On The Expected Deviation Of The Interplanetary Magnetic Field Lines From The Helioequatorial Plane And The Anisotropic Diffusion Tensor Of Galactic Cosmic Rays

M.V. Alania

(a) Institute of Math. And Physics of University of Podlasie, 3 Maja 54, Siedlce, Poland
(b) Institute of Geophysics, Georgian Academy of Sciences, Tbilisi, Georgia
Presenter: M.V. Alania (alania@ap.siedlce.pl), pol-alania-M-abs5-sh34-poster

We assume that a deviation of the interplanetary magnetic field (IMF) lines from the equatorial plane and the appearance of the latitudinal component of the IMF should be observed due to the asymmetry distribution of the solar wind velocity on the heliolatitudes. The *SWOOPS* instrument on Ulysses have revealed that the solar wind velocity is approximately constant $\approx$ 400-450 km/s in the low heliolatitudes ($\pm$ 0-35^0) and then it is doubled up to $\approx$ 800 km/s in the middle and high latitudes in the minima epoch of solar activity. This specific heliolatitudinal distribution of the solar wind velocity causes the violence of the equilibrium between the neighboring located regions with different solar wind velocities. It is supposed that the layer (stream tub) of the heliosphere with the high solar wind velocity (the dynamic P_{dyn} pressure increases and the static P_{stat} pressure decreases comparing with the low solar wind velocity layer) involves the solar wind plasma with the IMF lines from the lower velocity region, particularly from the helioequatorial region. The diverged lines of the IMF from the helioequatorial region must be a reason of the appearance of the IMF's latitudinal component B_{θ}.

1. Introduction

The latitudinal component B_{θ} of the IMF is one of the most geoeffective parameters and in general it is used to estimate the disturbances of the Earth magnetosphere [1]. The regular component B_{θ} of the IMF plays a vital role in the diffusion propagation of galactic cosmic rays in the heliosphere, too. However, the existence of the regular component B_{θ} of the IMF during the whole cycle of solar activity is uncertain, although according to [2] in the minima epoch of solar activity B_{θ} should be existed. Before, in the paper [3] was suggested that the large-scale field near the poles may be dominated by randomly-oriented transverse magnetic fields with magnitude much larger than the average spiral. The field direction is transverse to the radial direction most of the time instead of being nearly radial. We consider that the appearance of the regular component B_{θ} of the IMF can be related with the deviation (divergence) of the Parker's type IMF lines from the helioequatorial plane. The possible deviation of the IMF's lines from the equatorial plane was apparently first recognized in paper [4] and late in [5]. Recently, in paper [6] was found that the lines of the IMF are weakly diverged from the solar equatorial plane near the Earth's orbit based on the analyses of the IMF data for the period of 1966-1998. They explained this effect as a result of the super radial extension of solar wind related with the continuous solar activity. We think that the divergence of the IMF's lines from the equatorial plane is associated with the specific heliolatitudinal distribution of the solar wind velocity.

## 2. The Expected Structure of the IMF

The *SWOOPS* instrument on Ulysses [7] have revealed that the solar wind velocity is approximately constant $\approx$ 400-450 km/s in the low heliolatitudes ($\pm$ 0-35^0) and then it is doubled up to $\approx$800 km/s in the

