# The arrival direction distribution of Extremely High Energy cosmic rays observed by AGASA

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## Abstract

Study of the arrival direction distribution plays a key role in finding sources of the Extremely High Energy Cosmic Rays (EHECR). Greisen-Zatsepin-Kuz'min (GZK) mechanism [1,2] limits the propagation of EHE cosmic rays significantly and only nearby sources can contribute to the local EHECR flux[3-6]. Furthermore EHECRs travel intergalactic spaces almost linearly. Hence, we expect they can be traced back to their sources. Here we report a small-sacle anisotropy of the arrival direction distribution of EHECRs observed by AGASA above $10^{19} eV$. This result strongly suggests the existence of point sources of EHECRs.

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## 1. Introduction

There have been many studies of large-scale anisotropy[7-11], however, large-scale anisotropy has not been established in the highest energy range due to limited statistics. Recently, small-scale anisotropy was reported by several authors[12-15]. With the increase of experimental data from the AGASA[16], more sophisticated analysis become possible: A cross-correlation study with astronomical objects[17] and a self-correlation study[18].

In our previous report[14], we evaluated clustering by counting the number of clustered events within the angular separation of 2.5°. In this paper, we have extended the analysis of small-scale anisotropy of EHECRs using AGASA data collected through the end of 2000. We observed 775, 59 and 8 events above $10^{19}eV$, $4 \times 10^{19}eV$, and $10^{20}eV$, respectively. In the present data set, we observed five doublets and one triplet above $4 \times 10^{19}eV$.

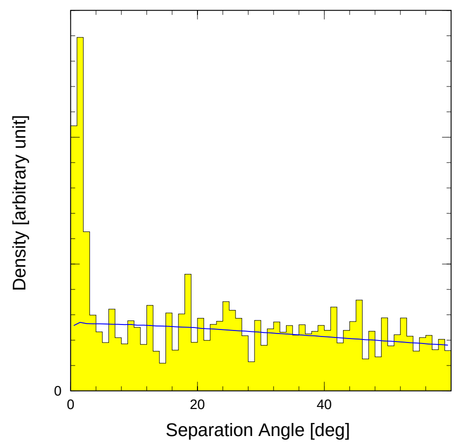


**Fig. 1.** The separation angle distribution of arbitrary two events above $4 \times 1019eV$. The histogram is the observed distribution and a solid curve is that expected under an isotropic distribution.

## 2. Results and Discussion

In this study, we employ a self-correlation analysis to evaluate the clustering in the arrival direction distribution of events. This method has a better sensitivity to detect the existence of multiple faint sources than the previous method. We have calculated the distribution of the separation angle between each event pair for all combinations among 59 events above $4 \times 10^{19}eV$. The number of pairs are normalized by the solid angle of each bin. Figure 1 shows the result of the self-correlation analysis. The histogram is the observed distribution and a solid curve is that expected under an isotropic distribution. There is a clear sharp peak at small separation angles. At separation angles greater than $4°$ the distribution is consistent with an isotropic distribution. This peak results from the six clusters: one triplet and five doublets. The observed number of pairs is $8(= 1 \times 3 + 5 \times 1)$, while the expected background is estimated to be 1.7 pairs. From our simulation we find the chance probability of observing 8 pairs, when 1.7 pairs are expected, is less than $10^{-4}$ .

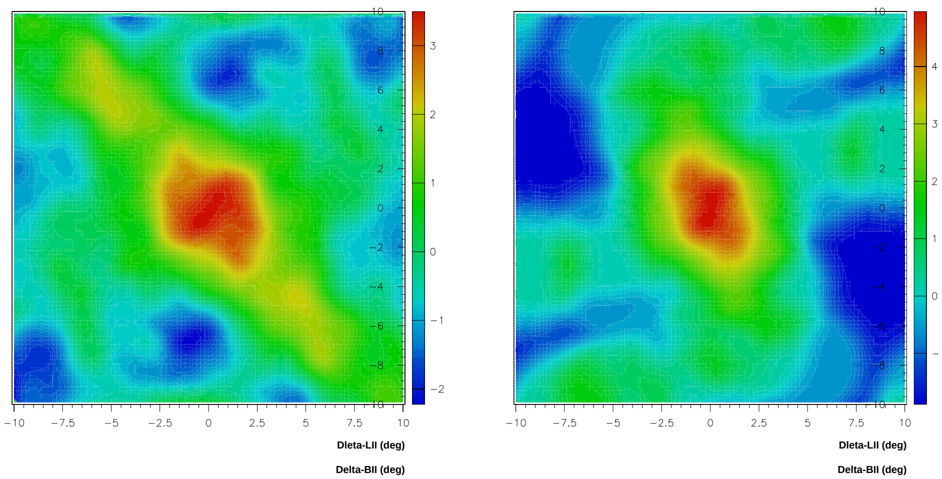


**Fig. 2.** Two events correlation on $\Delta l_{II}$, $\Delta b_{II}$ map. Maps show $\pm 10°$ area. The left: $\geq 10^{19} eV$, the right: $\geq 4 \times 10^{19} eV$.

The cosmic rays above $10^{19} eV$ are accepted widely as an extra-galactic component. Therefore, we have extended the correlation analysis from one dimension to two dimensions and treated the events above $10^{19} eV$ to examine the deflection of cosmic ray arrival directions by the galactic magnetic field. The vectors $(\Delta l_{II}, \Delta b_{II})$, the difference in the coordinates between two event directions, are calculated and are plotted on a two dimensional map. Since we do not know the particle rigidity, then two points $\pm(\Delta l_{II}, \Delta b_{II})$ are plotted. This procedure was carried out for all two-event combinations. The estimation of the background distribution was carried out by the Monte Carlo simulation. We obtained vector density maps after the subtraction of background distribution, as shown in figure 2, for the energy threshold of $10^{19} eV$ and $10^{19.6} eV$. The evaluation of significance was carried out using the normalized sigma developed by Li and Ma[19]. It is surprising that the excess can be seen even at $10^{19} eV$. Especially the $10^{19} eV$ map shows not only the central hot spot at (0,0), but also an excess in a linearly extended region from left-top to right-down. The excess pattern is tilted from the vertical towards the anti-clockwise direction by $40°$ and its length is $\sim 10°$. This length is larger than the instrumental angular resolution. This pattern is the same as we expected for the deflection of charged particles when we introduce the $B_z$ component of $\sim 0.3\mu G$ in the halo as suggested by Stanev[20]. The significance of linearly extended region was also examined and found to be $3\sigma$.

The cluster events, which contribute to the central hot spot in the figure 2, shows a harder differential energy spectrum than that of the entire sample. The spectrum of cluster events can be fit with the power spectrum of $dF/dE \sim E^{-1.8\pm0.5}$. Two possibilities can explain this hard energy spectrum. One natural explanation is the scattering of the low energy particles in Galactic Magnetic Field. The other is that the direct propagation of particles from nearby sources may reflect the source spectrum.

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