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Anomalous Behavior of Cosmic Ray Anisotropy in the Last Minimum of the Solar Activity

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Abstract

Variations of cosmic ray vector anisotropy, obtained by the global survey method from the worldwide neutron monitor network data are analyzed for 1990-1996. The anisotropy of the cosmic rays revealed unusual behavior in the last solar activity minimum, especially in the beginning of 1996. It showed extraordinary small amplitude and unusual amplitude-phase distribution without any certain direction. This anomalous behavior of anisotropy and gradients was in phase with cosmic ray density maximum and with the minima of interplanetary magnetic field module and heliospheric current sheet tilt. It is shown that the last circumstance is most important for the explaining of the observed anomaly.

1 Introduction:

Anisotropy of cosmic rays is highly changeable. It is well known (e.g. Forbush, 1969; Bieber & Chen, 1991) that solar-diurnal component of anisotropy varies as with the solar activity cycle (mainly amplitude), so with solar magnetic cycle (mainly phase). These changes are gradual and extended for many years. Abrupt and significant variations of anisotropy from hour to hour are observed during Forbush effects (e.g. Belov et al., 1997). Are the abrupt changes of anisotropy possible on the middle time scale (from month to month)? Bieber & Evenson (1997) noted very small amplitude of the solar diurnal cosmic ray anisotropy in 1996, differed radically from nearby periods and dropped out from the whole time series. In this work we study this anomaly to appreciate how much it unique is and what can be it associated with. We use hourly components of 10 GV CR anisotropy within the 1990-1996 years, inferred from the data of all neutron monitor network by global survey method (Belov et al., 1995)

2 Anisotropy within 1990-1996:

In Figure 1 long-term changes of the anisotropy vector in 1990-1996 are shown. The biggest changes

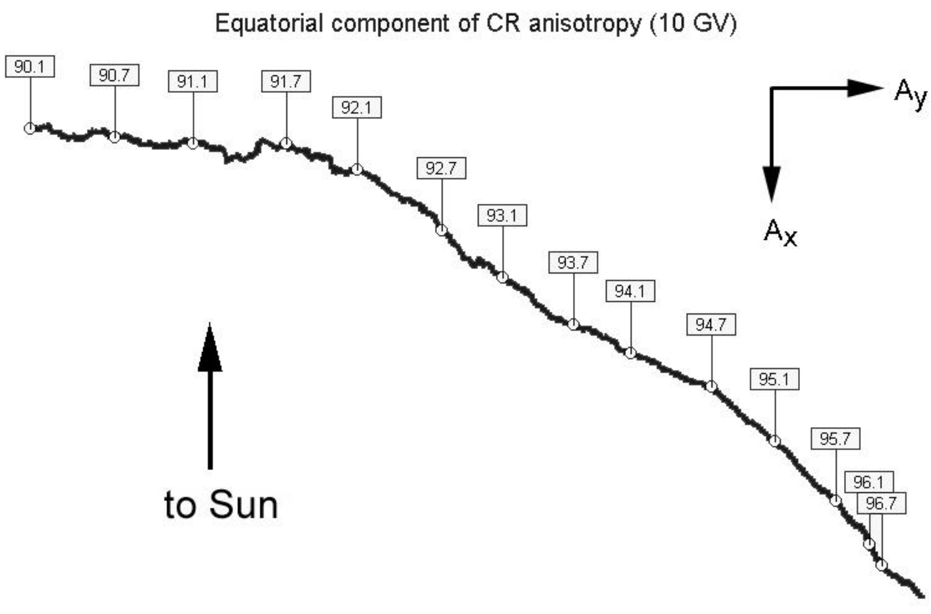

Figure 1: The vector diagram for solar-diurnal anisotropy in 1990-1996 years, obtained from hourly results of global survey method.

