



## NEW INDEX FOR THE EXPLANATION OF THE 11-YEAR VARIATIONS OF THE GALACTIC COSMIC RAY INTENSITY

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**Abstract:** We calculate the temporal changes of the exponent  $\gamma$  of the power law rigidity  $R$  spectrum ( $\delta D(R)/D(R) \propto R^{-\gamma}$ ) of the GCR isotropic intensity variations using neutron monitors experimental data for four 11-year cycles of solar activity (1960–2002). We show that ~70–80% of the 11-year variations of the GCR intensity is stipulated by the changes of the IMF turbulence versus solar activity. We believe that the temporal changes of the exponent  $\gamma$  of the power law rigidity  $R$  spectrum can be considered as the vital (new) index to explain the 11-year variations of GCR in the energy range of 5-50GeV, to which neutron monitors and ground meson telescopes respond.

### Introduction

We assume that a general reason of the 11-year variation of the GCR [1–3] should be a change of the character of diffusion of GCR particles versus solar activity. Of course, our assumption is concerning with the energy of GCR to which neutron monitors and ground muon telescopes respond (>5 GeV). The diffusion coefficient, according to the quasi linear theory [4–8], depends on the GCR particle's rigidity, and is significant among equally important dependencies of the diffusion coefficient on the other parameters of the heliosphere; a dependence of the diffusion coefficient on the GCR particles rigidity is defined by the structure of the IMF turbulence. Last decades, the quasi linear theory of GCR propagation was undergoing to the serious revision [6, 9–14]. A great inconsistency between quasi linear theory and observations is found for the low energy region, while for the energy > 1 GeV quasi linear theory is valid [13, 14]. In [1–2, 15–16] was shown that the temporal change of the diffusion coefficient of the GCR particles is related with the changes of the Power Spectrum Density (PSD) in the energy range of the IMF turbulence versus the solar ac-

tivity. For the diffusion-convection approximation the diffusion coefficient  $\mathbf{K}$  depends on the rigidity  $R$  of GCR particles as,  $K \propto R^\alpha$  [4–8]. The parameter  $\alpha$  is related with the parameter  $\nu$  as,  $\alpha = 2 - \nu$ ; the parameter  $\nu$  is the exponent of the PSD of the IMF turbulence ( $PSD \propto f^{-\nu}$ , where  $f$  is the frequency). Based on the experimental data and theoretical modeling it was shown that an apparent relationship exists between the rigidity spectrum exponent  $\gamma$  ( $\delta D(R)/D(R) \propto R^{-\gamma}$ ) of the GCR intensity variations and the exponent  $\nu$  of the PSD of the IMF turbulence, namely,  $\nu \approx 2 - \gamma$  [17–20]; the temporal changes of the exponent  $\nu$  of the PSD in the energy range of the IMF turbulence  $\sim(10^{-6}-10^{-5})\text{Hz}$  is clearly manifested in the temporal changes of the rigidity spectrum exponent  $\gamma$  of the GCR intensity variations measured by neutron monitors. So, the temporal changes of the rigidity spectrum exponent  $\gamma$  should be considered as a vital index (having the particular physical sense) to study the 11-year variations of the GCR intensity and to estimate the exponent  $\nu$  of

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the PSD of the IMF turbulence  $\sim(10^{-6}-10^{-5})\text{Hz}$ . A purpose of this paper is to find the temporal changes of the rigidity spectrum exponent  $\gamma$  of the GCR intensity variations using neutron monitors data for 1960–2002, and to establish the role of IMF turbulence in the formation of the 11-year variation of the GCR

Earth surface by two neutron monitors with different cut off rigidities; however, in free space (after corrections for the temporal changes of the energy spectrum) there is no difference between Climax and Huancayo neutron monitors data in the scope of the accuracy of the calculations (figure 1b).

