UCL
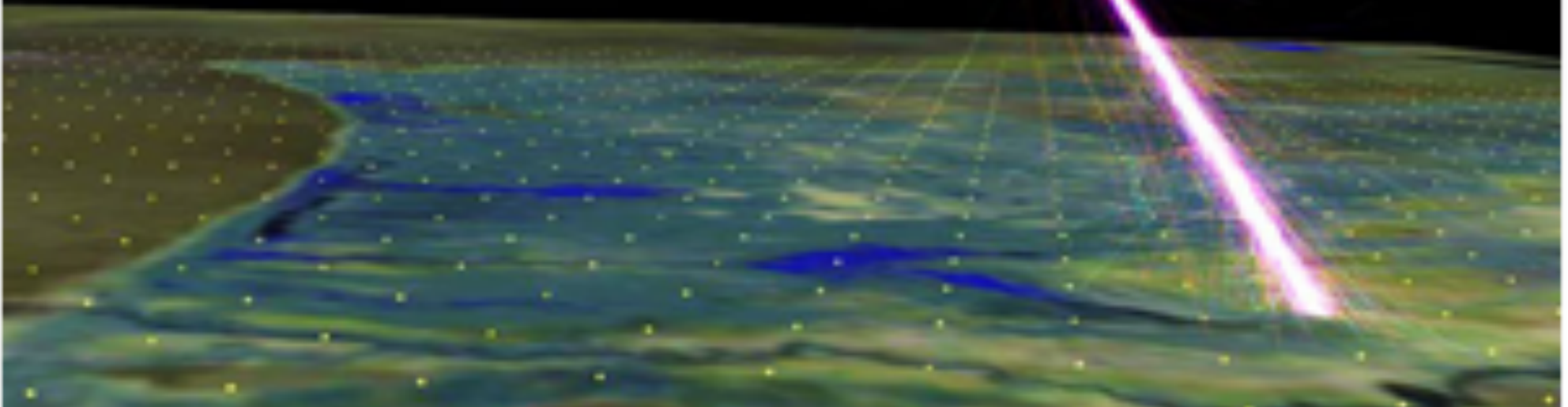
A Search for Correlation of the Highest Energy Cosmic Rays with nearby Luminous Matter
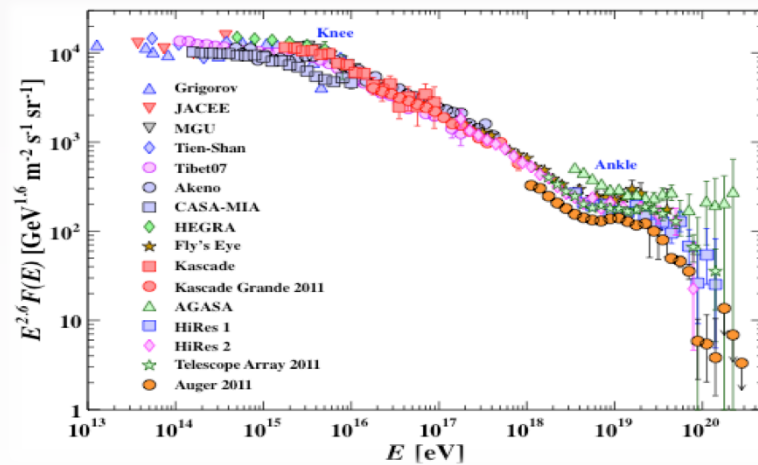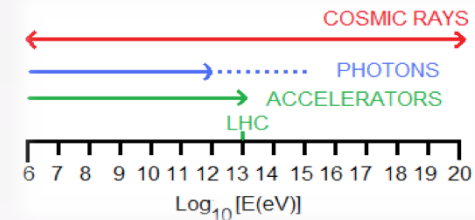
Foteini Oikonomou