middle and high latitudes in the minima epoch of solar activity. We consider solar wind as a motion of the axis symmetrical high conductivity fluid [8; 9]. Magnetic field lines are frozen in the moving high conductivity fluid (plasma) and they can not cross each other. For simplicity the magnetic field lines are considered as a radial for the spherical symmetric and constant solar wind velocity (Figure1).
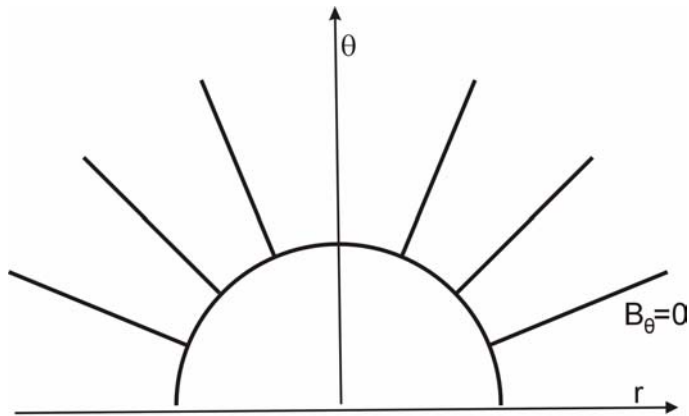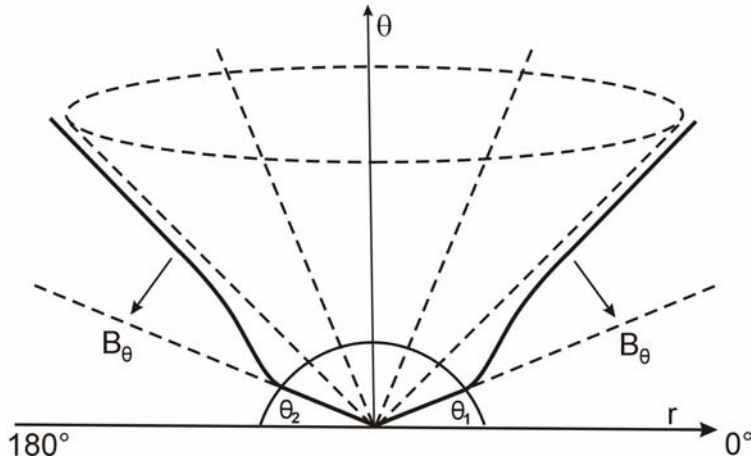

Figure1. Radial magnetic field lines in the heliosphere for spherical symmetric and constant solar wind velocity.

We apply the Bernoulli principle [9] : $P_{stat} + P_{dyn}$ = constant for any point of the motion fluid. When the velocity increases (dynamic pressure-P_{dyn}) a decrease of the static pressure (P_{stat}) takes place, i.e. In the high solar wind velocity layer(stream tube) the dynamic P_{dyn} pressure increases and the static P_{stat} pressure decreases comparing with the low solar wind velocity layer. So, the change of the solar wind velocity versus the heliolatitude causes the violence of the equilibrium between the neighboring located regions with different solar wind velocities. Generally stream tube of the heliosphere with the high solar wind velocity involves the solar wind plasma with the IMF lines from the lower velocity regions (Figure2).
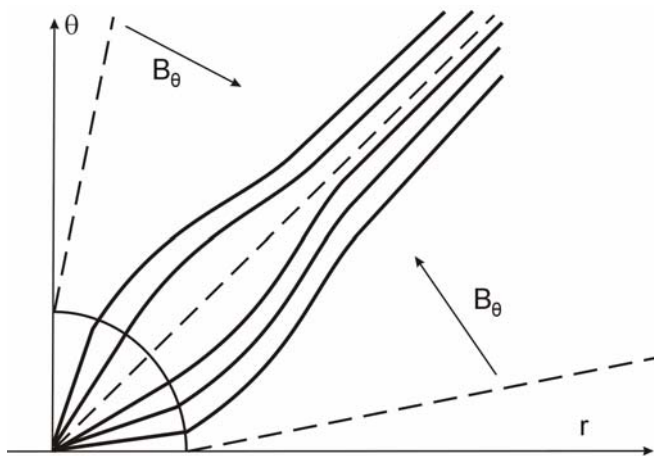
Figure 2 . Magnetic field lines in the heliosphere with asymmetry solar wind velocity vs heliolatitues. Dashed lines are undisturbed magnetic field lines (directed radial) and the bending solid magnetic field lines are diverged according to the Bernoulli principle

In figure 3 is shown the case approximately corresponding to the distribution of the solar wind velocity versus the heliolatitude according to the ULYSSES data. In the figures 2 and 3 dashed lines are corresponding to the radial magnetic field lines, but – bending solid lines (in figure 3) show the divergence from the helioequatorial plane. The divergence of the IMF's lines from the helioequatorial plane should be the motive of the appearance of the IMF's latitudinal component B_θ.

Figure.3. Magnetic field lines in the heliosphere with asymmetry solar wind velocity vs heliolatitues. For $0^0 \le \theta \le \theta_1$ and $\theta_2 \le \theta \le 180^0$ the solar wind velocity equqls ~400 km/s; for $\theta_1 \le \theta \le \theta_2$ the solar wind velocity is ~800 km/s (according to the ULYSSES data).Dashed lines are undisturbed magnetic field lines (directed radial) and the bending solid magnetic field lines are diverged according to the Bernoulli principle.

