ON THE EFFECTS OF SOLAR COSMIC RAY ACCELERATION AT INTERPLANETARY SHOCK WAVES[1])

ОБ ЭФФЕКТАХ УСКОРЕНИЯ СОЛНЕЧНЫХ КОСМИЧЕСКИХ ЛУЧЕЙ НА УДАРНЫХ ВОЛНАХ В МЕЖПЛАНЕТНОМ ПРОСТРАНСТВЕ

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Recently, theoretical and experimental investigations have been carried out on particle acceleration processes in interplanetary space. It is proposed that when a shock front is present in interplanetary space, particle acceleration can be caused by: first order Fermi mechanism [1, 5, 6], particle drift in the regular electric field of a shock wave [2, 7], a turbulized plasma layer ahead and behind of a shock front or confined between two shock fronts [3, 8].

Experimental evidence of the acceleration of solar cosmic ray particles in interplanetary space has been obtained in a number of investigations [2, 5, 9, 10]. The increase of electron and proton intensities was related to the passage of shock waves mainly identified by sudden commencements of geomagnetic storms. The events are characterized by short duration (not over 10 hours), a soft spectrum ($\gamma = 5$—7), and considerable anisotropy. In some cases a flux maximum was recorded simultaneously with the sudden commencement of a magnetic storm (SC), while in other cases it was behind or ahead of the passage of a shock front.

Papers [11, 12] deal with fairly rare events associated with particle acceleration in a system of converging shock waves (events on 17 July 1959, 12 November 1960, 4 August 1972). The peculiarities of temporal and spectral characteristics of proton events were accounted for by a subsequent acceleration of solar cosmic ray protons up to relativistic energies in interplanetary space due to a regular Fermi-acceleration of particles between two converging shock fronts.

In this report solar cosmic ray increases observed in 1969—1980 are considered, with their intensity temporal variation characterized by two maxima. The second short-time increase of particle fluxes (4—9 hours) is recorded at the decrease of fluxes from a flare observed in H_α. In this case the second maximum can be related to a shock wave passage in interplanetary space rather than to chromospheric flares on the Sun.

According to Explorer [13] and Meteor data, eight increases of this type were observed from 1969 to 1980 (on 29 September 1969, 24 July 1970, 6 November 1970, 17 June 1972, 5 August 1972, 9 September 1973, 3 May 1976, and 2 June 1978). The intensity of $E_p > 5$—10 MeV proton fluxes in the events associated with shock waves is 2—35 times the initial level and is independent of solar cosmic ray flux values prior to the increase.

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Figures 1, 2 show the time profiles and γ the spectral index variation (with power-type presentation of the spectrum $I \simeq I_0 E^{-\gamma}$) in the events on 29 September 1969, 24 July 1970, and 2 June 1978. The variation of the K_p-index, solar wind velocity V, in km s^{-1}, intensity of interplanetary magnetic field (IMF) B, as well as the sign of the IMF sector are also shown in the figures. Black triangles indicate commencements of magnetic storms with SC. The characteristics of the eight events which resulted from accelerating processes in interplanetary space are given in the table in more detail. The following data

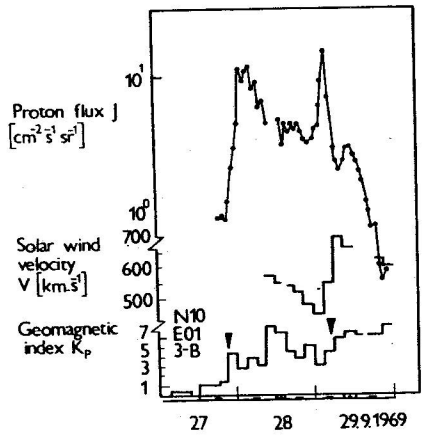

Fig. 1. The temporal profile of protons with $E_p >$ 10 MeV, solar wind velocity, K_p-index variation, and the sign of the interplanetary magnetic field sector for the event of September 28—29, 1969. A vertical line indicates the chromospheric flare in H_α, which generated solar cosmic ray protons, triangles — commencements of magnetic storms with SC.

are given: date and time of the maximum flux registration, event duration, energy of recorded protons, maximum proton flux, spectrum index in the maximum, asymmetry A, %, determined from Meteor data on fluxes in the northern and the southern polar zones ($A = (I_N - I_S)/(I_N + I_S) \times 100$ %). The table also presents the data on flares responsible for the general solar cosmic ray increase, the time of recording magnetic storms with SC [13], solar wind velocity, and the values of the IMF-B intensity vector prior to and after the passage of shock front [14].

As seen from the figures and table, the observed proton fluxes are primarily recorded in the range of 5—30 MeV; spectra in the events are soft: γ in the maximum varies from 3 to 9, except for the event on 5 august 1972, when γ was 1.4 and a significant flux of $E_p > 60$ MeV protons was observed; increase duration was 4—9 hours. In the events on 29 September 1969, 25 July 1970, and 2 June 1978 the time of the maximum coincides with the passage of a shock front; in the event on 17 June 1972 fluxes began to increase simultaneously with SC; on 5 August 1972 and 9 September 1973 particle acceleration occurred between shock waves, the velocity of the second wave exceeding that of the first one; on 3 May 1976 fluxes were localized beyond the shock front. According to Meteor measurements, the stage of the flux increase on 24 July 1970 and 2 June 1978 was characterized by a considerable asymmetry of $E_p > 5$ MeV proton fluxes, which could point to the formation of an anisotropic particle flux ahead of a shock wave. During the passage of shock fronts appreciable changes in solar wind velocity and in the IMF B vector value were noted (see the table). For example, in the event on 25 July 1970 solar wind velocity increased by 90 %.

