

Anomalous cosmic-ray correlations revisited with a complete full-sky sample of BL Lac type objects

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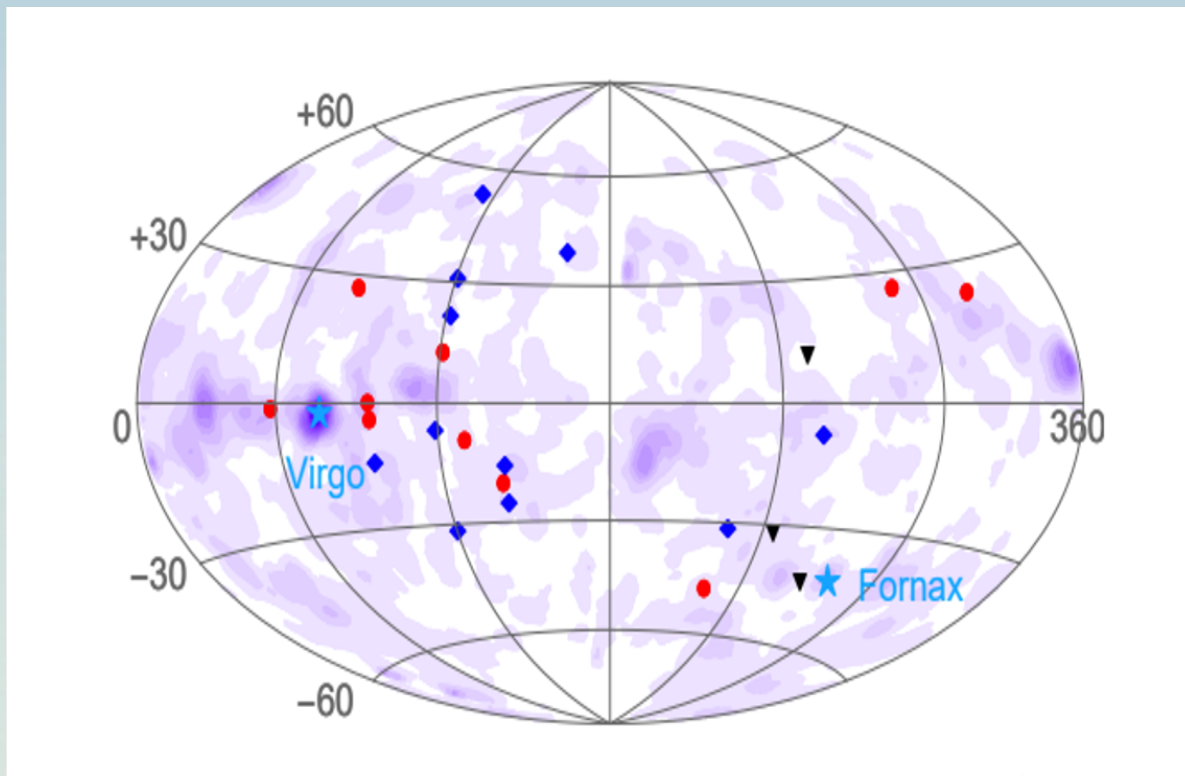
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Highlights

- BL Lacs, which constitute a subclass of blazars, are active galactic nuclei with jets pointing to the observer, and are located at cosmological distances.
- In 2004 correlations of arrival directions of UHECR and BL Lacs were detected in HiRes stereo data set [1,2]. For original analysis was used catalog [3] not complete by any criteria.
- What's more, the distribution in the sky of BL Lacs associated with cosmic rays was found to deviate from isotropy.
- The authors of the present work used a recently compiled isotropic complete sample of BL Lacs [4] and the same HiRes data to confirm the presence of correlations and to strengthen the case for the local large-scale structure pattern in the distribution of the correlating objects.

Motivation

As it can be seen from the picture, correlating objects found in 2004 analysis [1] are distributed not isotropically. This can be a pointer to new effects related to axion-like particles propagation through the Universe.



