EFFECTS OF SOLAR MAGNETIC FIELD ON COSMIC RAYS

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The paper is devoted to some aspects of problem of galactic cosmic ray (gcr) propagation including inversion of solar total magnetic field (stmf) and to analysis of experimental facts related to heliomagnetic cycle.

It is known (Jokipii I.R.,et al.,1977, Krainev M.V.,1979,Erkhov V.I.,et al.,1983) that the global structure of solar total magnetic field (Parker's field) results in additional flux of gcr generated by curvature and gradient drifts. Velocity of charged particles drift is

$$\mathcal{D}_i = \frac{\partial \mathscr{x}_{ij}^{(A)}}{\partial x_j} \qquad (1)$$

where $\mathscr{x}_{ij}^{(A)}$ – antisymmetric part of diffusion tensor. It can be written for stmf in the form

$$\vec{\mathcal{D}} = \vec{\mathcal{D}}_1 + \delta(\theta - \pi/2)\vec{\mathcal{D}}_2 \qquad (2)$$

where $\vec{\mathcal{D}}_1$ is regular part and $\vec{\mathcal{D}}_2$ – singular part of velocity. Delta function is connected with the fact of existence of boudary between inward and outward lines of force of magnetic field of the Sun that is neutral current sheet.

The main equation including diffusion, convection, energy changes and drifts in heliocentric system of coordinate is of the form:

$$\frac{1}{z^2}\frac{\partial}{\partial z}\left[z^2\left(\mathscr{x}_{zz}\frac{\partial n}{\partial z} - nu - n\mathcal{D}_z\right)\right] + \frac{1}{z\sin\theta}\frac{\partial}{\partial\theta}\left[\sin\theta\left(\frac{\mathscr{x}_{\theta\theta}}{z}\frac{\partial n}{\partial\theta} - n\mathcal{D}_\theta\right)\right] + \frac{2}{3}\frac{u}{z}\frac{\partial}{\partial\mathcal{E}}(\alpha\mathcal{E}n) = 0 \qquad (3)$$

where $\alpha = \frac{\mathcal{E}+2m_0}{\mathcal{E}+m_0}$, n is density of galactic cosmic rays, $\mathcal{E}$ – kinetic energy. To analyse effects related to redistribution of galactic cosmic rays due to drift motion let's consider the equation including only convection, diffusion along lines of force of magnetic field and drift. We obtain

$$\frac{1}{z^2}\frac{\partial}{\partial z}\left[z^2\left(\mathscr{x}\frac{\partial n}{\partial z} - nu - n\mathcal{D}_z\right)\right] - \frac{1}{z\sin\theta}\frac{\partial}{\partial\theta}\left[\sin\theta\, n\,\mathcal{D}_\theta\right] = 0 \qquad (4)$$

Integration of equation (4) over θ within the limits of $\pi/2 - \mathcal{E}$ and $\pi/2 + \mathcal{E}$ and approaching $\mathcal{E}$ to zero gives following condition:

$$n(z, \mathcal{E}, \theta = \pi/2) = n_0(\mathcal{E}) \qquad (5)$$

where $n_0(\mathcal{E})$ –density of galactic cosmic rays out of modulation region that is for $r \geqslant r_0$.

It shoud be noted that on the basis of general

mathematical considerations (Mors F.M.,Feshbach G.,1958)
condition(5) has sense only for odd cycles of solar activity.
In order to solve parabolic equation (4) we used traditional
boundary conditions for this kind of the problems (Ashirov
R.R. et al.,1979,Krylov V.I.,et al.,1977)

$$n(z=z_0,\varepsilon,\theta)=n_o(\varepsilon) \; ; \; \left[\delta n + (1-\delta)\frac{\partial n}{\partial z}\right]\Big|_{z=0} = 0 \quad (6)$$

where δ - parameter.

The set of boundary conditions (5) and (6) allows to
solve equation (4) correctly. Grid technique and Crank
Nicholson schemes (Krylov V.I.,Bobkov V.V.,Monastyrsky
V.I.,1977) were employed for solution. Equation (4) was
solved for the energy range ε>1GeV.Figure 1 shows radial
variation of n/n_o at the heliolatitude -7 for energies 1
and 10 GeV. Figure 2 illustrates latitudinal variations of
n/n_o for the energies. Following values of latitudinal
gradient of gcr were obtained at the orbit of the Earth:

$$\frac{1}{n}\frac{\partial n}{\partial \theta}(\varepsilon=1 GeV)=1.9\%/a.u \qquad \frac{1}{n}\frac{\partial n}{\partial \theta}(\varepsilon=10GeV)=0.16\%/a.u$$

Hence including in the equation of gcr
propagation the term describing drift of particles results
in redistribution of density ,appearance of latitudinal
gradient and reduction of modulation depth.

