# The Galactic Cosmic Ray Intensity and Anisotropy Variations for Different Ascending and Descending Epochs of Solar Activity

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The temporal changes of the rigidity spectrum of the Galactic Cosmic Rays intensity during the four ascending and the four descending epochs of solar activity (1960-2002) have been studied using neutron monitors experimental data. The rigidity spectrum is harder in the minima epoch than in the maxima for all the ascending and the descending epochs of solar activity and basically softly depends on the polarity of the Sun's global magnetic field. It is concluded that the temporal changes of the rigidity spectrum of the Galactic Cosmic Rays intensity is related with the changes of the structure in the energy range of the interplanetary magnetic field turbulence during the 11-year cycle of solar activity. The apparent 22-year variation of the radial component of the Galactic Cosmic Rays anisotropy related with the drift has been revealed.

## 1. Introduction

The 11-year wave of the Galactic Cosmic Rays (GCR) intensity variations generally is reversely related with the similar changes of the solar activity [1-3]. In [4] has been assumed that an index which incorporates the number of sunspot groups and their heliolatitudes could be used to interpret the changes of the GCR intensity during 1958–1968. In [5] was suggested that the major part of the 11–year variation is the result of the accumulative effects of the Forbush effects and in [6] was noted that besides the drift effects play a significant role in the GCR modulation process, however, other effects could be equally important. To explain the 11-year modulation of proton intensity a combination of drift and global merged interaction regions were included in time-dependent model [7]. Recently in [8], to explain the 11-year and 22-year variations of the galactic cosmic ray protons, electrons and helium a compound approach incorporating the concept of propagating diffusion barrier with other general modulation mechanisms in the time-dependent model (without any merging in propagating barriers) has been used. In [9] was shown a significant difference in the rigidity dependence of the 11-year modulation of galactic cosmic rays between the qA>0 and the qA<0 modulation periods. Particularly, the rigidity dependence of the diffusion coefficient was flatter for the 11–year decrease from 1987 to 1990 (qA<0) than for the decrease from 1977 to 1981 (qA>0). There was assumed that a modulation function was considered as a constant during the each period to be analyzed. In this case, of course, the time-dependent character of the modulation function was ignored and the effects of the scattering and drift of GCR particles due to the turbulent and regular Interplanetary Magnetic Field (IMF) are averaged. The dependence of the diffusion coefficient on the GCR particle's rigidity is significant [10-12] among the essential dependencies of the diffusion coefficient on the other parameters (e.g. the strength of the regular IMF and so on). Elsewhere [13-14] was suggested that the temporal changes of the rigidity spectrum exponent $\gamma$ of the GCR isotropic intensity variations can be considered as one of the basic indices to explain the general 11–year wave of the GCR intensity. The temporal change of the rigidity spectrum exponent $\gamma$ is caused by the changes of the structure in the range of the IMF turbulence (frequencies $10^{-6}$–$10^{-5}$ Hz) versus solar activity. Thus, the turbulence component of the IMF is responsible for the formation of the rigidity spectrum of the GCR intensity long-period modulation; however, the role of the regular IMF in changes of diffusion coefficient and as the source of GCR particles drift is significant. In connection with this the long period (11 and 22 year) variations of the GCR anisotropy determined by the diurnal variations of the GCR intensity also is much of interest.

The change of the radial component of the anisotropy gives an opportunity to judge what the periods of solar activity maximum might be considered as the diffusion dominated period or as the drift dominated period for the modeling of the GCR transport. The purpose of this paper is to study the temporal changes of the rigidity spectrum of the GCR intensity and anisotropy for the period of 1960-2002.

## 2. Experimental data and methods

The yearly average data of the GCR intensity were thoroughly selected from the worldwide network of neutron monitors which had as different cut off rigidities as possible and had functioned continuously throughout the period to be analyzed. This criterion is decisive to study the temporal changes of the rigidity spectra of the long-term variations (11–year) of the GCR intensity. There were considered four ascending and four descending phases of solar activity: 1960- 1970 (qA<0), 1971-1980 (qA>0), 1981-1992 (qA<0) and 1992-2001 (qA>0). In the calculations for each four ascending and four descending phases of solar activity were used data of 10-15 neutron monitors. In the Figure 1 are presented, as an example, the average (for all periods of ascending and descending branches of solar activity) 11–year variations of GCR based on the experimental data of Climax and Huancayo-Haleakala neutron monitors. Reference Point (RP) corresponds to 6th point in the Figure 1. Five points left side and five points right side correspond to the descending and ascending branches of solar activity.
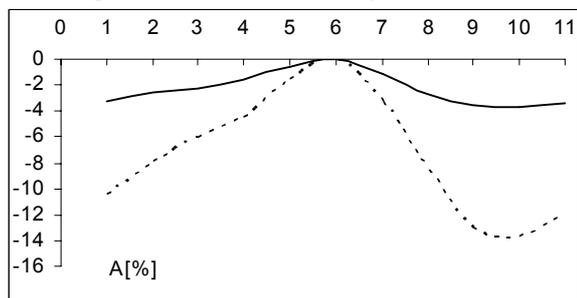