Amy Connolly, Ofer Lahav, Filipe Abdalla, Eli Waxman
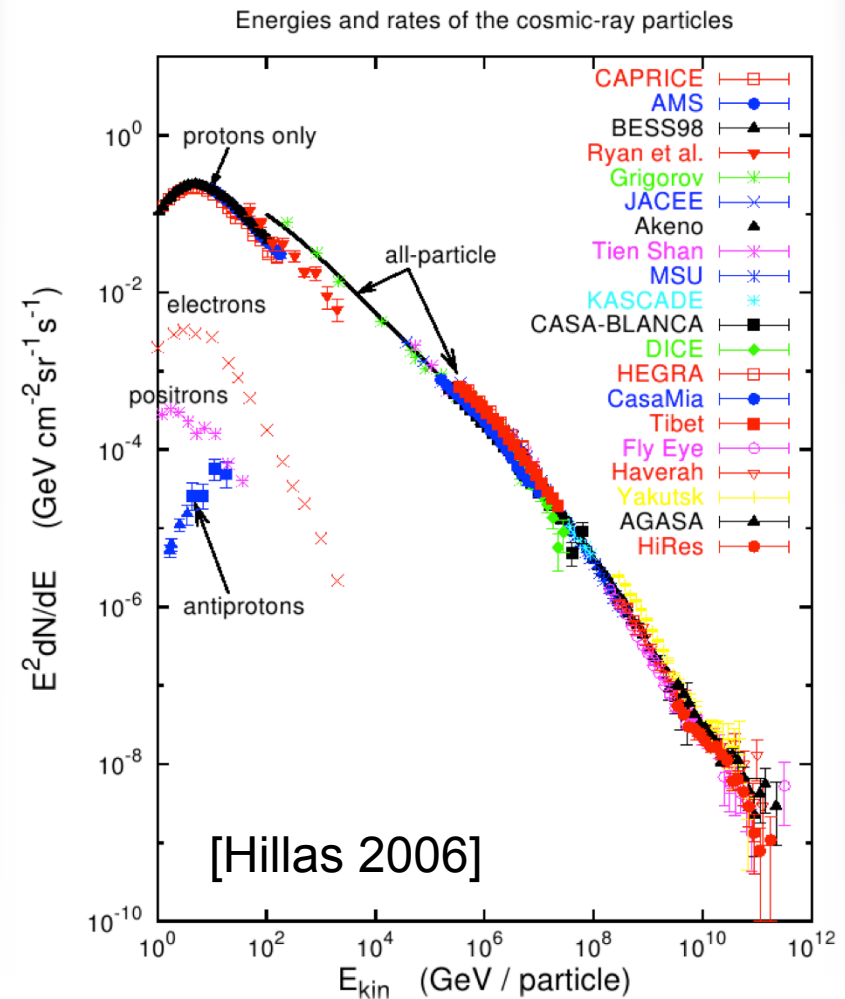
Cosmic Ray Spectrum

- Origin?
- Acceleration?
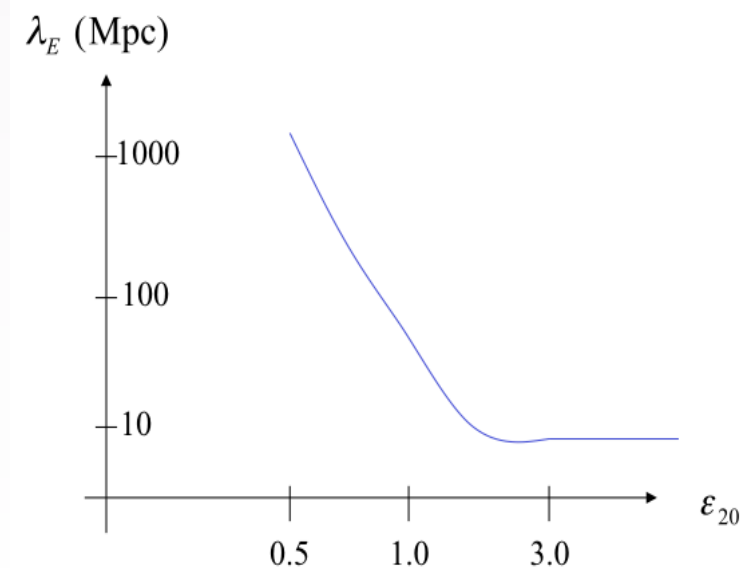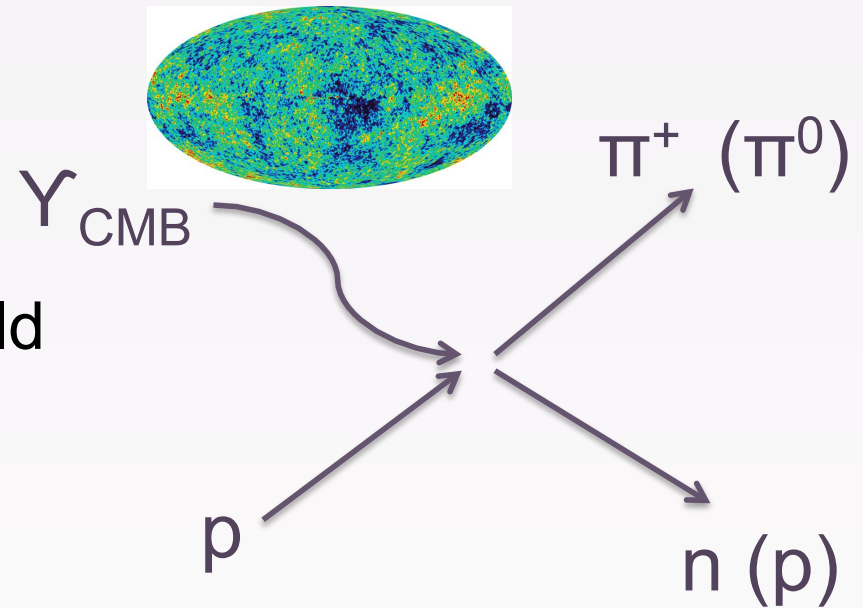- Composition?
- Flux ~ 1 km^{-2}centrury^{-2}.

