ICRC 2001

Energy spectrum of the 11-variation of galactic cosmic rays for different solar magnetic cycles

K. Iskra[1], M. Siluszyk[1], and M. V. Alania[1,2]

[1]Institute of Mathematics and Physics of University of Podlasie, Siedlce, Poland
[2]Institute of Geophysics of Academy of Sciences of Georgia, Tbilisi, Georgia

ABSTRACT

Neutron monitors data for 1957-1999 has been used to study the role of drift effect in the temporal changes of the energy spectrum index of the isotropic intensity variations of galactic cosmic rays for different qA>0 and qA<0 solar magnetic cycles. It is shown that the various character in the changes of the profiles of galactic cosmic ray intensity causing by drift effects for different qA>0 and qA<0 solar magnetic cycles (plateau and pick profiles in the qA>0 and in the qA<0, respectively) has not revealed in the temporal changes of the energy spectrum index of the isotropic intensity variations of galactic cosmic rays. A comparison of the changes of the energy spectrum index of the isotropic intensity variations obtained from experimental data of the neutron monitors with the expected changes obtained from the theoretical modeling of Parker's 2-D transport equation has been done. It is concluded that the decisive role in the formation of the 11-year variation of galactic cosmic rays (the amplitude of the 11-year variation) belongs to the structural changes of the fluctuations of the interplanetary magnetic field during the ascending and descending periods of solar activity.

INTRODUCTION

Up to present there is not well known which of the parameters or the group of the parameters of solar activity and of solar wind [1, 3] are responsible for the 11-year variation of galactic cosmic rays (GCR). In order to answer to this question, first of all, it is necessary to estimate separately, the roles of all processes: convection, diffusion, drift and adiabatic cooling causing a modulation of GCR. Theoretically, the contributions of each process are estimated by many authors, e.g. in [4], however it is difficult to do it based on the experimental data. In this paper is assumed that neither the solar wind velocity and adiabatic cooling nor drift are responsible for 11-year variation of galactic cosmic rays (GCR). It was shown in [5,6] that the energy spectrum exponent γ of GCR isotropic intensity variations ($\delta D(R)/D(R) \propto R^{-\gamma}$, where R is the GCR particle's rigidity) must be proportional to the energy spectrum exponent ν of the interplanetary magnetic field (IMF) strength fluctuations ($P \propto f^{-\nu}$, where P is a power and f a frequency of the IMF strength fluctuations) as, $\gamma \propto (2 - \nu)$. So, in this paper the general attention is paid to study a behavior of the energy spectrum exponent γ of GCR isotropic intensity variations separately for the periods of the ascending and descending parts of solar activity in different magnetic cycles of the qA>0 and the qA<0.

EXPERIMENTAL DATA AND DISCUSSION

The temporal changes of the energy spectrum exponent γ of GCR isotropic intensity variations for different solar magnetic cycles was found performing the following procedure. The intensity of GCR (obtained by neutron monitors) in the minima epochs of solar activity (maximum intensity of GCR) was considered as the 100% level and then to the right and to the left sides the energy spectrum exponent γ of GCR isotropic intensity variations has been calculated, e.g. the intensity of 1965 was considered as the 100% level and then up to 1958 (left direction) and up to 1971 (right direction) the temporal changes of the γ has been found based on the 13 months smoothing data of neutron monitors. In figure 1ab are presented time profiles of the intensity of GCR for the Climax, Hermanus and Huancayo neutron monitors for the period of 1958-1965 (fig.1a) and for the period of 1966-1971 (fig.1b). In figure 2ab are presented the temporal changes of the energy spectrum exponent γ of GCR calculated as in [7] for the period of 1959-1966 (fig.2a) and for the period of 1966-1972 (fig.2b). It is seen from this figure 2ab that the energy spectrum exponent γ of GCR isotropic intensity variations gradually decreases from maxima to
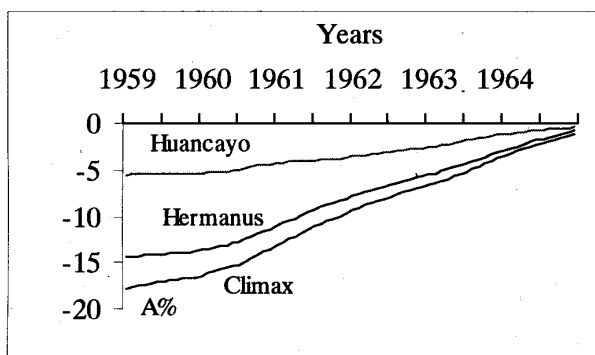
Fig.1a. Time profiles of the intensity of GCR for the Climax, Hermanus and Huancayo neutron monitors for the period of 1959-1965, qA<0. On the ordinate axis are presented the changes of the intensity in % (A%) with respect to 1965.
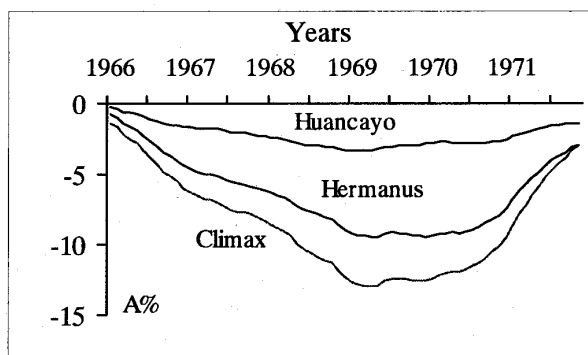
Fig.1b. Time profiles of the intensity of GCR for the Climax, Hermanus and Huancayo neutron monitors for the period of 1966-1971, qA<0. On the ordinate axis are presented the intensity in % (A%) with respect to 1965.
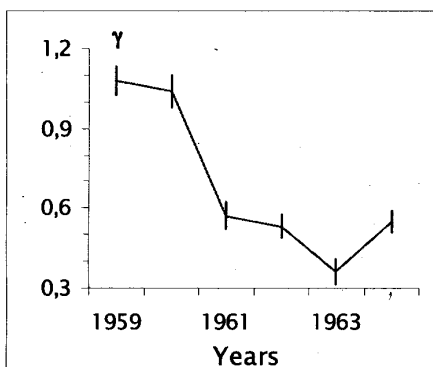

