Prospects of testing a minimal model for extragalactic cosmic rays and neutrinos with the K-EUSO orbital telescope

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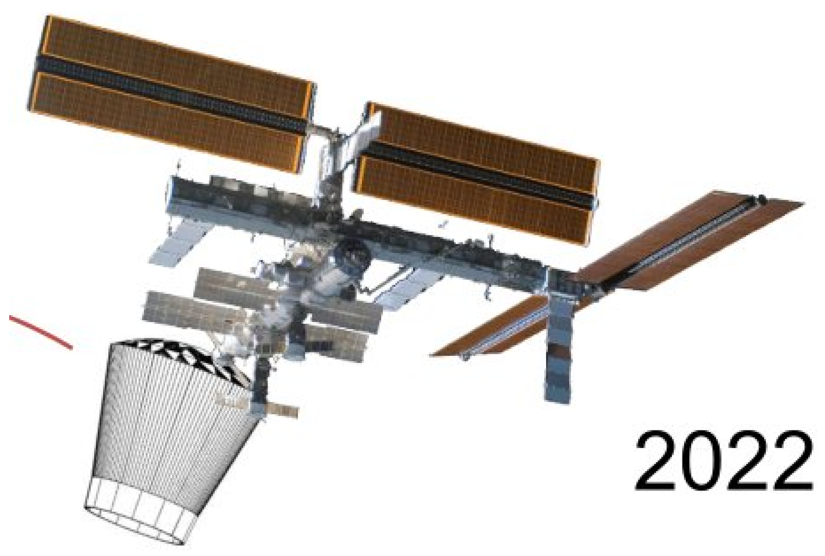
We employed the TransportCR and CRPropa 3 packages to estimate prospects of testing a minimal model for extragalactic cosmic rays and neutrinos by Kachelrieß, Kalashev, Ostapchenko and Semikoz (KKOS) [PRD 96 (2017) 083006; arXiv:1704.06893; see a talk by D. Semikoz] with the K-EUSO orbital detector in terms of the large-scale anisotropy. Nearby active galactic nuclei Centaurus A, M82, NGC 253, M87 and Fornax A were considered as possible sources of UHECRs. We demonstrated that an observation of 200 events will allow testing predictions of the model with a p-value $\lesssim 10^{-5}$ providing the fraction of from-source events is 12–19%, depending on a particular source, with a smaller contribution for larger samples.

K-EUSO detector

KLYPVE-EUSO (K-EUSO) is a planned orbital detector of UHECRs, to be deployed on board the International Space Station in 2022.



Main parameters:

- a Schmidt-type optical system with the main mirror-reflector of a 4 m diameter, an entrance pupil of a 2.5 m diameter and a 1.7 m focal length.
- a round-shaped field of view of $40°$ diameter, with an instantaneous geometrical area of nearly 6.7×10^4 km^2 at sea level for the ISS altitude of around 400 km.
- the yearly exposure above ~40 EeV: $\sim 3 \times 10^4$ km^2 sr yr.

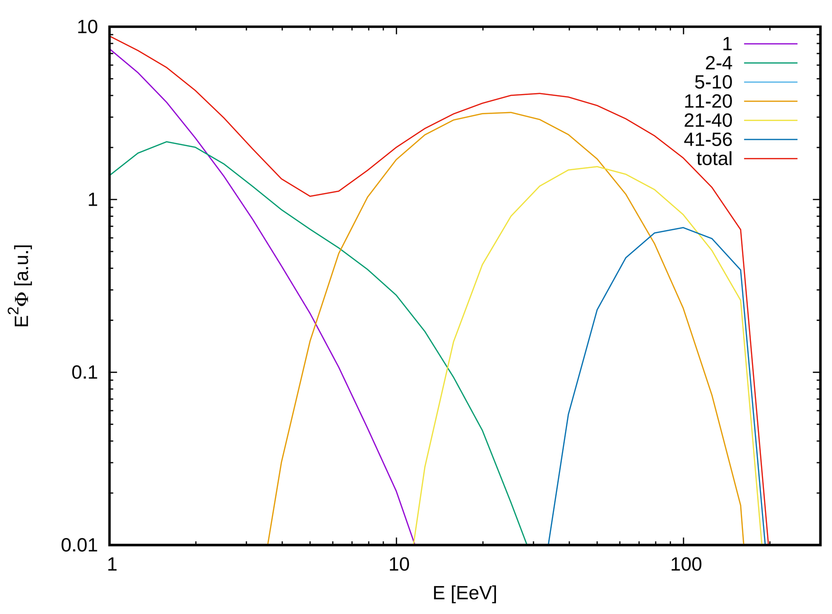
K-EUSO is expected to have a uniform exposure over the celestial sphere and register **from 120 to 500** UHECRs at energies **above 57 EeV** in a 2-year mission [Casolino+, PoS (ICRC2017) 368].