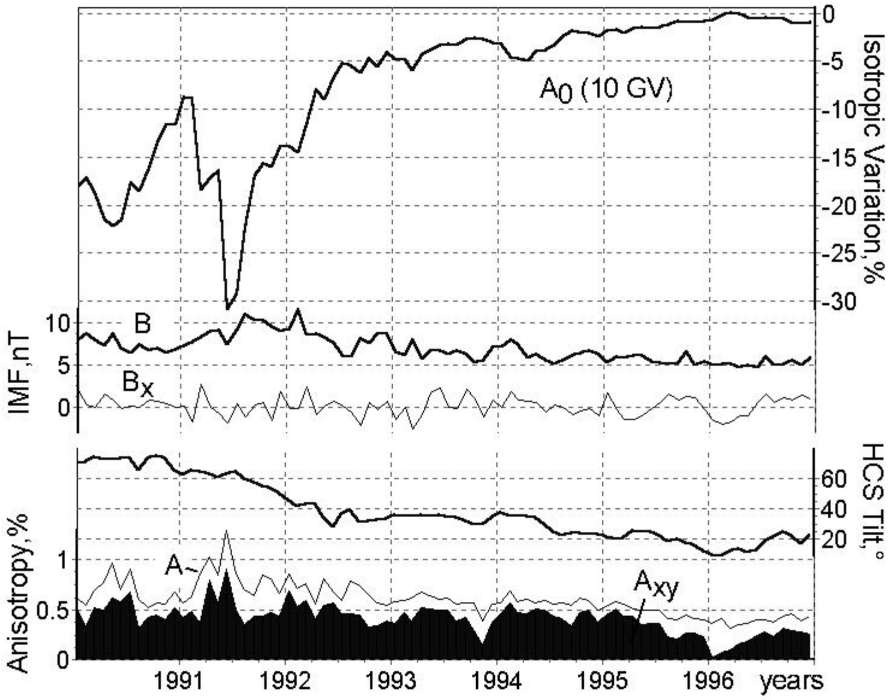

Figure 2: Variation of 10 GV cosmic ray density A_0, module B and radial component B_x of IMF, tilt of heliospheric current sheet, amplitude of CR solar-diurnal variation (A - scalar averaging, A_{xy} - vector averaging).

of anisotropy phase happen after polarity reversal in 1991-1992. However we see the pronounced changes as before reversal so much later, in the solar activity minimum. Closely placed marks on the beginning and on the end of the first half-year in 1996 argue a small anisotropy on this period. In Figure 2 monthly averaged amplitudes of solar diurnal anisotropy A are presented. This anisotropy is minimal on the beginning of 1996 (in the March A=0.31%). Approximately at those time a local maximum of CR density (March-April) and IMF module minimum are observed. Mostly unexpected is behavior of the amplitude A_{xy} obtained not by the scalar, but by vector averaging. In January-March it is much less than in other periods, and in January is practically equal zero (A_{xy}=0.02 %). Usually magnitudes A and A_{xy} are tightly correlated, but this correlation is failured on the beginning of 1996. It means that not amplitude but phase of anisotropy should have an unusual behavior on this period. This anomaly is in a good agreement with behavior of HCS tilt η (Hoeksema, 1999). It is rather small in the period of 1995.12-1996.06 and in January-February 1996 $\eta<10^o$ and minimal for decade.

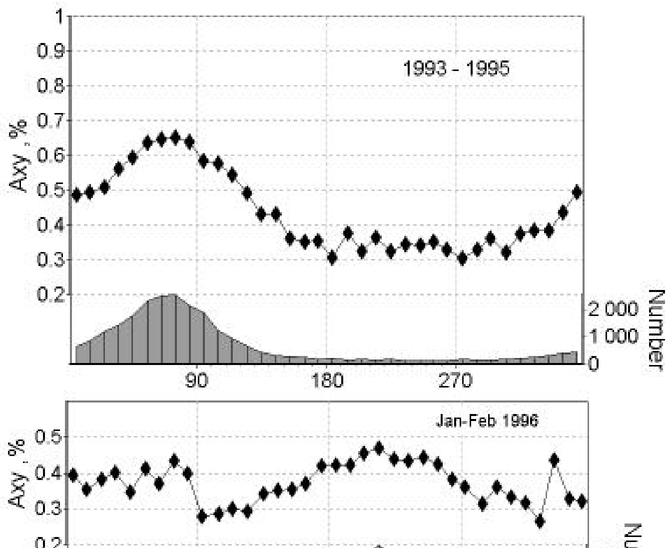

Figure 3: The mean amplitude-phase interrelation and phase distribution for solar-diurnal anisotropy in 1993-1995 (upper panel) and in January-February 1996 (lower panel)

