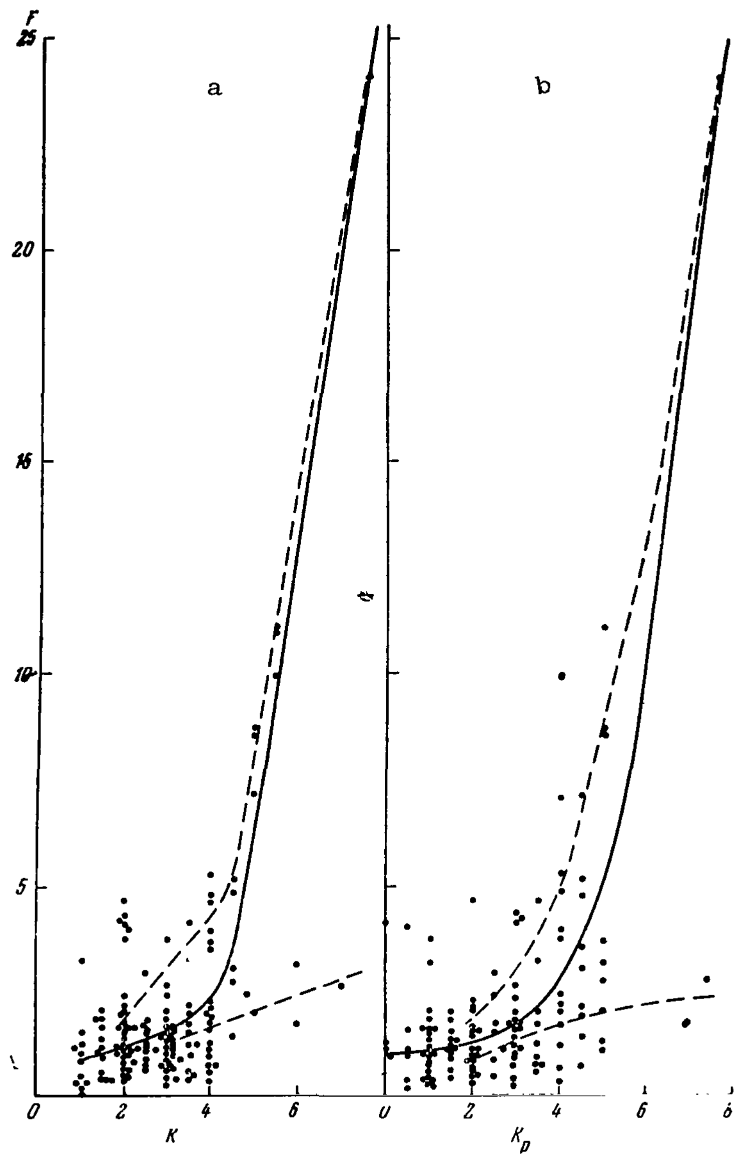

Fig. 3. Calculated Flux of Electrons with Energies of about 25 eV Versus Geomagnetic Activity. (a) Versus Local *K*-Index; (b) Versus Planetary *K*-Index.

