# *SMALL EFFECTS OF SOLAR FLARES AND THE ENERGY SPECTRUM OF PRIMARY VARIATION OF COSMIC RAYS*

E. V. KOLOMEETS

Kazakh State University

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The relation between the intensity of cosmic-ray neutrons and chromospheric flares on the sun was studied from the data obtained at four stations located at various latitudes. By the epoch-superposition method, a small flare effect has been found at each of these stations. The energy spectrum of particles of the supplementary flux has been determined with the aid of the coupling constants.

As is well known, the appearance of sun flares is accompanied by a small increase in the intensity of cosmic rays.

The author carried out investigations in order to 1) explain the character of variation of the neutron component intensity in cosmic rays during small solar flares and 2) determine the energy spectrum of the additional flux of cosmic rays. Data obtained at the stations listed in the table were utilized.

| Station | Altitude, m | Geographical coordinates | | Geomagnetic coordinates | |
|---|---|---|---|---|---|
| | | Latitude (N) | Longitude (E) | Latitude | Longitude |
| Alma-Ata (U.S.S.R.) | 806 | 43°14′ | 76°51′ | 33° | 150,5° |
| Rome (Italy) | 60 | 41°48′ | 12°36′ | 42,4° | 92,1° |
| Göttingen (Western Germany) | 2960 | 47°8′ | 09°5′ | 49,1° | 93,4° |
| Göttingen (Western Germany) | 273 | 51°32′ | 09°56′ | 52.3° | 93,6° |

The author participated in collecting the data at the first station. Results of all measurements were corrected for the barometric effect.

Since variations of the intensity of cosmic radiation for each case are small and their magnitude is not bigger than that of the statistical fluctuations, the data were averaged by the epoch superposition method.[1] Two-hour intervals, including the time of the beginning of the flares, were taken as zero time. Readings of all corresponding two-hour intervals before and after this period were then added. In such a manner, data for 41 flares with an index of 2 and higher,* observed from July to November 1957 between 22 h 00 min and 14 h 00 min World Time, were reduced.

Results are given in Fig. 1. The following facts can be noted:

1) A decrease in the intensity of 0.1 — 0.2% is observed before the flares.

2) The flare effect $\delta I/I$ (where I is the intensity of the neutron component of cosmic rays for the given station) is greater at high latitudes:

| Geomagnetic latitude (N) | 33.0° | 42.4° | 49.1° | 52.3° |
|---|---|---|---|---|
| $\delta I/I$, % of mean | 0.50±0.08 | 0.60±0.08 | 1.60±0.08 | 1.00±0.06 |

3) The neutron-intensity maximum occurs after the solar flare with a delay (2 — 5 hours) which increases with the latitude;

4) The duration of intensity decrease is larger at high latitudes: thus, at the latitude of 33° (N), the duration of decrease is 5 — 6 hours, while at the latitude of 52.3° (N) it is ~ 10 hours.

5) The duration of the intensity decrease is larger by 20 — 30% than the rise time.

Several of these effects were observed for large flares,[1,2] and are mentioned by Dorman[1] and by Sekido and Murakami.[2] Since the effect of single flares is not larger than the statistical fluctuations of the intensity for the given time interval, the data of the Alma-Ata station of period equal to the total time of the investigated 41 flares were reduced as a check. These data were selected from days when flares were absent, and were reduced in the same way as for flares. Results of the analysis are presented in Fig. 2. It can be seen from the figure that, within the limits

*The index characterizes the intensity of flares according to the scale: 1, $1^+$, 2, $2^+$, 3, $3^+$.

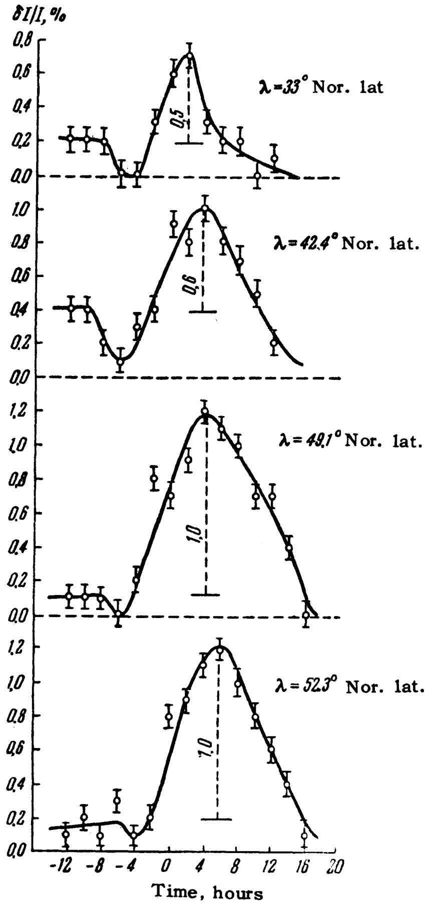


FIG. 1. Variation of the intensity of cosmic-ray neutrons, connected with solar flares.

of statistical errors, the effect has not been observed.

