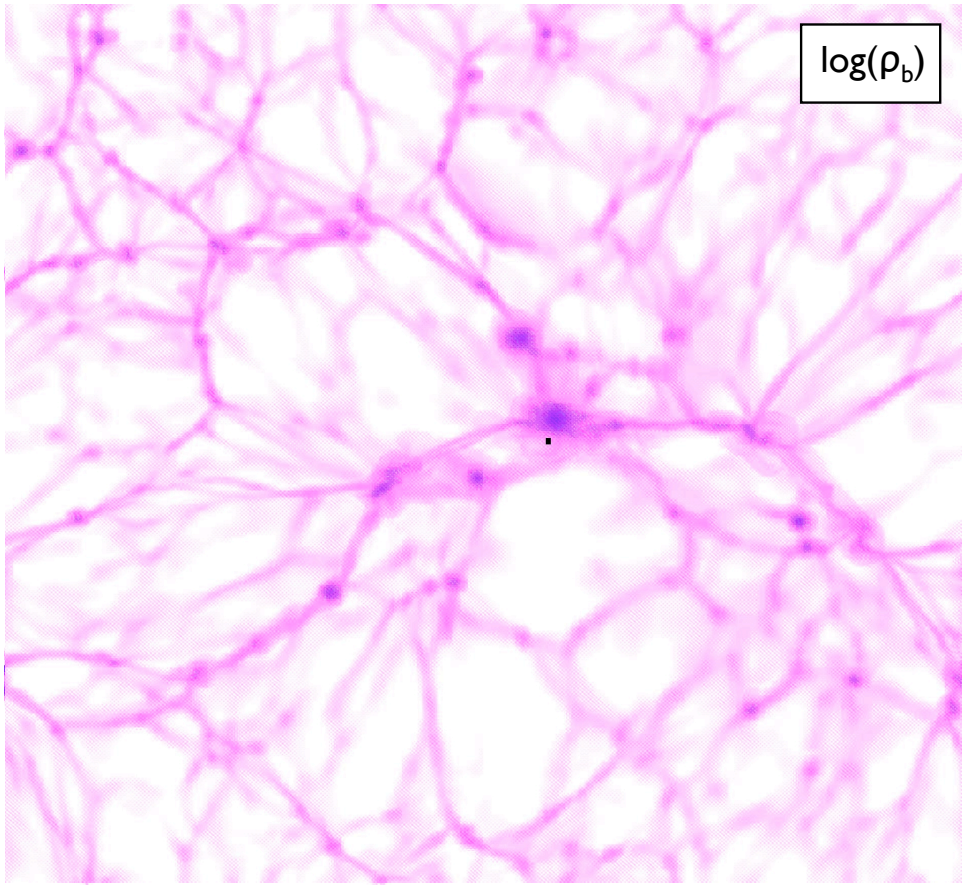
The optical depth of the Universe
seen through
ultrahigh energy cosmic ray spectacles