[Particle Data Group 2011]

[Hillas 2006]

Propagation (GZK)

- Flux suppression above threshold for pion-photoproduction,

  Ep > 6 × 10¹⁹ eV

- PAO /HiRes/TA confirm GZK

  (> 7σ).

- Protons above GZK must come from within ~200 Mpc.

[Greisen 66; Zatsepin & Kuzmin 66]

γ_{CMB}

π^+ (π^0)

p

n (p)

λ_E (Mpc)

1000

100

10

0.5   1.0   3.0

ε_{20}

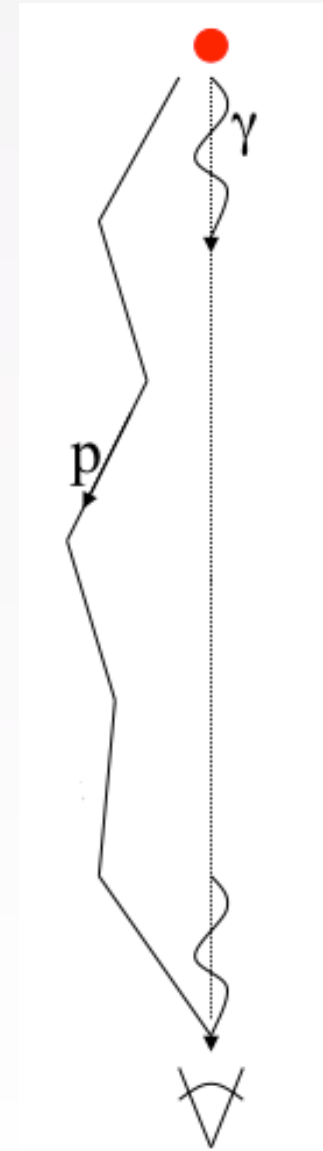## Magnetic Deflection

- Deflection proportional to Z/E.

- Extra-galactic magnetic fields not well known.

- δ_{prot} ~ 3° from simulations for proton UHECRs.
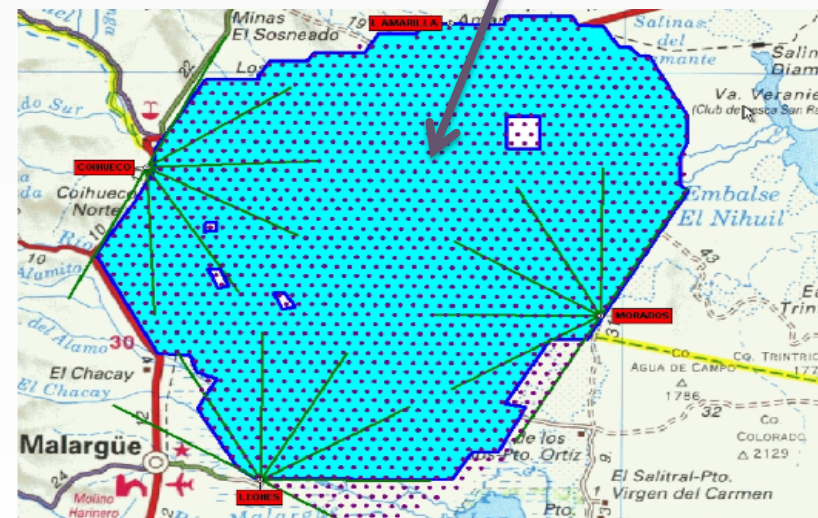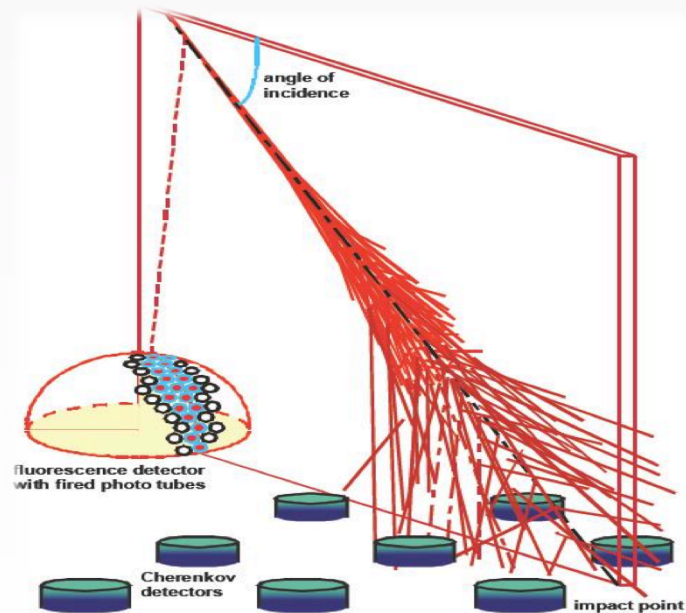
[e.g. Dolag 2004, arXiv:astro-ph/0410419]

