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# Cosmic ray fluctuations in the interplanetary magnetic field

**R. G. Aslamazashvili[1], M. A. Despotashvili[1], M. E. Katz[2], and N. A. Nachkebia[1]**

[1]V. Koiava Cosmophysical Observatory of M. Nodia Institute of Geophysics of Georgian Academy of Sciences, 1, M. Aleksidze St., Tbilisi, Georgia, 380093

[2]Mortimer and Raymond Sacler Institute of Advanced Studies, Tel Aviv University, POB 39040, Ramat Aviv, 69978, Israel

**Abstract**. The observational results of Tbilisi neutron monitor 5-min data and 4-minute data the measurements of the interplanetary magnetic field (IMF) are used for analysis of cosmic ray (CR) fluctuations. It is shown that the CR spectral functions are connected with helicity of IMF.The spectral indices of CR fluctuations have been linked to spectral indices of magnetic helicity. This linkage opens essentially from concrete model of the magnetic field turbulence. We use Bartlet filter for handless of the observational data. The obtained results are consistent with CR fluctuations theory founded on the kinetic equation.

## 1. Introduction

Various problems of CR fluctuations in stochastic magnetic fields have been intensively studied for a long time (Toptygin, 1985; Chuvilgin et al., 1989; Katz et al., 1990). This interest is stimulated by the investigation of CR modulation and by examination of interplanetary magnetic field (IMF) models. In its simplest version, correlation characteristics of the IMF are directly connected to parameters of CR distribution. If the random magnetic field is statistically isotropic, a spectral tensor of the magnetic field has the form (Moffat, 1978).

$$B_{\alpha\lambda}(\vec{k}) = B^{(s)}_{\alpha\lambda}(\vec{k}) + iB^{(a)}_{\alpha\lambda}(\vec{k}), \qquad (1)$$

where $\vec{k}$ is a wave vector and

$$B^{(s)}_{\alpha\lambda}(\vec{k}) = \Delta_{\alpha\lambda}(\vec{k})B(\vec{k}),$$
$$\Delta_{\alpha\lambda}(\vec{k})B(\vec{k}) = \delta_{\alpha\lambda} - k_\alpha k_\lambda / k^2 \qquad (2)$$

is an symmetric part of the spectral tensor , $\delta_{\alpha\lambda}$ is a Kronekker symbol and

$$B^{(a)}_{\alpha\lambda}(\vec{k}) = \varepsilon_{\alpha\lambda\mu}k_\mu\Phi(k) \qquad (3)$$

is an antisymmetric part of the spectral tensor $B_{\alpha\lambda}(k)$ , $\varepsilon_{\alpha\lambda\mu}$ is an absolutely antisymmetric tensor. $B(k)$ is a spectral function of the random magnetic field and $\Phi(k)$ is spectral function of the magnetic helicity (Moffat, 1978; Matthaeus, 1982; Matthaeus and Golgstein, 1982).

For isotropic turbulence, the spectral functions $B(k)$ and $\Phi(k)$ are connected to corresponding frequency spectral functions $B(\omega)$ and $\Phi(\omega)$ as follows (Moffat, 1978) :

$$B(\omega) = B_{\alpha\alpha}(\omega) = 4\frac{\pi}{u}\int_{\omega/u}^{\infty} dk\,k\,B(k) \;, \qquad (4)$$

$$\Phi(\omega) = 4\frac{\pi}{u^2}\omega\int_{\omega/u}^{\infty} dk\,k\,\Phi(k) \;, \qquad (5)$$

where $\vec{u}$ is a velocity of magnetic pulsations, and $\omega$ is their frequency.

For joint characteristic of CR distribution and random magnetic field, it is convenient to use a CR correlation vector (Jokipii and Owens, 1974; Katz et al., 1990)

$$P_\alpha\left(\vec{r},t;\vec{r}_1,t_1\right)=\left\langle f_{\vec{p}}\left(\vec{r},t\right)H_\alpha\left(\vec{r}_1,t_1\right)\right\rangle, \qquad (6)$$

where $f_{\vec{p}}\left(\vec{r},t\right)$ is CR distribution function and $\vec{H}\left(\vec{r},t\right)$ is a random magnetic field.

The angle brackets denote averaging over the random magnetic field. We rely on the theory of CR fluctuations (Toptygin, 1985; Katz et al., 1990) associated with the drift kinetic equation that describes CR transport in the random magnetic field. This approach allow to take into account the influence of the regular magnetic field on the motion of the charged particles and to obtain relations that connect components of the CR correlation vector with a spectral function of the magnetic field $B(\omega)$ and a spectral function of the magnetic helicity $\Phi(\omega)$.

