Letters to the Editor

RELATION BETWEEN SOLAR COSMIC RAY CHARACTERISTICS AND CORONAL MAGNETIC FIELD STRUCTURE[1])

СВЯЗЬ МЕЖДУ ХАРАКТЕРИСТИКАМИ СОЛНЕЧНЫХ КОСМИЧЕСКИХ ЛУЧЕЙ И СТРУКТУРОЙ МАГНИТНОГО ПОЛЯ СОЛНЕЧНОЙ КОРОНЫ

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It is impossible to describe the characteristics of flare-generated solar protons by spacecraft measurements within the framework of a model that takes into account only the particle propagation in interplanetary space. To explain the experimental results obtained, it is necessary to consider particle propagation near the Sun as well [1—7].

Dependence was investigated of the registration time of the particle intensity maximum near the Earth (Δt_m), counted off from the flare (the source of particles), on the flare heliolongitude. Data on solar cosmic ray events published in the catalogue "Svestka Simon" [8] were used as well as data of measurements on the satellite "Meteor" and data obtained on the satellite "Explorer" and published in [9]. All in all 176 events of solar cosmic rays observed in 1965—1976 were studied. The Carrington longitude of the Sun-Earth field line base was determined by the method described in paper [10] and using the data on solar wind [11]. Coordinates of flares (sources of particle injection) and the Sun-Earth field line base were plotted on weather charts with polarity boundaries being marked [9]. As a result all the events of the solar cosmic rays under consideration were divided into two classes:

— flare and projected longitude of coupling are in a common unipolar region (class 1, 106 events studied);

— flare and longitude of coupling are in separated unipolar regions (class 2, 70 events studied).

Time Δt_m differs greatly for events of class 1 and 2 (Fig. 1: crosses are events of class 1, circles — class 2). For class 1 events it is within 1 h $\leqslant \Delta t_m \leqslant$ 25 hs, while for class 2 events it is in the main more than 15 hs and may be 76 hs, and for class 2 events a stronger dependence of Δt_m on the heliolongitude of the injection source is observed. It should be noted that the method for determining the longitude of the Sun-Earth field line base using solar wind speed may introduce an error in the determination of the coordinates up to $\pm 10°$, that is why we singled out events whose field line bases are more than 10° away from the neutral field line. And an analogous relation was obtained.

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Results of the analysis of the available data on solar cosmic ray events based on a comparatively great statistical material (176 events) confirm the early conclusion that there are "regions of particle fast propagation" in the corona which are identified with the region of the unipolar magnetic field on the Sun [4, 6]. For the class 2 events, the unipolar region boundary prevents particles from fast propagation and leads to a particle delay in the corona. Thus the temporal profile of the solar cosmic ray events prior to the flux registration maximum depends greatly on the class of events. And having available data on

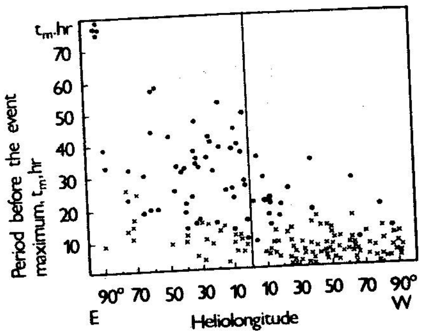

Fig. 1. Heliolongitudinal dependence of the time up to maximum in solar cosmic ray events of class 1 (crosses) and class 2 (dots).

solar magnetic fields and solar wind speed, one can predict temporal characteristics of solar cosmic ray events. The relation between the constant of the proton flux decay and the change of the Sun-Earth field line base heliolongitude was investigated with this aim. The decay constant T_0 was calculated from the time of maximum intensity registration J_{max} till the flux reduction by one half ($J_{max}/2$), assuming that the intensity changes according to the exponential law are

$$J(t) = A \exp\left(-\frac{t}{T_0}\right)$$

where t is the time from the moment of the solar cosmic ray intensity maximum. The speed of the coupling longitude change ($\Delta\Phi/\Delta t$, degree/h) was calculated for the same period of time. Fig. 2 presents the dependence of the decay constants (T_0) on $\Delta\Phi/\Delta t$ for protons with energies $E_p > 10$ MeV. A regressive relation was obtained for the dependences presented below:

$$T_0 = 8.9\,(\Delta\Phi/\Delta t)^{-0.77} \quad (E_p > 5\ \text{MeV})$$
$$T_0 = 6.2\,(\Delta\Phi/\Delta t)^{-0.89} \quad (E_p > 10\ \text{MeV})$$
$$T_0 = 6.9\,(\Delta\Phi/\Delta t)^{-0.73} \quad (E_p > 40\ \text{MeV})$$

