Cosmic Ray Anisotropy at the Energy $\sim 10^{19}$ eV

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Abstract

Arrival directions of the ultra-high energy extensive air showers (EAS') registered at the Yakutsk array have been considered. At $E \sim 10^{19}$ eV the statistically significant cosmic ray anisotropy of an amplitude $\sim 35\%$ is found. The expected anisotropy phase from the galactic sources for EAS Yakutsk and AUGER arrays is estimated. It is shown that a search for sources by one coordinate only can lead to the incorrectly conclusion.

1. Introduction

Here we analyze the arrival directions of showers registered for 1974-2001. The showers of energy $E > 10^{18}$ eV, zenith angles $\theta < 60°$ and cores located inside the array perimeter are considered.

2. The harmonic analysis

Fig.1 presents the amplitudes and phases of first harmonic of Fourier series obtained as the result of analysis of shower distribution through the energy interval $\triangle$logE=0.25. At such a separation of intervals the statistically significant amplitudes are not find, but in the energy interval of $10^{19} - 10^{19.25}$ eV the amplitude reaches the value $r_1 = 23\%$. A probability of chance to have $\geq r_1$ is equal to $P(> r_1) = 0.02$.

Previously we found the particle flux from the galactic plane in the narrow interval of latitudes $|b| < 6°$ [1]. It is established that the flux of the particles increases with the energy to $E \sim 2.10^{19}$ eV, then it progressively decreases.

If we analyze the showers in the maximum of the flux in the energy interval $E = (1 - 2.5) \times 10^{19}$ eV then we obtain the statistically significant amplitude $r_1 = 35\% \pm 9\%$ ($r_2 = 0.11\%$ is the second harmonic) with the phase $\phi_1 = 34° \pm 16°$ ($\phi_2 = 54°$) in right ascension. The probability of chance is P($\geq r_1$) = 0.0017. The number of events is n=214.

Note that earlier we shown the presence of large amplitude in the shower distribution in the narrow energy interval $E = (1 - 2) \times 10^{19}$ eV: $r_1 = 41.6\% \pm 11.7\%$, $\phi_1 = 35° \pm 16°$ [2]. The probability of chance is $P(\geq r_1) = 0.002$. In the

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wider energy interval $E = (1-3) \times 10^{19}$ eV [3] the amplitude is $r_1 = 26.4\% \pm 8.0\%$ and $\phi_1 = 34.5°$. The probability of chance is $P(\geq r_1) = 0.004$.

As seen from these results, the phases of the first harmonics coincide with each other, but the amplitudes of anisotropy depend on a width of considered energy interval.

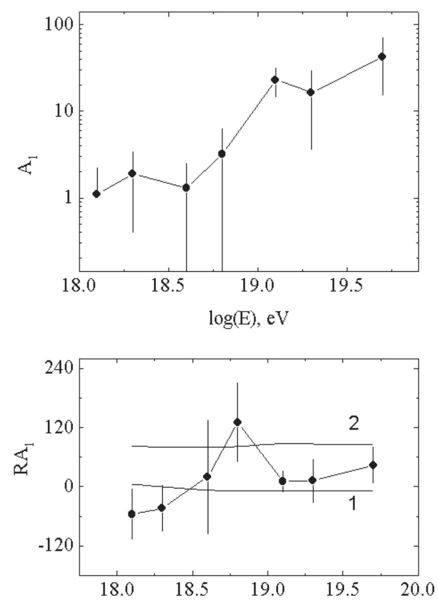

Fig. 1. Amplitudes and phases of the 1-st harmonic in the shower distribution depending on their energy. The straight lines are the expected phases for the Yakutsk array - 1, and Auger - 2.

Thus, the amplitude of cosmic ray anisotropy at $E \sim 10^{19}$ eV is $r_1 = 35\%$.

3. The expected phases

In Fig.1 there are also the expected phases of the first harmonic for the Yakutsk array (1) and Auger Observatory (2) in the case of galactic origin of particles at the uniform distribution of their sources in the Galaxy disk. The expected phases of anisotropy (amplitudes are not shown, as they strongly depend on model suppositions) are obtained by the calculation of individual trajectories of the antiprotons from the Earth in the magnetic field of the Galaxy. A model of bisymmetric magnetic field [4] with the basic azimuth component $\sim 2\mu G$ is taken as the magnetic field. The magnetic field of a halo is assumed to exist beyond the magnetic field of the disk. As seen from Fig.1, the observed and expected phases of anisotropy from galactic sources for Yakutsk array within experimental errors agree. This fact points to the galactic origin of particles with $E \sim 10^{19}$ eV.