Let's consider and analyse experimental data connected
with heliomagnetic cycle. As follows from abovementioned
facts latitudinal gradient results in N-S asymmetry (
Kolomeets K.V.,et al.,1977) . Let's consider asymmetry of
cosmic rays and solar activity. Figure 3 shows amplitude of
north-south asymmetry in the stratosphere data of Mirny and
Murmansk at the depths of 20 g/sm^2 (a) and 480 g/sm^2 (b). One
can see that amplutude of the effect grows with the depth in
the atmosphere, this fact demonstrates rigid energy spectrum
of the effect.

The investigation of solar activity during the last
magnetic cycle reveals pronounced N-S asymmetry at all
heliolatitudes. Figure 4 shows north-south asymmetry for the
ranges of heliolatitudes (20-30) (a); (30-40) (b); (40-50)
(c). One can see 22-year wave in N-S asymmetry. The change
of the sign of north-south asymmetry occurs during the
periods of inversion of solar total magnetic field. Periods
of inversion are shaded.

In order to study nature of 22-year variation of
neutron component of cosmic rays we analysed continuous set
of the data of neutron monitors of the worldwide network for
the last magnetic cycle. The wave averaged over two
eleven-year cycles was substructed from original data to
exclude 11-year variation. Figure 5(a) shows obtained 22-year
variation for Deep River station.

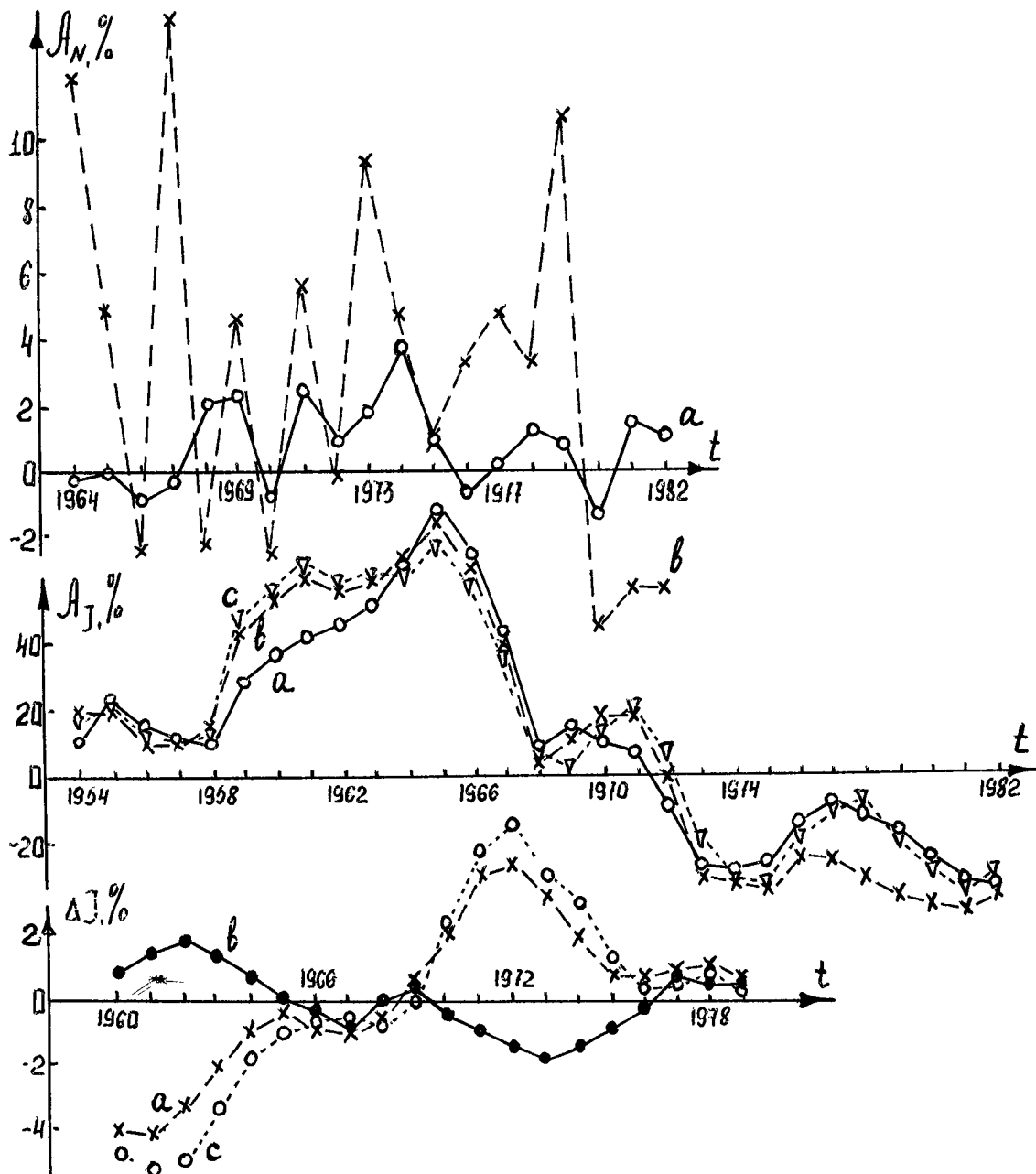Taking into account 22-year wave in solar activity we