Kumiko Kotera, *Institut d'Astrophysique de Paris*

Propagation in a magnetized universe

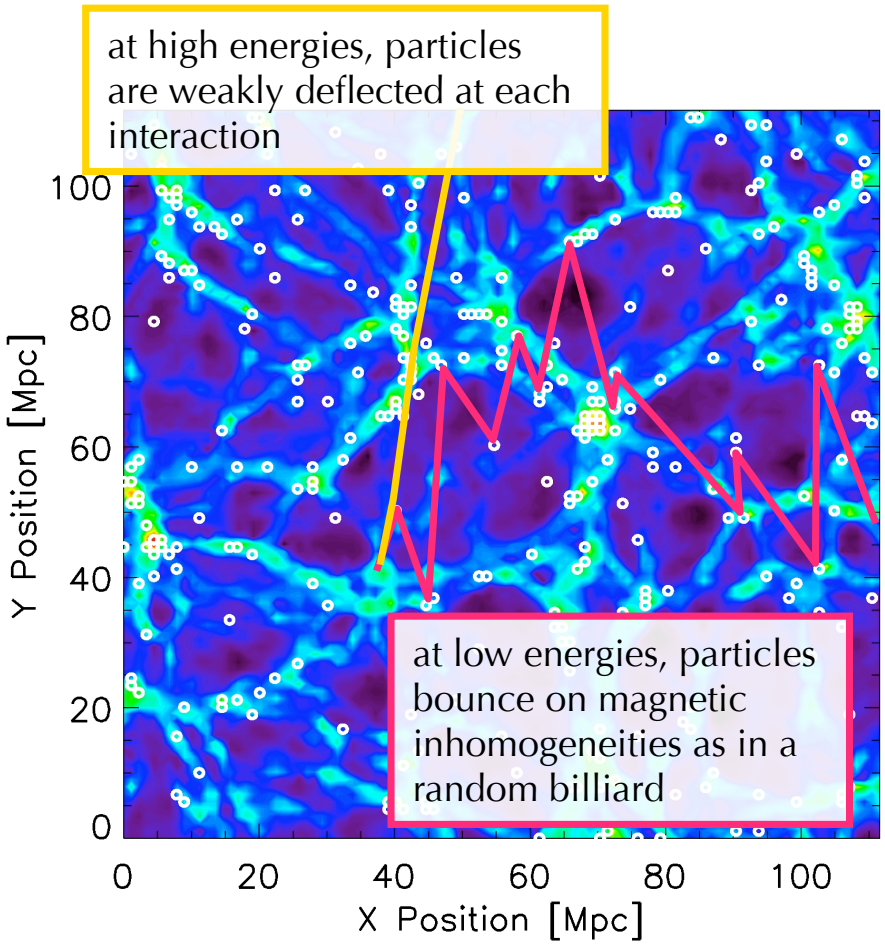


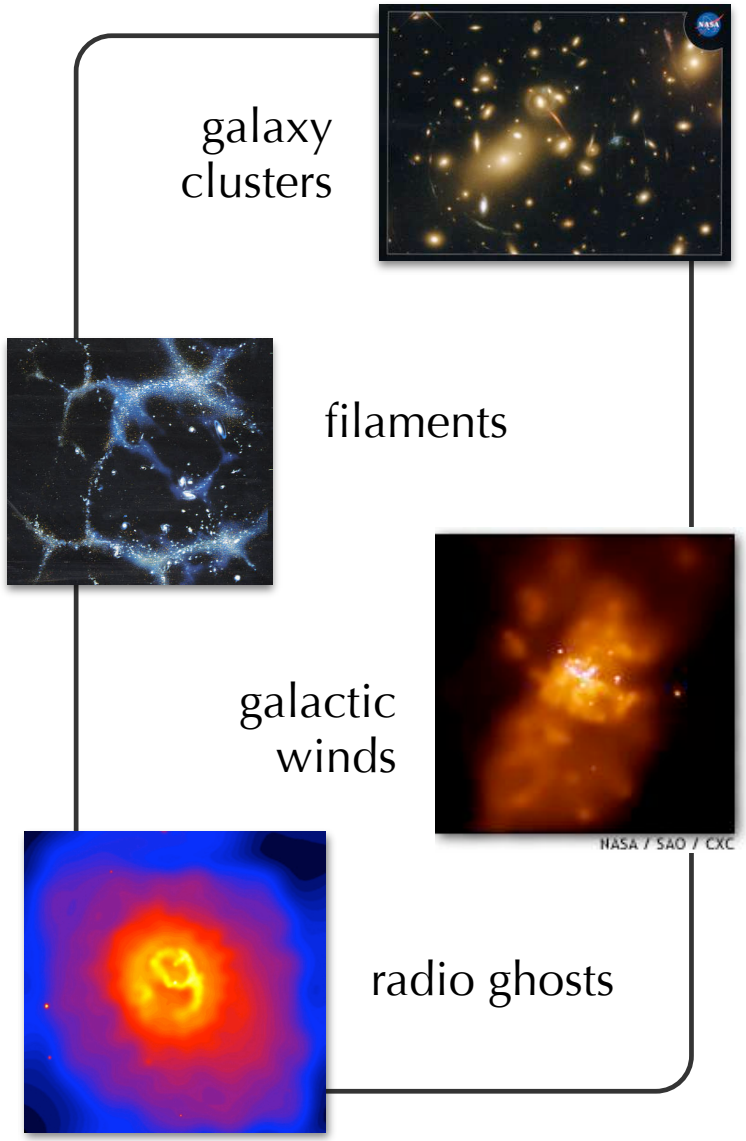
Sigl, Miniati, Ensslin 03

Extragalactic magnetic fields are likely distributed as the baryonic gas

Depending on energy and magnetic field strength, propagation can be **nearly rectilinear**, **diffusive**, or **'semi-diffusive'**…

