ON GALACTIC ORIGIN OF COSMIC RAYS WITH ENERGY UP TO 10^{19} eV

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Abstract

The experimental data on ultrahigh energy cosmic ray anisotropy are considered. In supposed models of galactic magnetic field the main characteristics of expected anisotropy are estimated and are compared with the experimental data. In is shown that particles with energy up to 10^{19} eV are of galactic origin.

Spectrum. The observed spectrum and cosmic ray intensity at 10^{17} - 10^{19} eV can be explained by galactic sources [1,2]. At present the most difficulties occur in the explanation of EAS experimental data on anisotropy.

Is there really anisotropy? One of the arguments in favour of anisotropy is the agreement of phases of the 1-st harmonic on data of Yakutsk and Haverah Park EAS arrays [3] (Fig.1). The common (Yakutsk and Haverah Park) chance probability of constancy of the 1-st harmonic phase at energy range $5\cdot10^{17} < E_0 < 2\cdot10^{19}$ eV is $10^{-4}\div10^{-5}$. The next argument in favour of anisotropy can be taken the presence of a gradient in particle distribution on galactic latitude [4,5]. The chance probability of such a gradient on data of Yakutsk and Haverah Park arrays in total is $10^{-5} \div 10^{-7}$ (Fig.2).

From the above it follows that cosmic ray anisotropy in energy range 10^{18}- 10^{19} eV is real.

Experimental anisotropy. Because of small statistics the experimentators on EAS data determine the anisotropy based on event number on large solid angle $\Delta\Omega$ ($\Delta\delta_1 \sim 90°$, $\Delta\alpha \sim 30\div60°$, δ_1 - declination, α - the right ascension). In [6] we showed that anisotropy determined in such a way differs from one δ determined by usual way on expected intensity: $\delta = (I_{max} - I_{min})/(I_{max} + I_{min})$ where I - cosmic ray intensity. Below we shall show it.

The particle number from the definite part of celestial sphere is

$$n(\alpha,\delta_1) = \int K(\theta(t)) J(\alpha,\delta_1)\Omega(\theta(t),\varphi(t))S(\theta(t))dt,$$

where K - the probability of detection; Ω, S - the solid

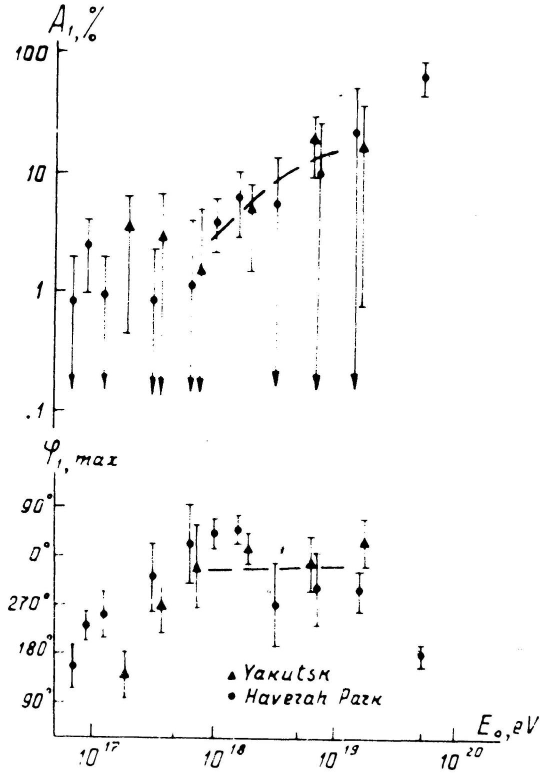

Fig.1. Amplitudes and phases of the 1-st harmonic; dashed line - the expected values in the case of protons from sources in the disc

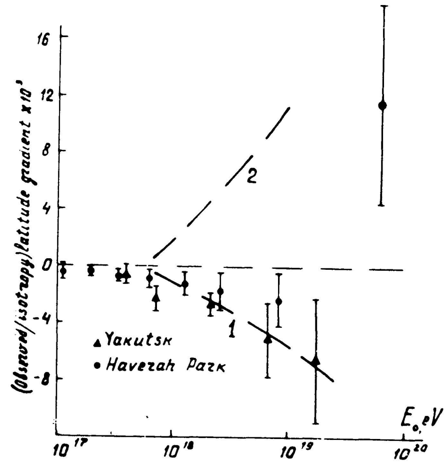

Fig.2. The gradient $n_{obs.}/n_{isotr.}$ on galactic latitude b. Dashed line - the expected values in the case of protons: 1 - Yakutsk, 2 - Sydney

angle and the effective area of the array; θ, φ - the zenith and azimuthal angles, t - observation time. The number of events on intervals of the right ascension is

$$n(\Delta\alpha_i) = \int_{\Delta\alpha_i}\int_{\Delta\delta} n(\alpha, \delta_1)\, d\alpha\, d\delta_1 .$$