KKOS model

The model assumes UHECRs are produced by (possibly a subclass of) AGN.

Basic assumptions:

- the energy spectra of nuclei after the acceleration phase follow a power-law with a rigidity-dependent cutoff
- the CR nuclei diffuse first through a zone dominated by photo-hadronic interactions, and then they escape into a second zone dominated by hadronic interactions with gas.



The effective CR source energy spectrum for different mass components in the KKOS model

The model matches:

- experimental data on the total CR flux, the mean EAS maximum depth $X_{\max}$ and its width RMS($X_{\max}$) above $\sim 10^{17}$ eV
- HE neutrino flux measured by IceCube

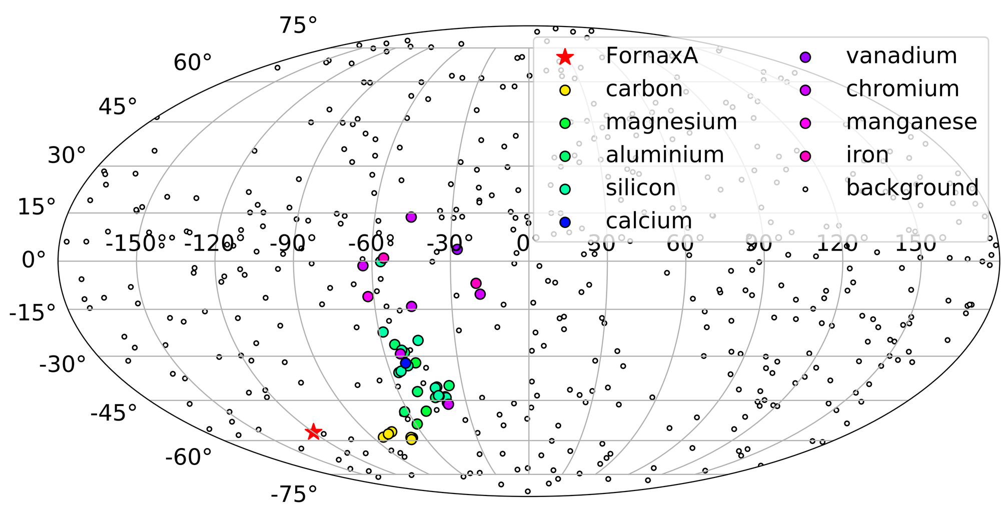
Simulations

Main steps:

