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Abstract

Full Text

GEOPHYSICS

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INVESTIGATION OF THE X-RAY RADIATION OF THE SUN DURING THE TOTAL SOLAR ECLIPSE OF FEBRUARY 15, 1961

(Presented by Academician A. A. Blagonravov on July 4, 1961)

This communication presents the results of measurements of the X-ray radiation of the Sun in the spectral region shorter than 10 Å during the total phase of the eclipse, carried out during the ascent of a geophysical rocket to an altitude of about 96 km.

As is known from radio observations, the ionization of the ionospheric *E*-layer during the total phase of a solar eclipse does not disappear completely; this indicates the presence of residual X-ray radiation, whose source is the solar corona. The character of the change in ionization as different portions of the solar disk are successively covered by the Moon led to the conclusion that the ionizing radiation comes partly from undisturbed regions of the corona, while the main part of it comes from regions of the corona located above active areas of the solar surface. This was confirmed by direct measurements by H. Friedman and co-workers, who measured the soft X-ray radiation of the Sun in the 44–60 Å region during the solar eclipse of 1958 as active formations on the solar disk were successively covered by the Moon ⁽¹⁾. The purpose of the experiment described below was to measure the residual intensity of the shortest-wavelength part of the solar spectrum—shorter than 10 Å—and to determine the regions of origin of this hottest radiation, studied in our previous works ^(2,3).

The apparatus was analogous to that used in works ^(2,3). The radiation receivers were two photon counters. The first counter had a window 7 mm in diameter, covered with beryllium foil of mass 15 mg/cm². The spectral sensitivity of counters of this type, measured at Leningrad State University jointly with A. P. Lukirskii by the method described in the work of A. P. Lukirskii, M. A. Rumsh, and L. A. Smirnov ⁽⁴⁾, is shown in Fig. 1. The second counter was similar to the first, but was additionally covered with gold and silver foils of masses 0.77 and 1.05 mg/cm², respectively; the calculated spectral sensitivity of the counter is shown in Fig. 2. This counter is 10–20 times less sensitive to the measured X-ray radiation of the Sun and has approximately the same sensitivity as the first counter to corpuscular fluxes. Comparison of the readings of both

Figure 1 and Figure 2

Figure 1: Figure 1 and Figure 2

Figure 3

Figure 2: Figure 3

counters made it possible to judge whether corpuscular fluxes were present in the measurement zone and to estimate their contribution to the recorded count rate.

The counters described were developed under the direction of I. A. Prager and S. M. Perel' man. The electronic apparatus for recording pulses from the counters was the same as in the preceding experiments ⁽⁵⁾; the readings of both counters were transmitted to the Earth by the telemetric system over two independent channels.

The counter unit was placed outside the instrument container in such a way that at the moment of launch of the rocket the counters were directed toward the Sun.

During the ascent of the rocket, the instrument container separated from the rocket and maintained its orientation both on the remaining ascending part of the trajectory and on the descending part. Thus, the counters were directed at the Sun the entire time.

The container reached an altitude of about 96 km, which approximately corresponded to the height above the Earth of the axis of the cone of total shadow. The launch time of the rocket was chosen so that the container reached the apex of its trajectory at the moment

Fig. 1. Spectral sensitivity for two specimens of counters with a beryllium window. 1 and 2 —experimental data (1 —counter No. 241, 2 —counter No. 242); 3 —calculated data

Fig. 2. Spectral sensitivity of a counter with a beryllium window covered with gold and silver foils. Calculated data

of its intersection with the axis of the shadow cone; throughout the ascending and descending portions of the registration interval the container was in the region of total shadow.

A noticeable increase in the counting rate of the main counter was recorded at an altitude of 87 km. Comparison of the counting rates of both counters at different altitudes made it possible to conclude that, as in previous launches, there were no appreciable corpuscular fluxes in the measurement zone. All the recorded radiation may be attributed to the X-ray radiation of the Sun.

Fig. 3. Energy distribution at the short-wavelength edge of the solar spectrum.