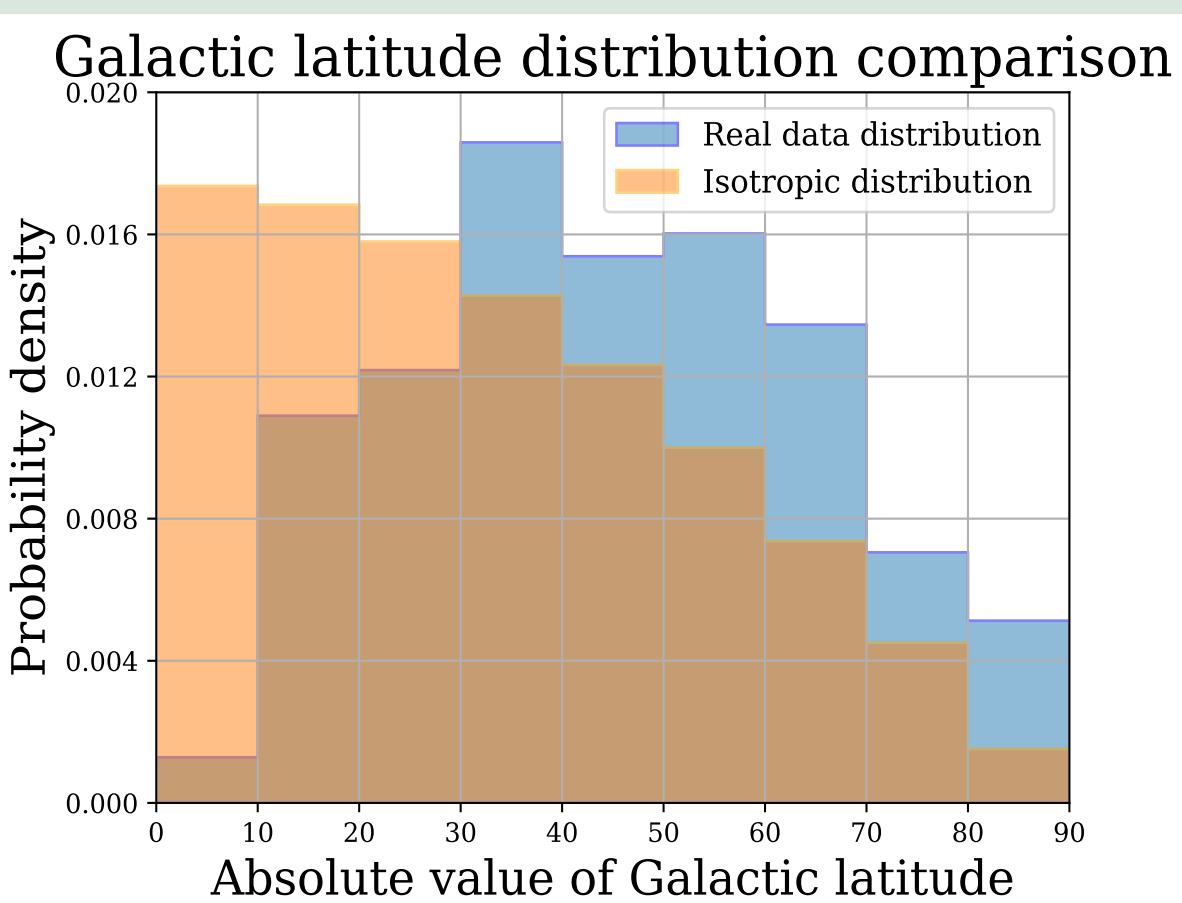
Picture is taken from [5]

Blue diamonds – BL Lac type objects correlating with UHECR.

Black triangles – gamma ray bursts detected in VHE.
Red circles – objects with anomalous hardenings in VHE.

