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Analysis of the Arrival Directions of Ultrahigh Energy Cosmic Rays

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Abstract: The arrival directions of ultrahigh energy extensive air showers (EAS) by Yakutsk, AGASA and SUGAR array data are analyzed by new method. For the first time, the maps of equal exposition of celestial sphere for the distribution of particles by AGASA and SUGAR arrays data have been constructed. The large-scale anisotropy of cosmic rays at $E>4.10^{19}$ eV from the sides Input and Output of the Galaxy Local Arm by Yakutsk, AGASA and SUGAR array data has been detected. The problem of cosmic ray origin is discussed.

Introduction

Until now there is an opinion, that cosmic rays (CR) with energy $E>4.10^{19}$ eV are isotropic (see for example [1, 2]). Here data of arrays EAS Yakutsk, AGASA, SUGAR with account exposition a celestial sphere to arrays are analyzed.
We used new method a search anisotropy CR suggested in [3-5]. This method was used in joint paper [6] and in a search a correlation of arrival directions of particles and BL Lacertae objects [7].

Experimental data and discussion

At first, we have analyzed Yakutsk EAS array data whose shower cores lie inside the array perimeter and the accuracy of the arrival angle determination is ~ 3°. The particle energy is estimated by a new formula according to [8]. Fig.1 presents the distribution of 34 particles with $E>4.10^{19}$ eV on the map of equal exposition of celestial sphere (the method to construct this map is based on the estimation of the expected number of showers [4, 5] and etc.). At the map of equal exposition the equal number of particles from the equal parts of sphere is expected. As seen in Fig.1, the particles practically have isotropic distribution on the celestial sphere. However, the most concentration of particles is observed from the side of Input of Galaxy Local Arm at galactic latitude $3.3°<b<29.7°$ and longitude $60.1°<l<116.8°$ (this region it is noted by dash quadrangles). In this coordinates there are 9 particles. The probability of chance to find 9 of 34 particles in this coordinates by method Monte Carlo [5] is P~0.014. If we decrease the considered range within $3.3°<b<19.1°$ and $60.1°<l<116.8°$ then the probability of chance to find 7 of 34 particles will be P~0.008.

For the distribution of particles with $E>4.10^{19}$ eV by AGASA array data [9] we construct the map of equal exposition of celestial sphere according to [4, 5]. As seen from this map, almost a half of events (25 particles of 58) are within of coordinates toward the side of Input the Local Arm $11.2°<b<69.3°$ and $38.9°<l<154°$ (this region it is noted by dash quadrangles too). The probability of chance to find 25 particles of 58 at above mentioned coordinates is P~0.0004. If we decrease the limits of considered coordinate range up to $19.4°<b<29.8°$ and $63.5°<l<108.8°$, then the probability to find 7 particles of 58 will be P~0.0003. Thus, the statistically significant particle flux in the case of the AGASA array is observed from the side of the Input of Local Arm as in the case data of Yakutsk EAS array.

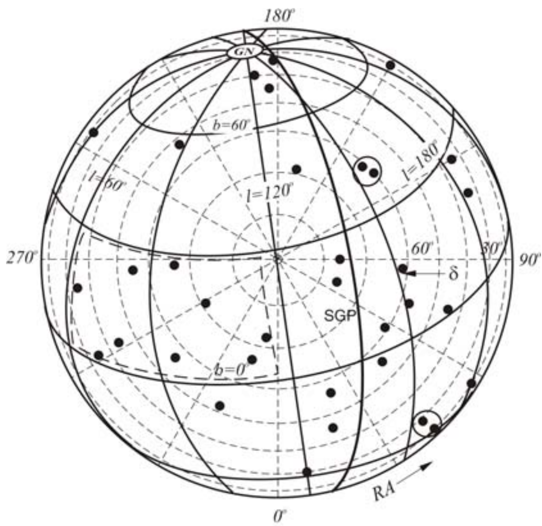

Figure1: On the map of equal exposition particles with E>4.10^{19} eV are shown by the Yakutsk EAS array data. SGP – Super Galactic Plane (plane of Local cluster). Dashed quadrangles on the left – a considered region of a celestial sphere. δ - declination, RA – right ascension, b, l – galactic latitude and longitude. Big circles – clusters.

