SOLAR ACTIVITY BEYOND THE DISK AND VARIATIONS OF THE COSMIC RAY GRADIENT

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Part of galactic cosmic rays (CR) observed near the Earth and on the Earth come from beyond-disk regions of circumsolar space. But CR of those energies which undergo substantial modulation cover too large a path (we mean a transport free pathr) across the lines of force of the interplanetary magnetic field (IMF) in order they could provide an effective transfer of information about beyond-disk solar activity. And if it is still possible, the most probable channel for tranferring such information must be a neutral layer of heliomagnetosphere in which the transverse CR transport is facilitated by their drift in an inhomogeneous magnetic field /I,2/

For charged particles of sufficiently high energy the thickness of the neutral layer is negligibly small as compared with the gyroradius of particles, ρ . In a plane neutral layer the driving centres of such particles will shift along the line (which can be called a drift trajectory) determined by the relation

$$\Delta\varphi = \varphi - \varphi_{\delta} = \int_{z}^{z_{\delta}} \frac{u}{\Omega}\frac{d\xi}{\xi^2} \qquad (I)$$

Here z and φ are heliocentric radius and heliolongitude, z_δ and φ_δ are coordinates of the observation point, u is solar wind velocity, Ω is angular velocity of synodic rotation of the Sun. The drift trajectories (Fig.I), contrary to the field lines to which they are perpendicular, are almost azimuthal near the Sun and approach the radial direction beyond the Earth's orbit. If u and Ω do not depend on the coordinates, it follows from (I) that $z/z_\delta=\left(1+\Delta\varphi\frac{\Omega z_\delta}{u}\right)^{-1}$. The direction of particle motion along the drift trajectories will be determined by polarity of the total magnetic field of the Sun. So, in the seventies, in the special region of "one-way" particle motion near the neutral layer, protons and other positively charged particles had mostly to shift from the Sun to overstep the Earth's orbit. At that time the drift trajectories could bring to the Earth the information of Forbush decreases which occurred in the opposite to us side of circumsolar space and were caused by powerful beyond-disk flares.

A simple diffusion model for an expected CR variation in a neutral layer near the Earth gives /3/

$$\delta(x_\delta)=\int_0^{x_\delta}\frac{\delta(x)}{v_d\tau}\exp\left(\frac{x-x_\delta}{v_d\tau}\right)dx \tag{2}$$

where x is the distance measured along the trajectory, $\delta(x)$ is variation of CR concentration at different points of the trajectory, v_d is effective drift velocity, τ is the mean time necessary for a particle to shift by one gyroradius across the field. High values of $\delta(x_\delta)$ (for example, $>$ 1 %) should hardly be expected even for large beyond-disk decreases. However, since the main effect must be concentrated on one gyroradius from the neutral layer, sufficiently large variations of the CR gradients are possible here. The CR gradient variations and consequent anisotropy variations are just the response to beyond-disk events which one may hope to discover by observing CR near the Earth.

The CR gradient near the Earth can be obtained by using the data on the CR concentration and anisotropy along with the data on the velocity of solar wind and IMF /4,5/.

If $\vec{A}$ is the CR anisotropy vector, $\vec{A}_c$ is its convective part, and $\vec{g}$ is the gradient of the logarithm of CR concentration, then in the convective-diffusion anisotropy model /6/ $\vec{A}-\vec{A}_c=-\Lambda\vec{g}$. In the local right-handed coordinate system in which the x-axis is directed along the solar wind velocity and the y-axis lies in the plane of IMF line, the matrix of transport free paths is

$$\Lambda=\rho\begin{pmatrix} \frac{c^2+ks^2}{\sqrt{k}} & cs\frac{1-k}{\sqrt{k}} & -s\sqrt{1-k} \\ sc\frac{1-k}{\sqrt{k}} & \frac{s^2+kc^2}{\sqrt{k}} & c\sqrt{1-k} \\ s\sqrt{1-k} & -c\sqrt{1-k} & \sqrt{k} \end{pmatrix}$$

Here ρ is gyroradius of particles in the total magnetic field /4/, k is the transverse-to-longitudinal diffusion coefficients ratio, $s=\sin\Psi$, $c=\cos\Psi$, Ψ is the angle between $\vec{A}_c$ and the IMF strength vector. It can be shown that the inverse Λ matrix has the following simple form

$$\Lambda^{-1}=\frac{1}{\rho}\begin{pmatrix} \sqrt{k} & 0 & s\sqrt{1-k} \\ 0 & \sqrt{k} & -c\sqrt{1-k} \\ -s\sqrt{1-k} & c\sqrt{1-k} & \sqrt{k} \end{pmatrix}$$

This matrix is convenient in the determination of $\vec{g}$ /5/.

