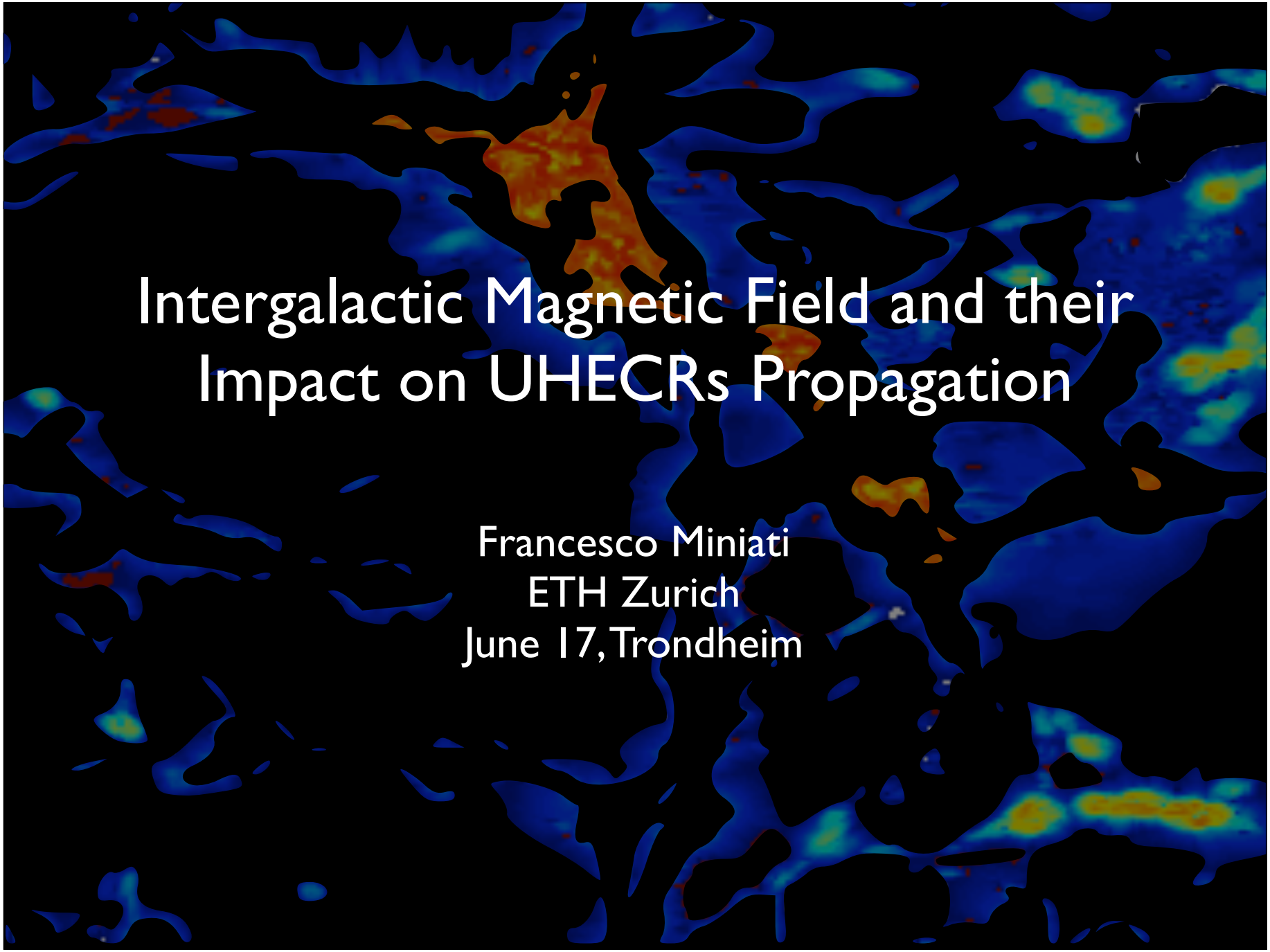

Intergalactic Magnetic Field and their Impact on UHECRs Propagation

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ETH Zurich
June 17, Trondheim