Fig.2a. Temporal changes of the energy spectrum exponent γ of GCR isotropic intensity variations for the period 1958-1964, qA<0
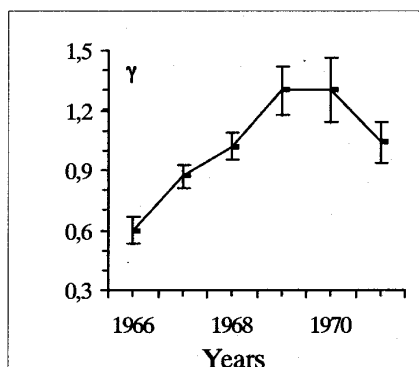
Fig.2b. Temporal changes of the energy spectrum exponent γ of GCR isotropic intensity variations for the period 1966-1972, qA<0

minima epochs of solar activity and its value is greater (more than 2 times) in the maxima epochs (1958-59 and 1970-71) than in the minimum and near minimum epochs of 1964-1966. Similar procedure for the finding of energy spectrum exponent γ of GCR has been done with respect to the periods of 1976 and 1997, when the observed maximum GCR intensities were considered as the 100% levels, respectively.

In figure 3a are presented time profiles of the intensities of GCR for the period of 1969-1976 observed by the neutron monitors Climax, Hermanus and Huancayo, and in the figure 3b-for the period of 1989-1997 observed by the neutron monitors Huancayo, Moscow and Washington.
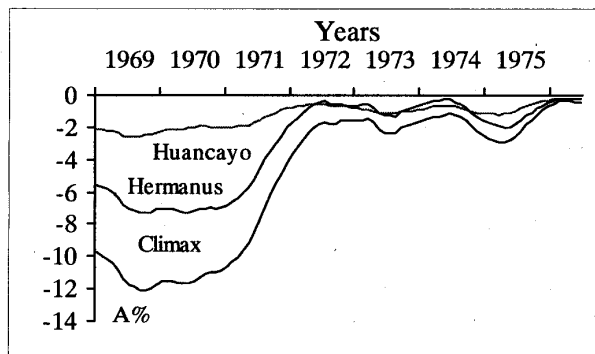