Table 1

Stations	Cut off R Rigidity [GV]	1960-1965 RP	1966-1970 RP	1971-1975 RP	1976-1977 RP	1978-1981 RP	1982-1985 RP	1986-1988 RP	1989-1991 RP	1992-1996 RP	1997-1998 RP
1 Apatity	0.65	-	-	-	-	-	-	-	-	-	+
2 Climax	3.03	+	+	+	+	+	+	+	+	+	+
3 Deep River	1.02	+	-	-	+	+	+	+	+	-	-
4 Goose Bay	0.52	-	-	-	+	+	+	+	+	+	-
5 Haleakala-Huancayo	13.4	+	+	+	+	+	+	+	+	+	+
6 Hermans	4.90	-	+	-	+	+	+	+	-	-	+
7 Inuvik	0.18	-	+	+	+	+	+	+	+	+	-
8 Jungfraujoch	4.48	-	-	-	+	-	-	-	-	-	-
9 Kerguelen Is	1.19	-	-	+	-	-	-	-	-	-	-
10 Kiel	2.29	+	+	+	+	+	+	+	+	+	+
11 Mc Murdo	0.01	-	-	-	-	-	-	-	-	-	+
12 Moscow	2.46	+	+	+	+	+	+	+	+	+	+
13 Mt Norikura	11.39	-	-	-	-	+	-	-	-	-	-
14 Mt. Washington	1.24	-	+	+	-	+	+	+	+	+	-
15 Pic-du-Midi	5.36	-	+	+	-	-	-	-	-	-	-
16 Potchefstroom	7.30	-	-	-	+	+	+	+	+	+	+
17 Rome	6.32	-	-	-	-	-	-	-	-	-	+
18 Tbilisi	6.91	-	-	-	+	+	+	+	-	-	-

In the Table 1 is presented a list of neutron monitors used for the calculations of  $\gamma$  in different considered periods (denoted by “+”) and Reference Point (RP) for the given period.

Discussion

The changes of the GCR intensity by Climax and Huancayo neutron monitors data on the Earth surface and in the free space for the period of 1981–1992 are presented in figures 1a, 1b.

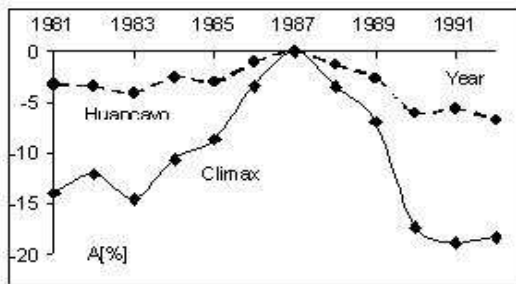


Fig. 1a The changes of the GCR intensity by Climax (solid) and Huancayo (dashed) neutron monitors data at the Earth for the period of 1981–1992

Figure 1a shows that there is a significant difference between the GCR intensity observed on the

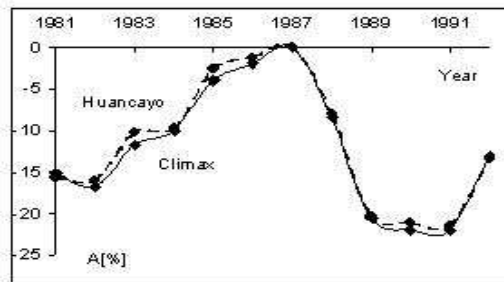


Fig. 1b The changes of the GCR intensity by Climax (solid) and Huancayo (dashed) neutron data in the free space for the period of 1981–1992

The temporal changes of the semi annual average magnitudes of the GCR intensity variations for Climax monitor data and the rigidity spectrum exponent  $\gamma$  are presented in figure 2 for the whole period of 1960–2002 (Table 1).

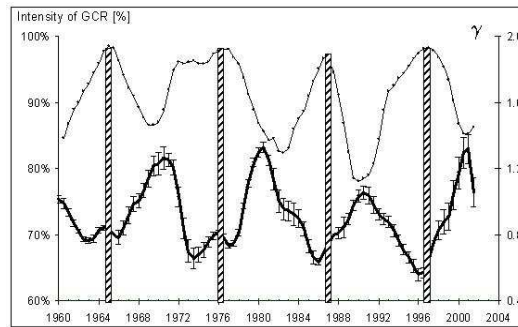


Fig 2. The temporal changes of the semi annual average magnitudes of the GCR intensity variations for Climax monitor data and the rigidity spectrum exponent  $\gamma$  for the period of 1960–2002

Figure 2 shows clearly established negative correlations between the changes of the exponent  $\gamma$  and the GCR intensity for each of eight ascending and descending periods of solar activity.

According to our assumption the temporal changes of the rigidity spectrum exponent  $\gamma$  of long period variations of the GCR intensity versus solar activity is observed owing to the temporal changes of the exponent  $\nu$  of the PSD of the IMF turbulence versus solar activity; when the  $\gamma$  increases the  $\nu$  should be decreased according to the expected relation  $\nu \approx 2 - \gamma$  [18]. Our assumption is confirmed in figure 3, where the yearly average values of the rigidity spectrum exponent  $\gamma$  (figure 3) and the exponent  $\nu$  of the PSD of the By component of the IMF turbulence (in the frequency range of  $\sim (10^{-6}-10^{-5})$  Hz) are presented for the period of 1976–2002; to increase the statistical accuracy the rigidity spectrum exponent  $\gamma$  and the exponent  $\nu$  of the PSD of the By component of the IMF were averaged for the periods of 1976–1978, 1979–1982, 1983–1984, 1985–1987, 1988–1989, 1990–1992, 1992–1993, 1994–1997, 1998–2000, and 2001–2002. The changes of the rigidity spectrum exponent  $\gamma$  versus the exponent  $\nu$  of the PSD of the By are presented in figure 3.