Outline

- Extragalactic Magnetic Fields Observations
- Extragalactic Magnetic Fields Models
- Deflections Statistics and UHERCs Correlations

Modeling Extragalactic Magnetic Fields

- Theory is incomplete: gal. outflows, AGNs, shock instabilities ?
  - mechanism unknown (assumed)
  - modeling limited (no *full* treatment)
- Numerical issues
  - Grid vs SPH
- Observations
  - very challenging, constraints still poor

Magnetic Fields in Galaxy Clusters

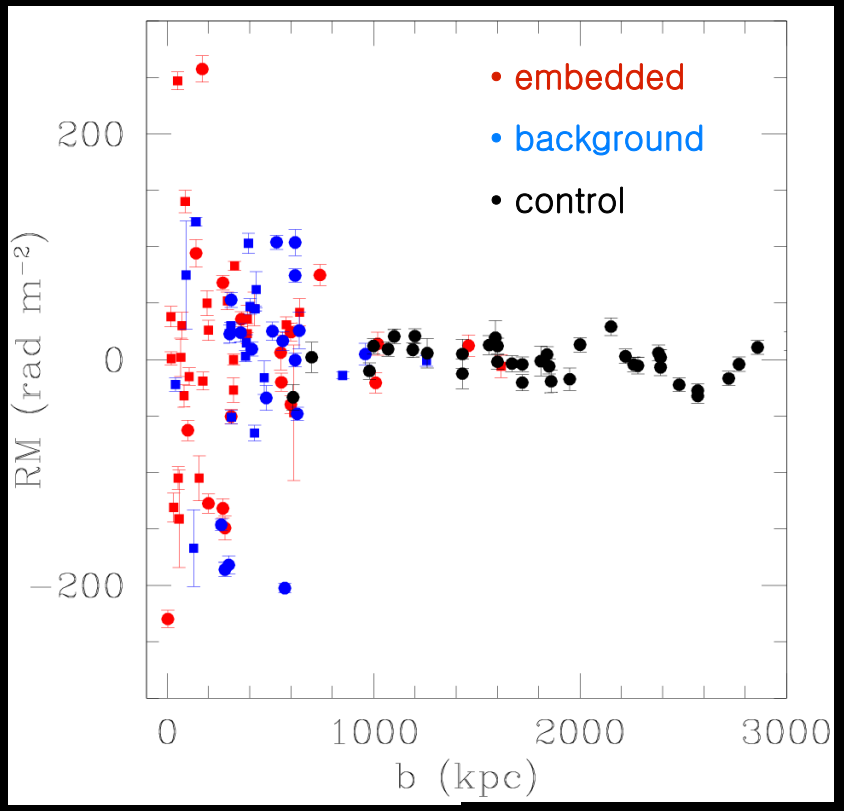
$$B \simeq 1-10\left(\frac{\ell}{10\,kpc}\right)^{-\frac{1}{2}}\ \mu G$$

