Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 1 (SH), pages 497–500

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

M.V. ALANIA[1,2], K. ISKRA [1], M. SILUSZYK[1]
[1] *Institute of Math. and Physics of University of Podlasie, Konarskiego 2, 08–110 Siedlce, Poland*
[2] *Institute of Geophysics, Georgian Academy of Sciences, Tbilisi, Georgia*
alania@ap.siedlce.pl; iskra@ap.siedlce.pl; sil_m@ap.siedlce.pl ;

Abstract: We calculate the temporal changes of the exponent γ 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 γ 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 neuron 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 inconsistence 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 activity. For the diffusion–convection approximation the diffusion coefficient **K** depends on the rigidity R of GCR particles as, $K \propto R^{\alpha}$ [4–8]. The parameter α is related with the parameter ν as, $\alpha = 2 - \nu$; the parameter ν 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 γ ($\delta D(R)/D(R) \propto R^{-\gamma}$) of the GCR intensity variations and the exponent ν of the PSD of the IMF turbulence, namely, $\nu \approx 2 - \gamma$ [17–20]; the temporal changes of the exponent ν of the PSD in the energy range of the IMF turbulence ~(10^{-6}–10^{-5})Hz is clearly manifested in the temporal changes of the rigidity spectrum exponent γ of the GCR intensity variations measured by neutron monitors. So, the temporal changes of the rigidity spectrum exponent γ 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 ν of the PSD of the IMF turbulence ~(10^{-6}–10^{-5})Hz. A purpose of this paper is to find the temporal changes of the rigidity spectrum exponent γ 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

Table 1

	Stations	Cut off Rigidity [GV]	1960-1964 RP 1965	1966-1970 RP 1965	1971-1975 RP 1976	1977-1981 RP 1976	1982-1985 RP 1986	1988-1991 RP 1987	1992-1996 RP 1997	1998-2002 RP 1997
1	Apatity	0.65	-	-	-	-	-	-	-	+
2	Climax	3.03	+	+	+	+	+	+	+	+
3	Deep River	1.02	+	-	-	+	+	+	-	-
4	Goose Bay	0.52	-	-	-	+	+	+	+	-
5	Haleakala-Huancayo	13.4	+	+	+	+	+	+	+	+
6	Hermanus	4.90	-	+	-	+	+	+	-	+
7	Inuvik	0.18	-	+	+	+	+	+	+	-
8	Jungfraujoch	4.48	-	-	-	+	-	-	-	-
9	Kergulen 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 theTable 1 is presented a list of neutron monitors used for the calculations of γ 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 1ab.

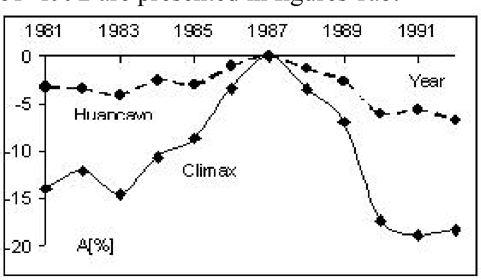

Figure 1a: The changes of the GCR intensity by Climax (solid) and Huancayo (dashed) neutron monitors data at the Earth for the period of 1981–1992

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

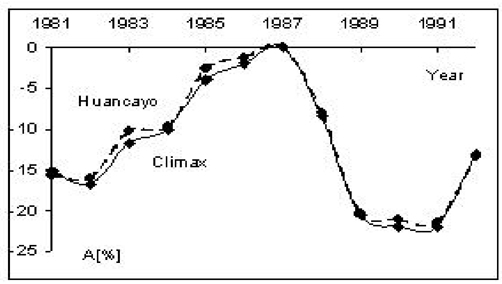

Figure 1b: The changes of the GCR intensity by Climax (solid) and Huancayo (dashed) neutron data in the free space for the period of 1981–1992

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

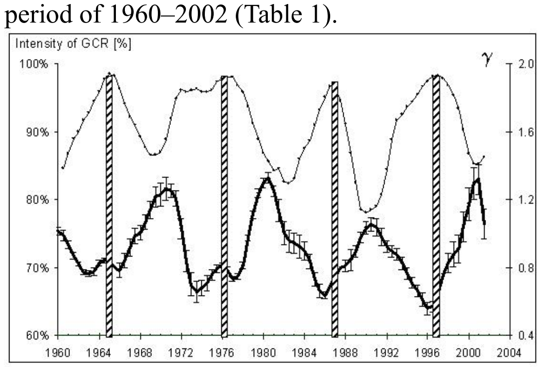

Figure 2: The temporal changes of the semi annual average magnitudes of the GCR intensity variations for Climax monitor data and the rigidity spectrum exponent γ for the period of 1960–2002

Figure 2 shows clearly established negative correlations between the changes of the exponent γ 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 γ of long period variations of the GCR intensity versus solar activity is observed owing to the temporal changes of the exponent ν of the PSD of the IMF turbulence versus solar activity; when the γ increases the ν 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 γ (figure 3) and the exponent ν of the PSD of the By component of the IMF turbulence (in the frequency range of ~ (10^{-6}–10^{-5})Hz) are presented for the period of 1976–2002; to increase the statistical accuracy the rigidity spectrum exponent γ and the exponent ν 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 γ versus the exponent ν of the PSD of the By are presented in figure 3.

