THE INFLUENCE OF NONSTATIONARITY OF THE SOLAR ACTIVITY AND GENERAL SOLAR FIELD ON MODULATION OF COSMIC RAYS

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ABSTRACT. It was conducted numerical model of the propagation of galactic cosmic rays in the interplanetary space for the case when the modulation depth determined by the level of the solar activity changed in time.Also the contribution of the particles drift in the regular field was calculated and it was shown the agreement with experimental data about the ratio of protons and electrons in two solar activity minima.

The stationary spherical-symmetric approach of weak modulation was applied for the investigation of galactic cosmic ray modulation /1-3/.For the cosmic rays intensity at the Earth's orbite we write

$$n(r,t) = n_0 \exp\left[-\int_r^{r_0} \frac{U(r)}{\varkappa(r)}\, dr\right], \qquad (1)$$

where U is the solar wind velocity, $\varkappa$ is the diffusion coefficient, r_0 is the dimension of modulation region.We'll consider the simple modelling problem.Let us break the integral in (1) for N equal parts assuming $U_i/\varkappa_i$ is constant for each interval Δr.Then we have for K-moment in case, when $\varkappa$ =const(r)

$$\frac{n_K}{n_0} = \exp\left[-\sum_{i=0}^{N} y_{iK}\right], \quad y_{iK} = \frac{U_{iK}}{\varkappa_{iK}}\Delta r \qquad (2)$$

and for gradient g_{ik}

$$g_{iK} = \left\{\exp\left[-\sum_{i+1}^{N} y_{iK}\right] - \exp\left[-\sum_{i-1}^{N} y_{iK}\right]\right\} \Big/ 2\exp\left[-\sum_{i}^{N} y_{iK}\right]\Delta r, \qquad i \geq 1 \qquad (3)$$

In case when $\varkappa \sim r$

$$\frac{n_K}{n_0} = \prod_{i=0}^{N}\left[\frac{1+6i}{1+6(i+1)}\right]^{y_{iK}}, \quad y_{iK} - \frac{U_{iK}}{\varkappa_{iK}} r_1, \qquad r_1 = 1\,au, \qquad (4)$$

$$g_{iK} = \left\{\prod_{i+1}^{N}\left[\frac{1+6i}{1+6(i+1)}\right]^{y_{iK}} - \prod_{i-1}^{N}\left[\frac{1+6i}{1+6(i+1)}\right]^{y_{iK}}\right\} \times \left\{2\prod_{i}^{N}\left[\frac{1+6i}{1+6(i+1)}\right]^{y_{iK}}\Delta r\right\}^{-1} \qquad (5)$$

The interval Δ r was chosen equal to 6 a.u. The values y_{ik} were generated as follows: for t=0 (i.e. k=0) the sum of all terms of y_{ik} sub i was filled up by numbers a_0 which were chosen so as their sum is equal to 1.8 (that correspond to modulation coefficient at solar activity maximum). Hence it follows a_0=0.164. For the first column $y_{0k} = a_0 - kb$ to k=15 then $y_{0k} = y_{15} + kb$ ($15 < k \leq 30$) and again $y_{0k} = y_{30} - kb$ ($k > 30$). The value b was chosen equal to 0.01. Thus the values y_{0k} (in Fig.1a) represent the solar activity cycle. The results obtained from (2) and (4) have been shown in Fig. 1a. One can see that the lag of cosmic rays intensity increase is bigger in case when the diffusion coefficient is independent on the distance from the Sun. The results of