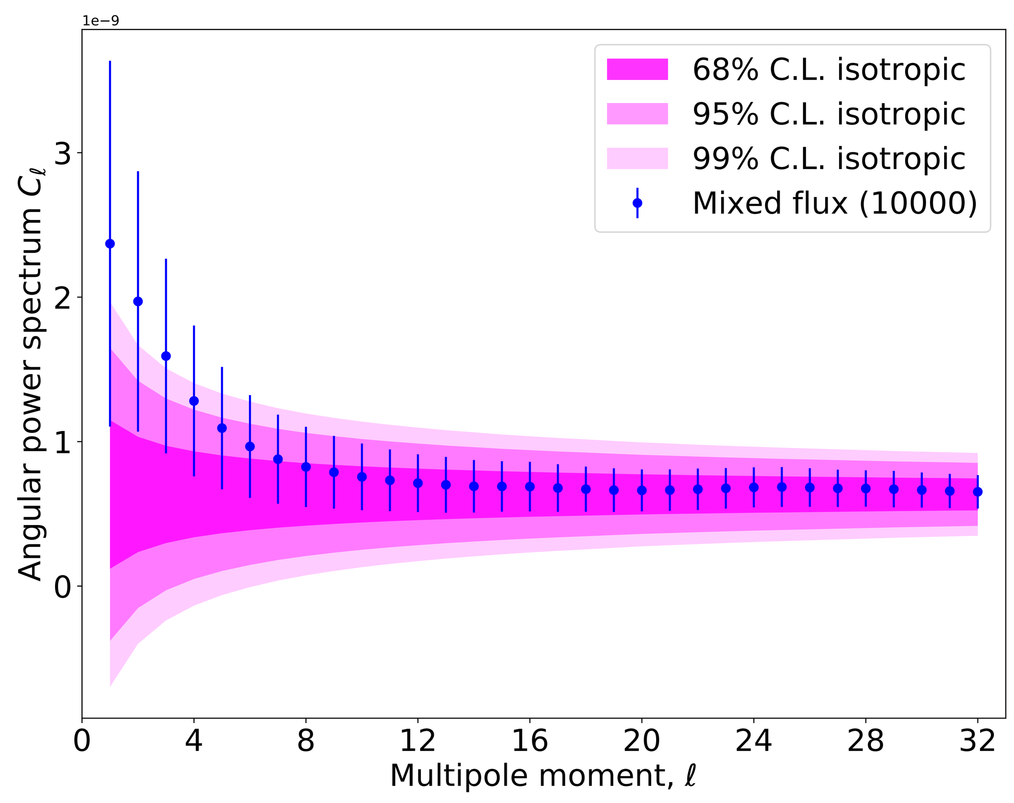
- Sources: radio-load AGN NGC 253, Centaurus A, M82, M87 and Fornax A (distances $d \simeq 3.5 \ldots 20$ Mpc)
- TransportCR [arXiv:1406.0735]: mass composition and energy spectra (Z, E) of the CR flux arriving from a source located at a given d. A contribution of other sources was approximated by an isotropic component.
- Assume there are no deflections of nuclei above 57 EeV in the inter-galactic space: nuclei arrive to the Milky Way within $1°$ from the actual direction to the source.
- CRPropa 3 [arXiv:1603.07142]: deflections of nuclei in the Galactic magnetic field assuming the Jansson–Farrar model [arXiv:1204.06812]. Backtracking on a high-resolution HEALPix grid
- Simulations for $N_{\rm UHECR} = 100, 200, \ldots, 500$: 5×10^5 isotropic and 10^4 mixed samples.

Results

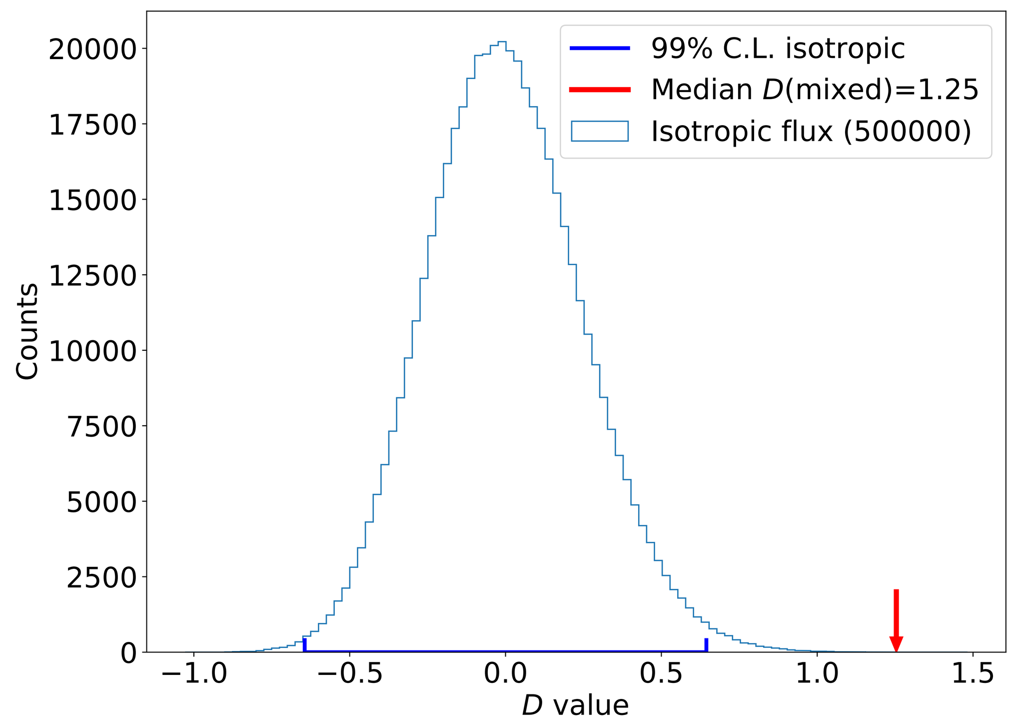
Example: Fornax A ($d \sim 20$ Mpc).
$N_{\rm UHECR} = 500$ with 8% from Fornax A:



An example of possible arrival directions



C_ℓ for isotropic and mixed samples



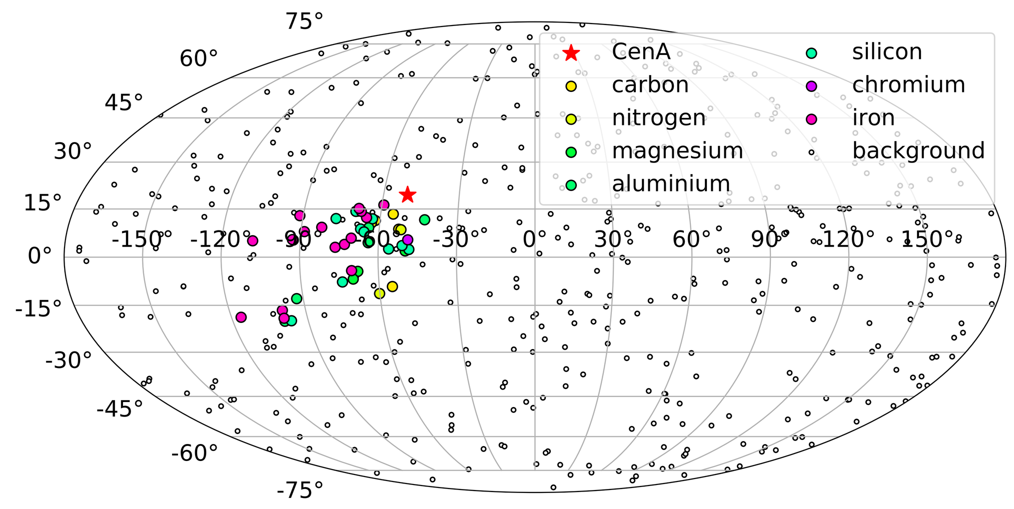
Distribution of $D_{\rm iso}$ and the median of $D_{\rm mix}$.

Estimator inspired by Auger [arXiv:1611.06812]:

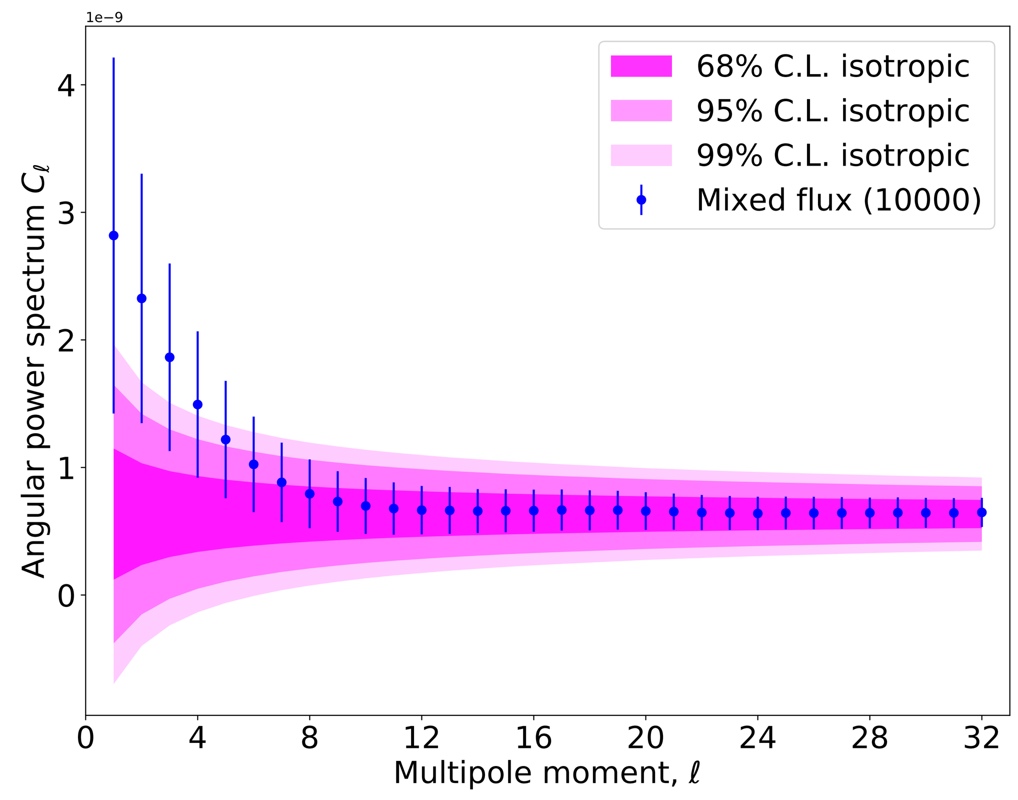
$$D = \frac{1}{\ell_{\max}} \sum_{\ell=1}^{\ell_{\max}} \frac{C_{\ell,\rm mix} - \langle C_{\ell,\rm iso} \rangle}{\sigma_{\ell,\rm iso}},$$