- Plane of the Milky Way excluded from most analyses.
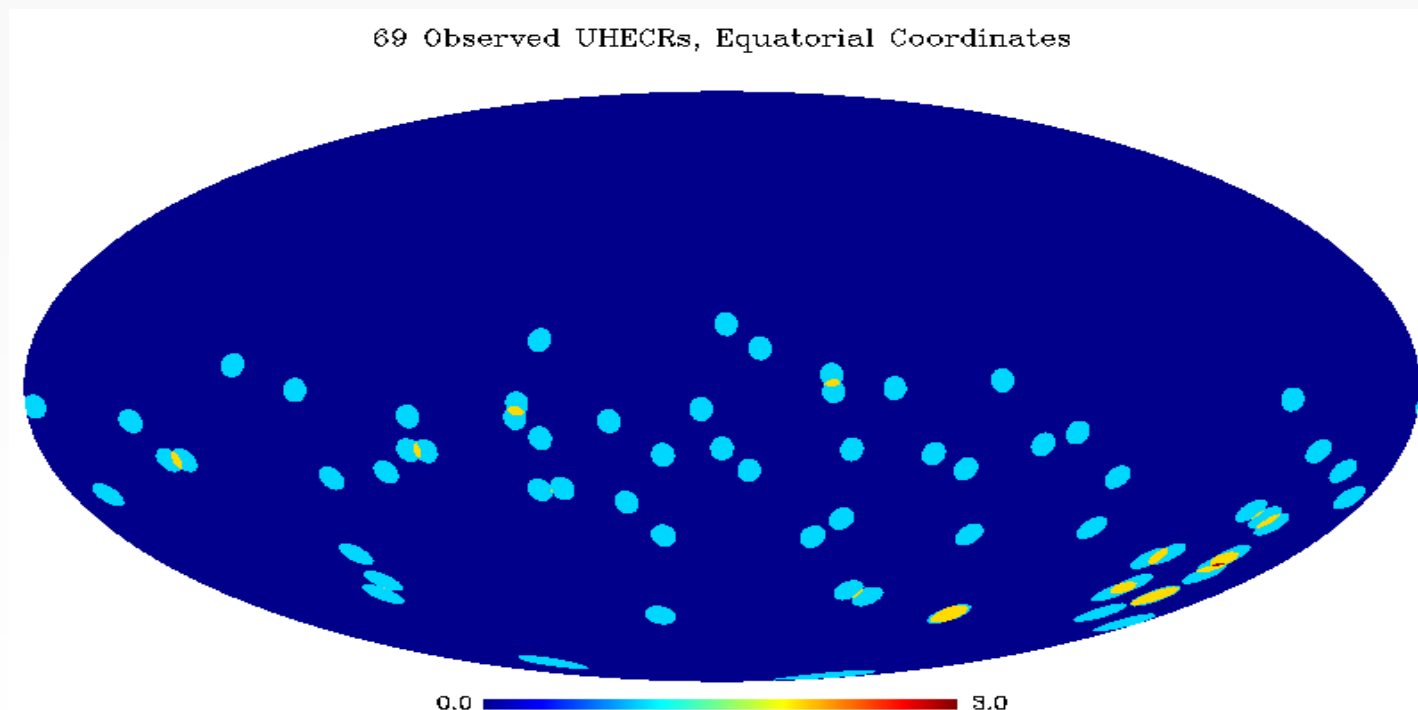
Pierre Auger Observatory

[Cronin 2002, Watson 2003]

- Completed 2008 (data since 2004)
- 3000 km^2
- Hybrid detection:
  - 1600 water Cherenkov detectors.
  - 24 Fluorescence telescopes.

Model of UHECR source distribution (1/3)

- We consider a source distribution which traces the distribution of luminous matter in the nearby universe.
- Density ~ galaxies (10^{-2} Mpc^{-3}).
- We consider **faint**, **identical** sources.