REFERENCES

1. Shefov, N. N.: Sur l'émission de l'hélium dans la haute atmosphère (The Helium Emission in the Upper Atmosphere). Ann Géophys., Vol. 18, No. 1, p. 125, 1962.
2. Shefov, N. N.: Emissiya geliya v verkhney atmosfere. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Helium Emission in the Upper Atmosphere. In the Collection: Aurorae and Airglow), No. 8, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1962, pp. 50-65.
3. Shefov, N. N.: Helium in the Upper Atmosphere. Planet. Space Sci., Vol. 10, pp. 73-77, 1963.
4. Krassovsky, V. I. and N. N. Shefov: Fast Photoelectrons and Helium Emission in the Upper Atmosphere. Planet. Space Sci., Vol. 12, No. 1, pp. 91-92, 1964.
5. Krasovskiy, V. I., Yu. I. Gal'perin, V. V. Tennyy, T. M. Mulyarchik, N. V. Dzhordzhio, M. Ya. Marov, A. D. Bolyunova, O. L. Vaysberg, B. P. Potapov and M. L. Bragin: Nekotoryye osobennosti geoaktivnykh korpuskul (Certain Features of Geo-Active Corpuscles). Geomagnetizm in Aeronomiya, Vol. 3, No. 3, pp. 401-407, 1963.
6. Krasovskiy, V. I., Yu. I. Gal'perin, V. V. Temnyy, T. M. Mulyarchik, N. V. Dzhordzhio, M. Ya. Marov and A. D. Bolyunova: Nekotoryye novyye rezul'taty geofizicheskikh issledovaniy pri pomoshchi sputnikov "Kosmos-3" i "Kosmos-5" (Some New Results of Geophysical Investigations with the Aid of the Satellites "Cosmos-3" and "Cosmos-5". Geomagnetizm i Aeronomiya, Vol. 3, No. 3, pp. 408-416, 1963.
7. Gal'perin, Yu. I., and V. I. Krasovskiy: Issledovaniye verkhney atmosfery pri pomoshchi sputnikov "Kosmos-3" i "Kosmos-5". 1. Apparatus. Kosmicheskiye Issledovaniya, Vol. 1, No. 1, pp. 126-131, 1963.
8. Krasovskiy, V. I., Yu. I. Gal'perin, N. V. Dzhordzhio, T. M. Mulyarchik and A. D. Bolyunova: Issledovaniya verkhney atmosfery pri pomoshchi sputnikov "Kosmos-3" i "Kosmos-5". 2. Myagkiye korpuskuly (Study of the Upper Atmosphere with the Aid of the Satellites "Cosmos-3" and "Cosmos-5". 2. Soft Corpuscles). Kosmicheskiye Issledovaniya, Vol. 1, No. 1, pp. 132-139, 1963.
9. Mulyarchik, T. M.: Obnaruzheniye v verkhney atmosfere elektronov s energiyey ot 40 ev do 5 kev (The Discovery of Electrons with Energies from 40 eV to 5 KeV in the Upper Atmosphere). Kosmicheskiya Issledovaniya, Vol. 1, No. 2, pp. 266-271, 1964.
10. Krassovsky, V. I., Yu. I. Galperin, T. M. Mulyarchik, N. V. Georgio and A. D. Bolunova: Investigations of the Upper Atmosphere Using the Artificial Earth Satellites Cosmos 3 and Cosmos 5. Space Research, Vol. 4, pp. 572-581, Amsterdam, North-Holland Publ. Co., 1964.

11. Dalgarno, A., M. B. McElroy and R. J. Moffet: Electron Temperatures in the Ionosphere. Planet. Space Sci., Vol. 11, No. 5, pp. 463-484, 1963. /68
12. Mariani, F.: Pitch-Angle Distribution of the Photoelectrons and Origin of the Geomagnetic Anomaly in the F_2 Layer. J. Geophys. Res., Vol. 69, No. 3, pp. 556-560, 1964.
13. Shefov, N. N.: Povedeniye emissii geliya λ 10,830 Å v sumerkakh. V sb.: Polyarnyye siyaniya i svecheniye nochnogo neba (The Behavior of the Helium Emission λ 10,830 Å at Twilight. In the Collection: Aurorae and Airglow), No. 10, seriya "Rezul'taty MGG". Izdat. Akad. Nauk S.S.S.R., 1963, pp. 56-64.
14. Nicolet, M.: Solar Radioflux and Temperature of the Upper Atmosphere. J. Geophys. Res., Vol. 68, No. 22, pp. 6121-6144, 1963.
15. Marov, M. Ya.: O plotnosti verkhney atmosfery v gody minimuma solnechnoy aktivnosti (The Density of the Upper Atmosphere During the Years of a Minimum Solar Activity). Kosmicheskiye Issledovaniya, Vol. 2, No. 6, pp. 909-916, 1959.
16. MacDonald, G.J.F.: The Escape of Helium from the Earth's Atmosphere. Rev. Geophys., Vol. 1, pp. 305-349, 1963.
17. Bourdeau, R. E., S. Chandra, and W. M. Neupert: Time Correlation of Extreme Ultraviolet Radiation and Thermospheric Temperature. J. Geophys. Res., Vol. 69, No. 21, pp. 4531-4535, 1964.
18. Anderson, A. D.: On the Inexactness of the 10.7 cm Flux from the Sun as an Index of the Total Extreme Ultraviolet Radiation. J. Atmos. Sci., Vol. 21, No. 1, pp. 1-14, 1964.
19. Shefov, N. N.: Nekotoryye svoystva gidroksil'nogo ezulcheniya (Some Properties of the Hydroxyl Emission). This Volume.
20. Fedorova, N. I.: Sumerechnaya fluorestsentsiya geliyevoy emissii λ 10,830 Å (The Twilight Fluorescence of the Helium Emission λ 10,830 Å. Izvest. Akad. Nauk S.S.S.R., No. 5, pp. 661-678, 1962.
21. Krassovsky, V. I. and N. N. Shefov: On the Mechanism of Production of Metastable Orthohelium Atoms in the Upper Atmosphere. Space Research, Vol. 5, pp. 822-825, Amsterdam, North-Holland Publ. Co., 1965.