DIAGNOSTIC OF ELECTROMAGNETIC CONDITIONS IN SPACE USING COSMIC RAYS

V.M.Dvornikov, V.E.Sdobnov, A.V.Sergeev

Siberian Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, USSR Academy of Sciences, Irkutsk 33, P.O.Box 4, USSR

Abstract. The method of spectrographic global survey was used to study the time variations in parameters of cosmic ray (CR) pitch-angle anisotropy and their relationship with the variations of some solar wind characteristics under different electromagnetic conditions in interplanetary space. A classification is made of the conditions that are accompanied by the increase in CR anisotropy.

According to the new ideas, under development now, of the physics of modulational effects of cosmic rays (CR) in the heliosphere /1, 2/, the crucial influence upon the CR distribution function in interplanetary space is exerted by effects that are accumulated during a multiple rotation of particles in a Larmor circumference: drift motions, variations in pitch-angle due to an approximate conservation of the transverse adiabatic invariant and particle energy variations in regular fields of solar wind (SW).

The development of these ideas has been stimulated by the obtained phenomena of strong pitch-angle anisotropy of CR during Forbush-effects /3/ whose explanation in terms of a convection-diffusion model /4/ renders itself impossible.

In the context of the model under development, strong pitch-angle CR anisotropy is a reflection of structural features of large-scale fields in interplanetary space due to dynamical processes in the heliosphere, i.e. it is some kind of an indicator of these processes.

The aim of the present work is to study the time variations in parameters of CR pitch-angle anisotropy and their relationships with the variations in some SW characteristics under different electromagnetic conditions in interplanetary space. The analysis has been carried out using the method of spectrographic global survey (SGS) that has been devised using the physics, under development now, of CR modulational effects in the heliosphere, according to which the variations in particle flux density in interplanetary space can be described by a function of the form

$$\frac{\delta J}{J}(R,\psi,\lambda) = \sum_{n=0}^{N}\Big(\sum_{k=1}^{m_n} a_{nk}R^{-k}\Big)P_n(\mu) =$$

$$= \sum_{n=0}^{N}\Big(\sum_{k=1}^{m_n} a_{nk}R^{-k}\Big)\Big[P_n(\sin\lambda)\,P_n(\sin\lambda_0) +$$

$$+ 2\sum_{m=1}^{n}\frac{(n-m)!}{(n+m)!}P_n^m(\sin\lambda)\,P_n^m(\sin\lambda_0)\cos m(\psi-\psi_0)$$

