VIRGO CLUSTER AS A HIGH ENERGY COSMIC RAYS SOURCE

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ABSTRACT

The extragalactic charged particles are reflecting from the Galaxy by its magnetic field. Assuming magnetic field in the Galaxy as quasilongitudinal we have evaluated mean transparency of Galaxy for extragalactic protons defined as a fraction of particles at a given energy from a given direction passing by the galactic plane. The anisotropy caused by the Galactic magnetic field reflection of protons can explain observed arrival directions of EAS at large angle to the galactic plane. Our analysis shows that the increase with energy observed in $\langle \sin b^{II} \rangle$ is self-consistent with changing in the cosmic ray energy spectrum at high energy ($E > 10^{19}$ eV) in the case when extragalactic cosmic ray source with spectral index -2.2 is at the position of the Virgo Cluster.

I. INTRODUCTION

The measurements of energy spectrum and anisotropy of cosmic rays are the basic source of information about its origin. The main difficulty to identify the cosmic rays sources is the Galactic magnetic field. In the past we analized propagations of cosmic rays protons emmited by Galactic sources distributed as Galactic matter (Karakuła et al., 1972). The comparison of the calculated and observed extensive air showers (EAS) anisotropy shows that if protons are the primary cosmic rays of energy greater than 10^{18} eV they should be predominantly extragalactic. The study of EAS (i.e. Watson, 1980: Linsley and Watson, 1981) shown that cosmic rays at energies above 10^{19} eV are likly to be of extragalactic origin. The anisotropy of arrival directions of the highest energy cosmic rays is observed from the directions of the large angle to the galactic plane ($b^{II} \cong 74^{o}$) (Cunningham et al., 1980 and 1983). The experimental data confirmed the flattening of the cosmic ray energy spectrum at energy greater than 10^{19} eV and the exponent of the integral energy spectrum is -1.4 ± 0.1 (Cunningham et al., 1980 and 1983: Bower et al., 1983).

In this paper we have considered the cluster or supercluster origin of high energy cosmic rays model, but for lower energy $E \leq 10^{18}$ eV we assumed Galactic location of cosmic ray sources. For the quasilongitudinal magnetic field in the Galaxy we have evaluated the mean transparency of the Galaxy for extragalactic protons. Our analysis shows that the increase with energy observed in $\langle \sin b^{II} \rangle$ (Cunningham et al., 1980) is self-consistent with changing in the cosmic ray energy spectrum at high energy ($\geq 10^{19}$ eV) in the case when extragalactic cosmic ray source with spectral index -2.2 is at the position of the Virgo Cluster ($b^{II} = 74^{o}$).

2. THE TRANSPARENCY OF THE GALAXY FOR EXTRA-GALACTIC PROTONS

The trajectory of arriving protons from the particular extragalactic directions were calculated assuming the mathematical model of the magnetic field in the Galaxy. In our calculations the magnetic field in the Galaxy was assumed as the quasilongitudinal model of Thielheim and Langhoff (1968). In this model the field lines are parallel to the spiral arms but with opposite orientation above and below the galactic plane. The strength of the component of the field parallel to the arms in details was described in our paper Karakuła et al., (1972). The galactic disc, where the trajectories of protons were calculated, was defined by $|z| \leq 0.4$ kpc (distance perpendicular to the galactic plane) and $R \leq 15$ kpc (radius from the Galactic Center). The equation of motion of the protons in the Galactic magnetic field was solved numerically. Our calculations indicated that some of the extragalactic particles are reflecting from the Galaxy by its magnetic field. Only extragalactic particles entering the Galaxy on the observing level can be registrated as an EAS. We have evaluated the mean transparency of the Galaxy which was defined as a fraction of the number of particles at a given energy from a given position of source passing through the plane located at a Solar System and perpendicular to the direction of the extragalactic source (observer plane). In practice for large b^{II} this plane is the galactic disc plane ($z=0$). We have followed large number of the protons trajectories for selected energies. The positions of the starting point of the protons trajectories was at random selected on the plane outside the Galactic disc. The real magnetic field in the Galaxy has a regular and irregular components (magnetic clouds). Our model of the magnetic field in large scale describes the regular component. The nature and feature of irregular component are not known up to now. For our considerations we also assume that the general properties of this component should be weaker than the regular component and should follow the last one in whole Galaxy. So from the point of view of our considerations there is no difference between random occuring irregularities of magnetic field in the time of protons propagation and at random selected positions of the starting point of the proton trajectory for the model of regular Galactic magnetic field. More over in that case we evoid the problem of focusing of particles in quasilongitudinal magnetic field. The mean transparency parameter defined above is characteristic for the whole Galaxy. Figure 1 shows the mean transparency of Galaxy for extragalactic protons for the selected directions of the group of galaxies. The transparency of Galaxy increases with energy. We can also notice that the energy of protons, when galactic mag-