Fig. 4. Map of the Sun for 15 II 1961. The solid line is the intensity of the green coronal line Fe XIV 5303 Å; the dotted line is the intensity of the red line Fe X 6374 Å

Figure 3: Fig. 4. Map of the Sun for 15 II 1961. The solid line is the intensity of the green coronal line Fe XIV 5303 Å; the dotted line is the intensity of the red line Fe X 6374 Å

1 –experimental data, 2 and 3 –calculated data for bremsstrahlung ($2 - T_e = 1 \cdot 10^6$ °K, $3 - T_e = 1.5 \cdot 10^6$ °K)

In the main, the radiation of the corona in the region shorter than 10 Å is apparently continuous and does not contain intense lines, and from data on the variation of the counting rate with altitude, the spectral sensitivity of the counters, and the mass absorption coefficients of air it is possible to obtain approximately the energy distribution of the solar radiation and the energy flux in this spectral region outside the atmosphere (^{3a}). The results of the calculation—the number of quanta per $\text{cm}^2 \cdot \text{sec}$ in a spectral interval 1 Å wide for the spectral region 5–10 Å—are presented in Fig. 3. Spectral regions shorter than 5 Å made a very small contribution to the registered counting rate in this experiment, and therefore the course of the curve in this spectral region cannot be established from these measurements.

The principal source of the continuous radiation of the corona is free-free transitions of electrons in the field of protons and doubly ionized helium atoms. It is therefore natural to compare the distribution obtained with the distribution of the number of quanta in bremsstrahlung:

$$N_\lambda = \text{const} \cdot N_i N_e T_e^{-1/2} e^{-hc/kT_e\lambda} \bar{g} \frac{d\lambda}{\lambda}.$$

The corresponding curves for $T_e = 1 \cdot 10^6$ °K and $T_e = 1.5 \cdot 10^6$ °K are shown in Fig. 3. The curves are normalized so that they pass through a common point with the experimental curve at $\lambda = 10$ Å; the Gaunt factor \bar{g} is taken to be equal to 1. As follows from these curves, the experimental distribution of energy in the radiation of the corona in the region 5–10 Å agrees well with bremsstrahlung radiation with an electron temperature $T_e = 1 \div 1.5 \cdot 10^6$ °K. For the energy flux in the region 2–10 Å outside the Earth's atmosphere, one obtains the value $8 \cdot 10^{-5}$ erg/ $\text{cm}^2 \cdot \text{s}$.

Fig. 4. Map of the Sun for 15 II 1961. The solid line is the intensity of the green coronal line Fe XIV 5303 Å; the dotted line is the intensity of the red line Fe X 6374 Å

On the day of the eclipse the Sun was very quiet; near the eastern and western limbs of the disk there were small active regions, which during the measurements were covered by the Moon. Apparently, it may be considered that the measured radiation flux characterizes mainly the undisturbed open regions of the corona.

Figure 4 shows a map of the Sun for 15 II 1961.

We can now, from the measured residual radiation, estimate the radiation flux that would correspond to a completely open corona. In doing so we use the work of Elwert (^{6,7}), who calculated the residual radiation of the corona in the full phase of an eclipse for various ratios of the apparent radius of the Moon to the radius of the Sun, varying somewhat from eclipse to eclipse. For a corona somewhat compressed at the poles, as corresponds to Fig. 4, with $r_1/r_\odot = 1.04$ and in the absence of self-absorption, Elwert's calculation gives for the flux of residual radiation a value equal to 0.2 of the radiation flux of the whole corona as a whole.* It follows from this that the radiation flux of a completely open corona in our case would be, in the region 2-10 Å, $4 \cdot 10^{-4}$ erg/cm² · s. This value, in order of magnitude,

* Continuous radiation, as follows from Elwert's calculations, does not undergo self-absorption in the body of the corona.

agrees with the energy flux in the same region of the spectrum obtained in measurements from the second spacecraft (19-20 VIII 1960), $7.6 \cdot 10^{-4}$ erg/cm² · sec, and from the third spacecraft (1-2 XII 1960), $2.4 \cdot 10^{-4}$ erg/cm² · sec (2). These values may be compared with the index characterizing the intensity of the coronal green line Fe 5303 Å, averaged over the visible surface of the corona for the corresponding days. These data are given in Table 1.

Table 1

Date	19 VIII 1960	20 VIII 1960	1 XII 1960	2 XII 1960	15 II 1961
Intensity of the Fe XIV 5303 Å line	91	88	51	47	65
Radiation flux in the region shorter than 10 Å (erg/cm ² · sec)	$7.6 \cdot 10^{-4}$	$7.6 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	$2.4 \cdot 10^{-4}$	$4 \cdot 10^{-4}$

As follows from the table, the correlation between the X-ray radiation flux and the green-line index proves to be very good. This confirms that the short-wavelength part of the solar spectrum comes from all regions of the corona in which the 5303 Å line is excited.

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