The regular Galactic magnetic field and primary cosmic ray energy spectrum at the knee region

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Abstract

The knee in the primary energy spectrum must be sharp enough to reproduce EAS size spectra properly. If the knee is due to the cosmic ray propagation in our Galaxy, so the structure of the regular magnetic field must provide a bump in the knee region. The popular Rand-Kulkarni model does not display such a feature. This paper presents a model of the regular magnetic field which coincides with Rand-Kulkarni's model in the Galactic plane and incorporates a large halo with antysimmetric configuration of the magnetic field thus ensuring a bump.

1 Introduction:

It is common knowledge that the knee in the primary energy spectrum at energy near $\sim 10^{15}$ eV may be due to the change of the cosmic ray propagation in our Galaxy. This is one of the most natural explanations and the updated diffusion theory (Ptuskin et al, 1993) which takes into account the drift of cosmic rays in the large scale regular magnetic field (the Hall diffusion) offers an opportunity to describe the knee in the framework of contemporary notions about Galactic magnetic fields (the characteristic scale of the random fields included). In our previous paper (Kalmykov and Pavlov, 1997a) we showed that the modern diffusion model makes it possible to reproduce satisfactory experimental EAS data on size spectra if a bump in the primary energy spectrum is provided. The necessity of this assumption was especially stressed out in (Erlykin and Wolfendale, 1997) where the presence of a local source was put forward to ensure the sufficient sharpness of the knee.

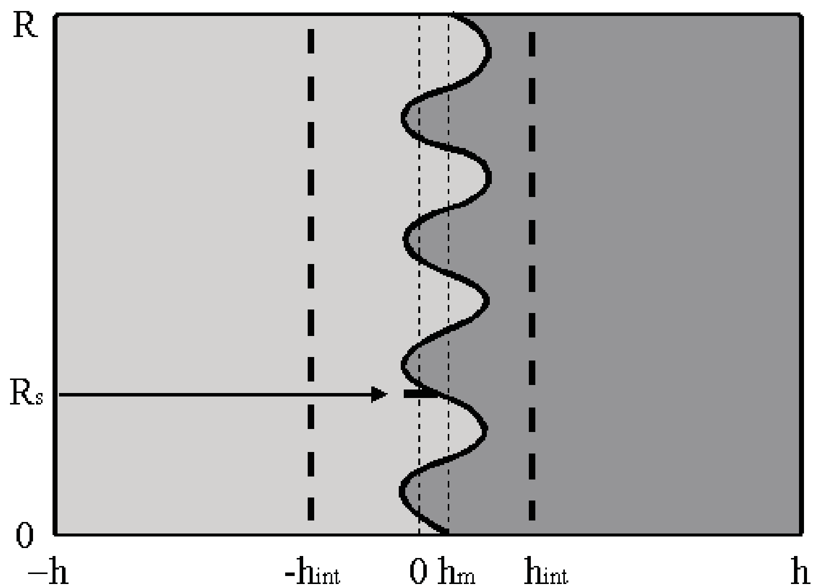

Figure 1: *Schematic view of Galaxy. Sinusoidal curve separates regions with opposite signs of magnetic field.* R_s *– denotes the position of the cosmic rays source.*

A needed bump may be easily obtained in the large halo model with antysimmetric configuration of the regular magnetic field (Ptuskin et al, 1993) but it does not exist in the Rand-Kulkarni model (Rand-Kulkarni, 1989) which correlates with experimental data in the Galactic plane and is of frequent use in calculations. The obvious difference between Rand-Kulkarni's model and others is the absence of an extended halo. So our approach should be to combine the Rand-Kulkarni and large halo models.

2 Diffusion and drift of cosmic rays:

Our new model inherits basic features of the large halo model. The region where cosmic rays propagate is presented in Fig.1. It has the form of a cylinder with $R = 15$ kpc and $h = 10$ kpc. The antysimmetric structure of the regular magnetic field should be accepted. As in (Ptuskin et al, 1993) we assume that cosmic ray sources are distributed in the disk with thickness $2h_s = 400$ pc. The line of demarcation ($h_m = 500$ pc) between the regions with different signs of the field is also shown in Fig.1. The sinusoidal boundary provides necessary signs of the field in the Galactic plane.