Then the anisotropy is

$$\delta^* = \left[n_{max}(\Delta\alpha) - n_{min}(\Delta\alpha)\right] / \left[n_{max}(\Delta\alpha) + n_{min}(\Delta\alpha)\right] .$$

It is seen that anisotropy δ^* determined on event number on a large solid angle is not identical with anisotropy δ determined on intensity. Note that the some correction of the 1-st harmonic amplitude in energy range 10^{18} - $2 \cdot 10^{19}$ eV (Fig.1) can be made deviding it into $\cos b$ where b - the average galactic latitude of the observed showers. The anisotropy vector (Fig.1) is observed at the angle b. Similar idea was supposed in [7] .

Galactic model. Discussed here anisotropy characteristics at $E_o > 10^{18}$ eV (the 1-st harmonic phases, a gradient of particle distribution at positive latitudes) at quasi-rectilinear motion of particles can be explained qualitatively by sources distributed in the galactic disc (evidently the maximum of particle arrival being from galactic plane where the number of sources is large). At allowed on radiodata magnetic fields of disc (2-3 μG) and halo ($\lesssim 1$ μG) the quasirectilinear motion is expected in the considered energy range in a case of protons [1,2] . The observed on experimental data ratio of showers equator-pole $n(|b|< 30°)/n(|b|> 30°) \approx 2$ about 10^{19} eV [5] can be also explained in the case of protons by sources in galactic disc (in the first approximation the particle number proportional to the radius of ball sectors of the region of sources).

Consider how these experimental data agree on amplitude with the expected one from galactic sources. Calculating the individual trajectories of antiprotons from the Earth in sign-constant longitudinal magnetic field of the disc and halo (the sign-constant field of the disc is considered to be more probable, see, for instance, [8]) we estimated the expected anisotropy from sources distributed uniform in galactic disc (the central sources can be excluded from the number of possible ones [2]). The expected anisotropy was estimated (Figs.1,3) by the expected particle number on a large solid angle as in the case of experimental data (in detail see [6]). The given anisotropy appears to be 2-3 times less than the expected one determined on intensity, though they coincide in phase. Note that the account of the inhomogeneous distribution of sources in the disc changes weekly the estimated anisotropy [6] . The observed ratio of showers equator-pole on Yakutsk array data [5] (Fig.3) is decreased due to the exposition time of regions of sky [5] .

We estimated the expected gradient of particles on galactic latitude (Fig.2, see also [9]) from calculated lengths of trajectories in galactic disc using formally the obtained dependence of particle number upon trajectory lengths [6] (in the case of small solid angle, $\Delta b = 10°$, $\Delta \ell \sim 120°$, we can not strictly use the this dependence).

On χ^2-criterium we compared the observed event number on right ascension [5] with the expected one in the case of protons from sources in the disc. We supposed that the observed number of events is a sum of anisotropic galactic (G-portion) and isotropic extragalactic cosmic ray components. In the Table are shown G at which χ^2 is minimum, in brackets - upper limits of G.

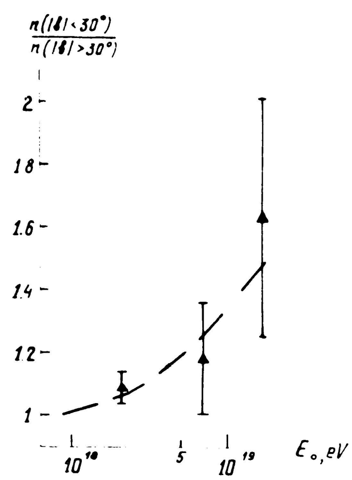

Fig.3. The ratio of showers equator-pole. Dashed line - expected in the case of protons from sources in the disc

Table

E_0, eV	Number of showers	G,%
$2,1\cdot10^{18}$	3147	80(100)
$6,7\cdot10^{18}$	256	100(100)
$1,7\cdot10^{19}$	115	100(100)

On results of comparison of the observed and expect anisotropies on amplitude and phase of the 1-st harmonic, on ratio of the number of showers equator-pole, on χ^2-criterium the particles with energies up to 10^{19} eV can be considered of galactic origin.

Our detailed calculations on galactic model show [2,6] that at energies above 10^{18} eV the maximum of particle arrival from the high galactic latitudes is not expected. The observed excess of particles from the high latitudes [4,5,7,10]at energies $E_o > 2\cdot10^{19}$ eV, to be more accurate, from direction of centre of the Local supercluster to be probably caused by extragalactic sources.

Conclusion. The particles with energies up to 10^{19} eV are of galactic origin and above $2\cdot10^{19}$ eV are rather of extragalactic origin.

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