As has been shown by Dorman,[1] one can determine the spectrum of the primary cosmic radiation in the energy range subjected to the influence of the magnetic field of the earth from measurements of any single component at various latitudes by the method of the coupling constants.

The determination of the energy spectrum of primary variation of cosmic rays was carried out according to the formula (see reference 1):

$$\frac{\delta D}{D} = [\delta N^i_{\lambda_k}(h_0) - \delta N^i_{\lambda_{k+1}}(h_0)] / N^i_{\lambda_0}(h_0) \int\limits_{\varepsilon^{min}_{\lambda_k}}^{\varepsilon^{min}_{\lambda_{k+1}}} W^i_{\lambda_0}(\varepsilon, h_0)\, d\varepsilon,$$

where $\delta D/D$ is the ratio of the differential energy spectrum of the additional radiation to the spectrum of the unperturbed primary cosmic radiation, $\delta N^i_{\lambda_k}(h_0)$ is the variation of the intensity of the i-th component at the latitude $\lambda_k$ and altitude $h_0$,

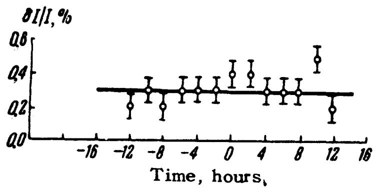


FIG. 2. Variation of neutron intensity in days without solar flares.

$\epsilon^{min}_{\lambda_k}$ is the effective value of the minimum energy resolved by the magnetic field of the earth (geomagnetic cutoff), and $W^i_{\lambda_0}(\epsilon, h_0)$ is the coupling constant between the primary and the observed variations of the i-th component at latitude $\lambda_0$.

The spectrum was calculated for various moments of time. The results of calculations at two hours after the beginning of flares, and also according to the maxima of the effect, are given in Fig. 3. Graphs of the dependence of $\delta D/D$ on the energy have, within the limits of errors, the same slope. This indicates that there was no fast redistribution of particles energy in the additional flux during that time. Extrapolation of the straight lines to the x axis determines approximately, the upper limit of the energy spectrum of primary variation, which can be seen in Fig. 3 and lies in the vicinity of 14 — 17 Bev.

With respect to the lower limit of the energy spectrum, one can state the following (provided that the value of the effect at 49.1° (N) latitude is not partly due to the altitude of the station, situated at an altitude of 2960 m above sea level): within the limits of errors, the effect at latitudes of 49.1 and 52.3° (N) is identical; hence particles with total energy not lower than ~ 3 Bev (geomagnetic cut-off at 49.1° (N) latitude were present in the additional flux.

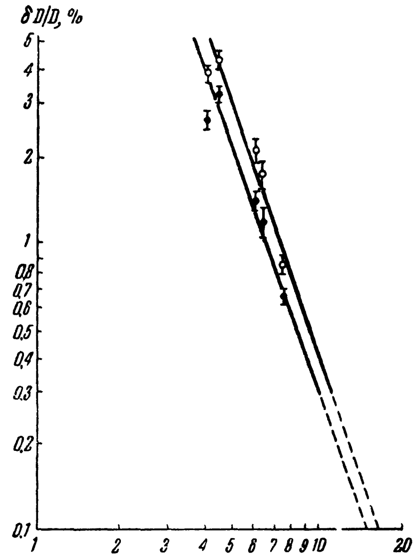


FIG. 3. Spectrum of primary variations, obtained from the effect of small solar flares on the neutron component. The y axis represents the ratio of the energy spectrum of the additional radiation to that of the undisturbed primary cosmic radiation: ● – from the data obtained 2 hours after the onset of flare, o – from the data at the maximum.

The observed spectrum is in agreement with the spectrum calculated for the large flare of cosmic rays which occurred on the 23rd of February 1956.[1] This agreement indicates that both the small and large increases of the intensity of the neutron component of cosmic rays are probably due to the additional flux of particles of the same energy and the same nature.

In conclusion, the author would like to express his deep gratitude to L. I. Dorman for helpful advice, to the students K. Tarasova and V. Pivneva who took part in the work, and also to the coworkers of the stations in Rome and Göttingen, whose results of measurements, submitted to the World Center for Collection of Data of the International Geophysical Year, were used as the basis for the present work.

[1] L. I. Dorman, Вариации космических лучей (Variations of Cosmic Rays), 1957.

[2] Y. Sekido and K. Murakami, Proc. of Guanajato Conference of Cosmic Ray Physics, Sept. 1955.

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