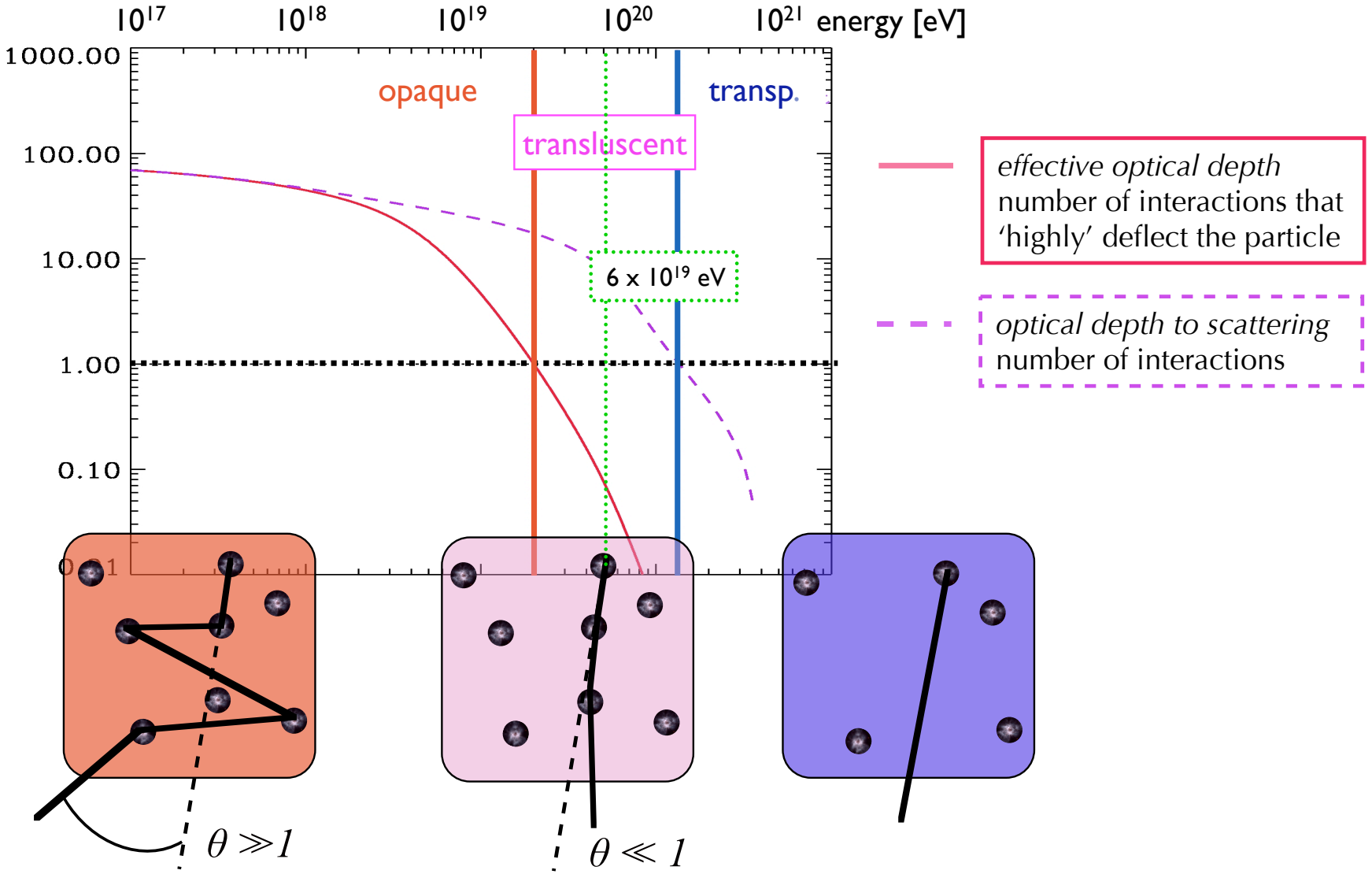
A simplified view of extragalactic magnetic fields for UHECR





