REAL DISTRIBUTION OF THE CORONAL GREEN LINE INTENSITY AND MODELLING STUDY OF GALACTIC COSMIC RAY PROPAGATION

Gushchina R.T. (1), M. V. Alania (2,3), A. Gil (2), K. Iskra (2), M. Siluszyk (2)
1. IZMIRAN, Troitsk, Moscow Region, Russia
2. Institute of Mathematics and Physics of University of Podlasie, Siedlce, Poland
3. Institute of Geophysics of Academy of Sciences of Georgia, Tbilisi, Georgia

ABSTRACT

Transport equation of galactic cosmic rays (GCR) has been numerically solved for different qA>0 (1996) and qA<0 (1987) epochs assuming that free path of GCR scattering in the interplanetary space is controlled by the Sun's coronal green line intensity (CGLI). We found some distinctions in the distribution of the expected heliolatitudinal gradients of GCR for two and three dimensional interplanetary magnetic field.

INTRODUCTION.

Modulation of GCR in the interplanetary space is generally determined by four processes- diffusion, convection, drift and energy change of GCR particles due to interaction with the solar wind. The joint effect of all above mentioned processes result the 11- year variation of GCR. In papers [1–3] are assumed that the general reason of the 11-year variation of GCR in the energy range more than 1 GeV is different structure of the irregularities of the IMF in the maxima and minima epochs of solar activity (SA) caused the radical changes of the dependence of diffusion coefficient on the rigidity of GCR particles.

EXPERIMENTAL DATA AND METHOD OF INVESTIGATION.

Experimental data of sunspot numbers, sunspots' areas and CGLI ($\lambda = 5303$Å) show a considerable changes during the 11-year cycle of SA, while e.g. the changes of the solar wind velocity are not so noticeable [4, 5]. An attempt to take into account influences of the real distributions of the sunspot's areas and the Sun's CGLI on the modulation of GCR considering delay time of the phenomena in the interplanetary space with respect to the processes on the Sun have been undertaken in papers [6–8]. One of parameters of SA contentiously observed on the Earth is the Sun's CGLI. One can suppose that a modulation of GCR by some means is controlled by the changes of the CGLI; particularly there is assumed that a scattering free path of GCR transport is related with the

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CGLI. A dependence of a scattering free path of GCR transport Λ'(r,θ,R,t) on the CGLI is supposed as:

$$\Lambda'(r,\theta,R,t) = \Lambda_{min}(R,t)/F(S,t-r/u) \quad (1)$$

Where $\Lambda_{\rm min}$(R,t) is a scattering free path of GCR transport in the minimum epoch of SA, t-time, U- the solar wind velocity, R- rigidity of GCR particles, r–radial distance from the Sun and θ - heliolatitudes. Function F(S, t- r/U) characterizes an influence of the CGLI on the scattering free path Λ'(r,θ,R,t) of GCR transport. This function F(S, t- r/U) changes in the range of 1.0 – 2.0 and 1.0 – 4.0 in the minimum and maximum epochs of SA, correspondingly. In addition the minimum value of the function F(S, t- r/U) corresponds to the level of the CGLI near the polar region and the maximum level — to the equatorial and near equatorial region of the Sun. Daily data of CGLI in the range of 5^0 of the heliolatitudes (36 values) observed on the Earth has been used [9]. In order to increase the statistical accuracy and eliminate a heliolongitudinal asymmetry data of CGLI was averaged for the period of one month. In the figure 1 are presented the changes of the CGLI for the periods of the qA<0 (1987) and the qA>0 (1992 and 1996). One can see from this fig.1 that the CGLI in the minima epochs (1987 and 1996) and in the maximum epoch of SA in high heliolatitudes coincide, while in the maximum epoch of SA there is a considerable distinction (about 3–4 times). According to the Ulysses measurements in the maximum epoch of SA the solar wind velocity U is more or less constant (U = 400–450 km/s) versus the heliolatitudes, while in the minimum epoch U is about two times greater in the high heliolatitudes (U ∼800 km/s). The levels of CGLI are near to the ground in the high heliolatitudes for the both minimum and maximum epochs of SA and basically are unchanged versus heliolatitudes (for $\theta < 50^0$–60^0 and $\theta > 125^0$–130^0). Bearing it in mind we assume that the changes of the CGLI uniformly are transferring to the interplanetary space with the constant solar wind velocity U = 400 km/s. It means that on the each interval of 0.23 astronomical unit (AU) the electromagnetic processes in the interplanetary space are controlled by the daily data of the CGLI, i.e. for occupied of the modulation region of 100 AU there are necessary data of ∼435 days. For example, when the boundary of the modulation region is controlled by the data of CGLI of the first decade of the January of a given year, then a modulation of GCR in proximity of the Sun surface is controlled by the third decade of the March of the next year. Thus, in the coordinate system ρ, θ (ρ=r/r_0) for the 435 equidistant distances from the Sun there are 435 values of the CGLI in the radial direction and 36 values for different heliolatitudes θ ($\theta = 0°$ at the north pole), i.e. there is a grid with $435 \times 36 = 15660$ nodes with different values of the CGLI. To eliminate irregular changes observed from day to day data of the CGLI was smoothed by method of moving average with the period of 5 days in the r direction.