Fig.3a. Time profiles of the intensity of GCR for the Climax, Hermanus and Huancayo neutron monitors for the period of 1969-1975, qA>0. On the ordinate axis are presented the changes of the intensity in % (A%) with respect to 1976.
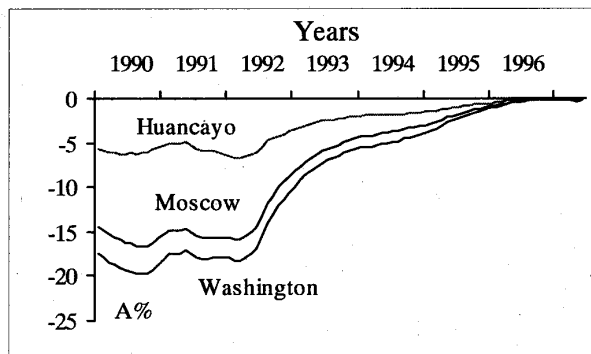
Fig.3b. Time profiles of the intensity of GCR for the Huancayo, Moscow and Washington neutron monitors for the period of 1989-1996, qA<0. On the ordinate axis are presented the changes of the intensity in % (A%) with respect to 1997.
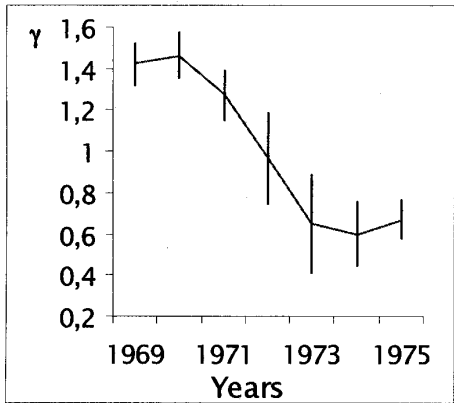
Fig4a. Temporal changes of the the energy spectrum exponent γ of GCR isotropic intensity variations for the period of 1969-1975, qA>0.
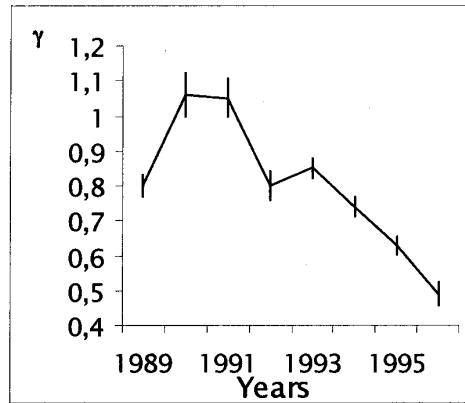

Fig.4b.Temporal changes of the the energy spectrum exponent γ of GCR isotropic intensity variations for the period of 1989-1996, qA>0

In figure 4ab are presented the temporal changes of the energy spectrum exponent γ of GCR for the period of 1969-1976 (fig.4a) and for the period of 1989-1996 (fig.4b). It is seen from this figure 4ab that the energy spectrum exponent γ of GCR isotropic intensity variations gradually changes from maxima to minima epochs of solar activity and its value is greater in the maxima epochs (1969-1971 and 1989-1991) than in the minima and near minima epochs of solar activities (1974-1976 and 1995-1996), similarly as one can see above in figure 2ab. These results once again confirm the universality of the fact that the energy spectrum of GCR isotropic intensity variations is soft for the maxima epochs (the exponent γ ≈ 1.2), and is hard for the minima epochs of solar activity (the exponent γ ≈ 0.5) [6]. The character of the temporal changes of the γ does not depend how it is calculated, consider the changes of GCR intensity for long period including several 11-year cycles (for different qA>0 and qA<0 solar magnetic cycles) with respect to the intensity for any one minimum epoch of solar activity or calculate γ for the ascending or descending parts of the separate 11-year period. Analyses of the results (fig. 2ab and fig. 4ab) show, that there were not found any remarkable changes of the γ depending on the solar magnetic cycles of the qA>0 and the qA<0. As before, we consider that the temporal changes of the energy spectrum exponent γ of GCR is an important key to understand a long-period modulation of GCR, because there must be a strong relation between γ and the exponent α showing the dependence of the parallel diffusion coefficient $K_{||}$ on the rigidity R of GCR particle's ($K_{||} \propto R^{\alpha}$). The existence of this relationship can be confirmed using the modeling of GCR long-period modulation by the Parker's transport equation [7] including convection, diffusion, adiabatic cooling and drift.

MODELING OF MODULATION OF GCR

To establish the relationship between the expected energy spectrum exponent γ_1 of the isotropic intensity variations and the exponent α showing the dependence of the parallel diffusion coefficient $K_{||}$ on the GCR particle's rigidity R ($K_{||} \propto R^{\alpha}$) the Parker's transport equation for the stationary case has been considered,

$$\nabla_i \left(K_{ij} \nabla_j N \right) - \nabla_i \left(U_i N \right) + \frac{1}{3R^2} \frac{\partial \left(R^3 N \right)}{\partial R} \left(\nabla_i U_i \right) = 0 \tag{1}$$

where N, and R are density (in the interplanetary space) and rigidity of GCR particles, respectively; K_{ij} is diffusion tensor consisting from the symmetric and antisymmetric (responsible for drift) parts; U_i is solar wind velocity and t- time. The equation (1) in the 2-dimentional ρ, θ coordinate system was written down for the relative density, n = N/N_0 and for the dimensionless distance r = ρ/r_0 (where N_0 is density of GCR in the interstellar medium accepted as, $N_0 \propto R^{-4.5}$ for the rigidities to which neutron monitors are sensitive, r_0 is the size of the modulation region and ρ is the distance from the Sun).
Then the equation (1) was numerically solved taking into account that: the parallel diffusion coefficient, $K_{||}$ has the expression,