3 Anomalous anisotropy on the beginning of 1996:

Figure 3 presents the phase distribution and amplitude-phase dependence of solar diurnal anisotropy on January-February 1996 and, in comparison, on preceded period of 1993-1995 years. In 1993-1995 the picture is close to those predicted from convective-diffusion theory (Belov, 1987). Amplitude maximum coincides very closely with the maximum of phase distribution, and anisotropy from «forbidden» directions is observed more rarely and has much less value. But on the beginning of 1996 anisotropy «forgets» its usual direction and shows almost homogenous distribution over the whole longitude region with some preference of direction across of the mean IMF. Actually in Jan-Mar 1996 vector of the solar-diurnal anisotropy behaves itself unusually (Figure 4). It rotates anti-clockwise,

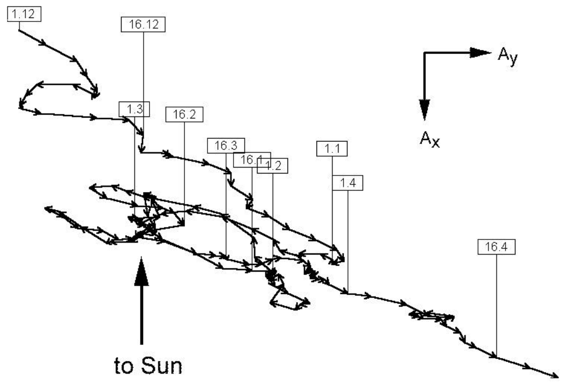

Figure 4: Vector diagram of solar-diurnal anisotropy in the period of December 1995-March 1996

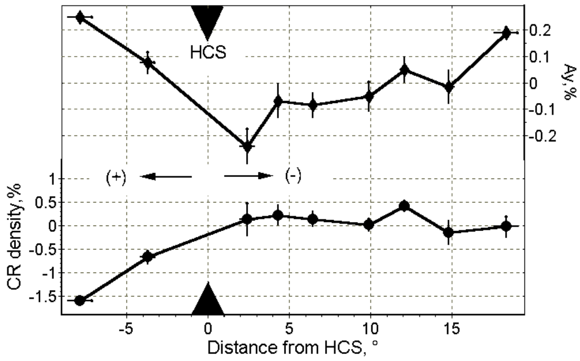

Figure 5: Relation of 10 GV CR density variation and azimuthal component A_y of solar-diurnal anisotropy through December 1995-March 1996

returns by own tracks, and, at last, on the end of March is found at the same place as in the beginning of January. Changes of anisotropy are associated with the Earth location relatively to heliospheric current sheet (Figure 5). Asimuthal component A_y of solar-diurnal anisotropy appears to be normal only in extreme points of the picture: in positive sector and deep inside of the negative one. Close to the neutral sheet a region of negative (anomalous) A_y, extending up to 15º into negative sector. Changes of the CR density in crossing of sector boundary may indicate both the difference of CR density into sectors of the opposite polarity and significant (up to 10%/a.u.) local gradient close to the current sheet.