Kotera & Lemoine 08

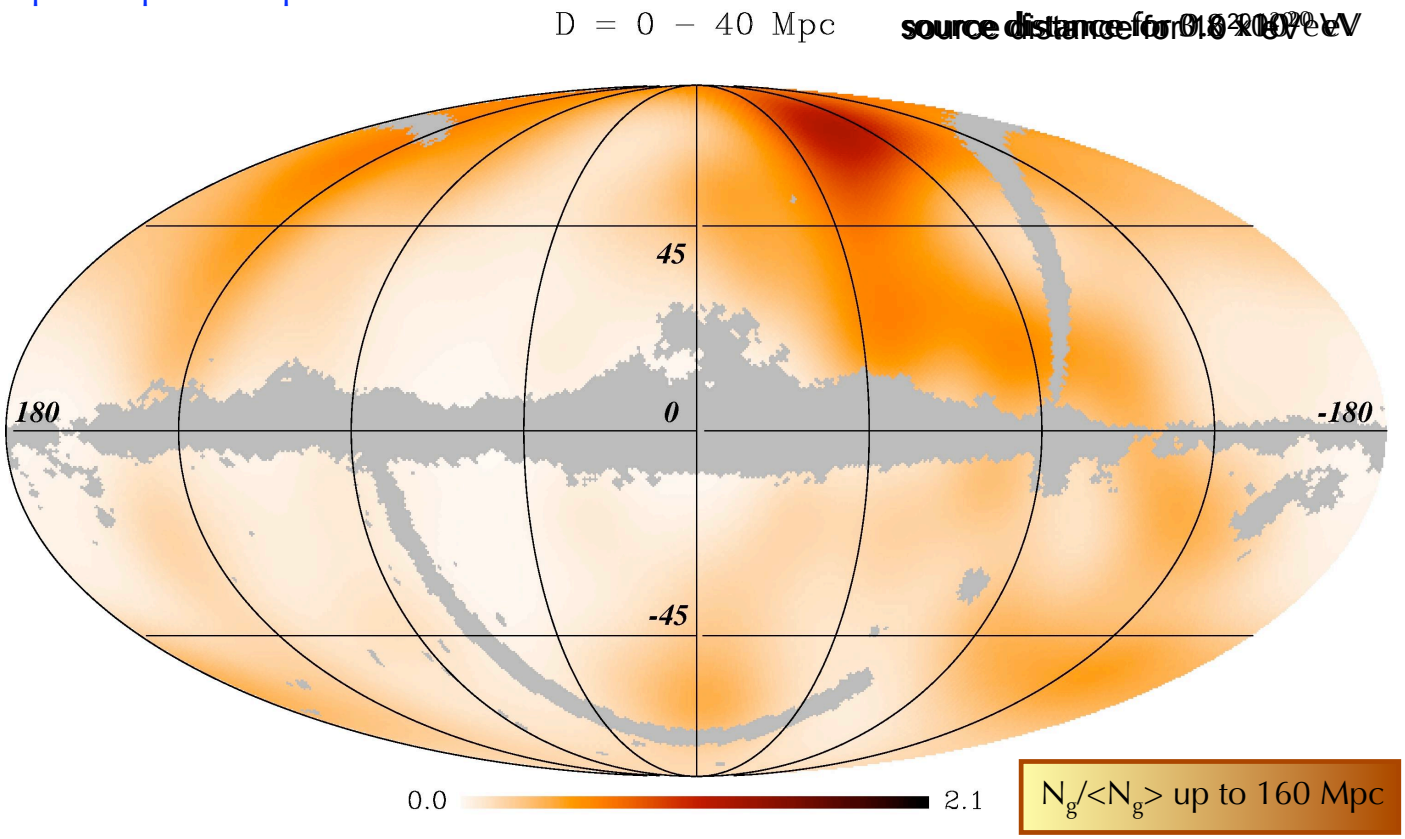
Optical depth to scattering



Maps of optical depth

Total deflection angle: $\delta\alpha^2 = \frac{\tau}{3}\delta\theta_i^2$

Maps of optical depth:

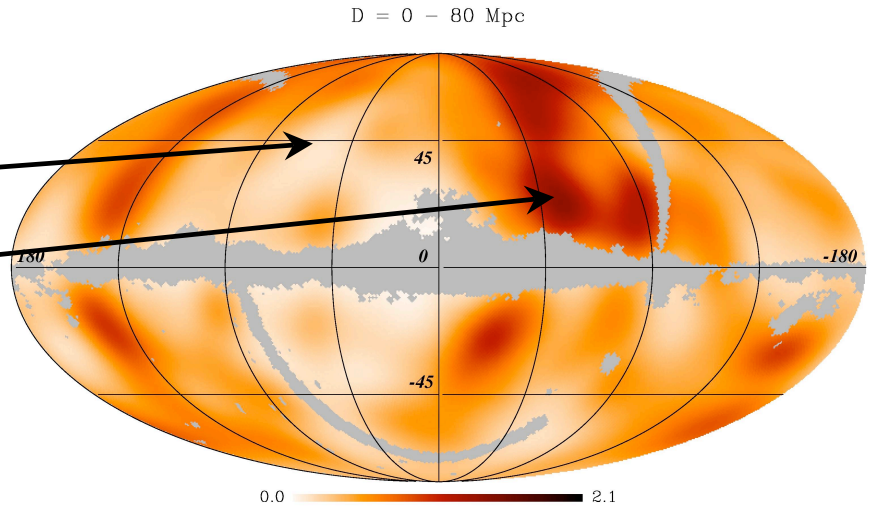


$\tau(l_{\rm gal}, b_{\rm gal}) = \langle\tau\rangle_{160\,\rm Mpc}\frac{N_{\rm g}}{\langle N_{\rm g}\rangle}$

τ varies from <1 to ~ 1 for typical parameters

Two effects of the optical depth

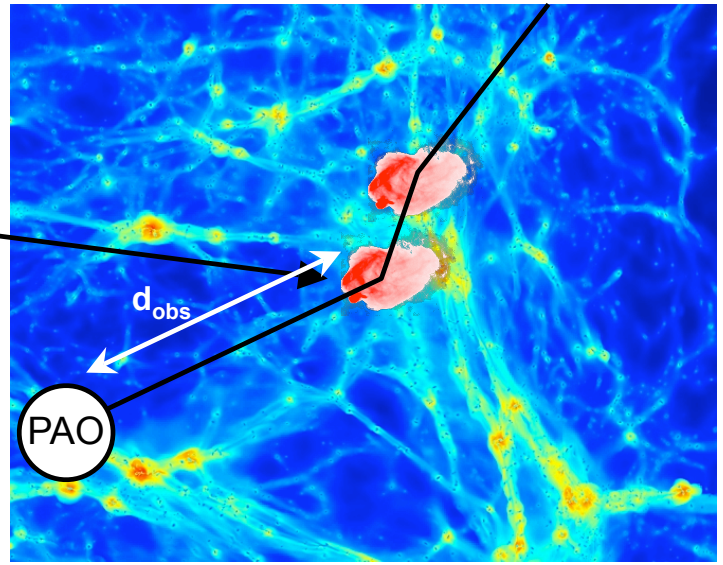
- if sources are gamma-ray bursts,
  flux from regions of $\tau < 1$
  smaller by τ than
  flux in regions with $\tau > 1$

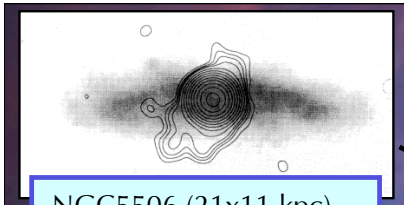


- sources of UHECRs and scattering centers
  share a similar property:
  large regions of intense magnetic field