The cosmic ray transport is described by the equation (see Ptuskin et al, 1993)

$$[-\frac{1}{r}\frac{\partial}{\partial r}rD_\perp\frac{\partial}{\partial r} - \frac{\partial}{\partial z}D_\perp\frac{\partial}{\partial z} - \frac{\partial}{\partial z}(D_A)\frac{\partial}{\partial r} + \frac{1}{r}\frac{\partial}{\partial r}(rD_A)\frac{\partial}{\partial z}]N(r,z) = Q(r,z), \quad (1)$$

where $D_\perp \sim E^m$ ($m \simeq 0.2$) and $D_A \sim E$ are transverse and Hall diffusion coefficients respectively, $Q(r,z)$ is a source term. The approach to solve the equation (1) is the same as in (Kalmykov and Pavlov, 1997a). The detailed description of the technics used may be found in (Kalmykov and Pavov, 1997b). Floating boundary conditions ($-h_{int}$, h_{int}) were applied in order to obtain cosmic ray concentration with appropriate accuracy near the Galactic plane. Equation (1) is valid up to energies $\gtrsim 10^{17}$ eV.

3 Results:

The calculated cosmic ray spectra (the observer is at $r = 10$ kpc) are presented in Fig.2. It may be clearly seen that the new model displays a desired bump. The radial distribution of sources follows the law $Q(r) \sim \delta(r - 3\,\mathrm{kpc})$. In Fig.3 we compare the predictions of the new magnetic field model with the experimental size spectrum of the MSU EAS array (Fomin et al., 1991). The value of γ (the integral exponent energy spectrum before the knee) is taken to be 1.6. Calculations are made in the framework of the QGSJET model (Kalmykov, Ostapchenko, Pavlov, 1997) and the primary mass composition is fitted to obtain the best agreement. The resulting energy spectrum as well as the spectra of different nuclei are shown in Fig.4. The mass composition obtained does not contradict to the conclusions derived by the MSU group from EAS muon number distributions (Fomin et al., 1996). The analysis of size spectra as measured by the KASCADE (KASCADE collaboration, 1997) and EAS-TOP (EAS-TOP collaboration) arrays has been also made. The results of each separate array can be reproduced quite satisfactory but with different γ and primary mass compositions. Certainly this problem needs mutual calibration of experimental data.

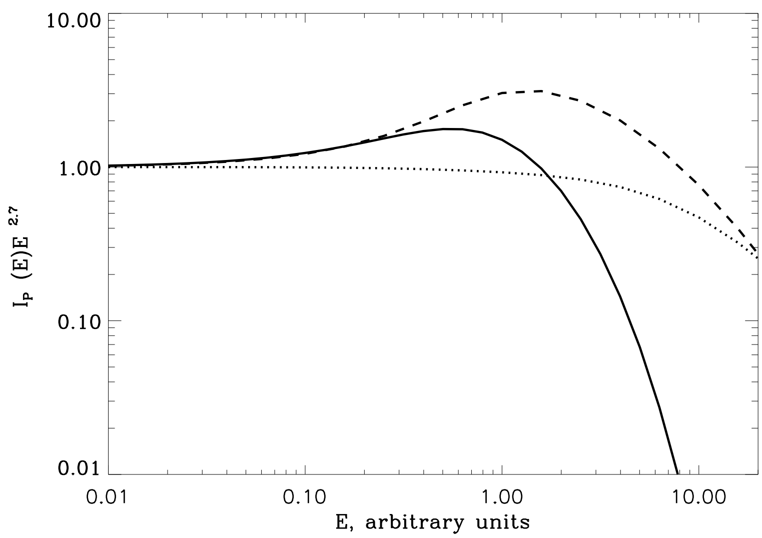

Figure 2: *Proton energy spectra near the knee: dashed curve – large halo model with antysimmetric configuration from (Ptuskin et al., 1993), dotted curve – Rand-Kulkarni model, solid curve – present work.*

4 Conclusion:

A realistic model of the Galactic regular magnetic field is constructed. This model ensures the existence of a bump in the primary energy spectrum and so enables one to reproduce experimental EAS size spectra and primary mass composition reasonably well.