Here $\mu = \cos\theta$, θ is the pitch-angle of a particle in

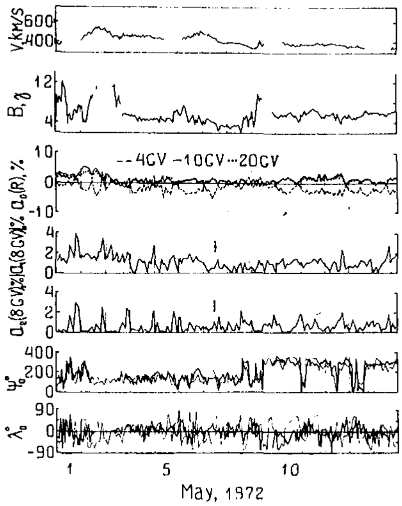

Fig. 1

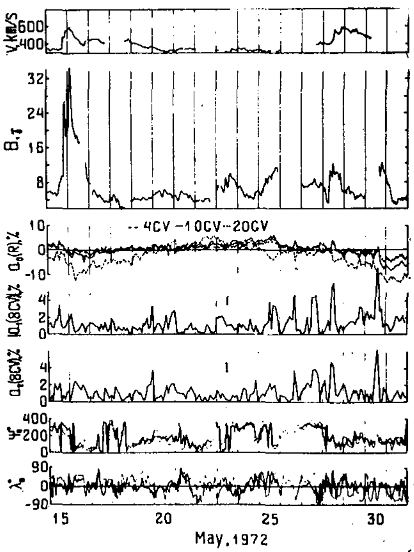

Fig. 2

the IMF, R is the magnetic rigidity of the particles, $P_n(\mu)$ and $P_n^m(\sin\lambda)$ are polynomials and associated Legendre polynomials, ψ and λ are asymptotic angles that determine the direction of the particles outside the magnetosphere in some selected system of coordinates, ψ_0 and λ_0 are the angles that characterize the direction of the IMF vector in this same system, and a_{nk} are the parameters characterizing the amplitudes and rigidity dependences of the isotropic component, and of the first and second harmonics of CR pitch-angle anisotropy. The SGS method makes it possible to determine using ground-based CR observations from the world-wide network of stations, the parameters a_{nk}, ψ_0, and λ_0 (accurate to within π) as well as the variations of the planetary system of geomagnetic cut-off rigidities for each hour of the observations.

The SGS method was used to analyze the variations of the CR distribution function for the periods 1 May through 30 June and 1 through 15 August 1972. The analysis results as well as direct measurements of SW characteristics are presented in Figs 1-5 in the following order (from top to bottom): V - SW velocity, B - IMF modulus; $a_0(R)$-amplitudes of the isotropic component of CR intensity variations for particles of different rigidity; a_1(8GV) and a_2(8GV) are respectively the amplitudes of the first and second harmonics of CR pitch-angle distribution (for R = 8 GV); and ψ_0, λ_0-angles characterising the IMF direction (heavy lines - direct measurements /5/, thin lines - CR data); in addition, Fig. 4 shows the variations in geomagnetic cut-off rigidity ΔR_c at Irkutsk, determined from CR variations, and D_{st} - index).

The comparison between the variations in CR pitch-angle anisotropy and SW characteristics has led to the following classification of the events accompanied by the increase in CR anisotropy of the type considered:

1. Anisotropy increases during powerful SW disturbances (see Figs 2, 4, and 5). During the growth phase of the IMF modulus, the amplitude of the first harmonic ($a_1 \gtrsim 3\%$) increases while during the declining phase, the amplitude of the second harmonic does ($a_2 \gtrsim 3\%$). A minimum flux density of