MODELING OF GCR PROPAGATION.

Parker's transport equation [10] in steady state case has been used for the modeling of GCR propagation in the interplanetary space:

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

Where N, and R are density (in interplanetary space) and rigidity of GCR particles, respectively; U_i is the solar wind velocity and κ_{ij} is generalized anisotropic diffusion for the three dimensional IMF [2, 11]. As far as in this paper is studied an influence of the CGLI changes on the long period GCR modulation, Eq (2) is considered for two dimensional case ρ, θ neglecting any kind of heliolongitudinal variations of GCR intensity. There are taken into account the following components of the generalized anisotropic diffusion tensor [2, 12]

$$\begin{aligned}
\kappa_{11} &= \kappa_0[\cos^2\gamma\cos^2\psi + \alpha(\cos^2\gamma\sin^2\psi + \sin^2\gamma)] \\
\kappa_{21} &= \kappa_0[\sin\gamma\cos\gamma\cos^2\psi(1-\alpha) + \alpha_1\sin\psi] \\
\kappa_{12} &= \kappa_0[\sin\gamma\cos\gamma\cos^2\psi(1-\alpha) - \alpha_1\sin\psi] \\
\kappa_{22} &= \kappa_0[\sin^2\gamma\cos^2\psi + \alpha(\sin^2\gamma\sin^2\psi + \cos^2\gamma)]
\end{aligned} \tag{3}$$

Where ψ is the angle between the magnetic field lines and radial direction, (is the angle between the magnetic field lines and radial direction in the meridian plane; $\alpha = \kappa_\perp/\kappa_\parallel, \alpha_1 = \kappa_d/\kappa_\parallel$, where $\kappa_\perp, \kappa_\parallel$ and κ_d are parallel, perpendicular and drift diffusion coefficients of GCR in the regular IMF, respectively.

Eq(2) was solved by difference scheme method using a grid with $94 \times 65 = 6110$ nodes (94 steps in ρ direction and 65 steps in θ direction). The corresponding values of the CGLI in ρ, θ plane for nodes i, j (i =1,2,...,94; j =1,2,...,65) have chosen from $435 \times 36 = 15660$ point-data of the CGLI by the Lagrange' interpolation method practically leading to use only its linear part (due to the smooth character of the CGLI changes); $\kappa_\parallel = \kappa_0(1+50\rho)$W(F) R^{α_2}, where $\kappa_0 = 2.5 \times 10^{22}$ cm^2/s and $\alpha_2 = 0.5$ in the epoch of SA minimum and $\alpha_2 = 1.0$ — in the maximum epoch of SA for GCR particles with rigidity more than 10 GV. W(F) = 1 / F(S, t − r/U); The radius r_0 of the modulation region equals 100AU; $\alpha = 0.1$ and $\alpha_1 = 0.3$ at the Earth orbit and gradually increase up to one to the boundary of the modulation region ($\alpha \to 1$ and $\alpha_1 \to 1$).