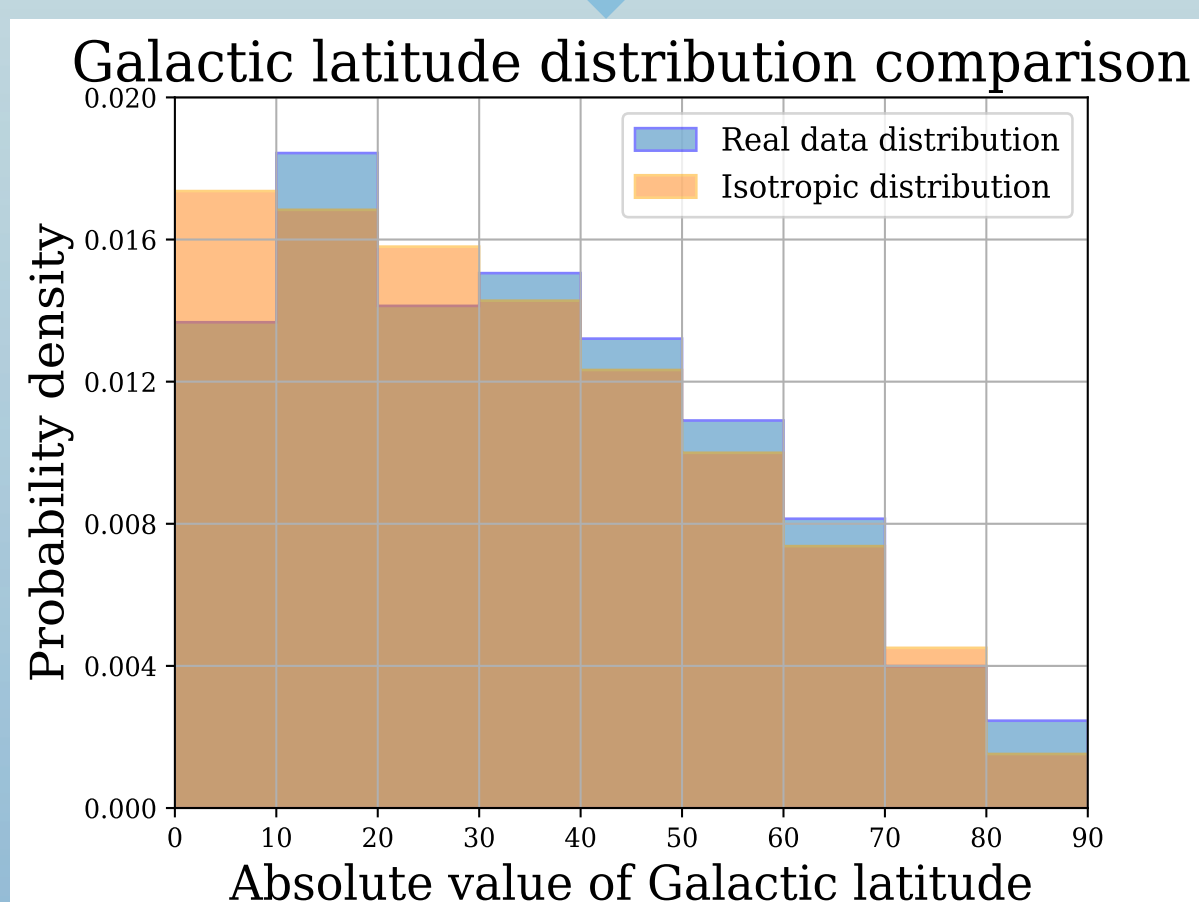
Density plot – weighted galaxy distribution.

Set of blazars



2004:

- 156 BL Lac type objects.
- $V < 18^m$, V – uncorrected optical magnitude in V-band.
- Significant lack of objects near the galactic plane.



2023:

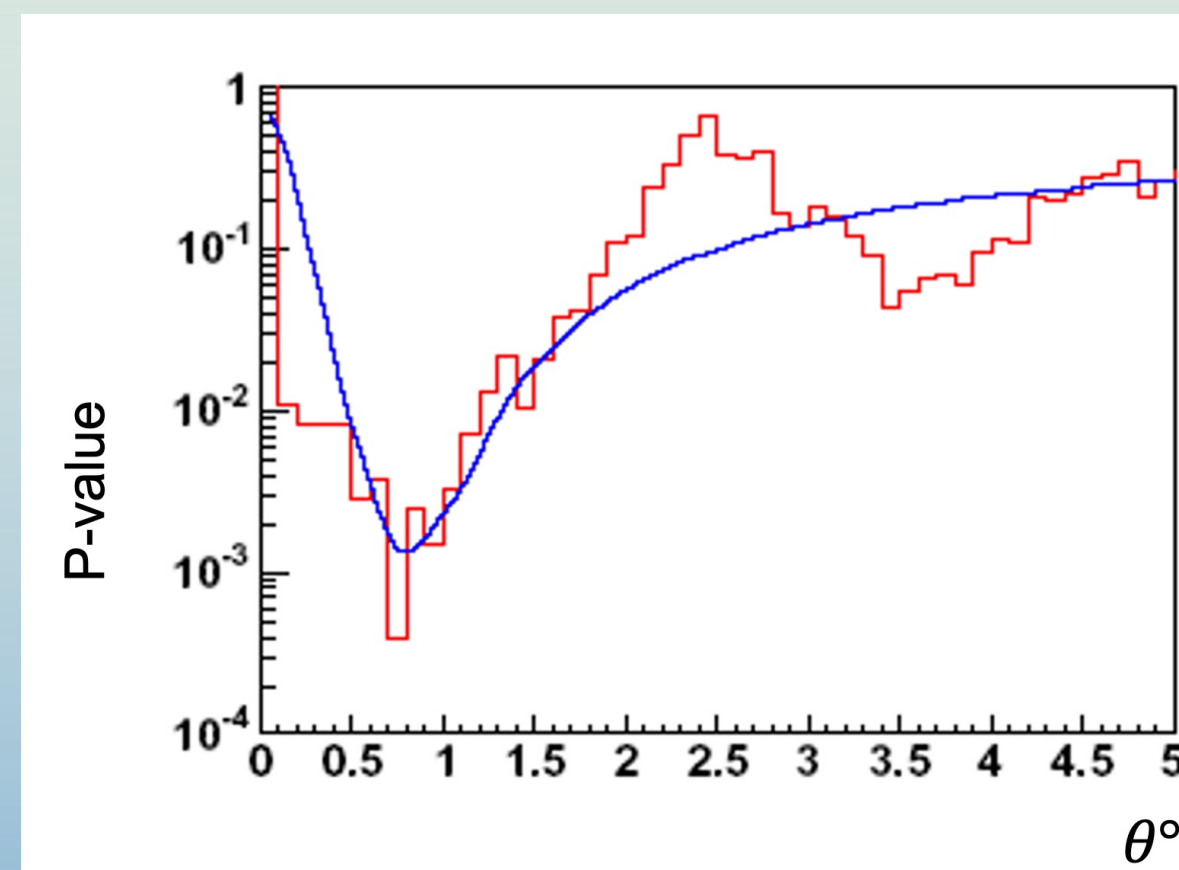
- 336 BL Lac type objects.
- $G_{cor} < 18^m$, G_{cor} – GAIA DR3 G-band magnitude corrected for the Galactic absorption.