$$\langle RM \rangle = 0$$

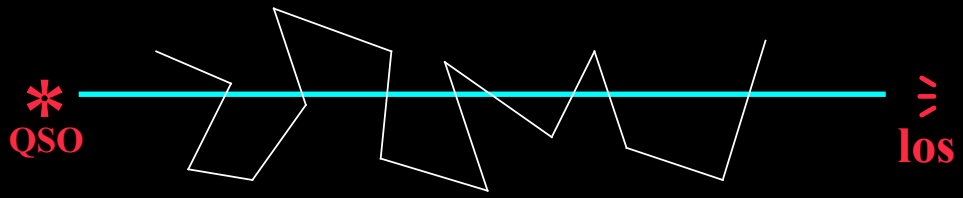
$$\sigma \propto B\ell_c^{1/2}$$

$$\chi = \chi_0 + RM\,\lambda^2$$

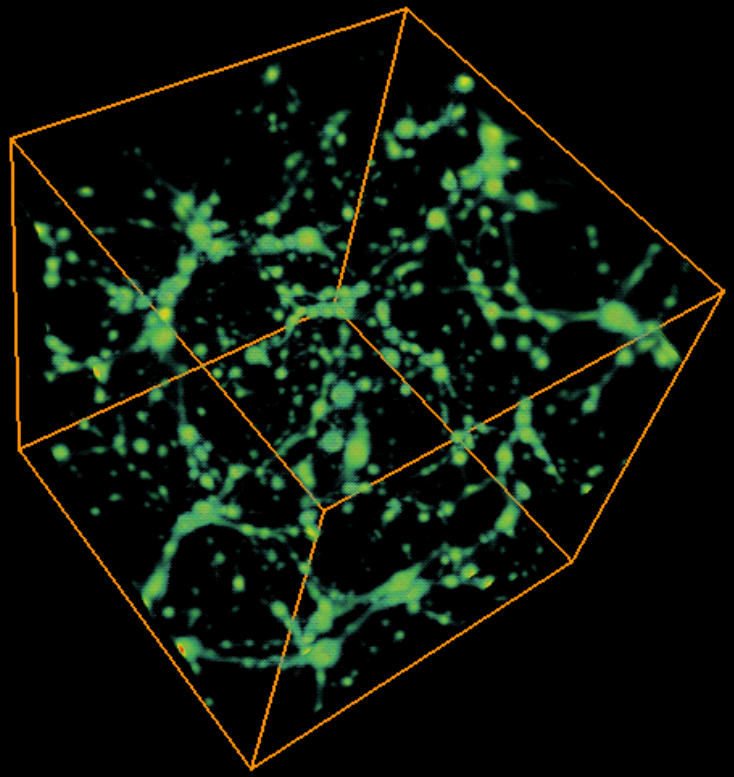
$$RM = 812\int n_e \vec{B}\cdot\vec{dl}\ \ \mathrm{rad/m^2}$$