In the events on 29 September, 1969, 25 July, 1970, and 2 June, 1978 solar cosmic ray protons from flares responsible for the general increase are accumulated between shock fronts. And if the rear front of accumulation zone is of minor transparency and overtakes the fore-front, conditions arise for acceleration and the formation of a maximum exactly corresponding to the shock front [15]. The event on 5 August 1972 is anomalous. As is seen from the Table, the IMF intensity at the forefront dropped

from 41 to 18.1 gamma, the field reversed, then increased from 20 to 40 nT. The authors of [16] assume the increase to results from spatial motion of an area of $\sim 3 \times 10^6$ km with a decreased magnetic field and boundaries formed by tangential breakdowns. The dynamics of the B vector change in the event on 17 June, 1972 can also account for the increase by proton acceleration at the shock front with a subsequent localization in the area of the decreased magnetic field. The B value at the front of the flux increase varied from 10 to 24 gammas, then dropped to 15 gammas (in the flux maximum), and again

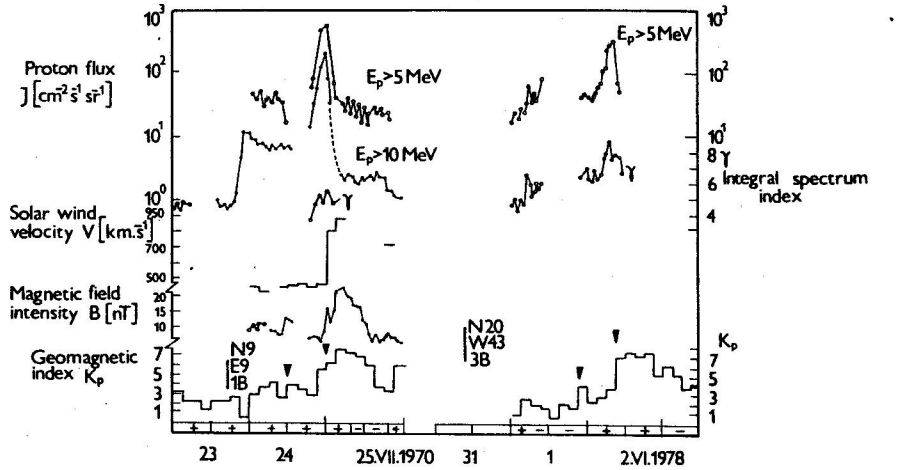

Fig. 2. Variation of the flux of solar cosmic ray protons, spectral index γ, solar wind velocity, intensity and the sector sign of the interplanetary magnetic field, and the K_p-index for the events of July 24—25, 1970 and June 1—2, 1978. (Designations are the same as in Fig. 1.)

increased to 25 gammas by the end of the event. The situation of 6 September, 1970 was similar to that: the B value at the forefront varied from 8.4 to 6.1 with a subsequent increase to 9 gammas by the end of flux record.

Thus, our data, as well as those obtained by other investigators, show that the events associated with accelerative processes in interplanetary space have the following morphological characteristics in common: short duration, limited energy range, soft spectrum, proton flux asymmetry. It is essential for their initiation that particles from flares responsible for the general increase of solar cosmic ray fluxes should be present in interplanetary space, provided that two shock fronts of different velocities pass through turbulized plasma.

REFERENCES

[1] Scholer, M., Morfill, G. E.: Solar Phys. *45* (1975), 227.
[2] Morfill, G. E., Scholer, M.: Astrophys. and Space Sci. *46* (1977), 73.
[3] Vasilyev, V. N., Gorchakov, E. V., Morozova, T. I., et al.: *Sbor. trudov IX. Leningr. seminara po kosmofizike.* L (1978), 159.
[4] Toptygin, I. N.: Izv. AN SSSR, ser. fiz. *43* (1979), 755.

[5] Palmer, I., Gosting, J.: J. Geophys. Res. *83* (1978), 2037.
[6] Krymsky, G. F.: Dokl. AN SSSR *234* (1977), 1306.
[7] Shabansky, V. P.: ZhETF *41* (1961), 1107.
[8] Tverskoy, B. A.: *Sbornik trudov leningr. seminara po probleme generatsii kosmicheshikh luchey na Solntse*, (1970), 159.
[9] Singer, S., Montgomery, M. D.: J. Geophys. Res. *76* (1971), 6628.
[10] Blokh, G. M., Zastenker, G. N., Kuzhevsky, B. M., et al.: Kozmicheskie issledovaniya *XIII* (1975), 695.
[11] Chirkov, N. P., Filipov, A. T.: *Sbornik trudov XIII mezhdunarodnogo seminara "Aktivnye protsessy na Solntse i problemy solnechnogo neittrono"*. L. (1976), 155.
[12] Levy, E. H., Duggal, S. P.: J. Geophys. Res. *81* (1976), 51.
[13] *Solar Geophysica Data*. NOAA, Boulder, Colo. 1969—1978.
[14] King, J. H.: *Interplanetary magnetic field*. Data Book National Space Science Data Center 7504. Greenbet April 1975.
[15] Pereslegina, N. V., Ljubimov, G. P.: Kosmicheskie issledovaniya XI *2* (1973), 236.
[16] Venkatasan, D., Mathews, T., Lanzerotti, L. J., Fairfield, D. W., Bostrom, C. O.: J. Geophys. Res. *80* (1975), 1715.

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