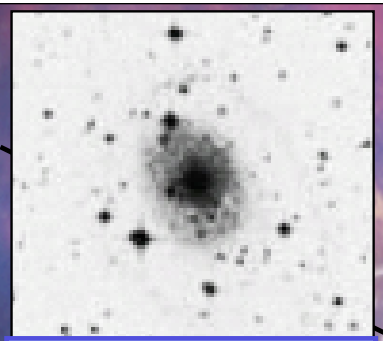
do not mistake the last scattering
center on the line of sight with the source!

signature:
inferred source distance scale d_{obs}
smaller than expected distance scale ~ $l_{max}(E)$

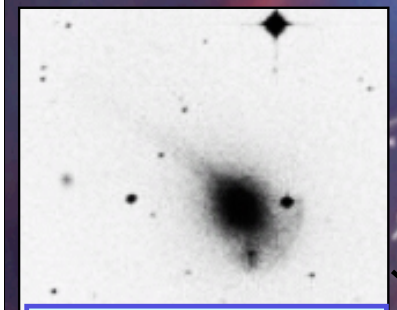




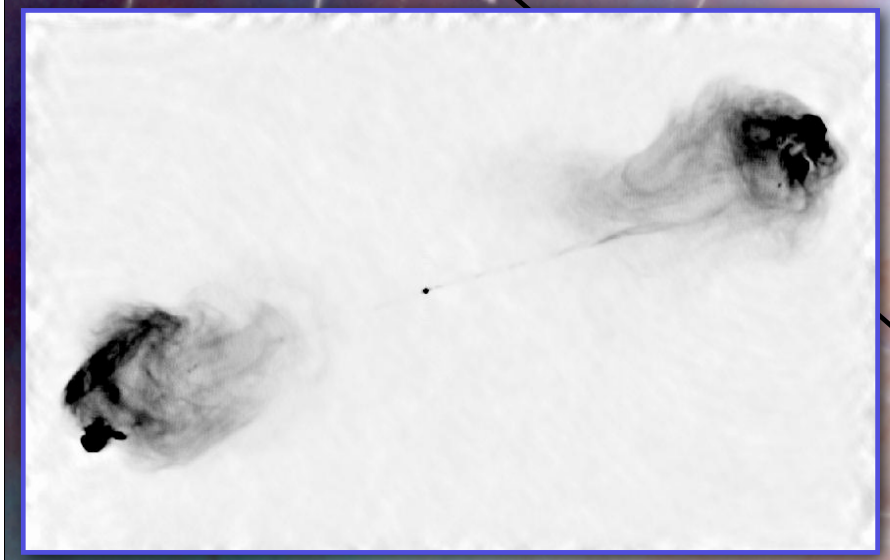
NGC5506 (21x11 kpc)



ESO 139-G12 (40x40 kpc)



NGC 7315 (40x40 kpc)

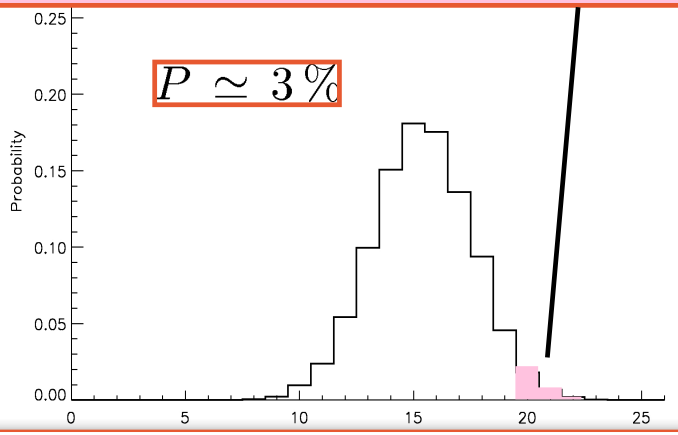


$$F(<l) = n_{\mathrm{source}} \dot{N}_{\mathrm{UHECR}} l$$

→ source distance scale ~ $l_{max}(E)$

~ 200 Mpc at 6×10^{19} eV

Probability of seeing 20+ events out of 27 above 6×10^{19} eV from within 75Mpc:



→ **PAO: inferred source distance scale appears smaller than expected source distance scale**

Two possibilities:

1. PAO energy scale is underestimated by ~ 30%
2. **PAO is imaging the last scattering surface…**

The PAO has detected a highly significant correlation of the arrival directions of cosmic rays with energy E > 5.7 10^{19} eV with the known AGN within 75Mpc…

If PAO is imaging the last scattering surface...

fraction of contaminated events:

fraction of background galaxies
(= source within 200 Mpc)
situated at less than 3° from an AGN
used by Auger:

$\delta\alpha = 0$ f ~ 31%

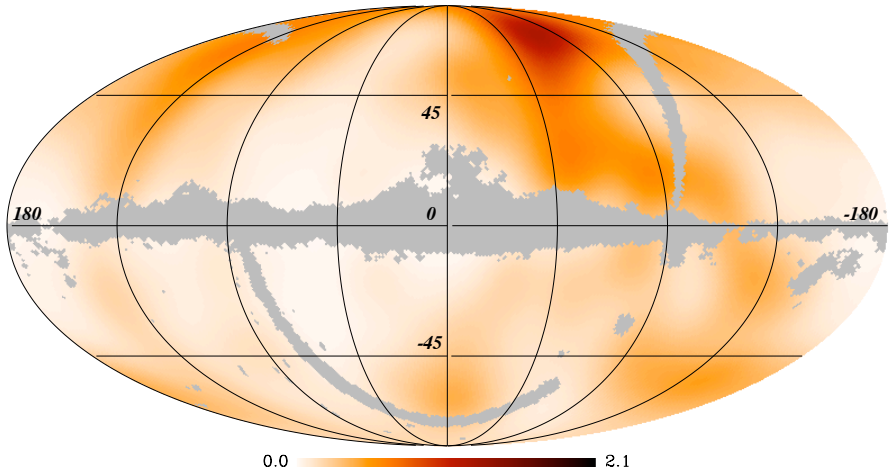
$\delta\alpha = 3^\circ$ f ~ 48%

$\delta\alpha = 6^\circ$ f ~ 44%

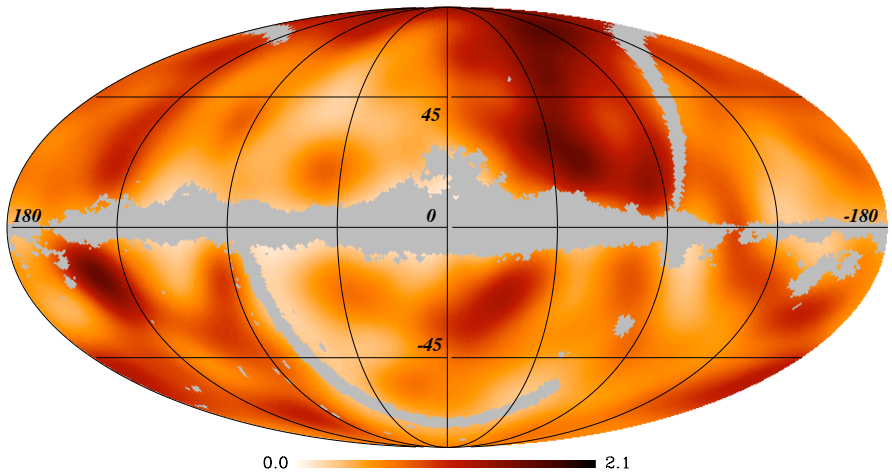
correlation should not exceed 50%

(unless GRB are sources of UHECR, in which case the correlation with the foreground density is artificially enhanced due to non-detection of GRB if $\tau < 1$)

D = 0 - 40 Mpc



D = 0 - 120 Mpc



Conclusion

the counterparts seen by the PAO are unlikely to be the source of UHECR

the PAO may be mistaking the counterparts with the last scattering centers

or, if the energy scale is underestimated (30%), the PAO may have located the invisible source within a few Mpc

no counterpart will ever be found: photons have passed by Argentina 10^4 years ago
no high energy gamma-ray, no neutrino, no gravitational wave will be seen from these sources

in any case, the PAO opens up a new era of data acquisition…