Variation of the High-Energy Cosmic Ray Anisotropy with a Solar Activity Cycle

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Abstract

The observation of cosmic ray anisotropy in Yakutsk for many years and their comparison with a theoretical model are given. It is shown that the cosmic ray anisotropy depends on a degree of curvature of neutral surface and the polarity sign of interplanetary magnetic field.

1. Data analysis

The heliospheric modulation of cosmic rays reflects characteristics of the solar wind of interplanetary magnetic field over the whole volume of the heliosphere. Their changes in a solar activity cycle leads, in particular to variations of the cosmic ray anisotropy. The observation of the anisotropy with the neutron monitors and ionization chamber for the period of about 40 years and with underground muon telescopes for 30-year period in Yakutsk have been treated by Krymsky et al. [1] in order to determine the parameters of 11-year and 22-year variations. These data are given in Table 1.

Here NM is a neutron monitor, T0, T7, T20, T60 are ground and underground telescopes at the depths of 7, 20 and 60 m w.e., respectively, and ASK-1 is the ionization chamber. The "receiving vectors" [2] of detectors which allow to obtain the anisotropy characteristics after the exclusion of influence of observation conditions (the geographical position and aperture of detector, influence of the magnetic field) are used at the treatment. In this case, the anisotropy is averaged in energy according to the coupling coefficients of a detector. The coefficients are approximated by the expression

$$W(p) = p_0^{-1}\left(\frac{p_0}{p}\right)^2 e^{-\frac{p_0}{p}}, \tag{1}$$

where characteristic value of p_0 is given in Table 1.

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Table 1. Radial A_{12} and azimuth A_{18} components of cosmic ray primary anisotropy

Detect.	P_0, GeV/c	A_{12} constant	A_{12} variable 22-year	A_{18} constant	A_{18} variable 11-year	A_{18} variable 22-year
NM	9,4	$0,077 \pm 0.001$	0,0961	$0,322 \pm 0,001$	0,0760	0,0678
T0	40	$0,082 \pm 0,003$	0,0404	$0,259 \pm 0,003$	0,0404	0,0541
ASK-1	50	$0,058 \pm 0,001$	0,0400	$0,215 \pm 0,001$	0,0393	0,0457
T7	60	$0,086 \pm 0,004$	0,0344	$0,214 \pm 0,004$	0,0762	0,0646
T20	85	$0,065 \pm 0,002$	0,0344	$0,152 \pm 0,002$	0,0559	0,0442
T60	170	$0,054 \pm 0,006$	0,0106	$0,073 \pm 0,006$	0,0393	0,0544

Table 2. Values of anisotropy parameters obtained from observations and calculated theoretically

Detect.	A_{12} $qA < 0$	A_{12} $qA > 0$	A_{18} $qA < 0$	A_{18} $qA > 0$	A_{18} A_{max}
NM	-0,02(0)	0,18(0,16)	0,31(0,32)	0,17(0,16)	0,40(0,40)
T0	0,04(0)	0,12(0,15)	0,27(0,30)	0,17(0,15)	0,30(0,31)
ASK-1	0,02(0)	0,10(0,12)	0,23(0,24)	0,13(0,12)	0,26(0,29)
T7	0,05(0)	0,11(0,10)	0,19(0,20)	0,07(0,10)	0,29(0,27)
T20	0,03(0)	0,09(0,07)	0,13(0,15)	0,05(0,07)	0,21(0,22)
T60	0,04(0)	0,06(0,04)	0,08(0,08)	-0,02(0,04)	0,11(0,11)

A_{max} is a maximum amplitude of anisotropy

2. Discussion and conclusion

11-year variations have a maximum of anisotropy during the period of maximum solar activity, and 22-year variations give maximum 18-h and minimum 12-h anisotropies during the minimum periods with the negative polarity of a general magnetic field of the Sun. Assuming that these changes are sinusoidal, we obtain smoothed values of anisotropy parameters. These values are given in Table 2 along with theoretically calculated values which are in brackets. See below about the theoretical values.