Fig. 1 The average amplitude of the 11–year variations of the GCR by Climax (doted) and Huancayo-Haleakala (solid) neutron monitors
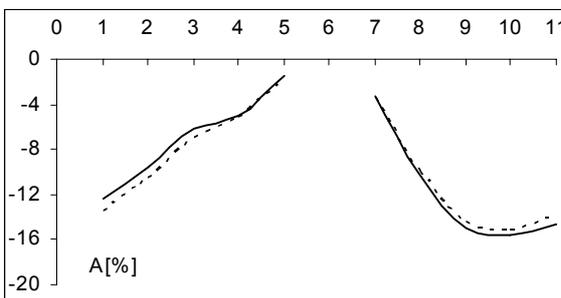


Fig. 3 The average amplitude recalculated to the heliosphere of the 11–year variations of the GCR Intensity by Climax (doted) and Huancayo-Haleakala (solid) neutron monitors
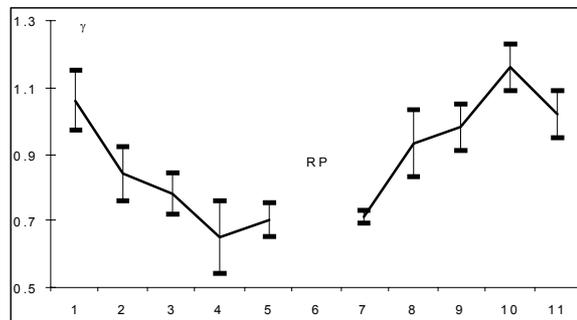


Fig. 2 Temporal changes of the rigidity spectrum exponent $\gamma$ corresponding to the data in Fig.1
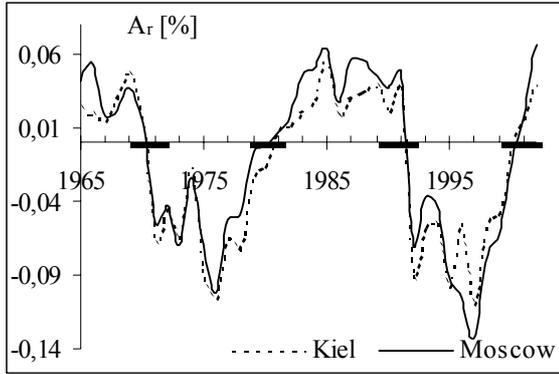
Fig. 4. Temporal change of the annual radial component $A_r$ of the anisotropy (bold-faced bars on the abscissa show time intervals of the global magnetic field reversals)
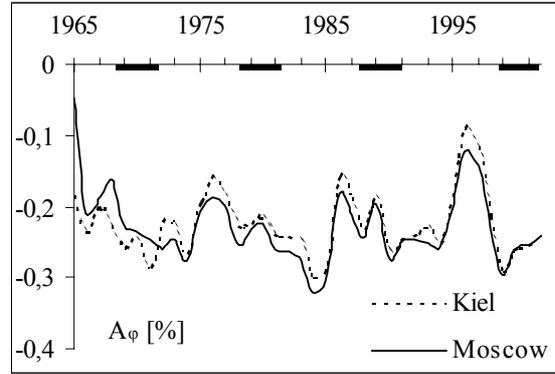
Fig. 5 Temporal change of the annual tangential component $A_\varphi$ of the GCR anisotropy

In Figure 2 is shown the temporal change of the rigidity spectrum exponent $\gamma$ of the GCR isotropic intensity variations calculated according to [15]. In the sixth point (Figure 2) there is a lack of the value of $\gamma$ as far this point corresponds to the RP. The recalculated to the heliosphere amplitudes of the GCR intensity variation based on the Climax and Huancayo-Halecala neutron monitors data (Fig.1) using the values $\gamma$ (Fig.2) are presented in Figure 3. It is seen that there is not any difference between the two curves corresponding to Climax and Huancayo-Halecala neutron monitors contrary to the changes in Figure 1, where the distinction is caused by the various response functions of Climax and Huancayo-Halecala neutron monitors. We believe that the turbulent component of the IMF is responsible for the formation of the rigidity spectrum of the GCR intensity long-period modulation, i.e. that the change of the power spectral density of the energy range region of the turbulence versus solar activity is one of the important reason of the 11-year variation of the GCR intensity.

