CHANGE OF COSMIC RAY ANISOTROPY WITH SOLAR ACTIVITY

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ABSTRACT

Muon telescope data at various depths underground in Yakutsk within energy range 10-300 GeV for 1957-1984 are analyzed. 22-year variation of the interplanetary magnetic field aligned component is found. The variation is caused by interaction of heliomagnetosphere with the local galactic field and interstellar wind.

In [1,2] was convincingly shown the existence of 22-year variation of cosmic ray anisotropy aligned with the interplanetary magnetic field. Unfortunately, there are no reliable results on data of ground and underground registration during the end of the 20-th and the beginning of the 21-st solar activity cycle which confirm the result of [1,2].

Here we investigate the long-term variations of cosmic ray anisotropy for 1937-1984 and define the energy range at which the variation is observed. For the analysis were used the Fourier components of mean annual diurnal variation of muon intensity on data of ionization chambers at Cheltenham, Huancayo (1937-1972) and at Yakutsk (1954-1983) and muon telescopes of the Yakutsk underground complex at depths 0, 7, 20 and 60 m w.e. (1958-1984). Data are pressure corrected. To estimate the contribution of the atmospheric temperature into the observed diurnal variation on data of ionization chambers we used the indirect methods. Firstly, we supposed the mean-annual total vector of diurnal temperature fluctuations on the whole depth of atmosphere is practically invariable, at least, for 22 years. In this case the difference vector of the cosmic ray diurnal variation $\Delta\vec{r}_i = \vec{r}_i - \vec{r}_{aver}$ ($\vec{r}_i$ is the observed vector of the diurnal variation for i-year, $\vec{r}_{aver}$ is the average vector for 22 years) is of extra-atmospheric origin.

The observed vector for 1951-1972 at Huancayo and Cheltenham and for 1954-1975 at Yakutsk as $\vec{r}_{aver}$ was taken. We calculated the receiving vectors of the diurnal variation for various mechanism of formation of the cosmic ray anisotropy. In the given case the receiving vectors were used: for Huancayo $z = 0.80e^{-i\cdot 51°}$, for Cheltenham $z = 0.82\ e^{-i\cdot 31°}$; for Yakutsk $z = 0.72\ e^{-i\cdot 31°}$. Secondary, one of the reliable methods of exclusion of the temperature effect is the crossed telescope method which allows to obtain the absolute anisotropy value. In the Table are presented the amplitude and the maximum time of primary anisotropy for 1958-1980 obtained on difference of telescope readings directed southward and northward at an angle 30° relative to vertical at depths 0, 7, 20 and 60 m w.e.

m w.e.	0	7	20	60
Amp., %	0.194±0.008	0.149±0.006	0.118±0.005	0.050±0.009
t_{max}, h	16.0±0.1	15.4±0.2	16.1±0.2	14.8±0.7

It is clear from the Table that at all the levels the maximum time differs significantly from 18^h.

Then we consider the problem on the separation of 11- and 22-year variations of the cosmic ray anisotropy. Two versions of decomposition of the primary anisotropy vector into two components on clock-dial were considered: the first version - into components along $9\text{-}21^h$ and $6\text{-}18^h$ lines (in Figures 1 and 2 the open circles), the second version - along $9\text{-}21^h$ line and the line of anisotropy maximum time for 22 years (the Table and closed circles in Figures 1,2).

In Fig.1 and 2 the ionization chamber data for 1937-1953 are for Huancayo and Cheltenham stations and for 1954-1983 are for ASK-1 Yakutsk. The statistical accuracy of determination of anisotropy components for the first period is ±0.01%, for the second one is ±0.004%.

In Fig.1 the 22-year cosmic ray anisotropy variation is shown. As seen from the Fig.1 it is observed at all the registration levels except 60 m w.e. At the 20 m w.e. depth where the effective energy of registered patricles is ~ 70 GeV, its amplitude is 0.05%.

Note that in the case of the first version of decomposition the point scattering increases. More pronounced variation is observed at a longer set of data of ionization chambers. The magnetic field of the northern solar hemisphere (a dashed line in Fig.1) which was estimated on a number of polar faculaes [3] evidences the negative correlation with 22-year anisotropy variation along the $9\text{-}21^h$ line. When the interplanetary magnetic field being in the north part of the ecliptic is directed from the Sun the cosmic ray anisotropy is field-aligned to the Sun. If in the same region the field sign changes to opposite then the anisotropy will be directed field-aligned from the Sun. At the moment of sign-change of general magnetic field of the Sun the 22-year wave in Fig.1 crosses the zero line. It is clear from Fig.2 that the 11-year cosmic ray anisotropy variation is observed as well at all the depths which is probably caused by the decrease of regularity degree of the interplanetary magnetic field at solar activity minima. From the Table it follows that the maximum time of anisotropy caused by convective-diffusive process for 23 observation years is $15-16^h$. It means that the inhomogeneous solar wind is of a flattened form.