The theory of cosmic ray modulation has been constructed in simple supposition. The diffusion coefficient is assumed to be anisotropic, so the transverse diffusion coefficient is much smaller than longitudinal diffusion coefficient. The anisotropy is only in the region where the heliolatitude gradient is smoothed (for example, at the expense of a goffer of the neutral surface). Therefore, for the

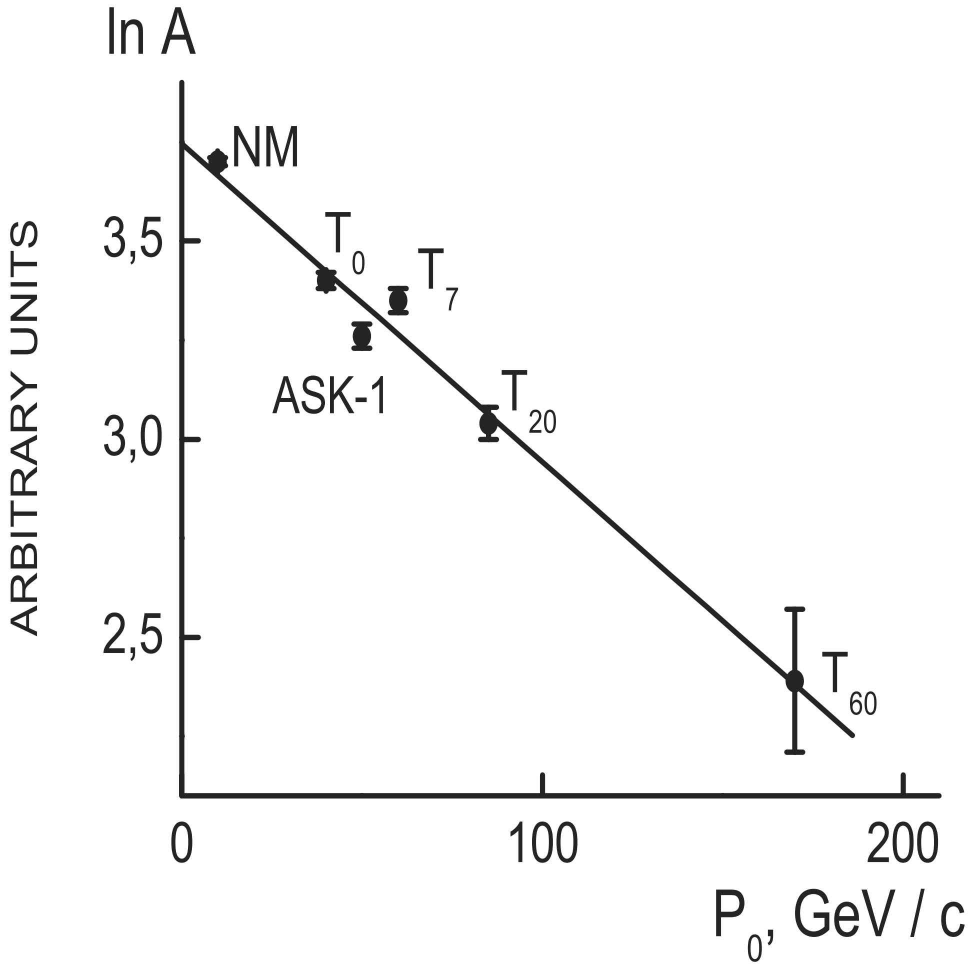

Fig. 1. lnA as a function of P_0.

high-energy particles whose gyroradius is comparable with a range enveloped by the goffer or more, the anisotropy has to become a zero. Near the solar activity maximum this number is about 130 GeV (it is defined by the slope of a straight line in Fig 1. The gyroradius of such particles is 10 13cm, i.e it is close to 1 AU. At such a cut-off of the anisotropy spectrum we obtain the expected amplitude shown in the last column of Table 2 in brockets. Theoretical values in other columns are normalized to the summary amplitude for each detector. It is sen that there is a satisfary agreement which is, however, slightly violated at high energies. Therefore, it may be argued that changes of anisotropy with the 22-year cycle indicate to the role of drift effects and the standard model of heliosphere with homogeneous solar wind satisfactorily describes the behaviour of cosmic rays.

3. Acknowledgements

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4. References

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