Reply to "Cuts and penalties: comment on 'The clustering of ultra-high energy cosmic rays and their sources' "

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We reiterate that there is no evidence that BL Lacs are sources of ultrahigh energy cosmic rays.

Tinyakov and Tkachev (TT) [1] have claimed that *"BL Lacertae are sources of the observed ultra-high energy cosmic rays"* (UHECRs). They considered a set of 39 UHECRs with $E > 4.8 \times 10^{19}$ eV observed by AGASA and 26 UHECRs with $E > 2.4 \times 10^{19}$ eV observed by Yakutsk, and compared their arrival directions with the positions of 22 BL Lacs selected by redshift ($z > 0.1$ or unknown), apparent magnitude ($m < 18$) and 6 cm radio flux ($F_6 > 0.17$ Jy). Eight UHECRs were found to be within 2.5° of 5 BL Lacs, the chance probability of which was estimated to be 6×10^{-5} including all penalties for the arbitrary cuts made [1]. We have shown [2] that the significance of the coincidences has been greatly exaggerated. In the preceding *Comment* [3] TT assert that our criticism is incorrect. We argue below that this is not the case and provide further evidence in support of our position.

Our first criticism was that TT did not take into account the (energy dependent) angular resolution of the experiments. Although the positions of the BL Lacs are known to arcsecond accuracy, the arrival directions of UHECRs in air shower arrays cannot be reconstructed to better than a few degrees. In particular for simulated events in AGASA, 68% have a reconstructed arrival direction within 1.8° of the true direction and 90% within 3°; the corresponding angles for all events above 10^{19} eV are 2.8° and 4.6° [4]. TT require, without providing specific justification, that the UHECR arrival direction be within 2.5^0 of a BL Lac in order to be considered a coincidence. This may appear to be a reasonable approximation for the AGASA data. When it comes to the Yakutsk data however, the angular resolution is far worse for the lower energy events considered, in particular it exceeds 4^0 for $E < 4 \times 10^{19}$ eV [5, 6]. Nevertheless the most significant correlation listed by TT is that of a 'triplet' of UHECRs in the Yakutsk data having energies of (3.4, 2.8, 2.5) $\times 10^{19}$ eV whose nominal arrival directions are within 2.5^0 of a BL Lac (1ES 0806+524). In their *Comment* [3], TT assert: *"By itself, worse angular resolution does not imply that correlations with sources must be absent in Yakutsk set: even though the angular resolution is worse, the density of UHECR events around actual sources is larger as compared to a random set, and one has excess in counts even at small angles"*. If this were indeed the case, then one would reasonably expect UHECRs observed by other experiments (with better angular resolution) to be (even better) aligned with the BL Lacs in question. In fact there are *no* such coincidences with any of the 39 AGASA events they considered! Therefore we reassert that there is no justification for ascribing any significance to coincidences between Yakutsk events and BL Lacs within 2.5^0.

To demonstrate this quantitatively we have calculated the autocorrelation functions of the selected AGASA and Yakutsk events [8], as well as their cross-correlation with the 22 selected BL Lacs [1], taking the angular resolution of the experiments into account. For each observed UHECR, a new arrival direction is generated from the distribution defined by the quoted experimental angular resolution at that energy, as has been done e.g. for BATSE data [7]. We generate 10^6 such data sets, for comparison with the data sets generated from an isotropic distribution. As seen in Fig. 1, this has a dramatic effect on the significance of the claimed clustering. We find the chance probability for an isotropic distribution to yield as many events (with $E > 4.8 \times 10^{19}$ eV) as was observed by AGASA in the first (2.5^0) angular bin to be 1.8×10^{-4}. Similarly the chance probability for an isotropic distribution to yield as many events (with $E > 2.4 \times 10^{19}$ eV) as was observed by Yakutsk in the first (4^0) angular bin is 6.5×10^{-4}. Both these numbers agree with TT's estimates in Table 1 of ref.[8], allowing for their 'penalty factor' of ~ 3. However when we take the angular smearing into account, these chance probabilities increase to 3.5% for AGASA and 18% for Yakutsk. Thus there is little basis for the claim that *"Correlation function of ultrahigh energy cosmic rays favours point sources"* [8]. The significance of the clustering in the AGASA data has also been questioned recently by other authors [9]; however they did not take the limited angular resolution of AGASA into account.

Concerning the cross-correlation with the 22 BL Lacs selected by TT , the probability for an isotropic distribution of UHECRs to yield as many coincidences between the AGASA events and these BL Lacs as is actually observed, is only 1.5×10^{-3}, but this chance probability increases to 4% when the angular smearing is taken into account. For the Yakutsk data, the chance probability is 8×10^{-2} without the angular smearing, but as high as 38% when this is included. Thus as shown in Fig. 2, there is *no* justification for TT's inclusion of the Yakutsk data; they do so simply because when the AGASA and Yakutsk datasets are combined, new clusters appear combining events from both datasets, thus artificially enhancing the significance of the coincidences.

