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Study of UHE particle arrival directions with Yakutsk EAS array data

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Abstract· Extensive analysis is carried out of arrival directions of cosmic rays at energies $E > 10^{17}$ eV detected with the Yakutsk array during the time period up to May 2000. An increased dataset has resulted in the significant first harmonic amplitude A_1~26% (p=0.004), $\varphi_1 \sim 2^h$ in the energy interval (1-3)x10^{19} eV. The presumed source of these particles is concluded to have coordinates $2^h < RA \leq 3^h$, $40^0 < \delta \leq 50^0$

1 Introduction

The research of the arrival directions of ultrahigh energy particles have been carried out for a long time at the Yakutsk complex EAS array. The first results on the cosmic ray anisotropy in the region of $E_0 \sim 10^{19}$ eV were published in Krasilnikov et al. (1974; 1977). Then the indication of the galactic nature of extra-high energy particles $E_0 \sim 10^{19}$ eV and correlation of anisotropy parameters with the change in differential energy spectrum index of cosmic rays was suggested Krasilnikov et al. (1983). The late indications of the large-scale anisotropy presence at ~ 10^{19} eV were received in Efimov et al., (1987), Krasilnikov et al. (1993). Afterwards, with the increased data no significant anisotropy was found. Instead, narrow effects were revealed, such as scanty sample effect, north-south asymmetry of showers (Ivanov et al. 1990; 1997), heterogeneity of the array sky survey and meteorological effect (Pravdin et al. 2000).

Recently very interesting results in ultrahigh energy were obtained by a group of scientists from AGASA array: Hayashida et al. (1999). They discovered a strong anisotropy A1~ 4% at E ~ 10^{18} eV with a chance probability of 0.005 % and found showers excess from the center of Galaxy and Cygnus region.

Here we present the analysis of showers, registered on the Yakutsk EAS array during 27 years of work: since the January, 1974 till May, 2000.

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2 Results

In the analysis, the shower events of $E > 10^{17}$ eV were selected which meet two conditions: showers` axes are within the array area perimeter, zenith angles are less than 60 degrees. A common method of harmonic analysis was applied to these showers. It should be noted here that with the energy below 10^{18} eV, anisotropy estimation depends on the effects caused by the inhomogeneity of the sky survey by the array and seasonal variations of shower frequency. That is why the method allowing a contribution of these effects (Pravdin et al. 2000) was used for the first two energy intervals to correct analysis. Data of October 1982 – May 2000 were used for showers with $E < 10^{18}$ eV. Events were selected by following: each of three neighboring stations forming a 'trigger' triangle with a side of 500 m has the particle density $\rho \geq$ 1,0. This leads to double reduction of the number of events in the range below 10^{18} eV. Table 1 lists the results of harmonic analysis. There is no anisotropy in the energy intervals except 10^{19}-$3\cdot10^{19}$ eV where we found a significant (~3σ) first harmonic amplitude in the right ascension: A_1=26.4±8%, φ_1=2.3±1.2^h. Reducing $\log_{10}(E)$ interval to (19-19.25) or (19-19.125) doesn't eliminate the anisotropy. It remains if we divide an observation period into two parts as well.

To find the excess of showers, the observed celestial sphere was divided into 216 cells ω_i, each of the size 15° in right ascension and 10° in declination. For each cell ω_i for the given declination belt $\Delta\delta_i$ expected number of showers was calculated and compared to the observed number n_i^{obs}. Concerned region was divided into four intervals: E_1=(1-2)$\cdot10^{18}$ eV, E_2=(2-4)$\cdot10^{18}$ eV, E_3=(4-8)$\cdot10^{18}$ eV and E_4 >8$\cdot10^{18}$ eV. Found deviations of the observed number of particles from the expected ones for three intervals of energy E_1, E_2 ,E_3 and E_4 are shown in Figs.1-4. On the map of equal expositions (each interval $\Delta\delta_i$ – const) for the Yakutsk array deviations from the expected number of events are in σ. Deviation from the expected in each cell was calculated:

$$\text{Deviation} = (n_i^{obs} - n_i^{exp})/\,\sigma\,, \quad \sigma = \sqrt{n_i^{exp}}$$

