Origin of the Galactic Cosmic Ray Anisotropy With a Hard Energy Spectrum

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Abstract

A long-standing investigations of the cosmic ray anisotropy with muon telescopes and the ionization chamber ASK-1 showed that the daily variation maximum in the high energy region as compared with the low energy occurred at more earlier time. In this paper the origin of the additional anisotropy component with the hard energy spectrum and a mechanism of the long-term anisotropy modulation have been discussed.

1 Introduction:

The totality of obtained knowledge about energetic characteristics of daily variations testifies the significant variability of the solar wind and interplanetary magnetic field features with a solar cycle. Characteristics of the cosmic ray anisotropy found from ground-based as well as underground observations, on the whole, are satisfactorily described by the convection-diffusion theory by Krymsky (1964). However, prolonged observations showed that there were anisotropy changes controlled by the solar activity. According to Duggal and Pomerantz (1975), Krymsky et al., (1976) after 1971 a shift of the maximum time to earlier hours was observed. The basic features of the anisotropy are satisfactorily described by a representation of the proper diffusion tensor of cosmic rays. Therefore, naturally we would try to understand there changes on the assumption that their reason is namely the diffusion tensor changes. If the "quasibome" approximation is used for this on the assumption that the longitudinal, lateral and Hall (antisymmetric) coefficients are (Krymsky, et al., 1981)

$$\kappa_{||}=\alpha\rho v/3,\ \kappa_{\perp}=\kappa_{||}/(1+\alpha^2),\ \kappa_H=\kappa_{||}\alpha/(1+\alpha^2),$$

where ρ is a hyroradius, v is a particle velocity, then all tensor is entirely characterized only a given parameter α. The antisymmetric part of the diffusion tensor creates the directional transport of particles with the velocity

$$\mathbf{U_{dr}}= 2v\rho H \text{ rot } (\mathbf{H}/H^2)\ \alpha^2 / 3(\alpha^2+1),$$

where **H** is the magnetic field vector. At $\alpha>>1$ this velocity is coincident with the particle drift velocity in the inhomogeneous magnetic field. Effects caused by the drift lead to essential changes of the anisotropy (Levy, 1976): at the positive polarity (scalar product of the magnetic and rotational momenta of the Sun is positive) the radial component arises which is responsible for the daily variation with the 12 h maximum. In this paper we again return to this interesting problem in order to make more extensive data of the Yakutsk ground-based and underground detector complex, to determine qualitatively a behavior of the approximating parameter α with the change of the particle energy and to coordinate anisotropy features with the diffusion tensor of the particles.

2 Data Analysis:

Annual data of the daily variation of cosmic ray neutron and muon components are used as the initial material. Neutron monitor data at Deep River for 1955-1995 and Yakutsk for 1996-1998 have been used. Of cosmic ray detectors the Yakutsk ionization chamber ASK-1 is characterized by its high stability and duration of measurements (1953-1998). For the analysis cosmic ray measurement data with muon telescopes at the ground and underground at depths of 7, 20 and 60 m w.e. (T0, T7, T20 and T60) have also been used. The observed daily variation obtained ASK-1 was corrected by the temperature effect A_T=0.07 % and t_{max}=4.4 h. Temperature effects at levels of T0, T7, T20 were corrected by using the cross telescope method. All vectors of the daily variation were corrected by the Compton-Getting effect caused by the orbit rotation of the Earth around the Sun.

Primary vectors of the cosmic ray anisotropy for each registration energy level were found by “received vector” method (Kuzmin, 1968). Obtained initial vectors were decomposed to the radial (A_{12}) and azimuthal (A_{18}) components. Results of such a treatment are presented in Figure. The approximations of time series by sinusoids of 11-year and 22-year periods are plotted in the same place which characterize the long-term anisotropy modulation.

Table

Radial A_{12} and azimuth A_{18} components of the primary cosmic ray anisotropy

detector	A_{12}, %		A_{18}, %		
	constant	variable	constant	variable	
		22-year		11-year	22-year
NM	0.099±0.001	0.0868	0.354±0.001	0.0551	0.0612
T0	0.090±0.003	0.0429	0.227±0.003	0.0653	0.0864
ASK-1	0.067±0.001	0.0388	0.217±0.001	0.0429	0.0433
T7	0.090±0.004	0.0292	0.211±0.004	0.0916	0.0660
T20	0.076±0.002	0.0338	0.131±0.002	0.0558	0.0583
T60	0.054±0.006	0.0106	0.068±0.006	0.0394	0.0628

Table lists the anisotropy parameters and its long-term changes found from measurements for several energetic regions. The effective energies for each observation channel increase from the neutron monitor to the T60 level. From the Table it is seen that the average anisotropy in the radial direction is of a significant