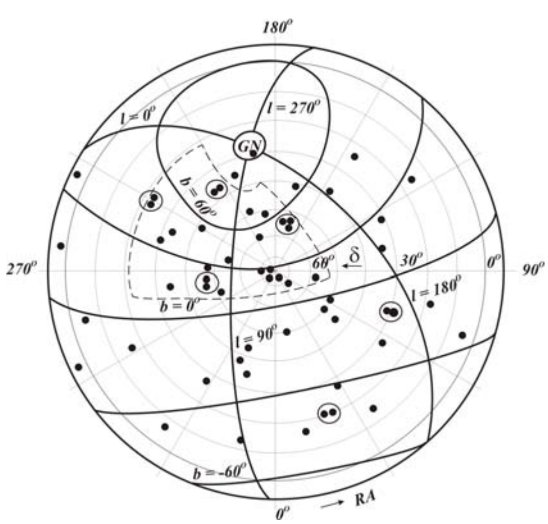

Figure 2: The same as in Fig.1 for the AGASA array data. Dashed quadrangles on the upper – a considered region of a celestial sphere.

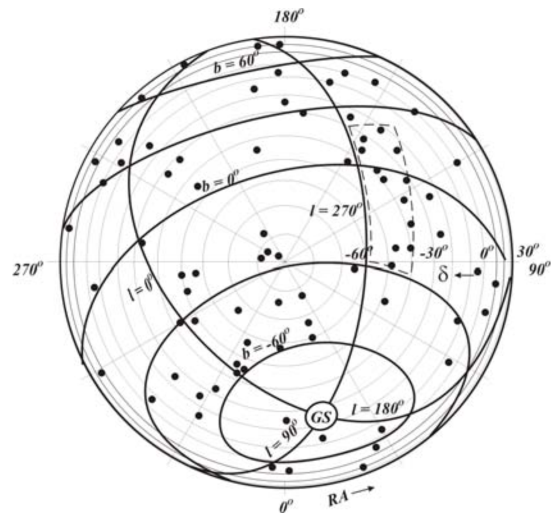

Figure 3: The same as in Fig.1 for the SUGAR array data. Dashed quadrangles on the right – a considered region of a celestial sphere.

For the distribution of particles with E>4.10^{19} eV of the SUGAR array [10] the map of equal exposition of celestial sphere is also constructed. In [11] have shown, that model 'Hillas" of an estimation of energy of EAS is more correct than model "Sydney", according to this model 80 particles with E>4.10^{19} eV are registered. The most concentration 12 of 80 particles is observed toward the Output of Local Arm within coordinates -28.9°< b <19.3° and 248°<b<267.3° with the probability of chance P~2.10^{-5}.

We found [12] if the sources of particles are distributed in the Galaxy disc, then the protons with E~10^{18} eV in main move along the field lines of the Galaxy Arms. Therefore, it may be suggested that the observed flux of particles with E>4.10^{19} eV from the side of the Input and Output of Galaxy Local Arm has a rigidity R~10^{18} eV and therefore they are the charged superheavy particles. The similar conclusion was made by us on the basis of experimental data analysis on the distribution of particles in zenith angle of observations and in muon composition in extensive air showers at E=10^{19}-10^{20} eV by Yakutsk EAS array data [11,13].

Note, that the increased flux of particles is observed from an Input of Arm (or from side of the center of the Galaxy) above a plane of the Galaxy, from an Output of Arm (or from side of the anticenter) – in main below a plane. Such distinction of flux of particles from the center and the anticenter of the Galaxy is expected in galactic model of origin cosmic rays with mainly azimuthally large-scale magnetic field [14].