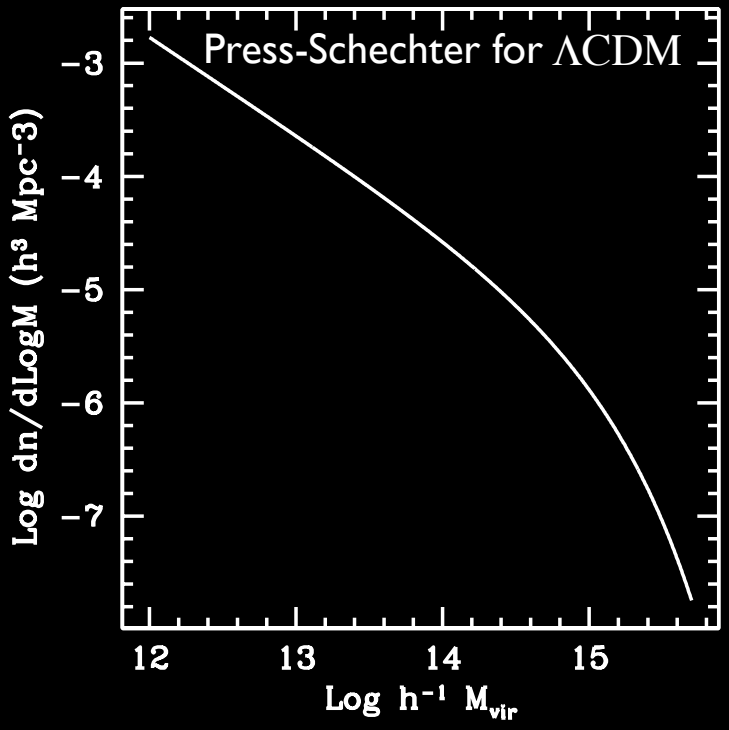


Clarke et al. 2004



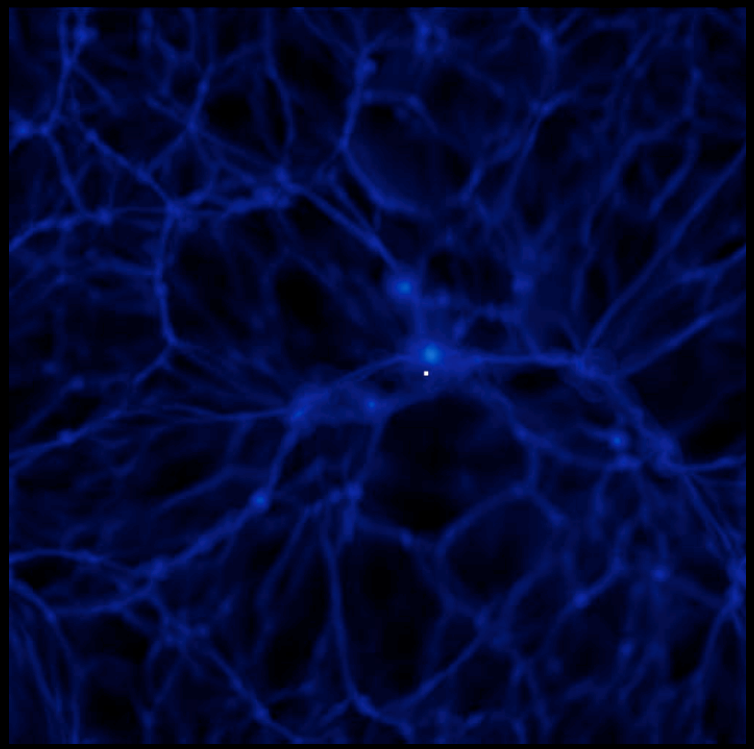
Deflections from Cluster Fields

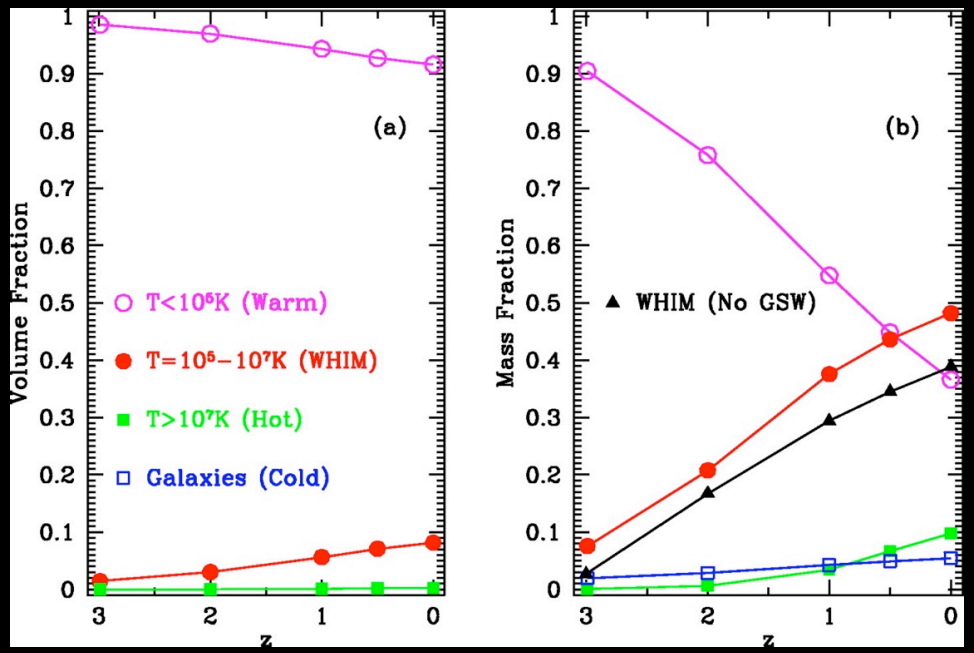