69 Observed UHECRs, Equatorial Coordinates

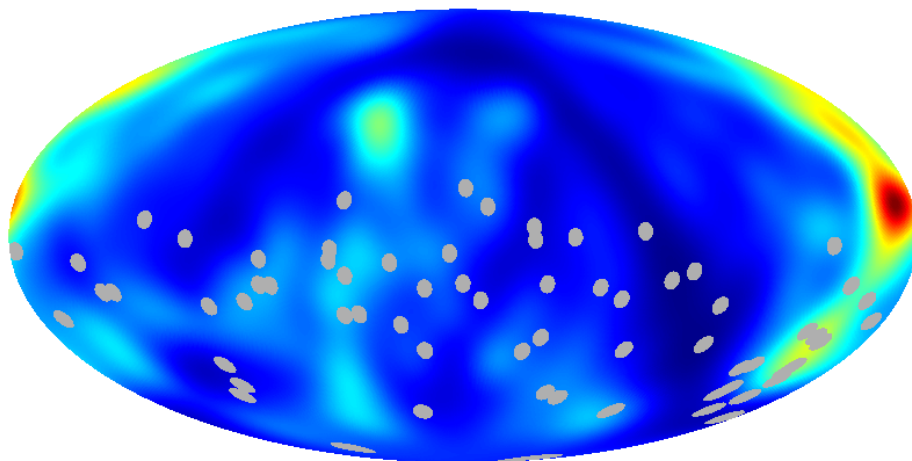0.0   3.0

Model of UHECR source distribution (2/3)

PSCz

- Median redshift , $z_{1/2}$ =0.028 (118 Mpc)
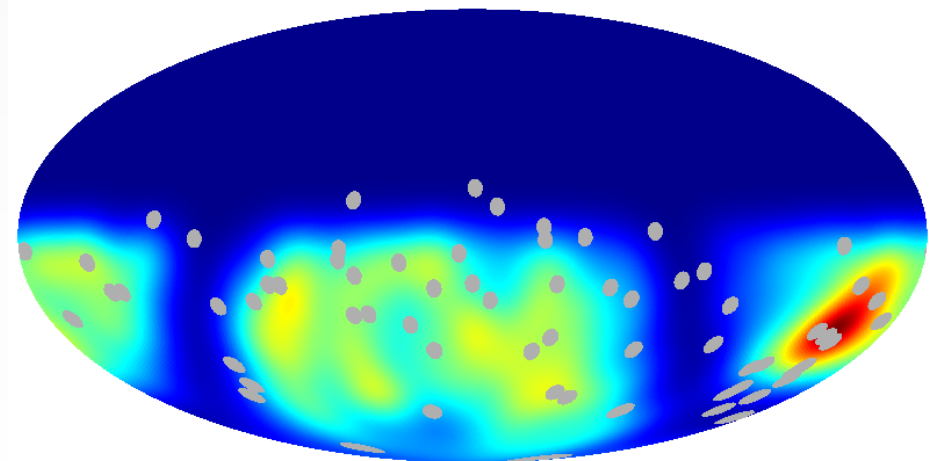
- 14,677 galaxy redshifts, 84% sky coverage

6dF

- Median redshift , $z_{1/2}$ =0.053 (~200 Mpc)

