Searches for cosmic ray anisotropies at ultra-high energies

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Searches for large scale modulations in right-ascension
**Large scale anisotropies at EeV energies?**

The galactic magnetic field «isotropises» EeV CRs

### Dipolar anisotropies due to:

**Propagation effects:**

Dipolar anisotropies at the % level could be left by diffusion/drift of galactic CRs

**Compton-Getting effect:**

If extragalactic, a small anisotropy may exist due to our motion with respect to the frame of extragalactic isotropy

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Searches for small effects

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Sidereal analysis - Amplitudes

Upper limits

Competitive w.r.t. other experiments

Constrains on models

Differential

Below the 2% detection level

Cumulative

No further evidence

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**Not randomly distributed**

**Suggests a smooth transition around 1 EeV**

**Posterior probability: \( \sim 2 \times 10^{-3} \)**
The phase test is ~2.5 more sensitive than the amplitude one to a genuine signal diluted within the background noise.

In case of real signal:

- Phase consistency occurs before the signal amplitude detection.

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Future work will profit from the lower energy threshold thanks to the low energy extension of the observatory.
Searches for point sources at UHE

Reference papers:
The Pierre Auger Coll.,
Science 318 938 (2007),
Astropart. Phys. 29 (2008) 188-204,
Angular distributions at UHE

Using 27 CR above 56 EeV
(01/01/04 - 31/08/07)

Correlation with the positions of nearby extragalactic objects
(12th VCV)

→ Correlation parameters fixed with early data:

- Energy (55 EeV)
- Angular separation (3.1°)
- Distance (75 Mpc)

Test with later data, built to reject isotropy with 1% chance probability:
Test passed with 6 correlated events out of 8

→ Isotropy rejected at 99% C.L.

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Correlation down: from (69±12)% to (38±7)%

(21% of random correlation from isotropic expectations)

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Search for correlations with other (more complete) catalogs of extra-galactic objects

Fitting the 69 events on map densities built from source models based on 2MRS and Swift-BAT catalogs and including the GZK effect

2 free parameters: deflection angle (magnetic field) and «isotropic fraction» (incompleteness, heavier elements, ...)

2MRS : (1.5°, 64%)
Swift : (7.8°, 56%)
More significant excess at 18° (13/69) above $E_z = 55$ EeV

NB : it is an a posteriori results

No C.L. can be given
Anisotropies
and
chemical composition

Reference paper:
The Pierre Auger Coll.,
JCAP06 (2011) 022

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We have detected some excesses above $E_z = 55\ E_{eV}$

We can search for excesses to occur at lower energies ($E : E_Z/Z$)
Anisotropy at lower energy threshold

Cen A: distributions consistent with isotropy

The results are similar for the VCV catalogue

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**Constrains on the composition**

**Main hypothesis:**
- These excesses at high energy are due to heavy nuclei (Z)
- CR acceleration depends only on the rigidity (E/Z) of the particle
- No propagation effects
- Power law for the spectral shape below $E_{\text{th}}$:
  $$\Phi \propto \left(\frac{E}{Z}\right)^{-s}$$

The constrains on the p-fraction are getting weaker as «s» is harder obtained independently of the $X_{\text{MAX}}$ measurements

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Conclusions
**Conclusion**

**Large scale modulation in RA**
- Amplitude: no evidences, still at the level of
  - Only upper limits
- Smooth transition in the phase of the dipole (evidence for anisotropy?)

**Point source searches**
- Compare the arrival directions with catalogues (VCV/2MRS/SWIFT)
- Cen A: the excess is still present (a posteriori: no c.l.)

**Constrain on the composition**
- No indication of overdensities in the lower energy bins
  - Limit on the relative proton fraction
- independent of $X_{\text{max}}$ measurements
Back Up
**Accounting for Experimental Effects**

**Challenge:** Estimation of the exposure with high accuracy

1. Monitoring of the number of elementar cells => geometrical exposure calculation in each direction
2. Energy corrections as a function of atmospheric pressure and density

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**2 Possible Sources of Spurious Modulations at the Sidereal Freq.:**

1. Pollution by the solar frequency
   (= canceled by the 6-yr exposure time)
2. Sideband mechanism due to any annual variation of the daily

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**N.B.:** Well below the energy saturation threshold, use of the «East/West» method to remove spurious effects [Bonino et al., ApJ, 2011]
Composition study with at the Auger Observatory

measured $X_{\text{max}}$ and $\text{RMS}(X_{\text{max}})$ vs 
MC simulations of EAS

as far as models are correct:

gradual increase in the average mass with the energy

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