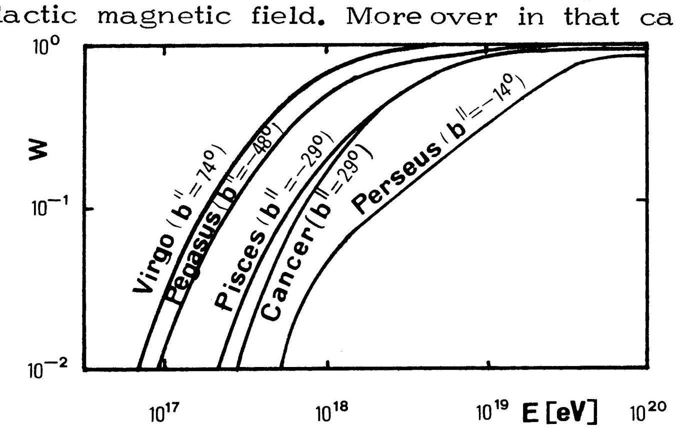

Fig. 1. The mean transparency of Galaxy as a function of proton energy.

netic field has a small influence on particles, strongly depends on the arriving positions relative to the Galactic plane.

3. THE EXPECTED FLUX OF THE COSMIC RAYS FROM THE VIRGO CLUSTER

The base of our analysis was the Haverah Park EAS data (Cunningham et al., 1980) indicating that the mean value of $\langle \sin b^{II} \rangle$ increases with energy.

In this paper we want to examine if the observed changes in energy spectrum of cosmic rays and $\langle \sin b^{II} \rangle$ are self- consistent, as far as our simple assumptions allow:

i) the galactic cosmic ray differential energy spectrum (I_G) for energy greater than 10^{19} eV has a power index -3.1,

ii) some extragalactic sources with an unknow spectrum (I_{Ex}) located at a position b_o^{II} can give contribution to the observed flux,

iii) the probability of the registration of the extragalactic charged particles depends on its energy, because of the influence of the Galactic magnetic field.

In such case the mean value of $\sin b^{II}$ can be expressed by:

$$\sin b^{II} = \frac{\int I_G \cdot P(b^{II}) \cdot \sin b^{II} \cdot db^{II} + w(b_o^{II}) \cdot I_{Ex} \cdot P(b_o^{II}) \cdot \sin b_o^{II}}{\int I_G \cdot P(b^{II}) \cdot db^{II} + w(b_o^{II}) \cdot I_{Ex} \cdot P(b_o^{II})},$$

where:

$P(b^{II})$ - the probability of registration by Haverah Park array as the function of b^{II},

$w(b^{II})$ - the transparency of the Galaxy versus energy for extra-galactic protons.

The integral in the numerator of above expression gives the con - tribution from the galactic cosmic ray flux. The second component of this sum represents the contribution from the extragalactic point source located at the position b_o^{II}, after integration over the galactic latitude with the delta Dirac function. The denominator expresses the normalization coef-ficient in the definition of the mean value $\sin b^{II}$.

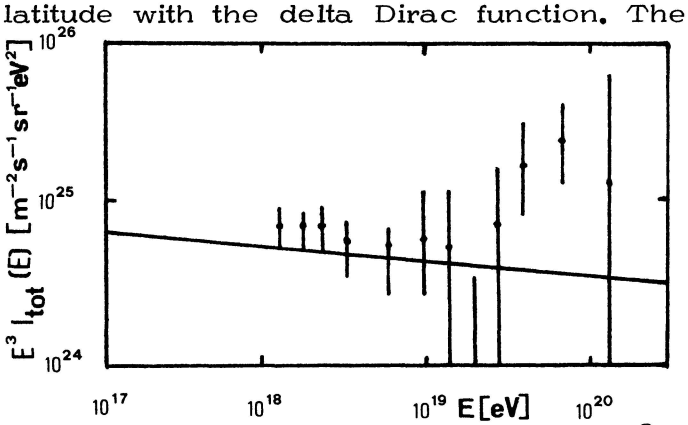

Fig. 2. The total flux (multiplied by E^3) calculated from $\langle \sin b^{II} \rangle$ as a function of energy.

The dependence of $\langle \sin b^{II} \rangle$ on the energy observed by Haverah Park was used to calculate the ra-tio of I_{Ex}/I_G for extra-galactic source which is located at the position of the Virgo Cluster. The ra-tio I_{tot}/I_G is a constant for energy $E < 10^{19}$ eV and increases for the greater energy. Fig. 2 shows the differential to-tal ($I_{tot} = I_G + I_{Ex}$) cosmic ray flux multiplied by E^3 calculated from Haverah Park measurements of $\langle \sin b^{II} \rangle$.

4. DISCUSSION AND CONCLUSIONS

From the comparisons of our results (Fig. 2) with experimental data of cosmic ray energy spectrum (Cunningham et al., 1980: Hillas, 1984) we can conclude good agreement. We have made the same calculations for different positions (b_o^{II}) of the extragalactic point sources but the best agreement we have got only for the position of the Virgo Cluster. It can be strong indication that high energy cosmic rays ($E > 10^{19}$ eV) are originated from this cluster. We can also notice that the differential cosmic rays energy spectrum of the Virgo Cluster has the spectral index $\simeq$ -2.2, and in the energy range $\simeq 10^{18}$ eV the intensity of the Galactic and extragalactic fluxes are equal. In the lower energy region the Galactic cosmic ray flux is dominand.

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