The role of the regular IMF as the source of GCR particles drift can be studied based on the analyses of the behavior of the GCR anisotropy. In order to study the roles of the drift effects in the GCR anisotropy during the Sun's global magnetic field reversal and in different the qA>0 and the qA<0 periods of solar magnetic cycles the behaviors of the radial $A_r$ and the tangential $A_\varphi$ components of the diurnal variation of GCR have been analyzed for the period of 1965-2002. The radial $A_r$ component of the diurnal variation of GCR shows a clear 22-year variation (Fig.4), while the tangential $A_\varphi$ component (Fig.5) has tendency to the 11-year cycle changes. Earlier, a similar result for period 1965-1993 was obtained in paper [16]. The changes of the $A_r$ are caused by the radial component of the drift stream $S_{dr}$ of GCR which changes direction in different periods of solar magnetic cycles. In the qA>0 period the stream $S_{dr}$ is directed outward from the Sun, while in the qA<0 solar magnetic cycle $S_{dr}$ has vice versa direction [17]. The changes of the $A_r$ component show very clearly the 22-year periodicity related with the drift effect in different the qA>0 and the qA<0 periods of solar magnetic cycle. There is observed nearly drastically transition from one type of drift to another during the Sun's global magnetic field reversal. Only, during 1979-1981 drift effect is not pronounced visibly in the changes of the $A_r$ component ( $A_r \approx$ 0), i.e. that for this interval of the solar activity maximum the diffusion dominated model of the GCR transport is more acceptable.

For other periods of the Sun's global magnetic field reversal (maximum epochs), according to the behavior of the $A_r$ component (Fig. 4), more acceptable is the moderate approaching to the modeling of the GCR transport; from point of view of GCR modulation the transition time from one kind of direction of the Sun's global magnetic field to another (reversal) should be lasted much shorter than the observed duration time reversal of the Sun's global magnetic field (bold bars on the horizontal axis in Fig. 4).

## 3. Conclusions

1.  The temporal changes of the rigidity spectrum of the GCR intensity are related with the changes of the structure in the energy range of the IMF turbulence during the 11-year cycle of solar activity. The rigidity spectrum is harder in the minima epoch than in the maxima and basically does not depend on the polarity of the Sun's global magnetic field.
2.  The radial $A_r$ component of the anisotropy of GCR shows the clear 22-year variation for the period of 1965-2002. It is caused by the radial component of the drift stream $S_{dr}$ of GCR which changes direction in different half periods of the solar magnetic cycles. In the qA>0 period the stream $S_{dr}$ is directed outward of the Sun, but in the qA<0 period the $S_{dr}$ is directed inward.

## References

[1]  L. I. Dorman, Cosmic rays variations and space exploration, Moscow (1963)
[2]  K. Nagashima and J. Morishita, Planet. Space Sci. 28, 195 (1980)
[3]  G.A. Bazilevskaya, A. E. Svirzhevskaya, Space Sci. Rev. 85, 431-521 (1998)
[4]  Yu. I. Stozhkov, T. N. Charakhchyan, Geomagn. Aeron. 9(5), 803 (1969) (In Russian)
[5]  J. A. Lockwood, W. R. Webber, J. Geophys. Res. 89, A1, 17 (1984)
[6]  W. R. Webber, J. A. Lockwood, ApJ. 317, 534  (1987)
[7]  J. A. Le Roux, M. S. Potgieter, ApJ. 442, 847 (1995)
[8]  S. E. S. Ferreira, M. S. Potgieter, ApJ. 603, 744 (2004)
[9]  J. A. Lockwood, W. R. Webber, J. Geophys. Res. 101, A10, 21573 (1996)
[10] J. R. Jokipii, Rev. of Geophysics and Space Physics. 9, 27 (1971)
[11] N. Toptygin, Cosmic rays in interplanetary magnetic fields. D. Redel Publishing Company. Dordrecht (1985)
[12] J.W. Bieber, W. H. Mathaeus, C. W. Smith, et al., Astrophys. J. 420, 294 (1994)
[13] M. V. Alania, K. Iskra, Adv. Space Res. 16, 9, 241 (1995)
[14] K. Iskra, M. V. Alania, A. Gil, R. Modzelewska, M. Siluszyk, Acta Phys. Polonica B. 35, 4, 1565 (2004)
[15] M. Siluszyk, K. Iskra, R. Modzelewska and M.V. Alania, Adv. Space Res. 35, 4, 677 (2005)
[16] H. S. Ahluwalia, S.S. Xue, M.M. Fikani,  Adv. Space Res. 23, 3, 475 (1999)
[17] M. V. Alania, R.G. Aslamazashvili, T.B. Bochorishvili, K. Iskra, M. Siluszyk, Adv. Space Res. 27, 3, 613 (2001)