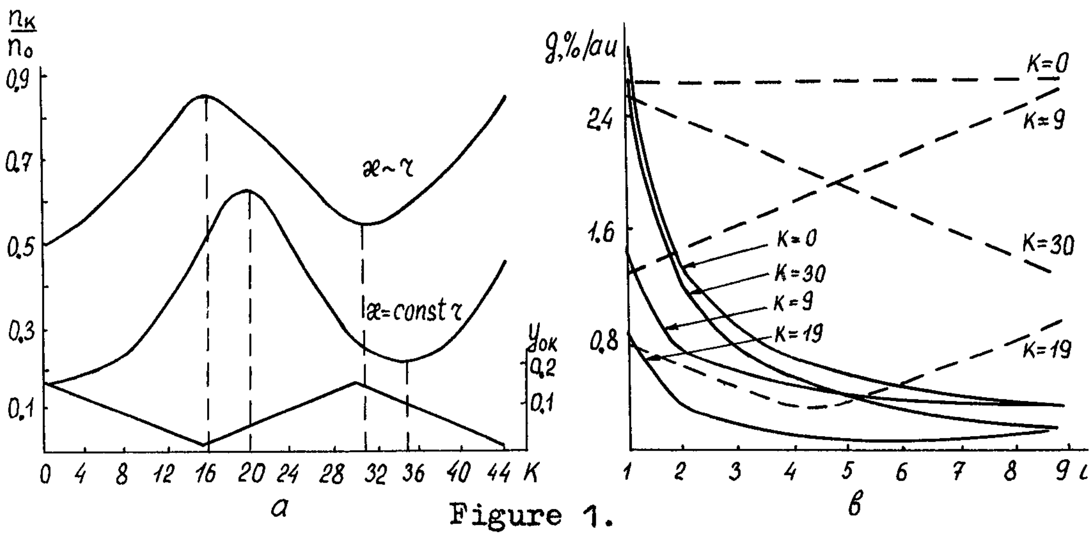

Figure 1.

the calculations of radial gradient for $\varkappa$ =const (r) (dotted line) and $\varkappa \sim r$ (solid line) have been shown in Fig.1b. We have constant gradient for uniform filling of modulation region (k= 0). Then gradient increases with distance at decreased "solar activity" branch and it decreases at the increased branch (k=30). The change of gradient with distance has complicated form at transition period (k=19). Introducing the dependence n_k/n_0 on the particle rigidity R through the dependence $\varkappa$ (R) in the form /4/

$$\varkappa(R) = \varkappa_0 f(R), \text{where } f(R) = \frac{R^{1.5}(R+R_0)^{1.5}}{(1+R_0)^{1.5}(R^2+0.88)^{0.5}}, \qquad (6)$$

we have for $\varkappa$ =const(r)

$$\frac{n_k}{n_0} = exp\left[-\frac{1}{f(R)}\sum_{i=0}^{N} y_{ik}\right] \qquad (7)$$

and for $\varkappa \sim r$

$$\frac{n_k}{n_0} = \prod_{i=0}^{N}\left(\frac{1+6i}{1+6(i+1)}\right)^{\frac{y_{ik}}{f(R)}} \qquad (8)$$

Energy spectra of the cosmic rays intensity normalized at the solar activity minimum have been shown in Fig.2.The solid lines correspond to the case $\varkappa$ =const(r),dotted lines - $\varkappa \sim$ r,symbols are values k-different moments of "solar activity" cycle.The curves with k=0 and k=30 correspond to the same "solar activity" level,however the curves differ greatly in appearance.Analogously the curves with k=7,37 and k=23 correspond to the same "solar activity" level.

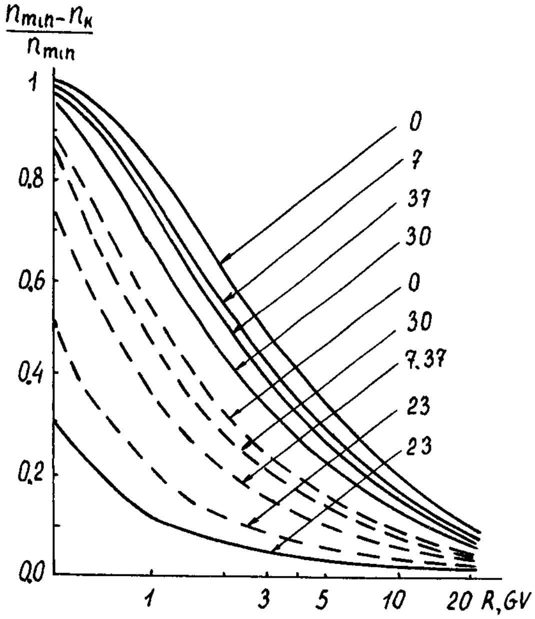

Figure 2.