E1= 1-2 EeV, N= 22240

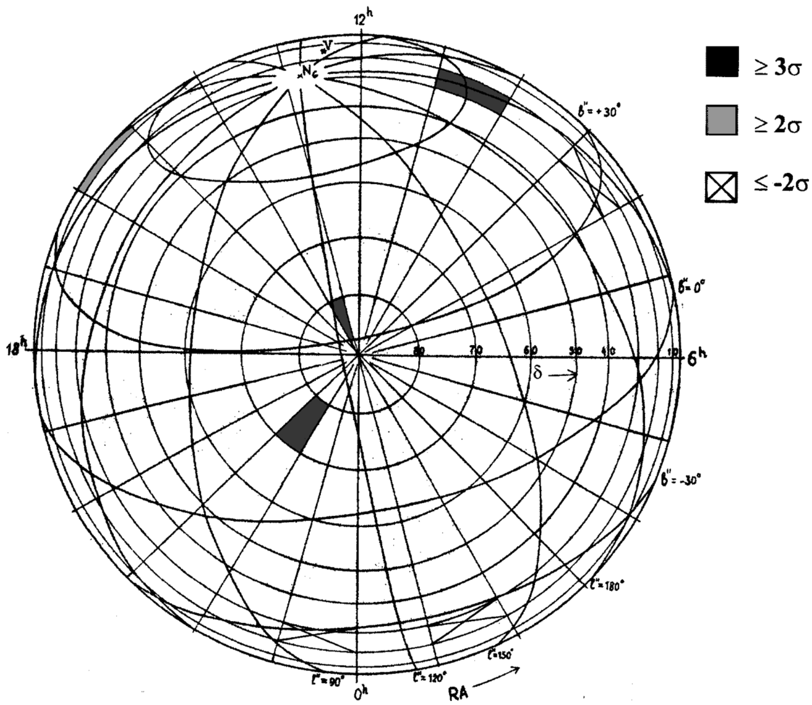

Fig.1. Observed-from-expected deviations of shower numbers in the celestial sphere cells. Deviation with $|\sigma| \geq 2$ are shown. E_1= 1-2 EeV.

E2= 2-4 EeV, N= 6483

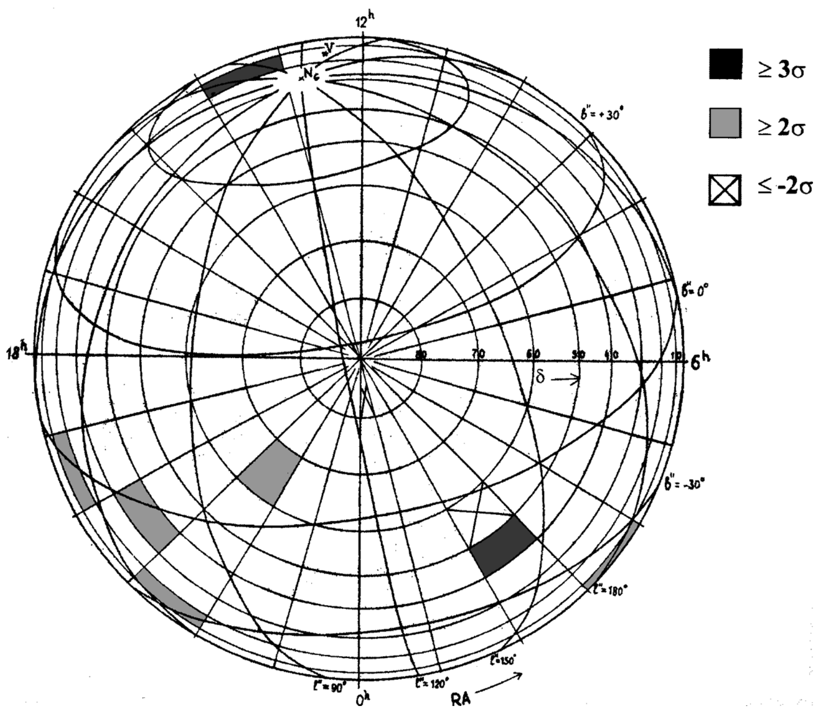

Fig.2. Observed-from-expected deviations of shower numbers in the celestial sphere cells. Deviation with $|\sigma| \geq 2$ are shown. E_2= 2-4 EeV.