Our second criticism was directed at TT's assumption that *" ...the energies of the events are not important for correlations at small angles ... "* [1]. We demonstrated [2] that by lowering the energy cut on the AGASA data from 4.6×10^{19} eV to 4×10^{19} eV, the significance of the coincidences in fact *decreases* by a factor of 5.

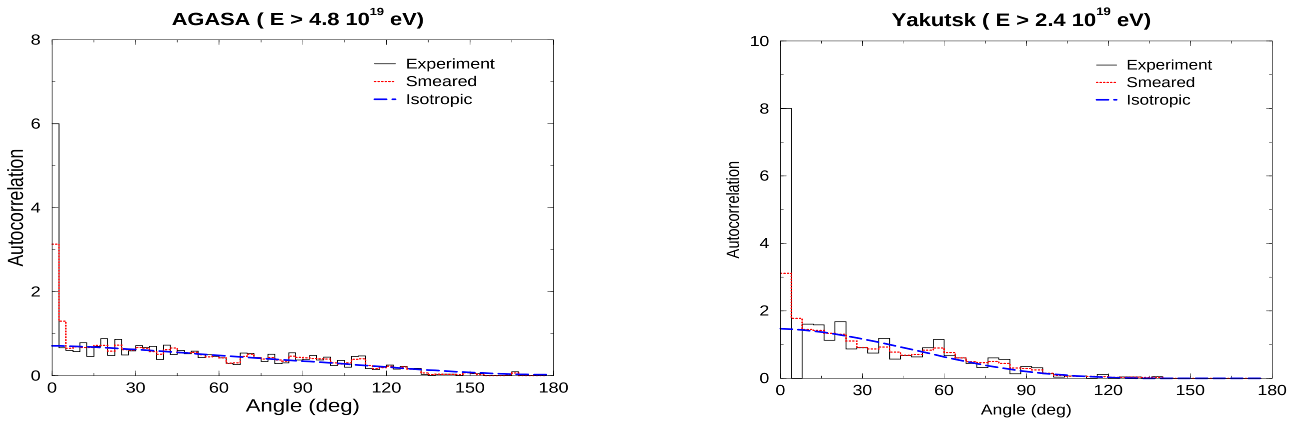

FIG. 1: Autocorrelation for AGASA and Yakutsk

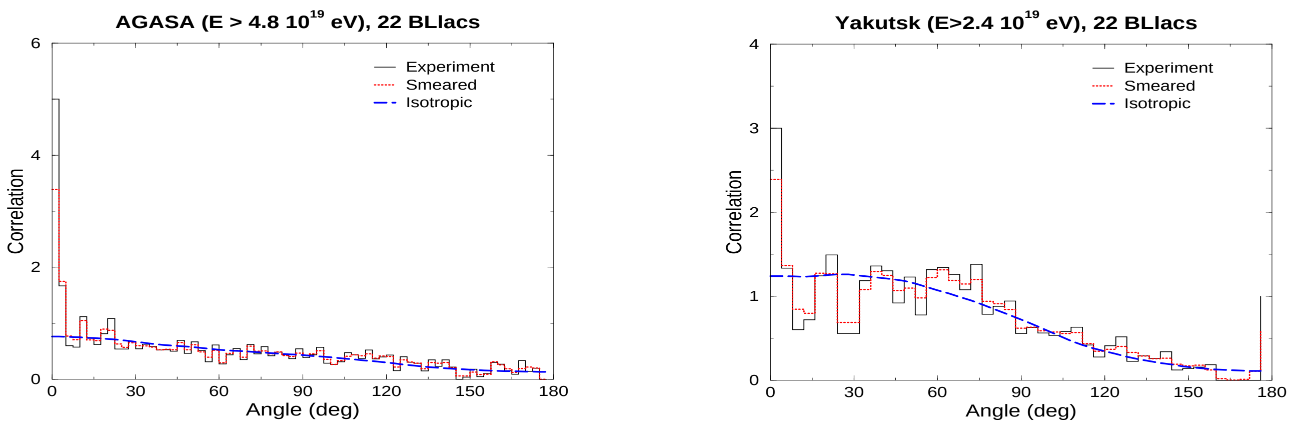

FIG. 2: Cross-correlation with selected BL Lacs for AGASA and Yakutsk

In closing we would like to draw attention to other recent papers which have a bearing on this issue. Using an independent sample of 33 UHECRs observed by Volcano Ranch and Haverah Park, *no* coincidences are found between their arrival directions and the 22 BL Lacs selected by TT [1]; the probability that this null result arises as a fluctuation from the strongly correlated case is less than 5% [10]. Secondly an independent analysis of the AGASA events finds *no* statistically significant correlations with BL Lacs [11].

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