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Influence of the Asymmetrical Character of the Solar Activity on the Annual Variation of Galactic Cosmic Rays.

T.B. Botchorishvili[a] and L. I. Dorman[b]
(a) Institute of Computer Science, University of Podlasie, Siedlce 08-110, Poland
(b) Cosmic Ray Dep. of IZMIRAN, Rus. Ac. of Science, Troitsk 142190, Moscow region, Russia;
Presenter: L. I. Dorman (lid@physics.technion.ac.il), pol-botchorishvili-T-abs1-sh34-poster

It is widely known fact that of the heliosphere asymmetry has a complex character. Not only distribution and structure of magnetic poles and inhomogeneities are complex but also sunspot numbers spatial distribution character is complicated. We believe that the sunspot numbers, in the epoch maxima of solar activity, toward the Apex are more. In other words the Sun activity has asymmetrical character and develops in the Apex direction. It should be one of the causes of the heliosphere asymmetry that should be mapped on distribution of density and gradients and also on annual variations of galactic cosmic rays (GCR). In the paper 3D simulations of the transport of the galactic cosmic rays in the nonsymmetrical heliosphere are presented.

1. Introduction.

Commonly, in order to simulate the transport of galactic cosmic rays, the symmetrical heliosphere is considered. Opposing to standard assumptions we examine the models of propagation of the cosmic rays in the non-symmetrical sphere. Different geometry of the termination shock causes the change of. the intensity and the distribution of the GCR According to our supposition complicated geometry of the heliosphere should result in annual variation of the GCR. Geometrical form of the heliosphere significantly differs in varying epochs of solar activity. According to our premises this phenomenon should be well mapped on distribution of density and gradients and also on annual variations of the GCR. The influence of heliospheric geometry on cosmic ray intensity were studied in several papers [1 – 3].

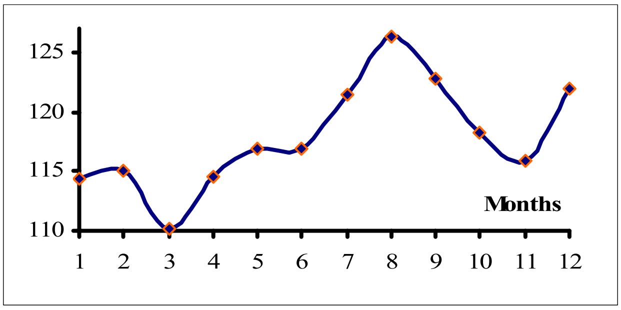


Figure. 1 Monthly average of sunspot numbers for period 1900-2000 years.

The results of solution of transport equation are dependent on parameters of the model and also on assumption about heliospheric magnetic field and on cosmic ray mean free path. Some kinds of variations must be influenced by shape of the heliosphere. The asymmetry of the solar disk is carried over to the outer heliosphere by solar wind.

We assumed, that in the epoch of the solar activity, when the Earth bring nearer to the Apex during its voyager around the Sun, the activity of the Sun increase. In other words, toward the Apex the Sun is more active. On the Figure 1 is shown a variation of a monthly average of the sunspot numbers during one year in the epoch maxima of the solar activity.

Due to, we assumed [5], [7], that the heliosphere is nonsymmetrical and it's form has the influence on distribution of GCR and is one of the significant factor which would determine the annual variation. Character of the influence of the distributions of the sunspot numbers on the shape of the heliosphere is good represented in GCR (Figure2). As we see in Figure 2 annual variation has cyclic character. It means that annual variation wouldn't be stipulated only by the asymmetry of the solar disk (solar disk asymmetry has not cyclic character).