E3= 4-8 EeV, N= 1736

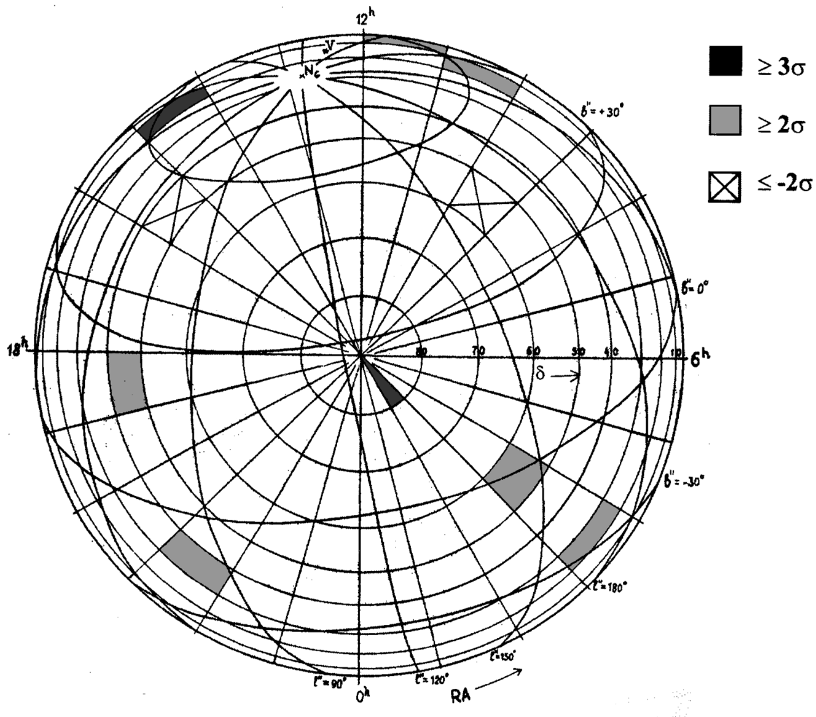

Fig.3. Observed-from-expected deviations of shower numbers in the celestial sphere cells. Deviation with $|\sigma| \geq 2$ are shown. E_4=4-8 EeV.