4 Discussion:

Attempt to explain obtained results in the frame of convective-diffusion model of anisotropy leads to unreasonable inference (negative radial gradient, near-isotropic diffusion). Such an attempt couldn't be successful. Diffusion approach is possible when medium is quasi-homogeneous on one larmor radius ρ at any rate, and solar wind measurements near the Earth characterize all this area. However, on the beginning of 1996 the Earth didn't depart from current sheet beyond of 20° and mainly was not far than 6-7° (Hoeksema, 1999). Flat current sheet explains as annual wave of B_x component of IMF (Figure 2) so a predominance of one negative IMF polarity in Figure 6, where vectors of the solar-diurnal anisotropy (convective component is subtracted) are presented joint with IMF vectors. In the interplanetary magnetic field of 5 nT near Earth latitude of 6° corresponds to ρ for particle rigidity ~23 GV. So, NM network, observed anisotropy in question, appears to be all this time inside of HCS that exerted crucial influence on the anisotropy behavior. In these conditions not only usual diffusion model is inapplicable, but assumption of rigidity independent anisotropy up to 100 GV seems to be erroneous. CR anisotropy observed near current sheet needs a special approach both to determine and to interpret it. However, anisotropy model as it may be, can't explain inferred anisotropy without Hall's component and great cosmic ray gradient near current sheet.

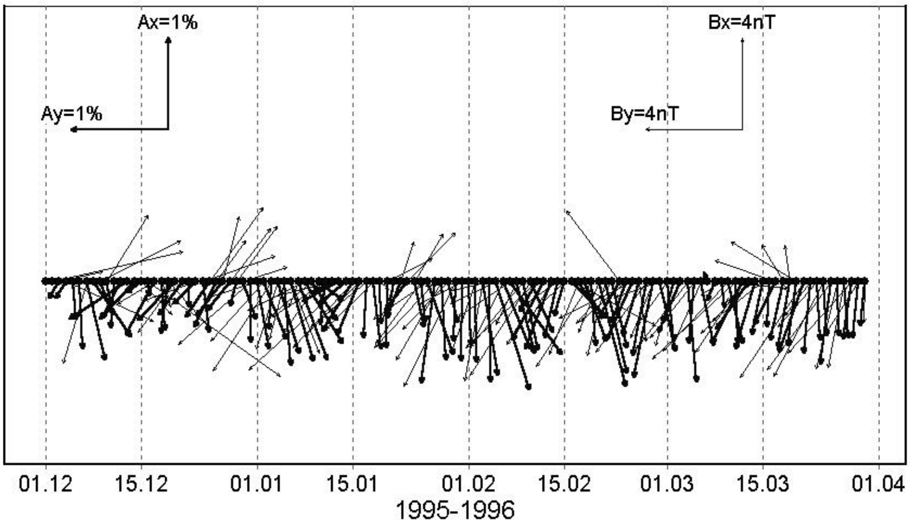

Figure 6: Vectors of solar-diurnal anisotropy of 10 GV cosmic rays (thin arrows) and interplanetary magnetic field (thick arrows) on the period of 12.1995-03.1996.

We could remember the significant latitudinal gradient derived from Ulysses observations of high energy (>2 GeV/n) protons and alpha-particles on high latitudes in the 1994-96 (Heber et al., 1997; Belov et al., 1998). When HCS became flat, the region of great latitudinal gradient went down to the low latitudes. As this dependence is not from heliolatitude, but sooner from heliomagnetic latitude, this gradient sometimes and somewhere can be manifested not only by latitudinal but also by radial and asimuthal one. Due to this anisotropy appears to be unsteady and anomalous.

5 Conclusion:

Significant and drastic changes of cosmic ray anisotropy from month to month are possible. It may occur not only under high solar activity and during fast reconstruction of heliomagnetosphere, but in the quiet periods with stable heliospheric structure. The beginning of 1996 is the bright example of such kind.

Being extraordinary, discussed anomaly is generated by the combination of usual phenomena. It has analogues in the past: first of all in the 1954 (Dorman, 1958) and (in a much lesser degree) in the 1976. Similar, but shorter (several days) variations are observed near minima of solar activity often enough. Such a behavior of anisotropy appears when HCS become nearly flat and great latitudinal gradient exists in the inner heliosphere, i.e. in the minima solar activity with positive polarity of general solar magnetic field. If it is not a simple coincidence, we should wait 15 years at least for the next such anomaly.

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