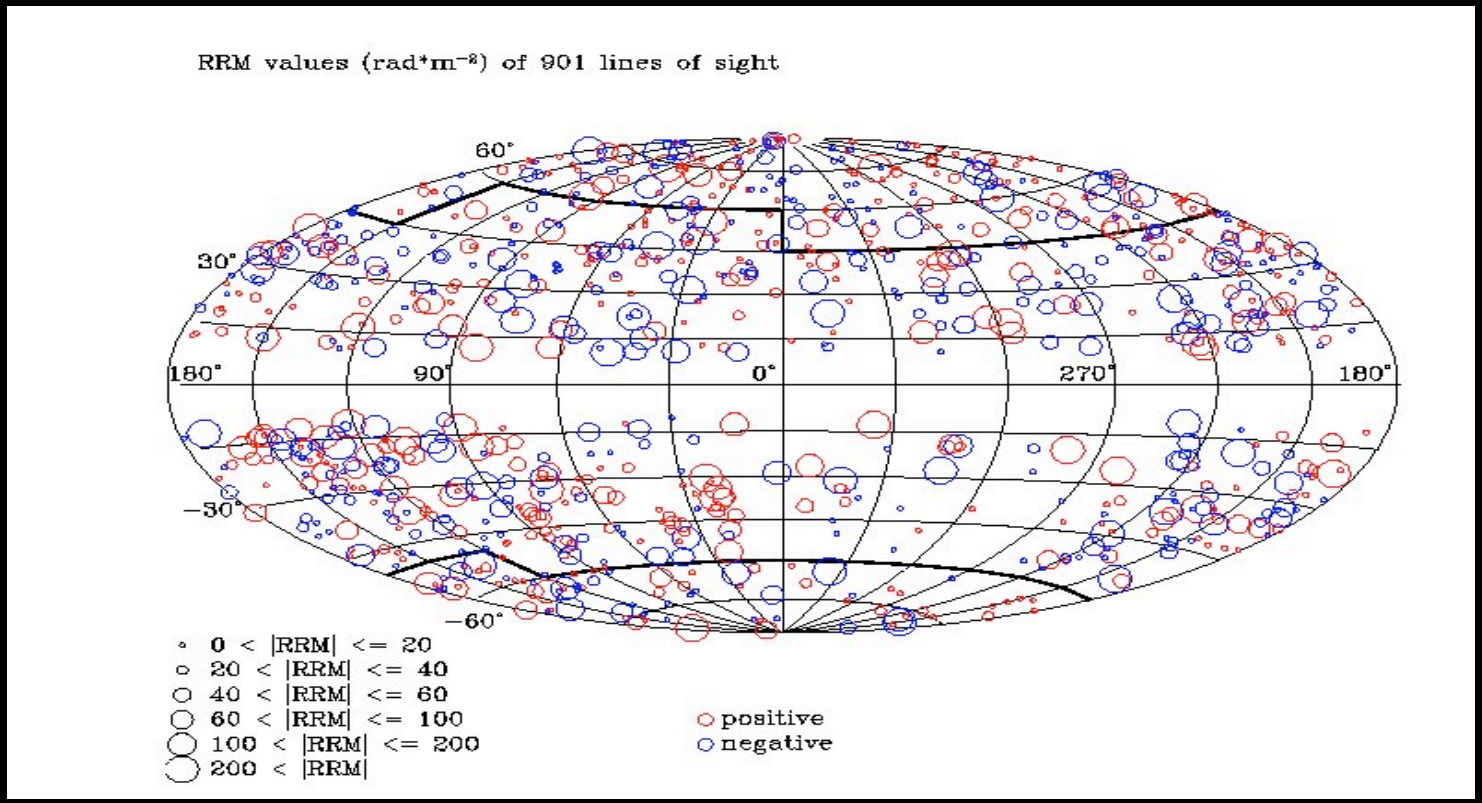
$$\ell_{\mathrm{mfp}} \simeq \frac{1}{n\sigma_{\mathrm{GC}}} \simeq 10^2 - 10^3 \left(\frac{R_{\mathrm{Vir}}}{2\mathrm{Mpc}} \right)^2 \mathrm{Gpc}$$