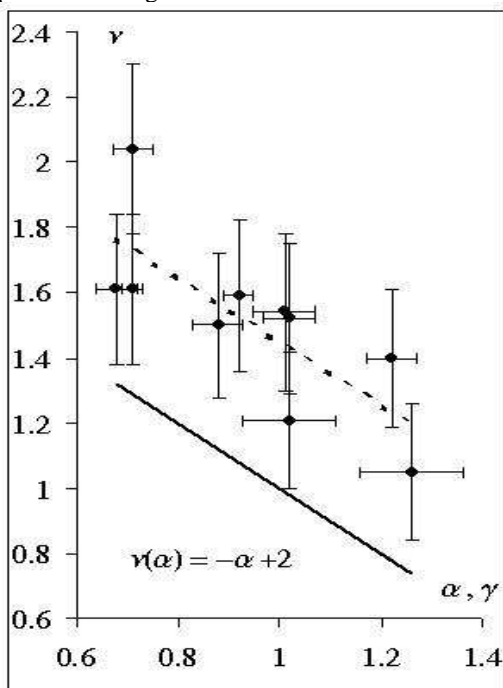


Fig 3. The changes of the rigidity spectrum exponent  $\gamma$  versus the exponent  $\nu$  of the PSD of the By component of the IMF

Figure 3 shows that when the exponent  $\nu$  decreases the exponent  $\gamma$  increases; the relationship between  $\gamma$  and  $\nu$  found by the least square method has the form  $\nu(\gamma) = -(0.99 \pm 0.16) \gamma + (2.4 \pm 0.15)$  (dashed straight line in figure.3); this equation is in a good agreement with equation  $\gamma \approx 2 - \nu$  found previously [18] based on the theoretically modeling and neutron monitors experimental data. For comparison in the figure 3 is drawn straight line corresponding to the theoretically expected dependence  $\alpha = 2 - \nu$ , where  $0 \leq \alpha \leq 2$  [4, 5]. Thus, this result confirms our assumption [18] that the changes of the rigidity spectrum exponent  $\gamma$  of the GCR intensity variations are stipulated by the changes of the exponent  $\nu$  of the PSD of the IMF turbulence, particularly by the fluctuations of the By component of the IMF ( $\gamma \approx 2 - \nu$ ). The relationship  $\gamma \approx 2 - \nu$  shows that the temporal changes of the exponent  $\nu$  of the PSD of the IMF turbulence, from the minima to maxima epoch of solar activity are the reason of the 11-variation of the rigidity spectrum exponent  $\gamma$  of the GCR variations; this relation confirms neutron monitors and IMF experimental data (figure 3).

### Summary and conclusion

1. We calculate the temporal changes of the exponent  $\gamma$  of the power law rigidity spectrum of the GCR isotropic intensity variations ( $\delta D(R) / D(R) \propto R^{-\gamma}$ ) using neutron monitors experimental data for the four ascending and four descending phases of solar activity (1960–2002). The dependence of the diffusion coefficient  $K$  on the rigidity  $R$  of the GCR particles ( $K \propto R^{2-\nu}$ ,  $\nu$  is the exponent of the PSD of the IMF turbulence;  $PSD \propto f^{-\nu}$  and  $f$  is the frequency) is a general reason of the soft rigidity spectrum ( $\gamma \approx 1.2$ ) of the GCR isotropic intensity variations for the maximum epoch and the hard rigidity spectrum ( $\gamma \approx 0.6$ ) for the minimum epoch of solar activity. This dependence is stronger in the maximum epoch than in the minimum epoch of solar activity and is provided by the essential rearrangements of the structure in the energy range of the IMF turbulence,  $f \approx 10^{-6} - 10^{-5}$  Hz.

2. It can be concluded that ~70–80% of the amplitudes of the 11-year variations of GCR intensity is stipulated by the changes of the IMF turbulence versus solar activity. The temporal changes of the power law rigidity spectrum exponent  $\gamma$  of the GCR isotropic intensity variations can be considered as the vital (new) index to explain the 11-year variations of GCR; this index can be used to determine the temporal changes of the exponent  $\nu$  of the PSD in the energy range of the IMF turbulence,  $f \approx 10^{-6} - 10^{-5}$  Hz.

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