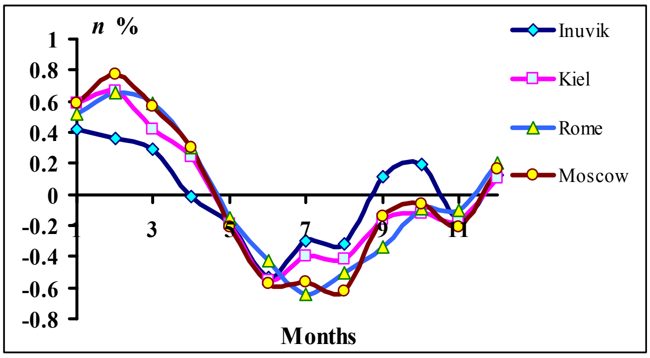


Figure. 2 Dynamics of annual variations in percents during one year for the stations: Inuvik, Kiel, Moscow and Rome. Monthly averages are shown for period of 1958-1994. Majority of stations from north hemisphere have minima in July, some others in June

We can see from previous figures(Figure1 and Figure2), that the correlation between minimum of intensity of GCR and maximum of the sunspot numbers is shifting one month. Statistical analyses (Cross correlation analyses) of data is given in Table 1. These results ones again convinced us, that the heliosphere is nonsymmetrical.

Table 1. correlation coefficients between intensity of GCR and the sunspot numbers for the stations: Inuvik, Kiel, Rome, Tbilisi, Tokyo and Moscow.
(a) First row: when data of the sunspot numbers is not sifted.
(b) Second row: when data of the sunspot numbers is sifted to left one month

	Inuvik	Kiel	Rome	Tbilisi	Tokyo	Moscow
Wolfa	**-0,54**	**-0,58**	**-0,59**	**-0,51**	**-0,51**	**-0,60**
Wolfa	**-0,88**	**-0,83**	**-0,87**	**-0,76**	**-0,77**	**-0,82**

From the above table appears that the influence of the active regions of the Sun on GCR is felt quickly, whereas it can only be observed after the period of one month, e.g. When the influence of the active regions of the Sun is felt in July, we observe it on the Earth in August. This phenomenon is caused by curvature of the global magnetic field of the Sun.(See Figure 3)

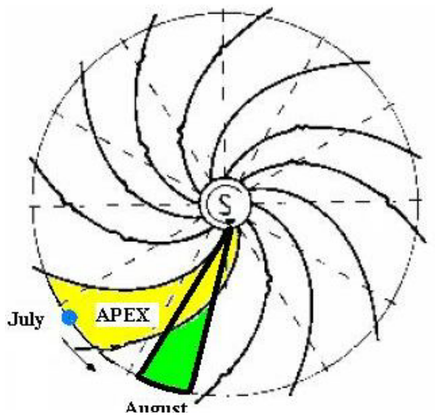


Figure. 3 The propagation of the influence of the actives regions in the Heliosphere

We investigate the influence of different geometries of the heliosphere on the cosmic ray density, latitudinal and radial gradients distributions in the interplanetary space. We consider an ellipsoidal heliosphere with termination shock at 100-150 AU and the solar wind speed 400 km/s. The forwardly elongated heliosphere with the case, when the boundary is elongated to the interstellar wind direction, is shown on Figure4.

The form of the heliosphere boundary is defined by term of:

$$r(\vartheta,\varphi) = \frac{a^2 - p^2}{a - p \cdot Cos(\varphi) \cdot Sin(\vartheta)} \left(1 + \beta \cdot Cos^2(\varphi) \cdot Sin(\vartheta)\right) \qquad (1)$$

where ϑ and φ are spherical coordinates, $p^2 = a^2 - b^2$, ***a***=120a.u., ***b***=100a.u. and β is a coefficient activity of the Sun.

The modeling of the heliosphere form is possible by changing of a parameter β. When β is small ∝ 0.3. we are modeling a quiet heliosphere and when it is bigger ∝ 0.5, we are modeling the disturbance heliosphere.

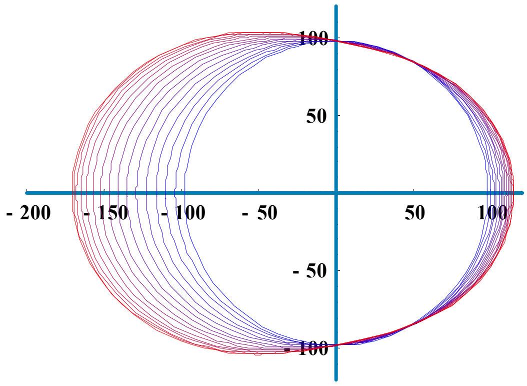


Figure. 4 The ellipsoidal shape of the heliosphere. Cross-section for different spherical angle θ. The Sun is in the focus of the ellipsoid. The distances on the axes are in a.u.