where $C_{\ell,\rm mix}$ and $C_{\ell,\rm iso}$ are angular power spectrum coefficients for mixed and isotropic fluxes respectively

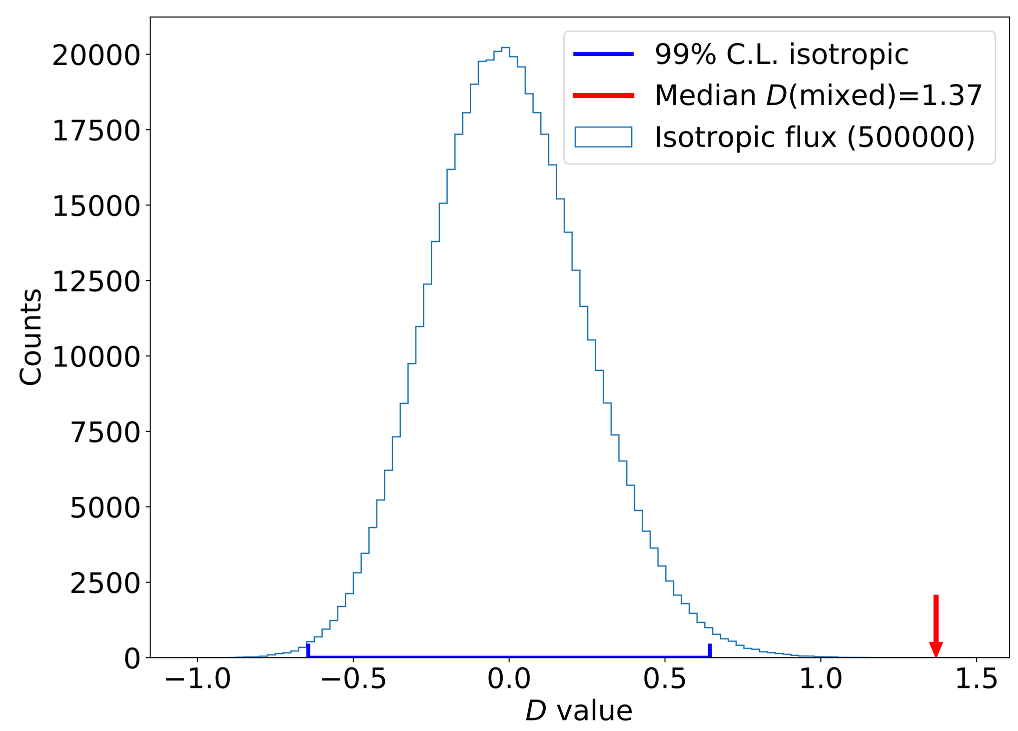
Example: Centaurus A ($d \sim 3.5$ Mpc).
$N_{\rm UHECR} = 500$ with 9% from Cen A:



An example of possible arrival directions



C_ℓ for isotropic and mixed samples



Distribution of $D_{\rm iso}$ and the median of $D_{\rm mix}$

Main result: percentage of UHECRs arriving from five candidate sources in samples of size $N_{\rm UHECR}$ such that the observed large-scale anisotropy estimated with D-values stands out of isotropic expectations with p-values $\lesssim 10^{-5}$:

$N_{\rm UHECR}$	100	200	300	400	500
NGC 253	17	12	9	8	7
Cen A	21	14	11	10	9
M82	24	16	13	11	10
M87	27	19	15	13	12
Fornax A	19	13	10	9	8

The accuracy of the numbers is ± 1.

See arXiv:1810.02284 for details