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FEATURES OF THE INTERPLANETARY MAGNETIC FIELD TURBULENCES IN DIFFERENT PERIODS OF SOLAR MAGNETIC CYCLES

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Data of By, Bz components of the interplanetary magnetic field (IMF) have been used to study a features of the IMF turbulences for two positive (A>0) and two negative (A<0) polarities epoch of solar magnetic cycles (1969-2011). We found that the changes of the exponents ν_y, ν_z, of the power spectral density (PSD) of the By, Bz, components shows a radical alternation of the large–scale structure of the IMF turbulence. It was also found a distinction between the temporal changes of the exponents ν_y, ν_z, for the A>0 and the A<0 polarity epoch of solar magnetic cycles, especially in minima and near minima epoch of solar activity. We suppose that the changes of the turbulence in the range of frequencies (10^{-6}-10^{-5}) Hz (responsible for the scattering of the GCR particles of the energy 5-50 GeV) and the module of the IMF versus solar activity can be considered as the general reasons of the long period variations of the GCR intensity. Rigidity spectrum of the long period variations of the GCR intensity is soft in positive A> 0 polarity epochs, than in negative A<0 epochs.

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1. Introduction

In [1,2,3] were shown that about 75–80% of the 11–year variation of GCR can be interpret based on the diffusion–convection model of GCR propagation. As far this is a case, there is necessary to estimate the contributions of the both processes –convection and diffusion, separately. A role of changes of the convection in the 11–year variation of the GCR intensity is not significant due to almost constant value of the solar wind velocity in the low region of heliolatitudes ($\leq 35^0$) at the Earth orbit during the 11–year cycle of solar activity [4]. Therefore, a change of the diffusion coefficient χ of GCR particles versus solar activity must be a general reason of the 11–year variation of the GCR intensity. Besides, a dependence of diffusion coefficient χ on the spatial coordinates, χ dependents on the GCR particle's rigidity R according to the quasi linear theory (QLT) as, $\chi \propto R^{\alpha}$ [5, 6], where α=2–ν, and ν is the exponent of the PSD of the IMF turbulence ($PSD = Pf^{-\nu}$, where P is power and f is frequency). Based on the modeling and experimental study (using neutron monitors data) we show [2, 3, 7, 8], that the exponent γ of the rigidity R spectrum $\delta D(R)/D(R)$ ($\delta D(R)/D(R) \propto R^{-\gamma}$) of the GCR intensity variations generally is determined by the parameter α ($\gamma \propto \alpha$). We show also, that the rigidity spectrum exponent γ has clearly established 11–year variation in positive correlation with the sunspot numbers, but in negative correlation with the GCR intensity measured by neutron monitors.

A dominant contribution to the scattering of GCR particles in the heliosphere is setting up by the turbulence of components B_y and B_z of the IMF perpendicular to the radial direction [5, 9]; although roles each of them are not equal at all. The average power P of the PSD of the B_y component is greater than the average power of the B_z component (about ~2 times), although the temporal changes of the exponents ν_y and ν_z are in good correlation. So, ascribing a decisive role to the turbulence of the B_y component of the IMF, we use for farther analyses the expression $\alpha = 2 - \nu_y$ (in correspondence with the results of our papers [10, 11, 12]), instead of the expression α=2–ν.

The QLT [6] has problems, e.g., (1) the parallel mean free paths calculated from the experimental data is significantly larger than theoretically expected, (2) impossible of the calculation of diffusion coefficient for pinch angles ~90^0, and so on; however, the QLT has been remaining as a vast inspiration to develop theories of turbulence and propagation of cosmic rays in the interplanetary space up to present. Essential contributions in developing of the theory of turbulence of solar wind, particularly in applicable to the transport of cosmic rays in the interplanetary space, has been bringing in by the group of Bartol Research Institute, University of Delaware, USA, since 80ties of last century up to present [9,13,14,15]. Especially during last 10–15 years, the QLT was undergone to the adjustment and development. In [9] were found good agreement between theoretical results and observations [16] for the damping model of dynamical turbulence, being confirmed in [17] for the composite a slab/2D turbulence geometry. In [18] was suggested a model (BAM) to solve problem of perpendicular diffusion of cosmic rays. The nonlinear guiding center theory (NLGCT) [19] and weakly nonlinear theory (WNLT) [15] were proposed. Considerable distinctions between the expected results from the QLT, and the expected results from the both NLGCT and WNLT theories were found up to few hundred MeV energy of cosmic rays. For the energy ≥ 1 GeV all theories (QLT, NLGCT and WNLT) give almost the same results [20, 21]. Correspondingly, the dependence of the diffusion coefficient χ on rigidity R of GCR particles, as $\chi \propto R^{\alpha}$ is valid for the energy of the GCR particles (5–50 GeV) to which neutron monitors and ground meson telescopes respond. An existence of this dependence are shown based on the study of the 11–year variations [29, 31] and Forbush effects of the GCR intensity [22, 23, 24], as well.