2. Transport equation of GCR

We use standard GCR transport equation for cosmic ray density n:

$$\frac{\partial n}{\partial t} = \nabla_i (\Re_{i,k} \nabla_k n) - \nabla_i (V_i n) + \frac{1}{3} \frac{\partial}{\partial R} (n \cdot R) \nabla_i V_i \quad (2)$$

with tensor diffusion coefficient

$$\Re_{ik} = \Re_0 \begin{pmatrix} 1 & 0 & 0 \\ 0 & \alpha & \alpha_1 \\ 0 & -\alpha_1 & \alpha \end{pmatrix} \quad (3)$$

where $\alpha = \frac{\Re_\perp}{\Re_\parallel} = \frac{1}{1+\omega^2\tau^2}$ and $\alpha_1 = \frac{\Re_x}{\Re_\parallel} = \frac{\omega\tau}{1+\omega^2\tau^2}$ (4)

$\Re_\parallel, \Re_\perp$ and $\Re_\times$ are - parallel, perpendicular and drift diffusion coefficients corresponding, *R* is rigidity, *r* - distance from the Sun, *V* is solar wind velocity and $\Re_0$ - parameter.

The assumed LISM spectrum of protons is following

$$n_0 = k_0 \frac{E_k^{0.7}}{(E_k + 0.25)^3} \quad (5)$$

where E_k is kinetic energy.

The equation (2) is solved in a stationary case.

3. Results of calculation

Preliminary results of 3D model calculation for the heliosphere which has ellipsoidal boundary 100-150 AU, is shown on Figure 5. Lower curves correspond near distance from the Sun. When we circuit around the Sun together with the Earth, during one year the intensity is changing and it is maybe possible cause of annual variation. The influence of the form of the heliosphere on the annual variations in the surrounding of the Sun (≤10a.u.) is very small. Amplitude of annual variation increases when we move away from the Sun (Figure5).

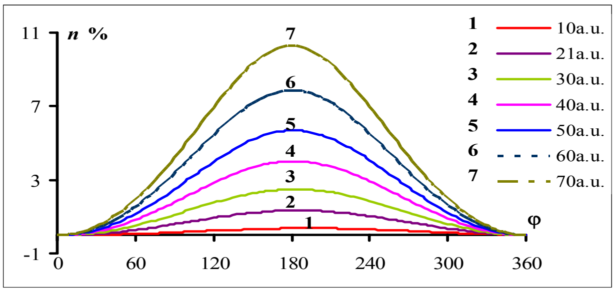
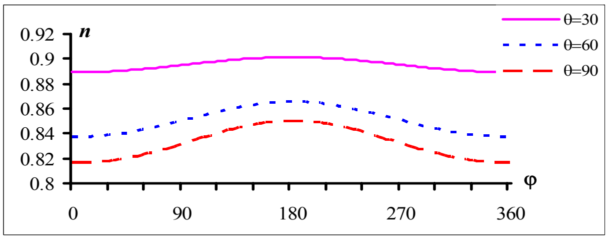


Figure 5 Here the dependence of amplitude of the annual variation of GCR on the altitude for different distances, in the Ecliptic plane and for rigidity 5Gv is shown. The angle φ=180 corresponds to the opposite Apex direction

Our calculations showed that the influence of the form of the heliosphere on the GCR must decrease, when we move from the lower latitude to the high one (see Figure6).

Figure. 6 The dependence of a density of GCR on the altitude for the different latitude angle for rigidity 5Gv and distance 40 au. is shown. The angle φ=180 corresponds to the opposite Apex direction.



4. Conclusion

The analyzing above models is possible to tell, that the value of an amplitude of annual variation is defined on the form of the heliosphere, deformed by strong activity by the Sun toward the Apex. Previous examinations show, that the amplitude of the annual variations in the epoch minimum should be ≈0.7%, while in the epoch maximum considerably increases up to 2%-3%.

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