Description of the catalog can be found in [4].

Correlation search

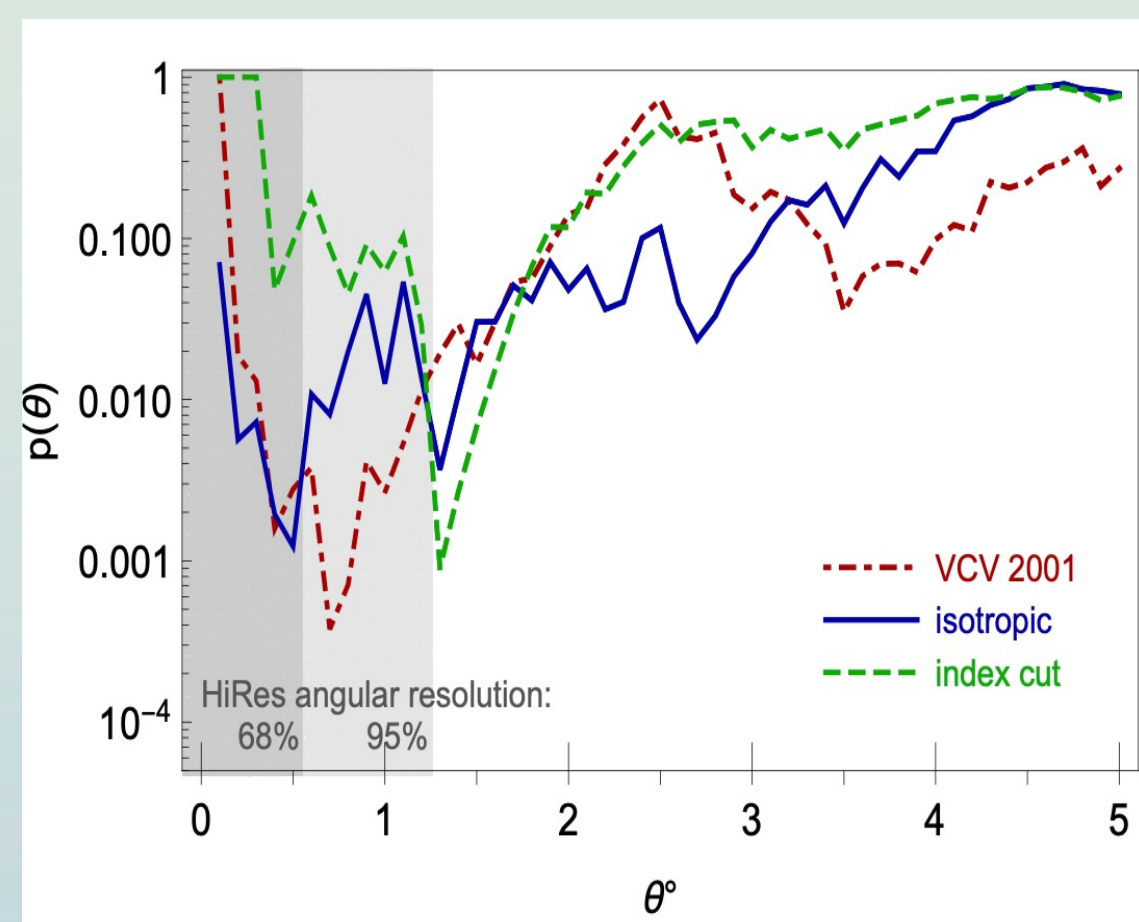
For a given angle θ , one count the number of pairs “BL Lac – HiRes arrival direction” separated by the angle $\leq \theta$. Then the same procedure is repeated for a large number of simulated sets of arrival directions, and the p-value measuring how often this or larger number of pairs can be observed by chance, is determined. Note that simulated arrival directions are not isotropic, but follow the HiRes stereo exposure.