The purpose of this paper is to study the changes of the exponents ν_y, ν_z of the power spectral density (PSD) of the By, Bz, components in period 1969-2011 for various A>0 and A<0 epoch of solar magnetic cycles.

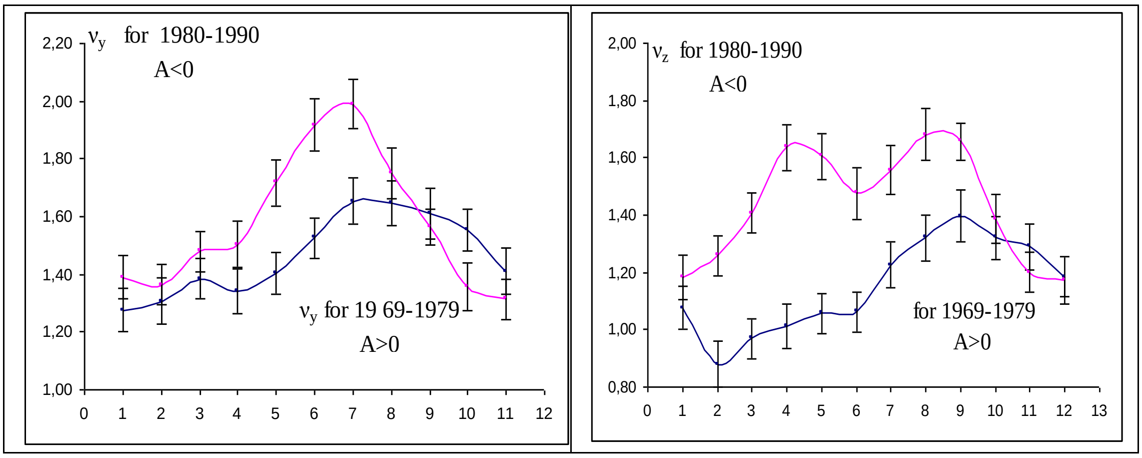
2. Analyze of experimental results and discussion

We calculated the power P and exponents νy, νz, of the PSD ($PSD = Pf^{-\nu_y}$, where f is frequency) of the component of By, Bz of the IMF using the discreet Fourier transform [25] of the autocorrelation function. We used data of the components By, Bz of the IMF for the period of 1969-2011 [OMNI, GSE(nT)] to calculate the exponent ν and power spectrum density PSD by method of Blackmana-Tukeya [25]. We also, calculated the powers P for Bx and Bz components of the IMF in the period of 1969–2011 [26].

We divided whole considered period 1969–2001 into four sub-periods, 1969-1979 with A>0 (positive part of solar magnetic cycle), 1980-1990 with A<0, (negative part of solar magnetic cycle), 1991-2001 (A>0) and 2002-2011 (A<0). We compare periods with different signs of IMF. Period 1969-1979 with period 1980-1990, then 1980-1990 with 1991-2001 and 1991-2001 with 2002-2011. In figure 1abc are presented temporal changes exponent νy for respective pairs of periods with different signs of IMF. In figure 1abc are presented temporal changes exponent νz for this same respective pairs of periods with different signs of IMF.

Fig,1abc show differences in the behavior of the exponent νy of the PSD in different epochs of solar magnetic cycle. Exponent νy for a negative part of solar magnetic cycle (A<0) is larger than for a positive part of solar magnetic cycle (A>0). It is especially visible in minima and near minima of solar activity. For pairs 2002-2011 and 1991-2001 these differences are insignificant.

Based on our finding [11, 12] γ ~ 2–ν, we can state that rigidity spectrum of the long period variations of the GCR intensity is soft in positive A>0 polarity epochs, than in negative A<0 epochs. It means, that averagely, in A<0 epochs an effective rigidity resonant frequency of the IMF turbulence for GCR particle is lower and the larger energy particles are involved in modulation. The consequence of that is a larger range (amplitudes) of any type of variations of cosmic rays in A<0 polarity epochs than in A>0 epochs, which generally is observed by NMs and muon telescopes.