$K_{||} = K_0 K(r) K(R),$ (2)

where $K(r) = 1 + \alpha_0 r$, $K(R) = R^\alpha$, and K_0 is equal to the 2×10^{22} $cm^2 s^{-1}$ for the energy of 10 GeV; the radius of the modulation region is 100 AU and the solar wind velocity U equals 4×10^7 cm/s; $\alpha_0 = 100$, and the ratio α_1 of the perpendicular $K_\perp$ and parallel $K_{||}$ diffusion coefficients, $\alpha_1 = K_\perp / K_{||} = (1 + \omega^2 \tau^2)^{-1}$, where $\omeg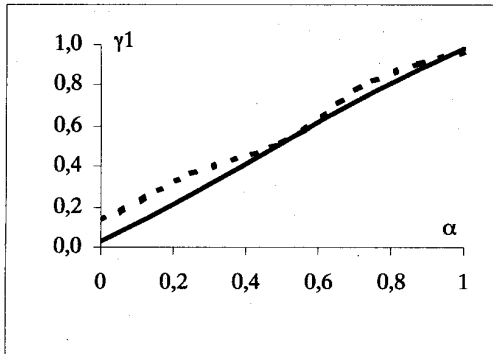a\tau = 300 H \lambda R^{-1}$; H is the strength of the IMF and λ- the transport free path of GCR particles. At the Earth's orbit H = 5 nT, $\lambda = 2 \times 10^{12}$ cm, and $\omega\tau = 3$, for the energy of 10GeV and then it changes depending on the spatial coordinates according to the Parker's spiral magnetic field [9]. At the boundary of the modulation region α_1 tends to 1. There is considered the plane heliospeheric neutral sheet. The equation (1) was solved for the qA>0 and qA<0 magnetic cycles assuming α =0, 0.25, 0.5, 0.75 and 1.0. In the fig.5 are presented the changes of the expected energy spectrum exponent γ_1 of the isotropic intensity variations versus the exponent α showing the dependence of the parallel diffusion coefficient $K_{||}$ on the GCR particle's rigidity R ($K_{||} \propto R^\alpha$) for the solar magnetic cycles, qA> 0 (solid line) and for the qA<0 (dashed line). It is seen from this figure 5 that there is almost

Fig.5. The changes of the γ_1 versus the α for solar magnetic cycles of the qA>0 (solid line) and of the qA<0 (dashed line),

linear dependence between the expected energy spectrum exponent γ_1 of the isotropic intensity variations and the exponent α for the both solar magnetic cycles of the qA>0 and the qA<0.

CONCLUSION

1.A strong relation between the expected energy spectrum exponent γ_1 of the isotropic intensity variations and the exponent α showing the dependence of the parallel diffusion coefficient on the GCR particle's rigidity R ($K_{||} \propto R^\alpha$) has been found based on the solutions of the Parker's transport equation.

2.The universality of the temporal changes of the energy spectrum of GCR isotropic intensity variations ($\delta D(R)/D(R) \propto R^{-\gamma}$, where R is the GCR particle's rigidity) for all 11-year cycles of solar activity of the period of 1953-1999 has been confirmed. The energy spectrum of GCR isotropic intensity variations is soft for the maxima epochs (the exponent $\gamma \approx 1.2$), and is hard for the minima epochs of solar activity (the exponent $\gamma \approx 0.5$), i.e. the character of the diffusion of GCR (to which neutron monitors are sensitive) in interplanetary space is different for the minima and maxima epochs of solar activity caused by the structural changes of the fluctuations of the IMF during the ascending and descending periods of solar activity. Thus, the decisive role in the formation of the 11-year variation of galactic cosmic rays (the amplitude of the 11-year variation) belongs to the structural changes of the fluctuations of the IMF.

REFERENCES

1.Dorman, L.I., Cosmic Rays Variations and Space Exploration, 'Nauka', Moscow,1963
2. Alania, M.V., Dorman, L.I., 'The Spatial Distribution of the Density and stream of Galactic Cosmic Rays', 'Mecniereba', Tbilisi, 1981,(in Russian)
3. Bazilevskaya, G. A., and Svirzhevskaya, A. K., Space Sci. Rev., 85, 431, 1998
4. Burger, R.A., and Podgieter, M. S., The astrophys. Journal, 339, 501- 511,1989
5. Alania, M.V., Iskra, K., Adv. Space Res., 16, 9, 241-244,1995.
6. Alania, M.V., Bochorishvili, T. B., Iskra K., Adv. Space Res.,19, 6, 925-928,1997
7.Alania et al., 22nd ICRC Proceedings, SH, Dublin, 581,1991
8.Parker, E. N., Planet. and Space Sci., 13, 9, 1965
9. Parker, E. N., "Interplanetary Dynamical Processes", Interscience Publishers, New York, 1963