There were considered: a) two dimensional IMF (radial component H_r = 4nT and azimuthally component H_φ = 4nT at the Earth orbit) and b) three dimensional IMF (H_r = 3.8 nT, H_φ = 3.8 nT and heliolatitidunal component H_θ = 1.5nT at the Earth orbit). The magnitude of the IMF's strength H = $(H_r + H_\varphi + H_\theta)^{1/2}$ is the same for the both two and three dimensional cases. An invariance of the value of the H in those cases is considered to show the distinctive role of the third H_θ components of the IMF in the modulation of GCR

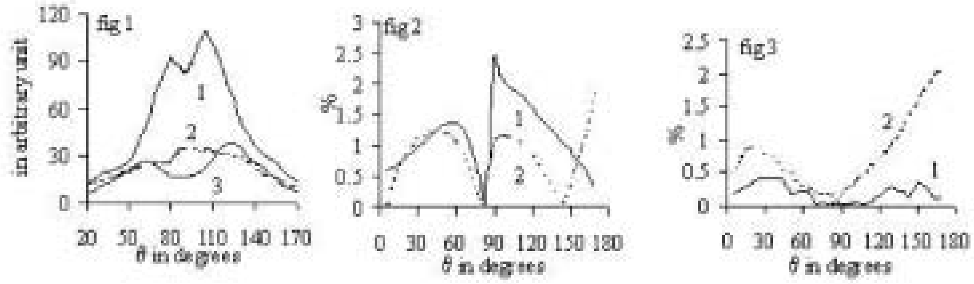

Fig.1. Heliolatitudinal distribution of the CGLI, 1 – 1992; 2 – 1996; 3 – 1987

Fig.2. Expected heliolatitudinal gradient of GCR in 1996 (qA>0), 1 for the two dimensional IMF (solid) and 2 for the three dimensional IMF

Fig.3. The same as in figure 2, for 1987 (qA<0)

in equal other conditions in interplanetary space for the qA>0 and qA<0 solar magnetic cycles. There were obtained the expected spatial distributions of the density, radial and heliolatitudinal gradients of GCR for the two minima epochs of solar magnetic cycles qA<0 (1987) and qA>0 (1996) of SA. In figure 2 and 3 are presented distributions of the heliolatitudinal gradients (∇_θf) of GCR for the above mentioned minima epochs of SA. It is seen from this fig.2 and 3 that ∇_θf for the period of 1996 (qA>0) is less for three dimensional IMF (dashed curve) than for two dimensional IMF (solid curve), while for the period of 1987 there is observed vice versa effect. These differences must be connected with different directions of the drift streams of GCR in 1987 and 1996. The analyses show that there are distinctions between the distributions of the heliolatitudinal gradients in different radial distances generally determined by the heliolatitudinal distributions of the CGLI corresponding to the concrete period of the observations on the Sun responsible for the local electromagnetic processes at the given concrete distances. As an example of such kind manifestation of the peculiarities of the CGLI distribution can be considered an insignificant increase of the expected heliolatitudinal gradient of GCR in the south heliosphere (fig.3, dashed curve 2, for $\theta > 125^0$–130^0).

CONCLUSION

1. An expected heliolatitudinal gradient of GCR in the minimum epoch of SA 1996 (qA>0) is less for the case of three dimensional IMF than that for two dimensional one, while in the period of another minimum 1987 (qA<0) there is obtained diametrically opposite result. This effect possibly is connected with different directions of the drift streams in 1987 (qA<0) and in 1996 (qA>0). Generally in the both minima epochs of SA the heliolatitudinal gradients of GCR are small. These results are qualitatively comparable with the observations by Ulysses in spite of that for calculations in this paper was used an uncomplicated

diffusion coefficient completely different e.g. from possible more realistic but with very complicated view [13].

2. It seems that using of the generalized anisotropic diffusion tensor for the three dimensional IMF in modeling of GCR propagation for the minima epochs of SA is probably necessary. For the minima epochs of SA the existence of the regular latitudinal H_θ component of the IMF [14–15] is not doubtable.

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