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We calculate angular correlation function between ultra-high energy cosmic rays (UHECR) observed by Yakutsk and AGASA experiments, and most powerful BL Lacertae objects (quasars with jets directed along the line of sight). We find significant correlation at 2.5° with the probability of chance coincidence 2×10^{-5} and conclude that some of BL Lacertae are sources of the observed UHECR. We also see correlations at $\sim 10°$ with the probability of coincidence 3×10^{-4}. A natural interpretation of this result is the existence of neutral and charged components of cosmic rays at highest energies, with charged primaries being deflected in extragalactic magnetic fields (EGMF) by an angle of order 10°. The magnitude of EGMF deduced from here is $\sim 10^{-9}$ G assuming correlation length 1 Mpc.

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Introduction. Identification of sources of ultra-high energy cosmic rays (UHECR) is extremely important. Knowing their production sites will help to explain the absence of the Greisen-Zatsepin-Kuzmin (GZK) cutoff [1] by selecting a particular class of models. In case of astrophysical origin it will give an invaluable information on physical conditions and mechanisms which may lead to acceleration of particles to energies of order 10^{20} eV. In case of extragalactic origin, it will provide a direct information about poorly known parameters which influence propagation of UHECR, such as extragalactic magnetic fields and universal radio background.

There are observational reasons to believe that UHECR are produced by compact sources. It has been known for quite a while that the observed highest energy cosmic rays contain doublets and triplets of events coming from close directions [2–4]. Our recent analysis [5] based on the calculation of angular correlation function shows that explanation of clusters by chance coincidence is highly unprobable: the correlation function for Yakutsk events with energies $E > 2.4\times10^{19}$ eV has an excess at 4° which would occur with probability 2×10^{-3} for the uniform distribution, while the correlation function for AGASA events with energies $E > 4.8\times10^{19}$ eV has an excess at 2.5° corresponding to chance probability 3×10^{-4}. The combined probability of the fluctuation in both sets is 4×10^{-6}. So significant autocorrelations should imply also large correlations of these events with their actual sources. It is a purpose of the present paper to identify these sources.

The clustering of UHECR by itself imposes certain constraints on possible source candidates. With the observed number of events in clusters, the total number of sources can be estimated along the lines of Ref. [6] to be of order several hundred. For extragalactic sources, this estimate gives their number in the entire Universe. Thus, to produce observed clustering, the extragalactic sources have to be extremely rare as compared to ordinary galaxies. Most of them should be at cosmological distances, since sources with redshift $z > 0.1$ contribute $\sim 90\%$ of all events in the case of the uniform distribution over the Universe.

Various astrophysical candidates such as neutron stars, supernovae, gamma-ray bursts, colliding galaxies, active galactic nuclei (AGN), lobes of radio-galaxies, dead quasars and others (for a review see Refs. [7] and references therein) have been proposed as sources of UHECR. Possible connection of highest-energy cosmic rays with these objects was considered in Refs. [3,4,8–14]. In this paper we study correlations of UHECR with BL Lacertae (BL Lac) objects. BL Lac objects are characterized by "featureless" optical spectra, rapid aperiodic variability in all wavelengths and high (up to 40%) polarization of their optical continuum emission. These unique properties are direct indication of seeing a relativistically beamed jet very close to the line of sight [15]. BL Lac objects are the rarest type of active galactic nuclei. The most recent catalog of AGNs and quasars contains 306 confirmed BL Lacs [16]. We find it particularly attractive candidate source of observed UHECR. Correlations of BL Lacs with UHECR were not considered before. We show that these correlations do exist and are statistically significant.

Our method is based on calculation of the angular correlation function and is similar to the one we have used in Ref. [5]. The calculation consists of the following steps. For each BL Lac we divide the sphere into concentric rings of equal angular width (angular bins) and count the number of cosmic ray events falling into each bin. We then average over the BL Lacs and obtain the average counts N_i, where i is the bin number. We repeat the same procedure for a large (typically 10^6) number of randomly generated sets of cosmic rays and calculate the expected counts $N_i^{\rm MC}$ and the standard deviations σ_i. Correlations at different angles are characterized by the ratios $(N_i - N_i^{\rm MC})/\sigma_i$ which measure deviations of