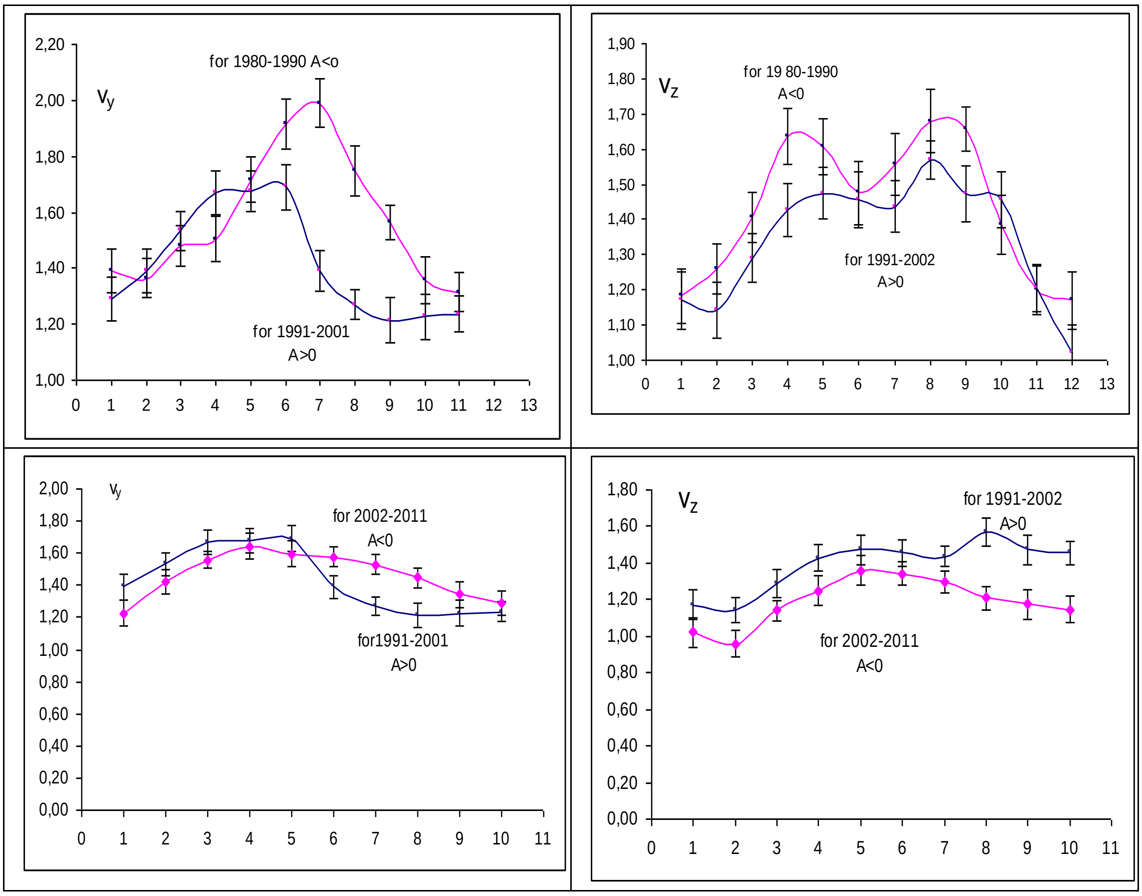


Figure 1abc Temporal changes of the exponents vy, of the PSD of the By (left panel) components and Bz (right panel) for respective pairs of periods with different signs of IMF.
a - 1969-1979 A>0 and 1980-1990 A<0,
b - 1980-1990 A<0 and 1991-2001 A>0,
c - 1991-2001 A>0 and 2002-2011 A<0

Conclusions

1. The exponent ν_y of PSD for negative part of solar magnetic cycle (A<0) is larger than for a positive part of solar magnetic cycle (A>0). As a consequence of that effect we can state that rigidity spectrum of the long period variations of the GCR intensity is soft in positive (A>0) polarity epochs, than in negative (A<0) epochs. A behavior of the exponent ν_z of PSD has the same tendency as ν_y with the exception of periods 2002-2011 and 1991-2001.

2. It can be stated that the changes of the exponents ν_y, ν_z of the of the B_y, B_z components show a radical alternation of the large–scale of the IMF turbulence in period 1969-2011 and an unimportant role of drift in the long period variations of the GCR intensity observed by NMs.

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