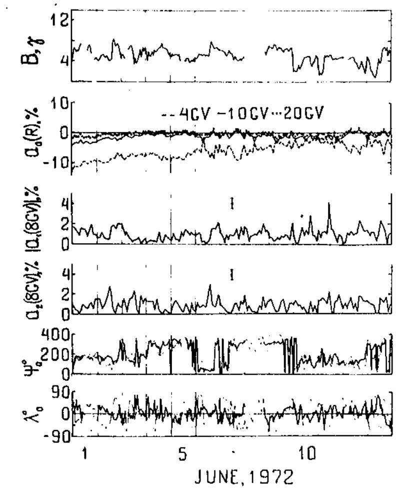

Fig. 3

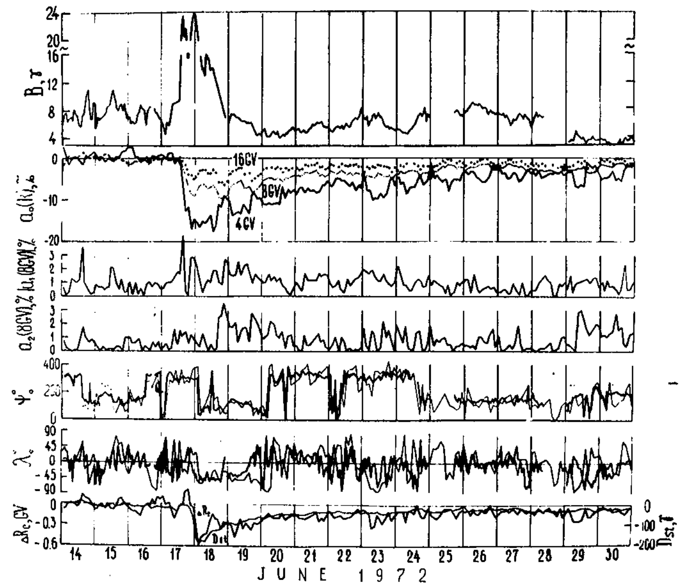

Fig. 4

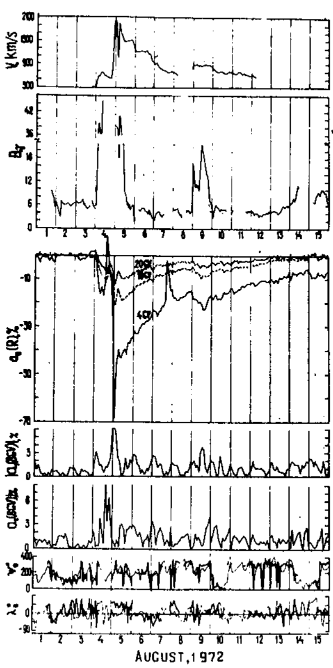

Fig. 5

flow is observed for particles with large pitch-angles. A likely reason might be the influence upon the CR angle distribution of large-scale magnetic traps that form in interplanetary space at propagation of high-speed solar wind streams.

II. Anisotropy increases at places of local decreases in IMF strength (a_1 and $a_2 \sim 2\%$). The character of pitch-angle distribution is the same as for type I events. The likely reason might be trapping and deceleration of particles with large pitch-angles in the traps between the maxima of a random field.

III. Anisotropy increases at places of local increases in IMF strength accompanied by an increase in flux density by 5-15% from some selected direction. In the opposite direction, throughout the entire hemisphere the intensity remains unaltered and is almost independent of the CR direction. This type of anisotropy was observed during 25 to 30 May 1972 (see Fig. 2), with a maximum of the flux density from directions 120-150° westward of the Earth-Sun line and 50-70° southward of the helioequatorial plane. A likely cause of the observed anisotropy may be IMF structures arising as the azimuthal and meridional components of the magnetic field are carried away from the corona. In this case, arrival of CR along the IMF flux tubes is possible from interplanetary space regions (for example, from middle heliolatitudes) where the CR density exceeds significantly the observed density in the helioequatorial region.

IV. Recurrent double enhancements of pitch-angle anisotropy were found assuming that geoeffective regions on the Sun have their mappings in the IMF structure corresponding to their structures. In this connection, an attempt was made to trace, using CR, from rotation to rotation the development of processes in the heliosphere prior to some geoeffective phenomenon with the aim to find distinctive features of the active region that is responsible for a given event. As the object of study, we selected one of the events of most geoeffective interest, the solar proton flares.

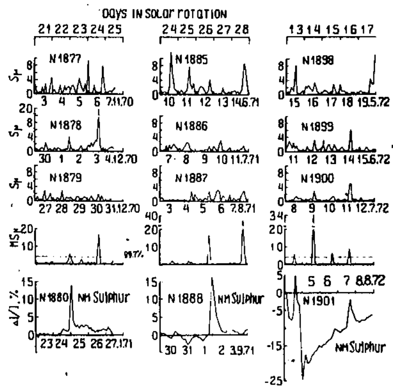

Fig. 6

The SGS method was used to analyze the fluctuations of CR pitch-angle anisotropy in three solar rotations preceding four powerful solar CR enhancements (outbursts) in 1971 and '72.

In order to simplify the analysis we introduced two indices, S_μ and MS_μ. The S_μ-index defines the amplitude of pitch-angle anisotropy at time t_i of the observation; it is calculated in the following way

$$S_\mu(t_i) = \int_R \int_\mu \left\{ \frac{\partial}{\partial \mu} \left[\frac{\delta J}{J}(t_i, R, \mu) \right] \right\}^2 dR \, d\mu$$

We used as the indicator of the recurrent event the multiplicative index $MS_\mu(t_i) = \prod_{k=0} S_\mu(t_i + k\tau)$, where τ is the period of solar rotation.

The analysis (see Fig. 6) revealed that three or four rotations before the onset of a solar proton event (SPE), two comparatively narrow recurrent IMF structures spaced by 15-30° in heliolongitude and causing recurrent double outbursts of CR pitch-angle anisotropy, form in interplanetary space. The character of pitch-angle distribution of the particles at these moments is the same as for type III events.

The four SCR outbursts were all observed on the ground at moments of passage through one of the detected structures. The fact that these structures are identifiable using CR pitch-angle anisotropy in solar rotations preceding SPE can be used for long-term prediction of regions of localization of radiation-dangerous zones in interplanetary space and of times when the Earth enters these zones.

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