The mean quadratic deviation of the individual values from the regression line is 6.6; 3.0 and 4.1 for $E_p > 5$, 10 and 40 MeV respectively.

For the class 2 events (flare of coupling longitude are in different unipolar regions), the spectrum index dynamics (γ) was considered when the Sun-Earth field line base crossed the unipolar region boundary and shifted into the unipolar region, where the injection source is located. Table 1 presents data on the above events: mean magnitude of spectrum index values (γ_{mean}^{degree}), determined by averaging spectrum indices for 24 hs till the crossing of the neutral field line, and the maximum observed value of the spectrum index (γ_{max}) after the crossing of the region boundary. A considerable softening of the proton integral spectra is observed after crossing the unipolar region boundaries, i.e. polarity boundaries are an effective barrier for low-energy particles.

Dependence was investigated of the proton integral spectrum index (γ) in the maximum of the solar cosmic ray event on the flare heliocoordinate. Events with $E_p > 10$ MeV and an intensity in the maximum $J_{max} > 1\ \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ were considered. 47 events of class 1 (crosses) and 47 events of class 2 (dots) were studied separately for flares of solar northern and southern hemisphere by "Explorer" and "Meteor" data (Fig. 3a). The results obtained showed that spectra of most class 2 solar cosmic ray events are softer, the γ value varies within 1.2—4.2 for northern hemisphere flares and 1.7—4.8 for

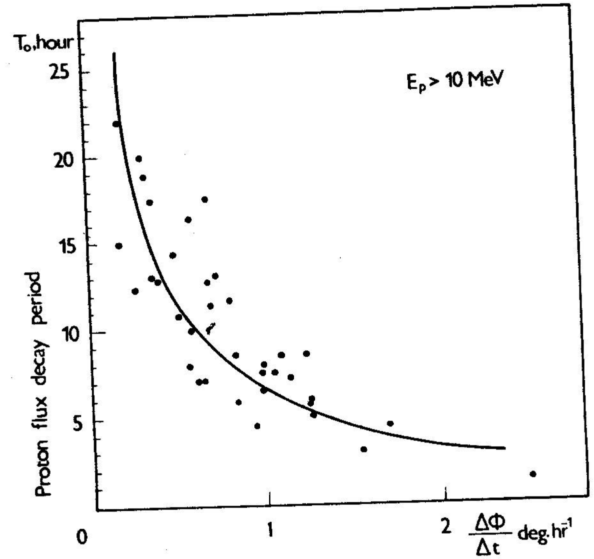

Fig. 2. Dependence of the proton flux decay constant on the speed of the Earth-Sun coupling longitude change.

southern ones. A clear dependence of γ on the heliolongitude is observed; spectra of the eastern hemisphere flares are much softer.

The spectrum index does not practically depend on the flare heliolongitude for the class 1 events. The γ value varies within 0.7—2 for events of the solar northern heliosphere flares and within 0.8—3 for the southern hemisphere. It is worth-while noting that proton spectra of the southern hemisphere flares are softer for the solar cosmic ray events of both class 1 and 2.