## 2. Observational Data

Observational estimates of the CR power spectra were analyzed based on the five-minute count rate of neutron monitors (NM) of Tbilisi, Oulu, and Apatity stations. This enables to investigate a temporal interval from 10 minutes to $10^2$ minutes. This interval corresponds to the frequency range( $10^{-4} - 10^{-3}$ ) Hz, which is characterized by a relatively poor level of noise , (Fig. 1)

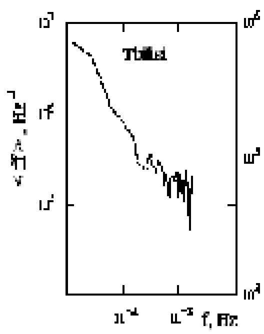


Fig. 1. Power spectrum of 5-minute Tbilisi NM data

An estimate of IMF fluctuations is based on the measurements of the WIND Spacecraft, (Fig. 2, 3).

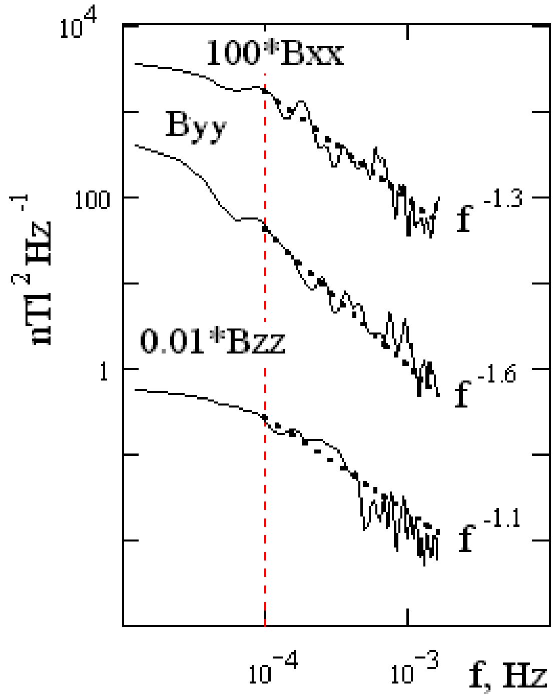


Fig. 2. Power spectrum of IMF (**WIND Spacecraft**) diagonal components.

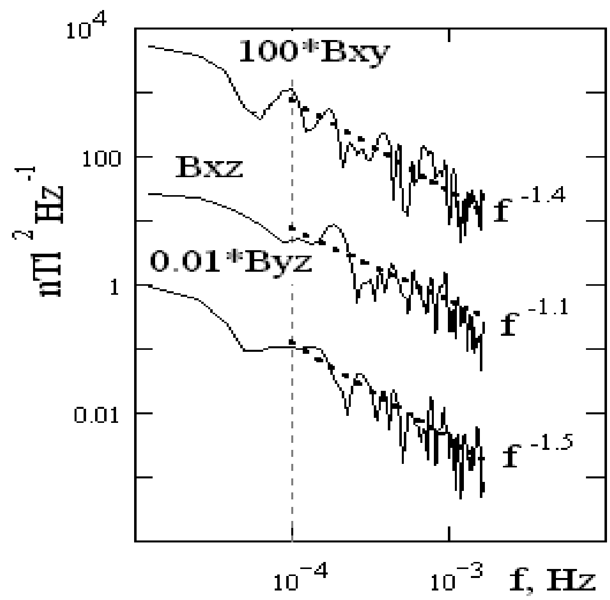


Fig. 3. Power spectrum of IMF (**WIND Spacecraft**) non-diagonal components.

A covariance matrix for the WIND Spacecraft data of IMF

$$B_{\alpha\lambda} = \begin{Vmatrix} 1.71 & 0.26 & -0.81 \\ 0.26 & 6.63 & -1.14 \\ -0.81 & -1.14 & 3.08 \end{Vmatrix} (nTl)^2 \qquad (7)$$

with the following values of the standard deviation:

$$stdev = < H_x^2 >^{1/2} = 1.3nTl,$$

$$stdev = < Hy^2 >^{1/2} = 2.6nTl,$$

$$stdev = < H_z^2 >^{1/2} = 1.8nTl,$$

Corresponding values of the total magnetic field and the standard deviation are respectively:

$$< H_{tot} > = 4.9nTl$$

$$< H^2{}_{tot} >^{1/2} = 0.5nTl$$

The mean value of the total field exceeds the mean value of the random field by approximately one order of magnitude. Cross-correlation matrices for Tbilisi, Oulu, and Apatity NM associated with matrix (7) have the following forms:

$$\begin{Vmatrix} 1 & 0.08 & -0.35 & 0.12 \\ 0.08 & 1 & -0.25 & 0.54 \\ -0.35 & -0.25 & 1 & 0.24 \\ 0.12 & 0.54 & 0.24 & 1 \end{Vmatrix}, \qquad (8)$$

$$\begin{Vmatrix} 1 & 0.08 & -0.35 & 0.06 \\ 0.08 & 1 & -0.25 & 0.21 \\ -0.35 & -0.25 & 1 & 0.03 \\ 0.06 & 0.21 & 0.03 & 1 \end{Vmatrix} \qquad (9)$$

$$\begin{Vmatrix} 1 & 0.08 & -0.35 & 0.01 \\ 0.08 & 1 & -0.25 & 0.30 \\ -0.35 & -0.25 & 1 & 0.14 \\ 0.01 & 0.30 & 0.14 & 1 \end{Vmatrix}. \qquad (10)$$

Each fourth row and column correspond to the CR intensity on Tbilisi, Oulu, and Apatity NMs, respectively. The matrix (7) displays that magnetic field components are correlated. There is an essential correlation of CR intensity with $H_y$-component of magnetic field (0.54 for Tbilisi NM). An analysis of observational data for the Wind Spacecraft displays that spectral powers of the diagonal components of the covariance matrix $B_{\alpha\lambda}$ are satisfactorily described by the power law $\omega^{-\nu}$ with spectral indices $\nu = 1.3$ for the $B_{xx}$-component, $\nu = 1.6$ for the $B_{yy}$-component, and $\nu = 1.1$ for $B_{zz}$-component. These components determine the spectral function of the random magnetic field $B(\omega)$. Non-diagonal components of the covariance matrix correspond to the power law as well. Their spectral indices are as follows:

$\nu = 1.4$ for $B_{xy}$-component,

$\nu = 1.1$ for $B_{xz}$-component,

and

$\nu = 1.5$ for $B_{yz}$-component.

Upon examining components of CR correlation vector for Wind Spacecraft data and Tbilisi NM five-minute data displays that frequency dependence of CR correlation vector components is satisfactorily described by the power law $\omega^{-\rho}$ as well.

In this case, the values of spectral indices for CR correlation vector components are as follows: $\rho = 0.8$ for $P_x$-component, $\rho = 1.6$ for $P_y$-component and $\rho = 1.1$ for $P_z$-component.

## 3. Conclusions

These data do not contradict to the theory of CR fluctuations based upon the drift kinetic equation (Toptygin, 1985; Katz, et al. 1990).

If the IMF is satisfactorily described by the model of isotropic non-mirror turbulence, then the spectral function of the random magnetic field (Katz et al., 1990) is as follows:

$$\pi\left(\vec{\eta}\left[\vec{v}_{\perp}\times\vec{n}\right]\right)\left(\hat{O}F\right)B(\omega) = \frac{\Omega}{\omega}\int_{0}^{\omega} d\omega\,\omega^{3}\frac{d}{d\omega}\frac{1}{\omega}\frac{dP_y(\omega)}{d\omega} \tag{11}$$

and the spectral function of the magnetic helicity

$$\pi\left(\vec{\eta}\left[\vec{n}\times\vec{v}_{\perp}\right]\right)v_{\|}\left(\hat{O}F\right)\Phi(\omega) = u\frac{\Omega}{\omega}\int_{0}^{\omega} d\omega\,\omega\frac{dP_y(\omega)}{d\omega}, \tag{12}$$

where $\vec{\eta} = \vec{u}/u$, $\vec{v}_{\perp}$ and $v_{\|}$ are the components of the particle velocity across and along regular magnetic field $\vec{H}_0$, $\vec{n} = \vec{H}_0/H_0$,

$\hat{O} = \frac{e}{cp}\frac{\partial}{\partial\mu}$, $p$ is particle momentum,

$\mu = \cos\vartheta$, $\vartheta$ is

particle pitch-angle, $\Omega$ is Larmor frequency, $F_{\vec{p}}(\vec{r},t)$ is CR mean distribution function. These relations results in coinciding spectral indices of the random magnetic field and the Y-component of the CR correlation vector. A coincidence of spectral indices takes place for both the magnetic field spectral function and the magnetic helicity spectral function. The observed CR fluctuations are due to existence of the pitch-angle anisotropy in the particles' distribution. This result does not contradict to the observed high value of the $P_y$-component of the CR correlation vector.

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