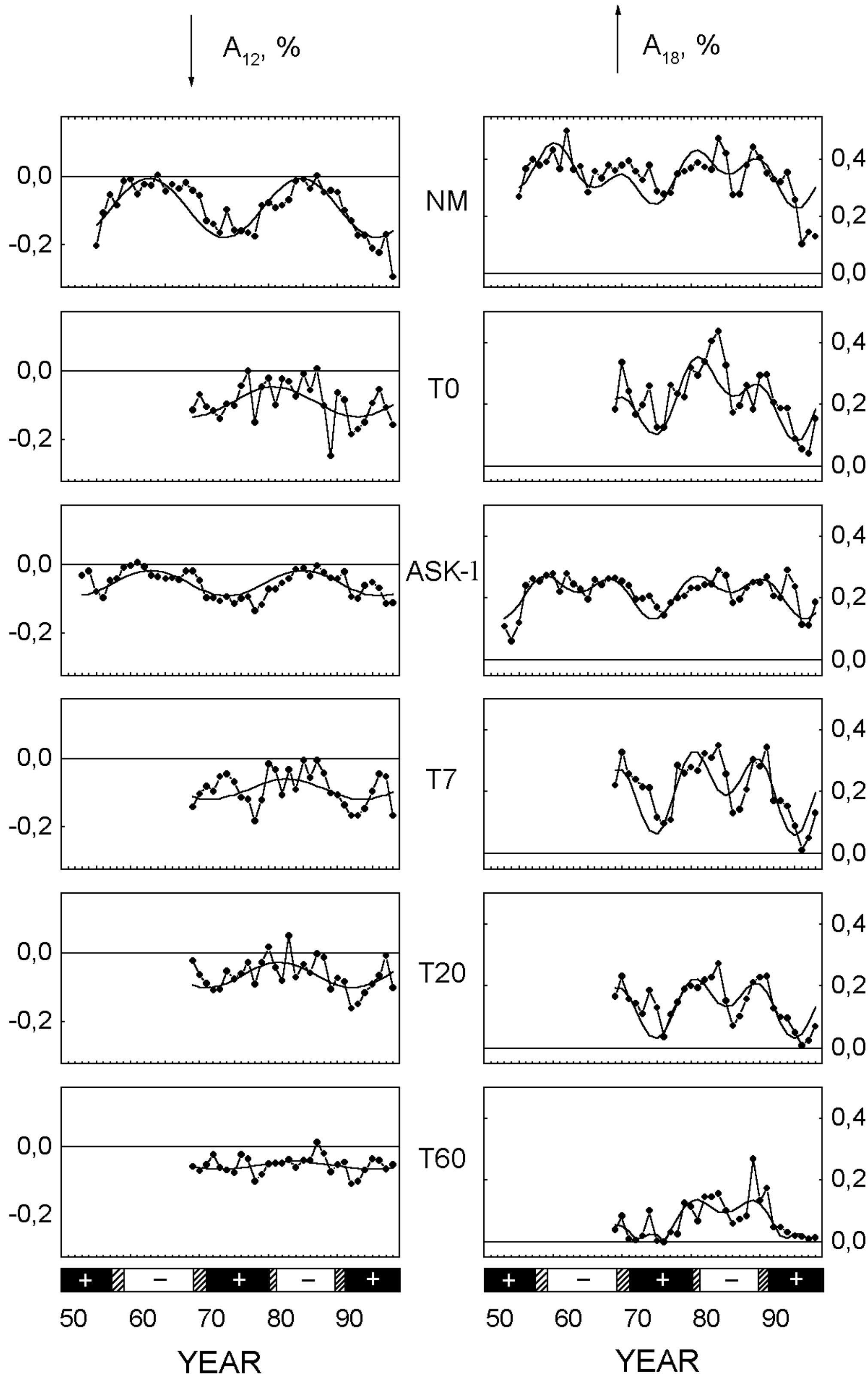

Figure 1: Radial A_{12} and azimuth A_{18} components of the primary cosmic ray anisotropy

harder spectrum than the azimuth one. In this case in low energy part of the region (~10 GeV) this component has almost total modulation with the 22-year period. As to the azimuth component, then, on the contrary, its modulation is close to 100 % in the high energy region.

3 Discussion:

Such a behavior of the anisotropy and its long-term modulation has the following qualitative explanation. It is necessary to suggest that the diffusion parameter α decreases as the particle energy increases. In the low energy region where $\alpha^2 >> 1$ the anisotropic diffusion is prevalent to which 18 h – component corresponds. In this energy region a capture of particles from high heliolatitudes creating 12 h component is negligible and almost entirely is determined by the particle drift at the positive polarity of the magnetic field. A change of the parameter α in the low energy region does not violate the indicated strong inequality (i.e. the diffusion continues to be in the saturation region), therefore the 18 h component modulation is small. On the contrary, in the high energy region where $\alpha \leq 1$ the diffusion is close to the isotropic one, the capture of particles from the high heliolatitudes plays a large role, and average amplitudes of 18 h and 12 h components will be about the same. In this case the relative role of the drift manifesting in the 22-year modulation of the 12 h component is negligible. However, changes of the value of α with the solar activity cycle here would influence strongly on the value of the 18 h component. Then, all peculiarities in the anisotropy behavior listed in the Table receive so the natural interpretation.

From here it is concluded that the above picture of the heliospheric modulation with the quasibome diffusion tensor on the whole is correct and is usable to obtain more proper quantitative conclusions about a character of the magnetic turbulence in the heliosphere.

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