In 1965—1979 17 solar cosmic ray events were observed, they were registered simultaneously by satellites and neutron monitors ($E_p > 1$ Gev) [9, 10, 13, 14]. We carried out a joint analysis of the solar cosmic ray event dynamic characteristics, observed by neutron monitors, weather charts and interlocation of the Sun-Earth field line base and a flare. The analysis showed that all the events are of class 1. They are characterized by a quick azimuthal distribution of particles: Δt_m is within 0.5—4 hs. The exception is the event of March 30, 1969 for which Δt_m was 12 hs. We studied the intensity of events registered in the maximum on the satellite in 1965—1978. Solar cosmic ray events with $E_p > 10$ MeV and $J_{max} > 1\ \text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}$ were considered by "Explorer" [8, 9] and "Meteor" data. Fig. 3b shows the dependence of J_{max} on the flare heliolongitude with the account of the class of the events (crosses are

Table 1

Flare in H_α			Index of solar cosmic ray proton integral spectrum		Carrington longitudes, degrees		
Date	Time of beginning UT	Coordinates $\varphi°$ $\lambda°$	γ (up to the boundary) mean	γ_{max}	Heliolongitude of Eart-Sun coupling	Heliolongitude of a flare	Heliolongitude of a neutral line
8. 7. 1968	17 08	N13 E58	1.1±0.1	2.0±0.1	268	155	250
10. 4. 1969	04 10	N11 E90	1.7±0.1	2.2±0.1	240	90	220
27. 9. 1969	03 50	N09 E02	2.7±0.1	3.9±0.1	138	88	130
28. 5. 1972	13 10	N09 E30	1.3±0.1	1.8±0.1	245	162	238
15. 6. 1972	09 51	S10 E11	3.3±0.1	5.0±0.2	275	308	90
2. 8. 1972	18 39	N14 E26	2.9±0.1	4.1±0.2	120	8	90
4. 7. 1974	13 38	S16 W08	3.0±0.1*	3.6±0.2*	208	156	200
11. 7. 1978	10 31	N18 E45	3.5±0.2*	4.5±0.2*	275	167	258

* Data from the satellite "Meteor". $5<E_p<15$; data from the satellite "Explorer" [9] $10<E_p<30$ MeV.

class 1 events; dots — class 2). For an overwhelming majority of events the intensity is within the limits $1<J_{max}<4\times10$ cm^{-2}s^{-1}sr^{-1}, independently on the class of events. When $J_{max}>4\times10$ cm^{-2}s^{-1}sr^{-1}, most events (27) are referred to class 2; a magnetic storm with SC is observed in three of them simultaneously or before the maximum; that could increase the number of particles registered in the maximum of the event [14]. It should be noted that the proton activity of the western hemisphere is considerably higher: 72 events were due to flares in the western hemisphere and 45 in the eastern; and

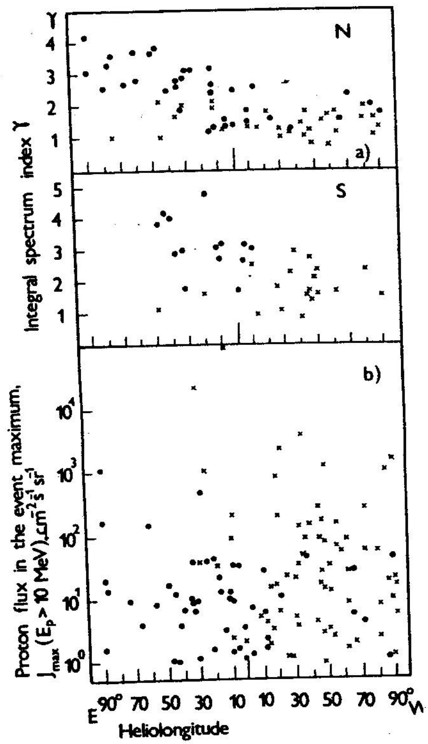

Fig. 3. Heliolongitudinal dependence of solar cosmic ray characteristics: a) index of proton integral spectrum of flares of solar northern and southern hemisphere; b) proton flux in the event maximum (designations are the same as in Fig. 1).

the more easterly from the central meridian the flare is located, the fewer are the solar cosmic ray events. However, "superextremal" events of August 2—4, 1972 were observed due to solar eastern hemisphere flares and referred to class 1 events. This dependence is evidently related to peculiarities of the proton coronal propagation.

Concluding the investigations conducted we established that the heliolongitudinal dependence of solar cosmic ray radiation characteristics may be accounted for within the framework of a coronal propagation model and is determined by the structure of the solar photospheric magnetic field and the location of the Sun-Earth field line base in relation to the injection source.

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