It should be noted, that from northern and southern poles of the Earth at $\delta \sim \pm 90°$ by data of arrays AGASA and SUGAR (Fig.2, 3) concentration of density of distribution of particles is observed.

We considered the arrival directions of showers by data Yakutsk, AGASA, SUGAR for the center/anticenter of Galaxy and upper/below galactic plane. Total number of particles of 3 arrays is equal 172.

In Fig.4 it is shown the ratio particles at side center\anticenter $C\backslash AC=n_1S_2/n_2S_1$, where n_1, n_2 – number of particles at $|l|<90°$ and $90°<l<270°$ correspondingly, S_1 and S_2 are exposure of the celestial sphere at $|l|<90°$ and $90°<b<270°$ to arrays [5]. When the cosmic rays are isotropy then R=1. Ratio of fluxes of particles $C/AC=2.3\pm0.12$, deviation from isotropy is ~ 11σ.

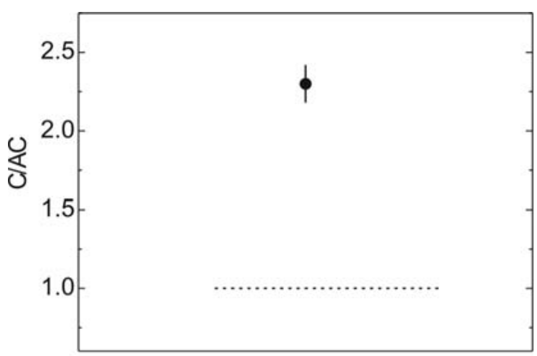

Figure 4: Ratio fluxes of particles at C\AC (center\anticenter) with take account exposure corresponding part of a sphere to arrays.

Earlier from data of EAS arrays Haverah Park and Yakutsk at $E \sim 10^{19}$ eV the increased flux of particles from the anticenter at latitude $b<0°$ was found [4, 15].

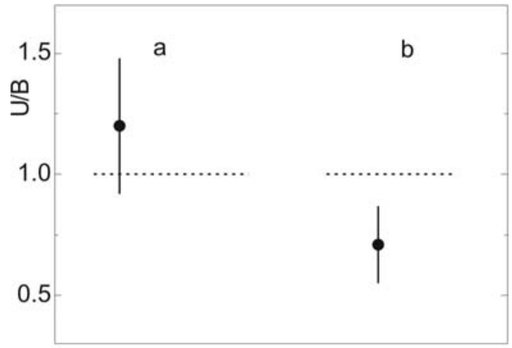

Figure 5: Ratio fluxes particles at U/B (upper\below) $b>0°/b<0°$ with take account exposure corresponding part of sphere to arrays: a – from side of the center of Galaxy, b - from side of the anticenter of Galaxy.

In Fig.5a from side of the center Galaxy it is shown the ratio number particles with take account exposure of celestial sphere to arrays $U\backslash B=n_1(b>0°)S_2/n_2(b<0°)S_1$, where n_1, n_2 – number of particles at $b>0°$ and $b<0°$, S_1 and S_2 are exposure of the celestial sphere at $b>0°$ and $b<0°$ to arrays [5].

When the cosmic rays are isotropy then R =1. According to Fig.5a the increased flux of particles is observed from the center of the Galaxy at latitude $b>0°$ and to Fig.4b the increased flux of particles - from the anticenter at latitude $b<0°$, as predict in galactic model of an origin cosmic rays [14] (see above too).

Conclusion

The distribution particles with $E>4.10^{19}$ eV at a celestial sphere by data arrays EAS Yakutsk, AGASA, SUGAR is not isotropy. The large–scale anisotropy of particles with $E>4.10^{19}$ eV from the side of the Input and Output of Galaxy Local Arm has been found. The particles of ultrahigh energies are most likely the superheavy nuclei and they have a galactic origin.

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