E4 > 8 EeV, N= 541

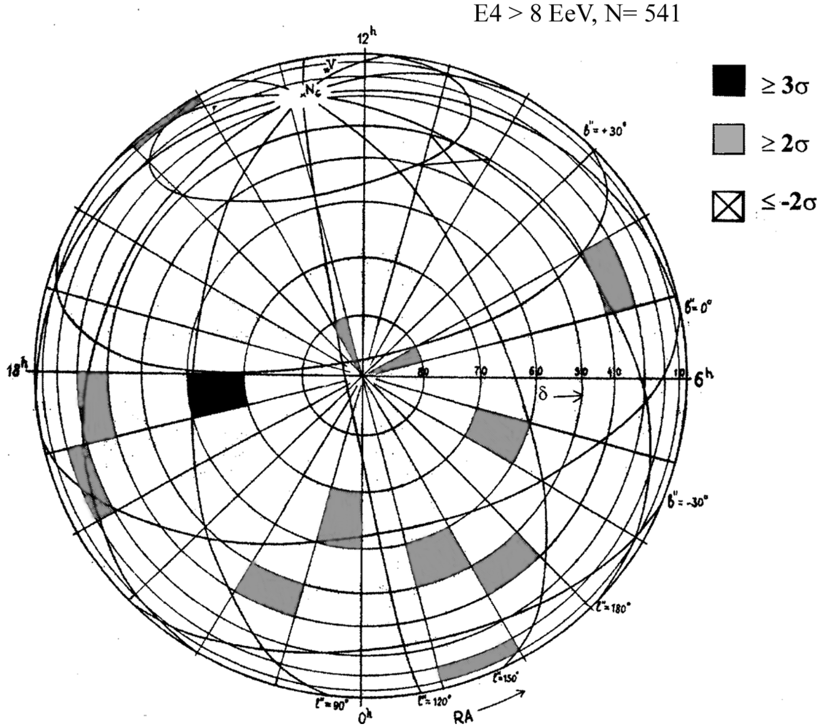

Fig.4. Observed-from-expected deviations of shower numbers in the celestial sphere cells. Deviation with $|\sigma| \geq 2$ are shown. E_4>8 EeV.

3. Discussion and summary

The observed significant anisotropy is in the range of energy spectrum irregularity. It can be attributed to nonzero galactic component contribution at E ~10^{19} eV which reveals itself as a north-south asymmetry of the galactic latitude distribution (Ivanov et al. 1997).

It is seen from the results of harmonic analysis that the phase of maximum insufficiently deviate from 0^h on the considered regions from 10^{17} to 10^{20} eV. The phase behaviour shows that the major arrival direction of UHECR is galactic plane and the sources of such energy particles may be in our Galaxy. If consider that the source is situated in the center of Galaxy (Hayashida et al., 1999), the expected anisotropy can be estimated using the diffusion model of Galaxy (Ginzburg and Syrovatsky 1963):

$$A \sim E / 300H\cdot R,$$

where E – a particle energy, eV

H = $3\cdot 10^{-6}$ gauss – a regular magnetic field strenth of Galaxy;

R = 15 kpc – the Galaxy radius.

This rough estimate gives anisotropy A_1 ~ 10% for the particles with E = $5\cdot 10^{18}$ eV, and A_1 ~ 20% for E = 10^{19} eV, that corresponds to the experiment by the order of magnitude.

On the celestial sphere (Fig.1-4) distributions of the observed shower excesses are shown for energy intervals: E_1=(1-2)$\cdot 10^{18}$ eV, E_2=(2-4) $\cdot 10^{18}$ eV, E_3=(4-8) $\cdot 10^{18}$ eV and E_4 >$8\cdot 10^{18}$ eV. It is seen that distributions are different and unsteady. For E_1 excess of showers occurs in the northern hemisphere predominantly and for E_4 one is in southern hemisphere. Southern excess are predominant in all the following energy intervals E_2, E_3, E_4. Two regions with shower excess more than 2σ are detected: a) 13^h< RA ≤ 14^h , 80°< δ ≤ 90° in E_1 and E_4 and b) 2^h< RA ≤ 3^h , 40°< δ ≤ 50° in E_2 and E_4. The large number of cells with shower excess at E_4 is due to the lack of statistics at high energies but the region 2^h< RA ≤ 3^h , 40°< δ ≤ 50° is in regard because of ~3σ excess of showers in the merged E_2, E_3, E_4 intervals (82 observed showers against to 58.9 expected ones). It is possible that there is (towards the Perseus region) a source responsible for the detected anisotropy at E = (1-3)$\cdot 10^{19}$eV.

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Table 1. Results of harmonic analysis

Energy bins	Neas	A_1 %	δA_1 %	φ_1, hrs	$\delta\varphi_1$ hrs	p(>A_1)	Observation period
17.0-17.5	147314	0.5	0.5	21.1	3.8	0.399	May1982-May2000
17.5-18.0	88208	1.1	0.7	23.6	2.4	0.069	May1982-May2000
18.0-18.5	27301	0.7	0.9	22.7	4.6	0.712	Jan1974-May2000
18.5-19.0	3250	3.6	2.5	2.9	2.7	0.355	Jan1974-May2000
19.0-19.5	312	26.4	8.0	2.3	1.2	0.004	Jan1974-May2000
> 19.5	37	6.8	23.2	6.3	13.1	0.959	Jan1974-May2000