- 110,256 new extragalactic redshifts

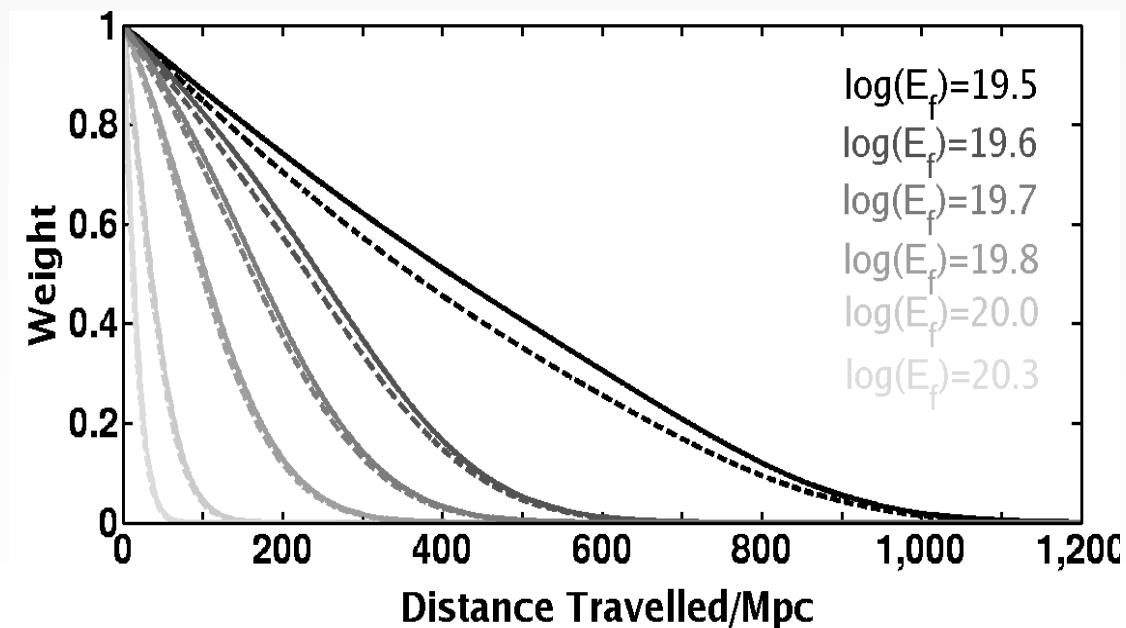PSCz, GZK weighted and 69 PAO events

6dF, GZK weighted and 69 PAO events

Model of UHECR source distribution (3/3)

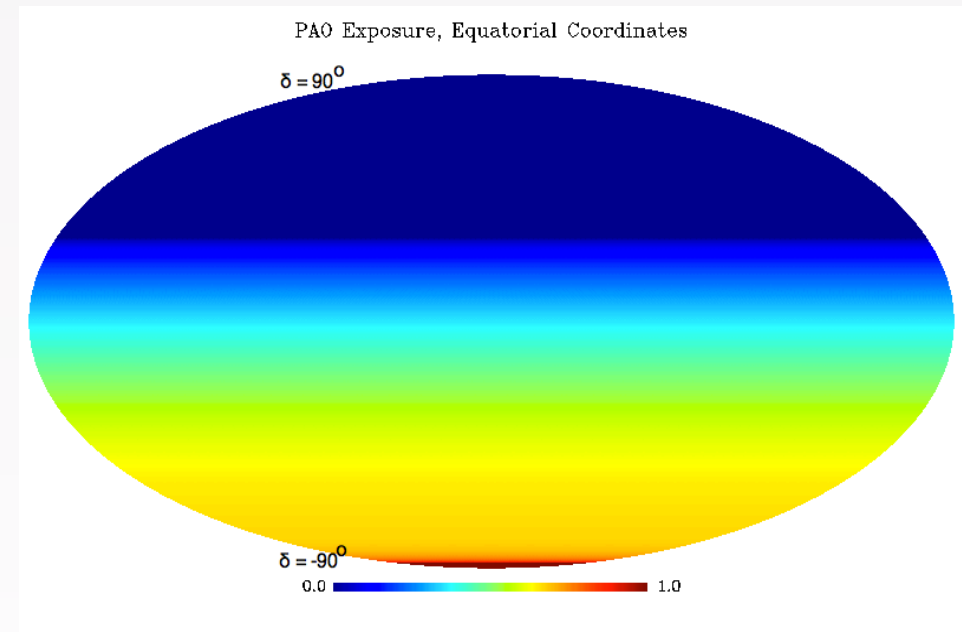- Weigh galaxies according to the flux expected on Earth:

$$W_i\big|_{r=r_0} = \frac{1}{r^2} \int_{E_f}^{E_{max}} dE \int_{E_{i,cut}}^{E_{i,max}} dE_i \left| \frac{\partial P_p(E; E_i; r_0)}{\partial E} \right| I(E_i, t)$$

[Z. Fodor, S.D. Katz, Phys. Rev. D63 023002 (2001)]