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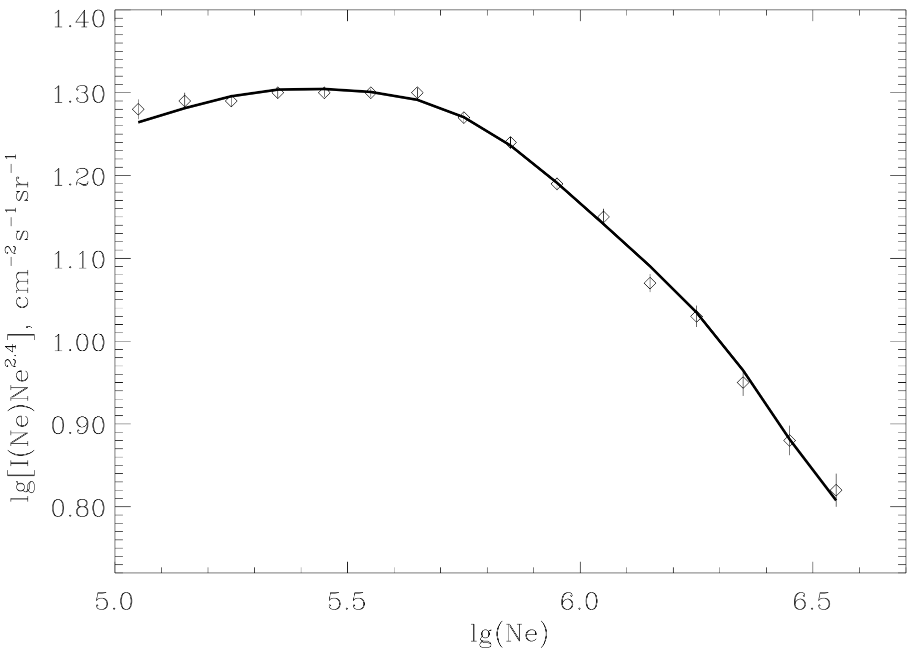

Figure 3: *Calculated EAS spectrum at sea level and MSU experimental data.*

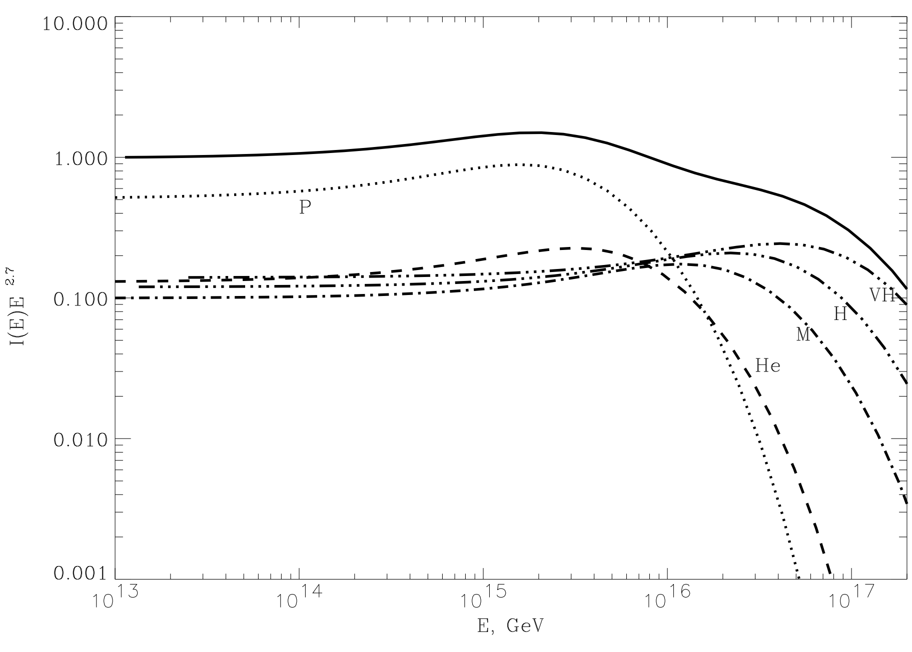

Figure 4: *Total energy spectrum and partial spectra derived from MSU size spectrum.*

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