The existence of the regular component B_θ of the IMF plays an important role in the diffusion propagation of galactic cosmic rays in the heliosphere. For the modeling of the galactic cosmic propagation in the heliosphere a transformation of the anisotropic diffusion tensor of galactic cosmic rays for the three dimensional IMF has been done [e.g. 10; 11]. The generalized tensor of the anisotropic diffusion of GCR for qA>0 has the form:

$$K_{11} = K_{II}\left[\cos^2\delta\cos^2\psi + \beta\left(\cos^2\delta\sin^2\psi + \sin^2\delta\right)\right]$$

$$K_{12} = K_{II}\left[\sin\delta\cos\delta\cos^2\psi(1-\beta) - \beta_1\sin\psi\right]$$

$$K_{13} = K_{II}\left[\sin\psi\cos\delta\cos\psi(\beta-1) - \beta_1\sin\delta\cos\psi\right]$$

$$K_{21} = K_{II}\left[\sin\delta\cos\delta\cos^2\psi(1-\beta) + \beta_1\sin\psi\right]$$

$$K_{22} = K_{II}\left[\sin^2\delta\cos^2\psi + \beta\left(\sin^2\delta\sin^2\psi + \cos^2\delta\right)\right]$$

$$K_{23} = K_{II}\left[\sin\delta\sin\psi\cos\psi(\beta-1) + \beta_1\cos\delta\cos\psi\right]$$

$$K_{31} = K_{II}\left[\cos\delta\sin\psi\cos\psi(\beta-1)+\beta_1\sin\delta\cos\psi\right]$$

$$K_{32} = K_{II}\left[\sin\delta\sin\psi\cos\psi(\beta-1)-\beta_1\cos\delta\cos\psi\right]$$

$$K_{33} = K_{II}\left[\sin^2\psi+\beta\cos^2\psi\right]$$

Where, δ is the angle between the lines of the IMF and the radial direction in the meridian plane ($\delta = \text{arctn}\frac{B_\Theta}{B_r}$) and ψ is an angle between the radial direction and IMF lines ($\psi = arctn\frac{B_\varphi}{B_r}$) in the equatorial plane in the spherical coordinate system (ρ,θ,φ); $\beta = K_\perp / K_\parallel$ and $\beta_1 = K_d / K_\parallel$ are the ratios of the perpendicular $K_\perp$ and drift K_d diffusion coefficients to the parallel diffusion coefficient $K_\parallel$ with respect to the regular IMF lines.

3. Conclusion

The layer (stream tube) of the heliosphere with the high solar wind velocity (the dynamic P_{dyn} pressure increases and the static P_{stat} pressure decreases comparing with the low solar wind velocity layer) involves the solar wind plasma with the IMF lines (frozen in) from the lower velocity region (helioequatorial) according to the Bernoulli principle. So, the asymmetry distribution of the solar wind velocity versus the heliolatitudes causes the divergence of the IMF lines from the equatorial plane and the appearance of the regular component B_θ of the IMF.

4. Acknowledgement

Referencess

[1] Feynman, I., Gabriel, S.B., Solar physics, V. 131, pp 187-209, 1991
[2] Fisk, L. A. JGR, V. 101, A7, p. 15547-15554, 1996
[3] Jokipii, J.R, J. Kota,   Geophysical Research Letters ,V.16, p. 1-4, 1989
[4] Rosenberg, R.L., Coleman, P .J., JGR,V.74, p.5611-5622,1969
[5] Ponyavyn, D.L, Usmanov, A.V., Geomagnetism and Aeronomy , V.25, 1, p.128-129,1985 .
[6] Obridko, V.N., Golishev, S.A., Levityn, A.E., Geomagnetism and Aeronomy, V. 44, #4, NAUKA, 2004
[7] McComas, D. J.; et al., JGR 105, A5, p. 10419-10434, 2000
[8] Parker, E.N., ApJ. V. 128, p.664 , 1958
[9] Landau, L.D., and E.M. Lifshitz, Fluid Mechanics, Pergamon Press, 539 pp., 1959
[10] Alania, M.V., Proc. of the Institute of Geophysics Georgian Academy of Sciences, "Modulation of Cosmic Rays", Vol. XLIII, p.5., Tbilisi, 1978 (in Russian)
[11]Alania, M.V. , Dzhapiashvili, T.V., Pros.16th Int. Cosmic Ray Conference,3,p.19, (Kyoto), 1979