2004 Result



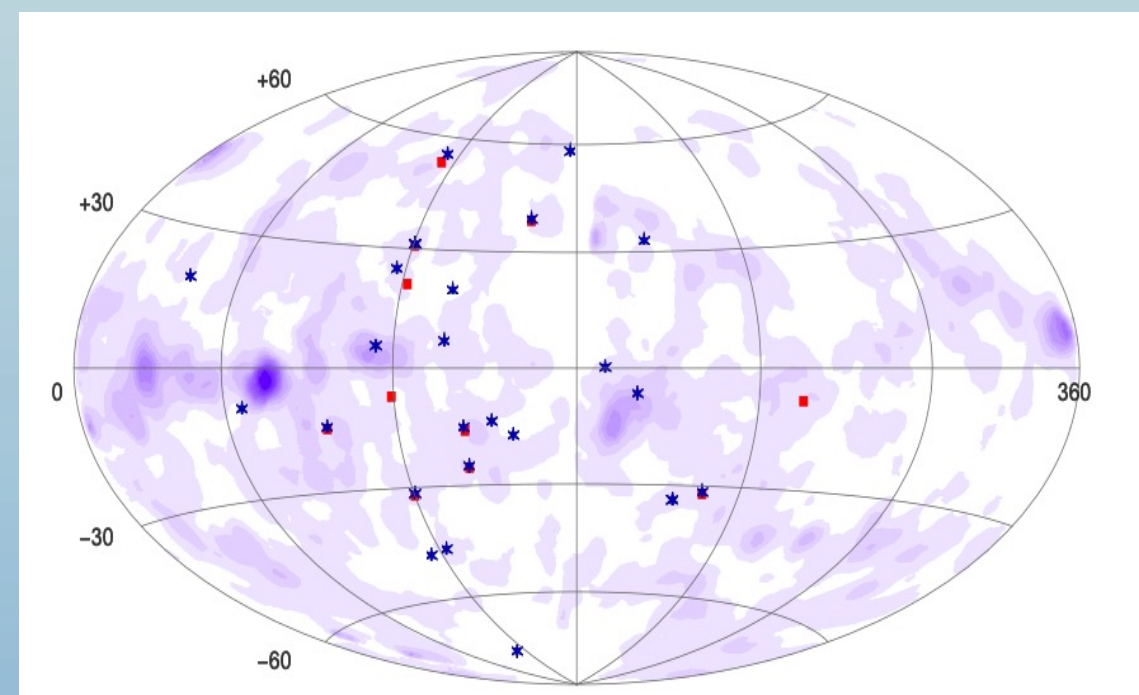
- Set of 156 BL Lacs [3].
- 271 HiRes event with energy $E \geq 10^{19}$ eV.
- Picture taken from [6].

2023 Result



- VCV 2001 – repeat of 2004 analysis.
- Isotropic – set of 336 BL Lacs from [4].
- Index cut – set of 73 objects with applied spectral index constraints.

2023 Result



Sky map with positions of BL Lacs associated with HiRes cosmic rays.

Red boxes: the sample used in [1], $\theta=0.8^\circ$.

Blue stars: the isotropic sample, $\theta = 1.3^\circ$.

Density plot: weighted galaxy distribution.

Perspectives

- In the nearest future, tests of the BL Lac correlations with cosmic rays could be performed, in particular, with the help of the data collected by the Telescope Array experiment, which is successor HiRes.
- It might be interesting to explore photon content of correlating events or establish what primary particles are responsible for correlations with the use of Telescope Array data.

References:

1. D. S. Gorbunov, P. G. Tinyakov, I. I. Tkachev, S. V. Troitsky, arXiv:astro-ph/0406654v1;
2. HiRes Collaboration 2005;
3. M. P. Veron-Cetty and P. Veron, ESO scientific report (2000); M. P. Veron-Cetty and P. Veron, Astron. Astrophys.374 (2001) 92;
4. Kudenko M., Troitsky S., arXiv:2312.07508;
5. Troitsky S., Eur. Phys. J. C 81 (2021) 264;
6. D. Gorbunov et al., JETP letters, 2004;
7. Kudenko M., Troitsky S., arXiv:2312.07525.