The obtained temporal change of the galactic cosmic ray anisotropy can be caused by the peculiarities of interaction of the heliomagnetosphere with the local interstellar magnetic field. It is known that the local galactic magnetic field (Orion's arm field) is oriented in the direction of solar apex ($\alpha = 20°$, $\delta = 35°$) and the speed vector of the interstellar wind ($\sim$ 20 km/s) lies in the plane of the ecliptic at the angle 53° with respect to the direction of the field (see references in [4]).

In [5,6] a model of opened and closed configurations of the heliosphere was proposed. The opened heliosphere is formed if the solar magnetic field in the northern hemisphere is derected outward, the closed one - at the opposite field orientation. In the first case the galactic cosmic rays penetrate into the heliosphere along force lines in polar regions, in the second case the penetration occurs by a diffusion way.

In the given here model it is not taken into account that the solar wind speed increases while moving away from the solar equator [7] and the magnetic field in heliosphere polar regions forms a structure of magnetic cork type. Therefore even in the case of the "opened" heliosphere the galactic cosmic rays penetrate mainly by a diffusive way. Besides, particle transfer within the inner part of the heliosphere from high latitudes to low ones is rather slow due to a small ratio of perpendicular diffusion coefficient to the parallel one ($D_\perp / D_\parallel \ll 1$). On the whole the approach to be solution of considered problem can be retained if to assume that at the opened configuration the local galactic field and the heliosphere field under interaction dissipate in a restricted narrow layer enveloping the part of the heliosphere where the interstellar wind blows. The energy of magnetic fields passes to the plasma of the interaction region and spreads along force lines [8] .

Thus in the case of the opened heliosphere an additional diffusion outflow of particles from the heliosphere in the plane of ecliptic can be formed which compensates the wind speed increase at high latitudes. Due to the condition $D_\perp / D_\parallel \ll 1$ the additional current for particles, at least, at 20 m w.e. will be directed along force lines, mainly. At the opposite orientation of the magnetic field of the heliosphere the supersonic interstellar wind causes the field increase (beyond the region of a possible heliomagnetosphere "tail") and therefore some excess of cosmic rays. It leads, in its turn, to the increase of the diffusive stream of cosmic rays directed inside the heliosphere.

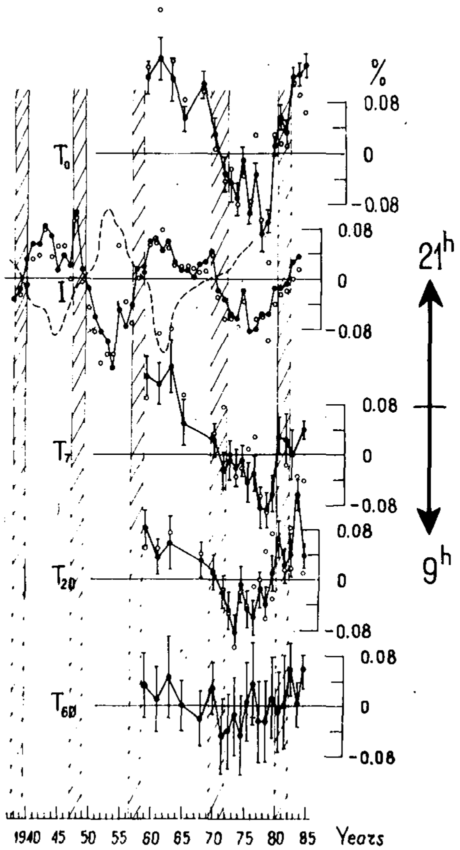

Fig.1. 22-year variation of cosmic ray anisotropy. T_0, T_7, T_{20}, T_{60} are muon telescope data at the 0, 7, 20 and 60 m w.e., I is ionization chamber data. Dashed line - magneric field of northern hemisphere of the Sun

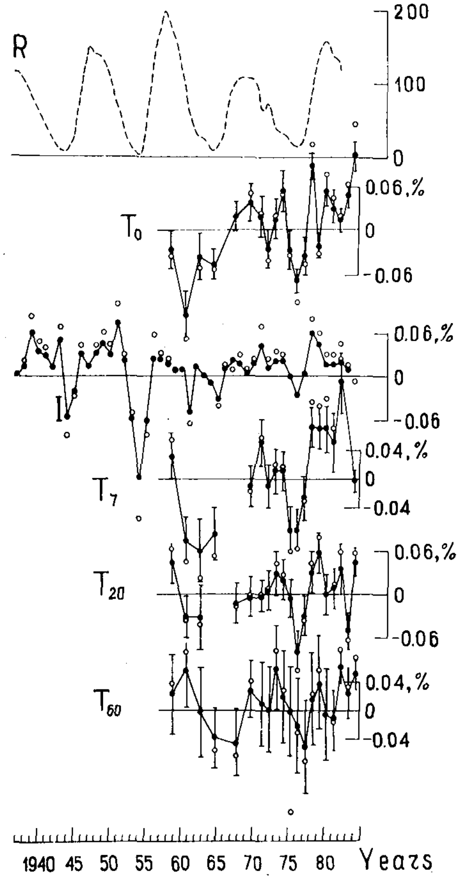

Fig.2. 11-year variation of cosmic ray anisotropy. R is solar activity (sunspot numbers). I, T_0, T_7, T_{20}, T_{60} the same as in Fig.1

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