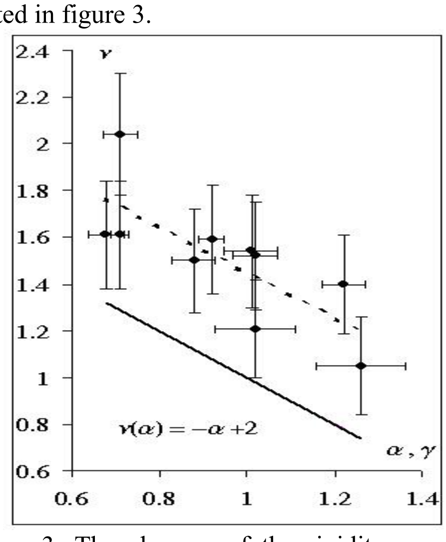

Figure 3: The changes of the rigidity spectrum exponent γ versus the exponent ν of the PSD of the B_y component of the IMF

Figure 3 shows that when the exponent ν decreases the exponent γ increases; the relationship between γ and ν found by the least square method has the form ν(γ) =–(0.99 ± 0.16) γ + (2.4 ± 0.15) (dashed straight line in figure.3); this equation is in a good agreement with equation γ ≈ 2–ν 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 α = 2–ν, where 0 ≤ α ≤ 2 [4, 5]. Thus, this result confirms our assumption [18] that the changes of the rigidity spectrum exponent γ of the GCR intensity variations are stipulated by the changes of the exponent ν of the PSD of the IMF turbulence, particularly by the fluctuations of the By component of the IMF (γ ≈ 2–ν). The relationship γ ≈ 2–ν shows that the temporal changes of the exponent ν 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 γ 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 γ 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 ($K \propto R^{2-\nu}$, ν 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 (γ ≈ 1.2) of the GCR isotropic intensity variations for the maximum epoch and the hard rigidity spectrum (γ ≈ 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 ≈ 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 γ 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 ν of the PSD in the energy range of the IMF turbulence, $f \approx 10^{-6} - 10^{-5}$ Hz.

References

[1] Alania, M.V., R.G., Aslamazashvili, T.B., Bochorishvili, K., Iskra, M., Siluszyk, The Role of drift on the diurnal anisotropy and on temporal changes in the energy spectra of the 11–year variation for galactic cosmic rays, Adv. Space Res. 27, 3, 613–618, 2001

[2] Alania, M.V., Stochastic variations of galactic cosmic rays, Acta Phys. Polonica B, 33, 4, 1149–1166, 2002

[3] Dorman, Long–term cosmic ray intensity variation and part of global climate change, controlled by solar activity through cosmic rays, Advances in Space Research 37, 1621–1628, 2006

[4] Jokipii, J.R., Propagation of cosmic rays in the solar wind, Rev. of Geophysics and Space Physics, 9, 27–87, 1971

[5] Toptygin, I. N. Cosmic rays in interplanetary magnetic fields, D. Redel Publishing Company, Dordrecht, 1985

[6] Bieber, J.W., W. H., Mathaeus, C. W., Smith, et al., Proton and electron mean free paths: the Palmer consensus revisited, Astrophys. J., 420, 294–306, 1994

[7] Melnikov, Y.P., General correlation scales of random component of IMF, Geomagnetism and Aeoronomia , vol 45, 4 p. 445–452, 2005

[8] Hasslmann, K., and Wibberenz, G. Zs. f. Geophys., 34, 353, 1968

[9] Matthaeus, W. H. Qin, G. Bieber, J. W.and Zank, G. P. "Nonlinear Collisionless Perpendicular Diffusion Of Charged Particles" , The Astrophysical Journal, 590, L53–L56, 2003

[10] Shalchi, A. Bieber, J. W. Matthaeus W. H.and Qin G."Nonlinear Parallel And Perpendicular Diffusion Of Charged Cosmic Rays In Weak Turbulence", The Astrophysical Journal, 616, 617–629, 2004

[11] Shalchi, A. Bieber, J. W. and Matthaeus W. H. „Analytic Forms Of The Perpendicular Diffusion Coefficient In Magnetostatic Turbulence", The Astrophysical Journal, 604, 675–686, 2004

[12] Shalchi, A. Schlickeiser R., „The Parallel Mean Free Path Of Heliospheric Cosmic Rays In Composite Slab/Two–Dimensional Geometry. I. The Damping Model Of Dynamical Turbulence", The Astrophysical Journal, 604, 861–873, 2004

[13] Droge W. „Solar Particle Transport In A Dynamical Quasi–Linear Theory„The Astrophysical Journal, 589, 1027–1039, 2003

[14] Droge W. Probing heliospheric diffusion coefficients with solar energetic particles Advances in Space Research 35, 532–542, 2005

[15] Siluszyk M., Iskra K., Modzelewska R. and Alania M.V., Features of the 11–year variation of galactic cosmic rays in different periods of solar magnetic cycles Adv. Space Res. 35, 4, 677, 2005

[16] Alania M.V., Iskra K., Siluszyk M., „New Index of Long-Term Variations of Galactic Cosmic Ray Intensity" Advances in Space Research, 2007

[17] Alania, M.V., K., Iskra, Features of the Solar Wind Large–Scale Structure in the Different Periods of Solar Activity Based on the Variations of Cosmic Rays, Adv. Space Res., 16(9), 241–244, 1995.

[18] Alania, M.V., K., Iskra, M., Siluszyk, Experimental and theoretical investigations of the 11–year variation of galactic cosmic rays, Adv. Space Res., 32, 4, 651–656, 2003

[19] Fisk, L.A., Goldstein, M.L., Klimas, A.J., et al., The Fokker–Planck Coefficient for Pitch–Angle Scatering of Cosmic Rays, *Astrophys. J.*, 190, 417–428, 1974

[20] Alania, M.V., K., Iskra, R., Modzelewska, M., Siluszyk, On the relationship of the energy spectrum indexes of the 11–year variation of galactic cosmic rays and the interplanetary magnetic field strength fluctuations, Proceedings of 28th ICRC, Japan, 3881–3886, 2003