The influence this factor on the lag time modulation effects relatively to changes of the solar activity level is shown in Fig.3 (solid lines for case $\varkappa$ =const(r), dotted lines for the case $\varkappa \sim$ r,symbols are values k). The values of the lag time τ_i were calculated with method described in /5/,then total lag time determined by $\tau = \sum_{i=0}^{10} \tau_i$

Thus one can see that the nonstationarity of modulation properties of the solar wind and its distribution with distance from the Sun essentially influences on the energy spectra of particles,gradients of cosmic rays intensity in the interplanetary space and the lag time of modulation effects relatively to changes of the solar activity level observed near the Earth when the dimension of the cosmic ray modulation region is greater than 50 a.u.

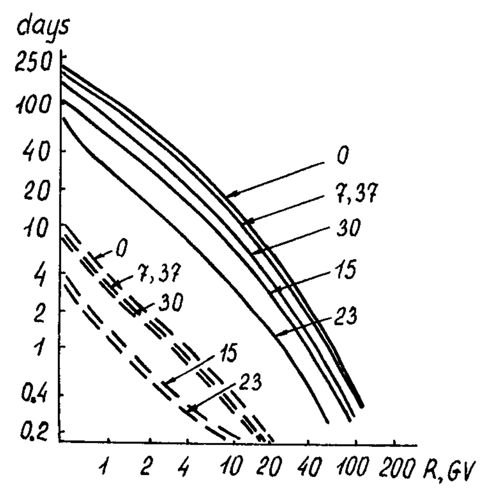

Figure 3.

Moreover the particles drift in the regular magnetic field connected with general solar field /6-8/ gives certain contribution to the break of the relation between cosmic ray intensity and the observed solar activity level.

In /9/ the values of the absolute coefficients of "usual" convective-diffusion modulation (determined by the solar activity level) K_1 and effect of the influence of general solar fields K_2 were determined by investigation the connection between the cosmic ray intensity and HL-index of solar activity. On the whole the observed intensity is determined in this model by

$$J(\varepsilon, K_1, K_2) = J_0(\varepsilon) \exp\left[-\frac{K_1}{f(R)} + \frac{K_2}{f_2(R)}\right], \qquad (9)$$

where f(R) is the same that in (6), $f_2(R) = \lambda\rho/(\lambda^2 + \rho^2)$, ρ is Larmor radius, λ is determined from (6), ($\varkappa = \lambda v/3$). The sign before K_2 is positive for 1954 and 1976, and negative for 1965. In /9/ it was found that $K_1 = 0.21 \pm 0.08$; 0.32 ± 0.10 and 0.35 ± 0.10 for 1954, 1965 and 1976 respectively, the values K_2 are equal $+0.14 \pm 0.03$; -0.09 ± 0.04 and $+0.11 \pm 0.03$ for the same periods. Hence we have:

$$\frac{J_{1977}}{J_{1965}} = \exp\left[-\frac{0.03}{f(R)} + \frac{0.2}{f_2(R)}\right] \qquad (10)$$

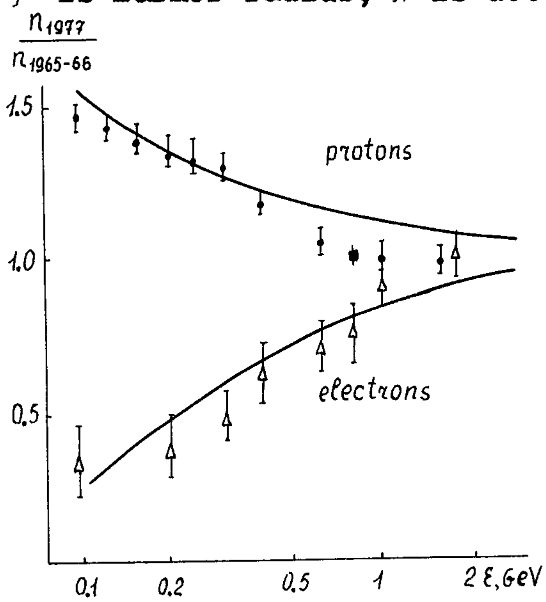

Figure 4.

The results of the calculations using (10) for $R_0 = 15$ GV have been shown by curves in Fig. 4 for protons and electrons. In this figure we have presented the direct experimental data from /10/ for these ratios in the energy interval 0.1 - 2 GeV. It is seems a good agreement between our calculations and the experimental ratios.

We have shown that the effects connected with nonstationarity of the modulation properties of the solar wind and the particles drift in the regular field exerts essential influence on galactic cosmic ray modulation.

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