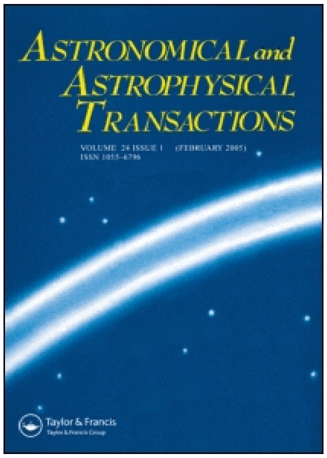

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Identification of active galactic nuclei as possible sources of UHECR

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IDENTIFICATION OF ACTIVE GALACTIC NUCLEI AS POSSIBLE SOURCES OF UHECR

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51 showers initiated by ultra-high energy cosmic rays (UHECR) ($4 \times 10^{19} < E \leq 3 \times 10^{20}$ eV) and detected by different arrays were investigated. Astrophysical objects: x-ray pulsars (as the most powerful), radio galaxies, Seyfert galaxies, and BL Lac objects were searched in the 3-error box around the particle arrival direction of each shower. The probabilities for objects of each type to fall by chance into the 3-error boxes were determined. They appear to be small for Seyfert galaxies with red shifts $z < 0.01$, $P = 1.5 \times 10^{-3}$ and for BL Lac's, $P = 1.8 \times 10^{-3}$. For other objects they are: $P > 0.1$. The probabilities show that nearby Seyfert galaxies and BL Lac's may be possible sources of UHECR.

KEY WORDS Cosmic rays, active galactic nuclei

The origin of UHECR is a most actively investigated problem. Study of extensive air showers generated by UHECR has revealed that particles at $E > 4 \times 10^{19}$ eV are very likely of extragalactic origin (Takeda *et al.*, 1999). UHECR coming from distances larger than (50–100) Mpc (Stecker, 1998) lose energy in interactions with the cosmic microwave background radiation. As a result the detected cosmic ray spectrum will have a break at energies $E > 5 \times 10^{19}$ eV and there will be no particles at $E > 10^{20}$ eV in the spectrum (Greisen, 1966; Zatsepin and Kuz'min, 1996). UHECR with $E > 10^{20}$ eV have been detected at various arrays (Takeda *et al.*, 1999) and so they might be produced not more than 100 Mpc from us. The sources discussed in the literature are of two kinds. Firstly they are various astrophysical objects (Norman, Melrose and Achterberg, 1995; Kardashev, 1995). Secondly, UHECR can be generated in cold dark matter (Kuzmin and Rubakov, 1998), and in gamma-ray bursts (Totani, 1998). In the second case the incidence of any object in the region around the particle direction will be random.

We supposed that UHECR sources are astrophysical objects, that UHECR propagate in extragalactic space along straight lines (for details see Uryson (1999) and that their deflection in the Galactic magnetic fields can be neglected (Takeda *et al.*, 1999). At present particle arrival directions are determined with errors of a few degrees, whereas errors in the location of astrophysical objects are within seconds. So the latter can be neglected. For analysis we use 51 showers: 48 showers (Takeda *et al.*, 1999), 2 showers (Afanasiev *et al.*, 1996), and 1 shower (Watson, 1995), having errors in arrival directions in equatorial coordinates $\Delta\alpha \approx 3^0$, $\Delta\delta \approx 3^0$, 8 of them with $E > 10^{20}$ eV. The showers were divided into several groups depending on the galactic latitude b of their arrival directions to escape the 'zone of avoidance' of galaxies. Objects were sought in the 3-error box of each shower with catalogues Spinrad *et al.* (1985), Popov (2000), Veron-Cetty and Veron (1998).

To determine the probability that objects of a given type fell into the box accidentally we simulated showers with random arrivals. The number K_{sim} of simulated showers and the number N_{sim} having objects of the given type in the 3-error boxes were chosen equal to those observed. The probability P that an object from Spinrad *et al.* (1985), Popov (2000), Veron-Cetty and Veron (1998) fell randomly into the 3-error box of N_{sim} showers is: $P = \sum_{i=1}^{M}(N_{sim})_i/M$, where M is the number of tests performed for each group with given K_{sim}, $M = 10^5$. The values of P are: at $|b| > 31^0$, $P = 1.8 \times 10^{-3} \approx 3.10\sigma$ for BL Lac objects, $P = 1.510^{-3} \approx 3.15\sigma$ for Seyfert galaxies with $z \leq 0.0092$, where σ is the Gaussian parameter, $P = 0.17$ for x-ray pulsars, and $P = 0.29$ for radiogalaxies. Probabilities $P > 3\sigma$ permit us to conclude that nearby Seyfert galaxies and BL Lac objects are possible UHECR sources. Processes of proton acceleration up to $E > 10^{21}$ eV in AGN were suggested in Kardashev(1995).

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