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Abstract

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GEOPHYSICS

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COSMIC-RAY FLARES OF NOVEMBER 12-15, 1960

(Presented by Academician M. A. Lavrentiev, 16 XII 1960)

On November 12–17, 1960, a series of unusual events connected with phenomena on the Sun was recorded by installations for continuous observations of cosmic-ray intensity in Yakutsk (geomagnetic latitude 51° N) ([1]).

Figure 1 presents two-hour values of the intensity of the neutron and hard components of cosmic rays from 10 to 20 XI 1960, corrected for the barometric effect. During this period, three large flares were observed in the neutron component (see Fig. 2). The times of onset and maximum and the magnitude of the flare were estimated from 15-minute values.

A sharp increase in intensity began on 12 XI at 13 hr 45 min universal time (1345 UT) and coincided with the onset of a very large magnetic storm (1348 UT). At 1630 UT the intensity reached a maximum value exceeding the normal level by 65%. This flare was preceded by a smooth increase in intensity of up to 10%.

At 1815 UT a second increase in cosmic rays began, reaching a maximum at 2000 UT. The increase in intensity at the maximum was 100%. Both increases were accompanied by complete absorption of radio waves in the ionosphere over Yakutsk.

Simultaneously with the onset of the second increase, all recorders of the hard component of cosmic rays noted a Forbush-type decrease. The ratio of the magnitudes of the effects in the neutron and hard components at the moment of the maximum of the first flare shows that, if the energy spectrum of the additional flux of cosmic particles is represented in the form

$$\delta D(\varepsilon) \sim \varepsilon^{-\alpha}, \qquad (1)$$

then $\alpha = 5 \div 7$.

Figure 1. Two-hour values of cosmic-ray intensity according to data from the Yakutsk complex of installations for the period 10–12 XI 1960.

Figure 1: Figure 1. Two-hour values of cosmic-ray intensity according to data from the Yakutsk complex of installations for the period 10–12 XI 1960.

The energy spectrum of the decrease coincides with the mean spectrum of Forbush-type effects and is satisfactorily described by the expression

$$\frac{\delta D(\varepsilon)}{D(\varepsilon)} = -f \begin{cases} 1, & \text{if } \varepsilon < \varepsilon_1/4; \\ \frac{2}{\pi}\arcsin(\varepsilon_1/2\varepsilon - 1), & \text{if } \varepsilon_1/4 < \varepsilon < \varepsilon_1/2; \\ 0, & \text{if } \varepsilon > \varepsilon_1/2. \end{cases} \quad (2)$$

where $\varepsilon_1 = 130 \div 170$ Bev.

As can be seen from Fig. 1, at 9–10 hr UT on 13 XI a second decrease in the intensity of the hard component of cosmic rays began, with an energy spectrum of the form (2). From 14 to 17 XI, disturbed diurnal variations were observed.

The third cosmic-ray flare began on 15 XI at 0245 UT and was accompanied by a Dellinger effect. At 4 hr UT, at the maximum of the flare, the increase in intensity was $\sim 40\%$. During the decline of the flare, at 1245 UT, an increase in intensity of $55 \pm 5\%$ was noted in the stratosphere.

Fig. 1. Two-hour values of cosmic-ray intensity according to data from the Yakutsk complex of installations for the period 10–12 XI 1960. **H. M.**—neutron monitor; I_1, I_2—ionization chambers C-2 and ASK-1; $T(B)$, T^{39}(Yu), and $T^{30}(C)$—counter telescopes directed vertically and at an angle of 30° to the zenith in the north and, correspondingly, south direction (the lower index $0, 7, 20$, and 60 denotes the recording depth in meters of water equivalent). To the right of the corresponding curve is shown the two-hour statistical error of the instrument. The dotted lines mark the beginning and end of the magnetic storm.

The ratio of the effect in the stratosphere to the effect in the neutron component at this moment is consistent with the spectrum of the additional flux $\delta D(\varepsilon) \sim \varepsilon^{-\text{[[unclear: exponent]]}}$.

The coincidence of the onset of the magnetic storm and of the first cosmic-ray flare indicates that the particles that produced the flare were brought by a corpuscular flux responsible for the magnetic storm. The small increase before the first flare was apparently caused by cosmic-ray particles emitted from the Sun during the ejection of the corpuscular flux. The velocity of the flux, determined from the delay time of the onset

Fig. 2. Hourly values of the intensity of the neutron component of cosmic

rays according to registration data in Yakutsk, 10–15 XI 1960. The dashed line marks the onset of the magnetic storm.

of the magnetic storm relative to the increase in the intensity of cosmic rays is equal to $\sim 3 \cdot 10^8$ cm/sec.

If one assumes that the Forbush-type decrease was caused by a regular magnetic field frozen into the stream, then from the delay of the Forbush effect relative to the onset of the magnetic storm (~ 5 hr) it may be concluded that the magnetic field in the front part of the stream was to a considerable extent irregular. It is possible that the energy density of cosmic particles in this part of the stream was comparable with the density of magnetic energy in it, which led to turbulence of the magnetic field.

The observed decrease in the intensity of cosmic rays is consistent with a magnetic-field strength in the stream of $(3 \div 5) \cdot 10^{-5}$ gauss, with an angular width of the stream of $40 \div 70^{\circ}$.

The second Forbush-type decrease in the hard component and the abrupt break in the decline of the flare are due to the Earth entering a second corpuscular stream, carrying a regular magnetic field of the same order of magnitude as in the first stream. The relatively small magnitude of the second decrease in the intensity of the hard component at the Earth' s surface and the absence of a decrease in the neutron component are apparently connected with the presence of accelerated particles in the stream.

Taking into account the discrepancy between the decrease in the hard and neutron components and that expected from (2) gives the exponent in the spectrum (1) of the captured particles in the second stream as $a = 4 \div 5$.

The amplitude and time of the maximum of the disturbed diurnal variations agree with a stream velocity of $\sim 3 \cdot 10^8$ cm/sec and with the direction of the magnetic field in the stream being antiparallel to the field of the Earth' s dipole. If the moment of ejection of the stream from the Sun is determined from the found value of the velocity, this moment coincides with the onset of the second flare. This suggests that the ejection of the stream was apparently caused by solar cosmic rays ([3]), some of which produced the flare on the Earth, while some were captured by the stream. In this case particles were captured up to energies of ~ 7 Bev. For the particles of the second flare to fall freely onto the Earth, it is necessary that the direction of the magnetic field of the first stream coincide with the axis of the stream.

The long duration of the magnetic storm (~ 5 days) and the presence of several active periods, one of which began ~ 20 hr after the third flare, indicate that simultaneously with this flare yet another corpuscular stream was emitted.

The connection of flares with corpuscular streams testifies in favor of the mechanism of stream ejection by the pressure of solar cosmic rays.

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Note: Figure translations are in progress. See original paper for figures.