The active regions whose appearance from behind the eastern disk or disappearance behind the western one was accompanied by active phenomena were distinguished with the help of (7). Thus, the periods with a high probability of powerful flares in the invisible side of the Sun were chosen. One of such periods is shown in Fig.2. We can see there substantial variations of the CR gradient and especially its heliolatitudinal component g_z. A considerable part of such variations is observed in a close vicinity of the neutral layer. It is of importance that variations of the CR gradient are not at all always accompanied by considerable variations of IMF and solar wind velocity at the point of observation. And although the observed variations of anisotropy and CR gradient should not necesserily be associated just with beyond-disk events, the experimental data, along with the above estimates and qualitative considerations give grounds for further search for the evidence in favour of beyond-disk solar activity in the behaviour of galactic CR near the Earth.

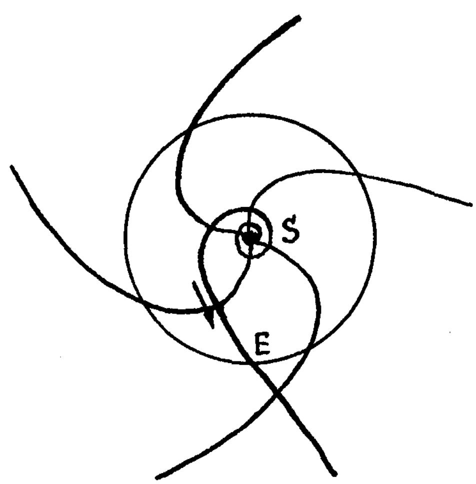

Fig.I. The drift trajectory passing near the Earth. It is calculated by formula (I). Arrow indicates the proton drift direction in the seventies.

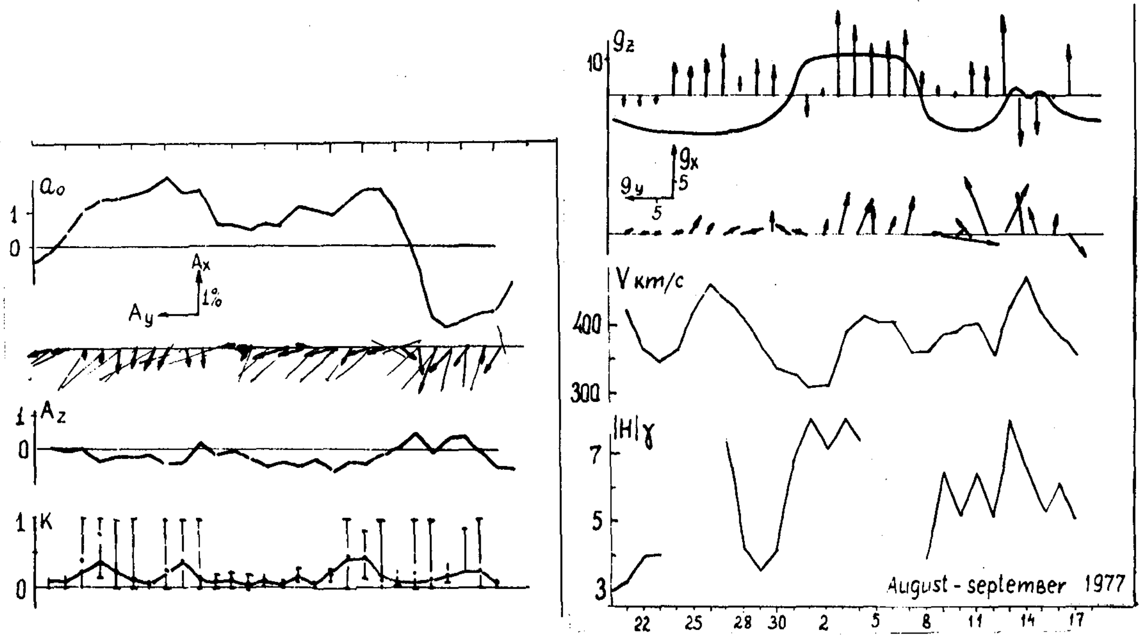

Fig.2. Example of the behaviour of the characteristics of cosmic rays and interplanetary medium in August-September, I977.

a_o - variation of concentration of CR with a rigidity of IO GV.

A_x, A_y, A_z - components of the first harmonic of CR anisotropy. The position of IMF line is shown along with A_x, A_y.

g, g_x, g_y, g_z - gradient and its components for CR with a rigidity of IO GV. The hypothetic configuration of the neutral layer of heliomagnetosphere is shown along with g_z.

K is the degree of anisotropy of CR diffusion (O k I). The directly calculated values of K are shown by points, the smoothed ones - by a solid line.

u - solar wind velocity

H - IMF strength /8/.

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