Fig.3. Temporal variation of amplitude of N-S asymmetry stratosphere data of Mirny and Murmansk).

Fig.4. Temporal variation of N-S asymmetry of solar activity at various heliolatitude regions.

Fig 5. 22-year variation of cosmic ray intensity, observed at Deep River. (a) -22-year wave in cosmic rays expected due to corresponding variation of solar activity. (b)- variation of cosmic ray intensity due to drift effects.

determined contribution of the wave to cosmic ray intensity.
22-year wave in cosmic rays expected due to 22-year variation
of solar activity was found on the basis of empirical
relation between solar activity and cosmic ray intensity.
The result is given in figure 5 (b).   One can see that
obtained change in cosmic rays due to solar activity is in
opposite phase with the observed variation of cosmic rays.
Substructing from obtained 22-year wave wave expected due to
corresponding variation of solar activity we obtained
variation of cosmic ray intensity produced by other
mechanisms and among them drift of particles in solar total
magnetic field.   So corresponding variation of solar
activity, inversion of solar total magnetic field, drift
effects and other space distributions contribute to the
observed 22-year variation.

R E F E R E N C E S

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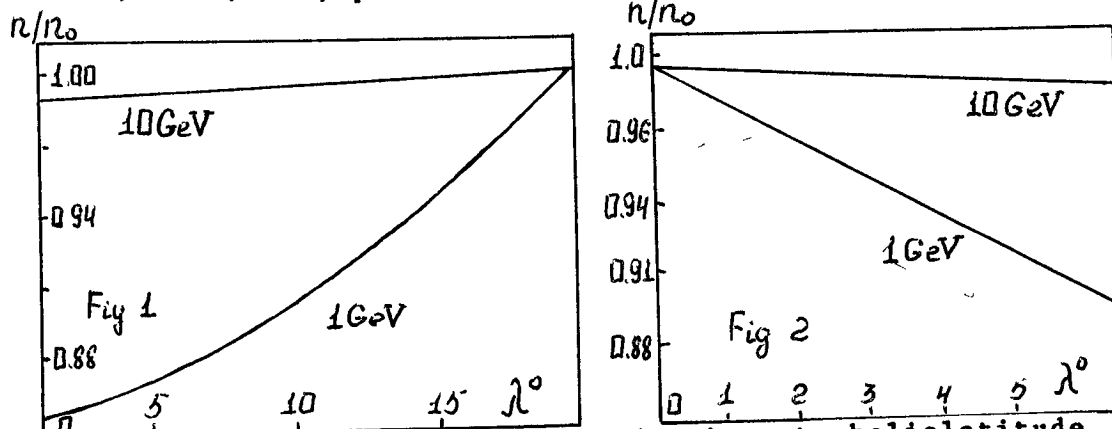Moskva, 1958, v.1, p.657.

Fig.1. Radial dependence of gcr density at heliolatitude
at energy 1 and 10 GeV.
Fig.2. Latitudinal dependence of gcr density at energies 1
and 10 GeV.