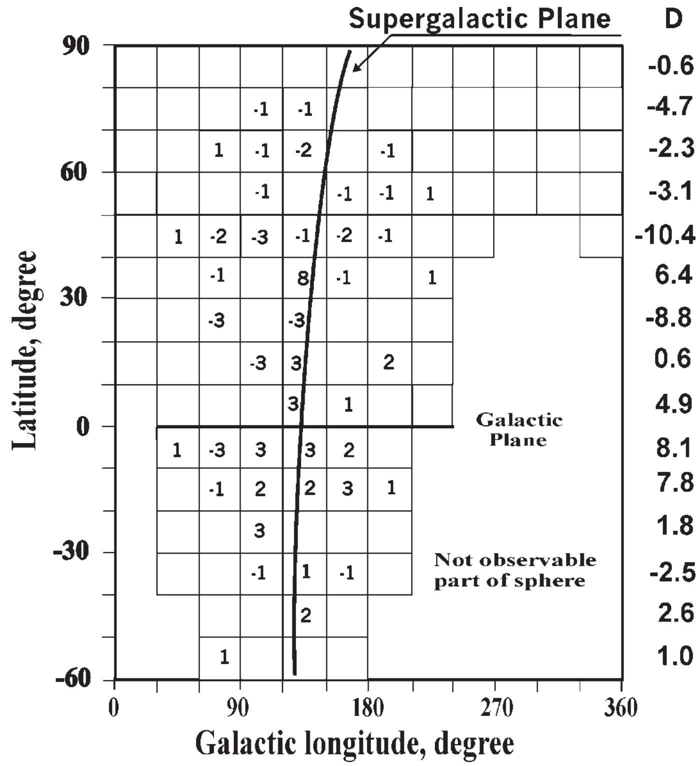

Fig. 2. The map of deviations of the observed number of showers from the expected value in the case of the isotropy. Figures are $n_{obs} - n_{exp}$ without the fractional part. The open squares are $|n_{obs} - n_{exp}| < 1$. The difference $D = n_{obs} - n_{exp}$ for corresponding galactic latitudes is shown on the right.

4. The analysis in galactic coordinates

Further we analyze the showers with $E = (1 - 2.5) \times 10^{19}$ eV in galactic coordinates b and l. The results are presented in the form of a map of deviations for the number of observed showers n_{obs} from the number of expected events in the case of primary isotropy n_{exp} (Fig.2). The expected number of showers is found by the Monte-Carlo method simulating random events distributed uniformly in right ascension and taking into account the array exposition in declination [5], and then convention to the galactic coordinate system and normalizing to the number of observed showers. The map is constructed by the angular intervals $10^\circ \times 10^\circ$. The figures in Fig.2 are the difference of events ($n_{obs} - n_{exp}$) without a fractional part. The open squares are $|n_{obs} - n_{exp}| < 1$. As seen in Fig.2, the exceeding number of showers, $n_{obs} - n_{exp} \geq 1$, is observed for by latitudes $20^\circ > b > -20^\circ$ and longitudes $180^\circ > l > 90^\circ$, on the whole, i.e. on the side of the galactic plane (see D, Fig.2).

Thus, the large amplitude in distribution of showers at $E \sim 10^{19}$ eV is caused by the particle flux from the galactic plane [1].

5. A typical error of some authors

Consider typical error of some authors. As seen in Fig.2, the exceeding number of showers $n_{obs} > n_{exp}$ is observed along the Supergalaxy plane at galactic longitudinal $150° > l > 120°$. Also in the Supergalaxy coordinate the mean latitude of showers is $<|b_{SG}|>=\sum|b|/n = 25.6°$ at the expected $<|b_{SG}|>= 30.2°$ in the case of the isotropy (it is found by the Monte-Carlo method). In these cases, the conclusion is usually inferred that the Supergalaxy is a source of primary particles.

However, the number of showers on the side of high galactic latitudes along the Supergalaxy plane (Fig.2, $b \sim 80°$, $l \sim 150°$), where there exist the greatest concentration of galaxies, among them the M87 radiogalaxy ($b = 74.5°$, $l = 283°$), is less than expected value in the case of isotropy. The exceeding particle flux is limited by galactic latitudes $40° > b > -20°$. This means that the primary particles with the energy of $\sim 10^{19}$ eV are of galactic origin. Thus, in the case of finding of exceeding particle fluxes on the side of Supergalaxy plane by one coordinate b_{SG}, it is necessary to carry out the additional analysis either along the Supergalaxy plane l_{SG} or by two coordinates of the Galaxy b and l.

6. Conclusion

In conclusion, it may be said that the cosmic ray anisotropy at $E \sim 10^{19}$ eV depends on the width of considered energy interval, it is equal to $r_1 = 35\%$ in the narrow energy interval of $(1 - 2.5) \times 10^{19}$ eV and caused by the anisotropic flux of particles from the Galaxy plane.

E=Energy, eV n=Number of EAS
r=Amplitude, % ϕ=Phase, degree
b,l=Galactic latitude and longitude
b_{SG}, l_{SG}=Supergalactic latitude and longitude

7. References

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