Cross-correlation

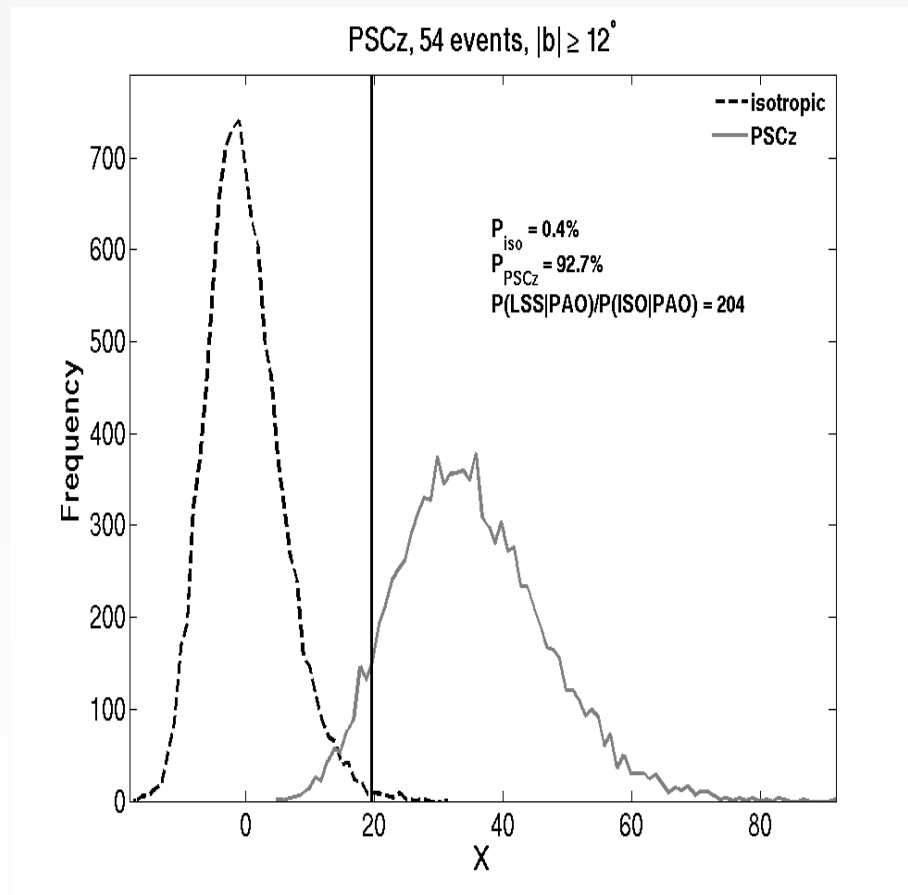- Account for non-uniform PAO exposure:

- We consider a statistic of the form:

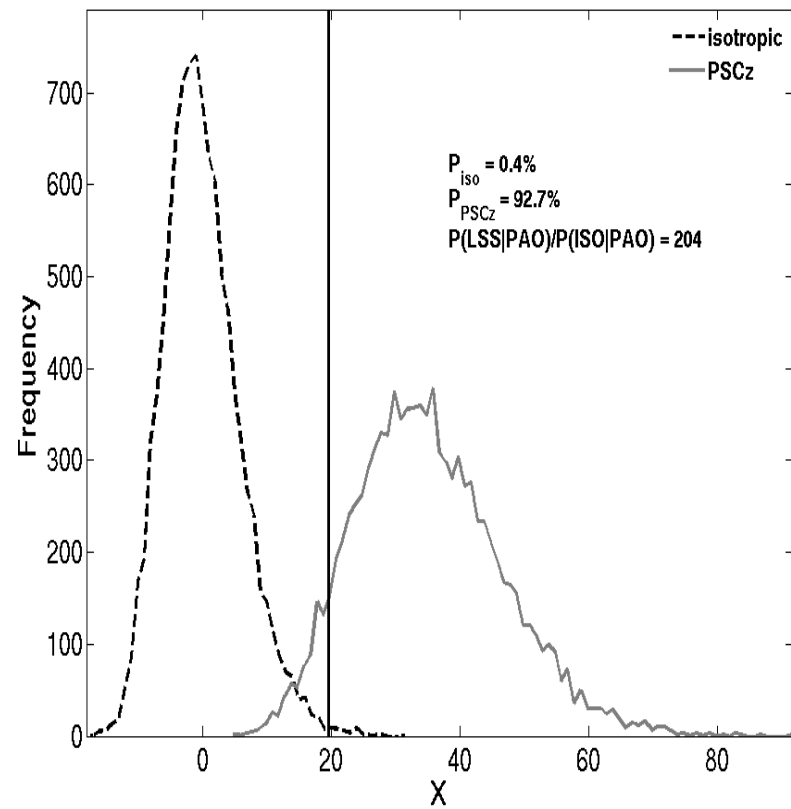$$X_{c,M} = \sum_i \frac{(N_i - N_{i,iso})(N_{i,M} - N_{i,iso})}{N_{i,iso}}$$

