Search for point sources of ultrahigh-energy cosmic rays

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(Submitted 22 December 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **57**, No. 3, 145–147 (10 February 1993)

Ultrahigh-energy particles are bunched in four regions on the celestial sphere according to data from cosmic-ray extensive-air-shower installations.

Chi *et al.*[1] and Lawrence *et al.*[2] have reported observing regions of arrival directions in which there is a bunching of particles with energies above 10^{19} eV. As has been shown in several places (e.g., Ref. 3), the effect of the magnetic field of the local galaxy, $\sim 2\ \mu$G, is weak for the trajectories of protons with energies above 10^{19} eV. In some cases, e.g., for nearby sources, particles of such energies can reach the earth essentially undeflected, and their arrival directions will point to their sources. Near a source there will be a region of a bunching of particles, which we will call a "cluster."

In this letter we examine the arrival directions of extensive air showers formed by cosmic rays with energies above 10^{19} eV. Specifically, we analyze data from the installations at Yakutsk,[4] Havera Park[5] (in England), Volcano Ranch[5] (in the US), Sydney[6] (Australia), and Akeno (Japan; 47 events; preliminary report). We studied the arrival directions of cosmic rays above a declination $\delta > 0$, from which most of the particles at the Yakutsk and Havera Park installations are observed. A total of 722 events with the specified coordinates were analyzed.

For each shower, the distance between the shower and another event was calculated. The number of events stemming from this shower was then determined for distances with radii $R = 3°$, 6°, and 10°. We call the number of events, M, the "multiplicity" of the clusters. We found clusters with various multiplicities. We were interested in whether the number of events around a given s however, i.e., M, is a random number. To answer this question, we used the following procedure. We determined the probability that the number of events within a region of radius R was random by working from the Poisson formula $P = \Sigma_{i=M+1}^{\infty} \exp(-\bar{n})\bar{n}^i/i!$, where $\bar{n}$ is the expected number of events in the case of an isotropic distribution of cosmic rays. The expected number of events was studied by generating random events uniformly over right ascension, allowing for the exposure of each installation in terms of declination. The procedure for determining the expected number of events is described in detail in Ref. 7.

A statistically significant result with a probability $P < 2.7 \times 10^{-3}$ was found for the radius $R = 3°$; see the filled circles in Fig. 1. Also shown in this figure, by the open circles, are clusters for which the probabilities are statistically insignificant but close to $P = 2.7 \times 110^{-3}$. For the radii $R = 6°$ and 10°, the probabilities for the number of random events within the circles become statistically insignificant.

According to the criterion outlined above, all the observed clusters[1] are statisti-

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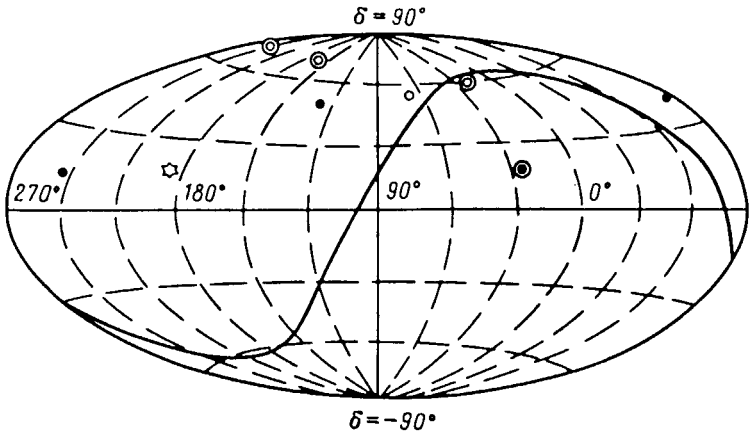

FIG. 1. Filled circles—clusters with a probability $P < 2.7 \times 10^{-3}$; open circles—clusters with a probability greater than but close to this value; double circles—clusters which coincide with the clusters of Ref. 1; solid line—galactic plane; δ, α—declination and right ascension.

cally insignificant. The maximum number of clusters near the galactic plane[1,2] may be a consequence of an anisotropy of the cosmic rays, $14+4.1\%$, on the side of the galactic plane at energies $\sim 10^{19}$ eV (Ref. 8). In the data shown above, we find 142 events instead of the expected 132.4 at latitudes $|b| < 10°$. However, four clusters (shown by the double circles in Fig. 1) agree, within the errors, in arrival direction with clusters observed in Ref. 1. We might add that the four observed clusters lie at high galactic latitudes, where the effect of magnetic fields on the particle trajectories would apparently be relatively weak.

In summary, four clusters have been observed in the direction of high galactic latitudes. It is possible that they are formed by point sources of ultrahigh-energy cosmic rays.

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Translated by D. Parsons