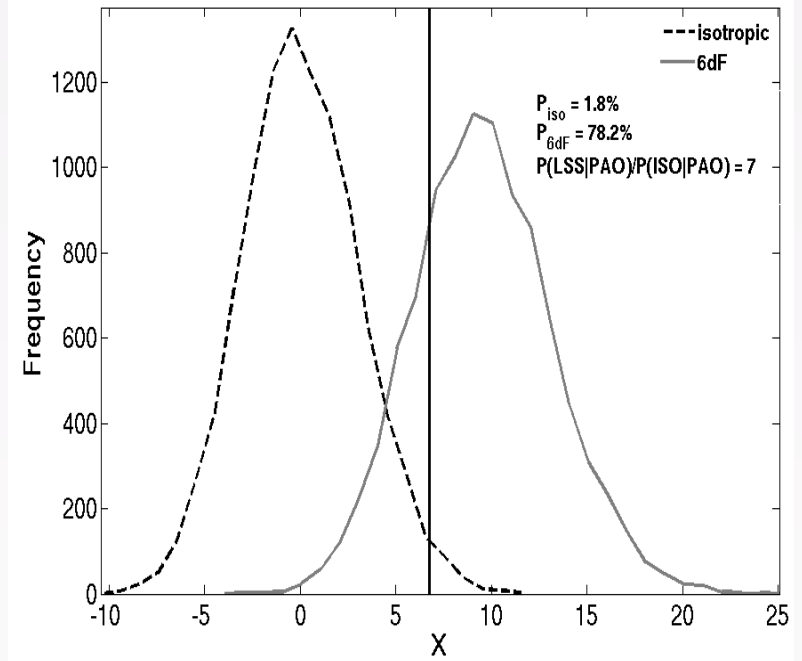[Kashti Waxman 2008, arXiv:0801.4516]

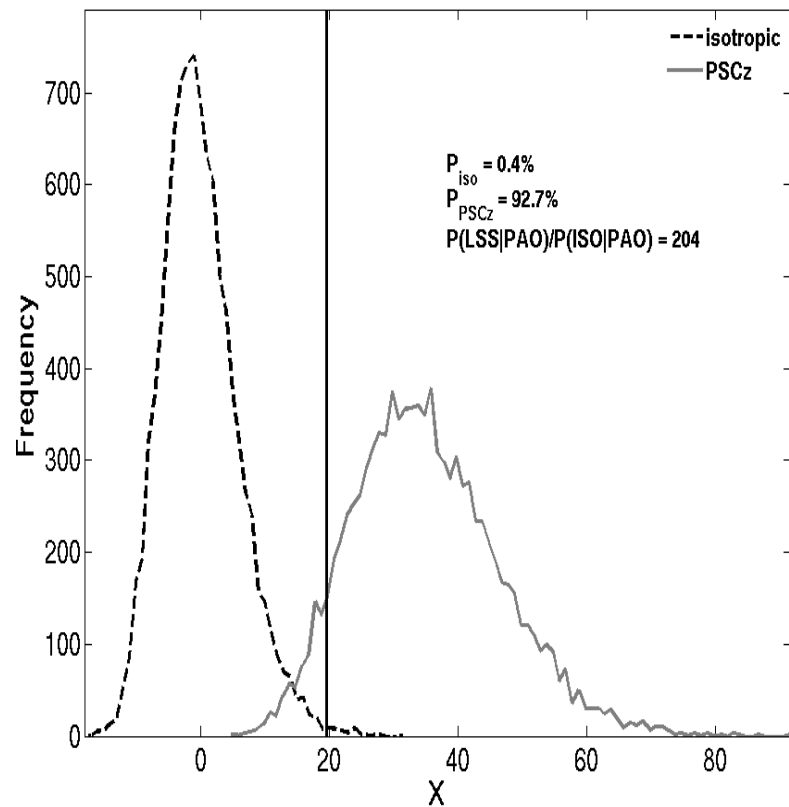# Results

Results

PSCz, 54 events, $|b| \geq 12°$

$P_{iso} = 0.4\%$
$P_{PSCz} = 92.7\%$
$P(LSS|PAO)/P(ISO|PAO) = 204$

6dF, 50 events, $|b| \geq 12°$, $\delta = 0°$

$P_{iso} = 1.8\%$
$P_{6dF} = 78.2\%$
$P(LSS|PAO)/P(ISO|PAO) = 7$

Results

Sensitivity to deflection angle

- Currently no constraints.
- With a larger dataset one can exclude large deflections / determine preferred distribution.

Conclusions

- 69 super-GZK UHECRs **not consistent with an isotropic source distribution** (CL > 98%).
- Exhibit a weak correlation with nearby extragalactic matter.

Outlook

- More data will allow us to exclude isotropy with higher significance and distinguish between candidate source populations.
- **Composition** and **magnetic field measurements** will allow us to further constrain models of the origin of UHECRs.

Extra

Comparison to earlier 27 events
[Pierre Auger Collaboration arXiv:0712.2843v2]

PSCz, 22 out of 56 events

Legend: 22 out of 56, isotropic, PSCz, original 22 events

Cell Size = $7.3° \times 7.3°$

$P_{iso} = 0.2\%$
$P_{PSCz} = 35\%$

6dF, 19 out of 50 events

Legend: 19 out of 50, isotropic, 6dF, original 19 events

Cell Size = $7.3° \times 7.3°$