The WHIM





Cen & Ostriker 2006


RRM values (rad*m⁻²) of 901 lines of sight
60°
30°
180°
90°
0°
270°
180°
−30°
−60°
0 < |RRM| <= 20
20 < |RRM| <= 40
40 < |RRM| <= 60
60 < |RRM| <= 100
100 < |RRM| <= 200
200 < |RRM|
positive
negative

Upper limits on B_{IGM}

frozen-in toy model

$$B \leq 1\mu G \left(\frac{\Omega_b}{0.04}\right)^{-1} \left(\frac{\ell_c}{\mathrm{Mpc}}\right)^{-\frac{1}{2}} \left(\frac{\sigma_{RM}}{60 \mathrm{rad\ m}^{-2}}\right)$$

More complicated geometry (LSS filaments) gives similar results (Ryu et al 1998); see also Blasi et al. (1999).

Large scale B-fields in filaments ?

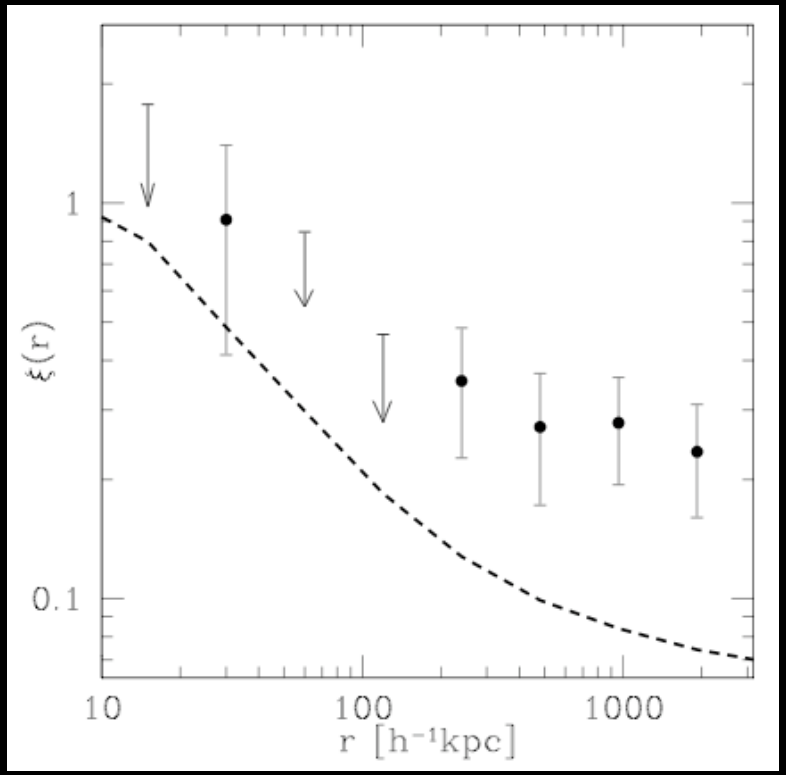
Cross correlation between excess |RM| and galaxies overdensity field (Sloan).

$$\Delta|RM| \text{ vs } \Delta\rho_{gal}$$

$$\Delta|RM| = |RM| - \overline{|RM|}$$

$$\Delta\rho_{gal} = \rho_{gal} - \overline{\rho_{gal}}$$

Authors conclude:
B~30 nG, L~Mpc.



Lee, Pen, Taylor, Stil, Sunstrum (arXiv:0906.1631)

IGMF models

Sigl,Miniati, Ensslin (2003,2004a,b); Armengaud, Sigl, Miniati (2005,2006)

- Injection at shocks (Kulsrud et al. 1997, Medvedev 2006, Schlihckeiser & Shukla 2003,) rate proportional to the baroclynic term (borrowed by Biermann's model)

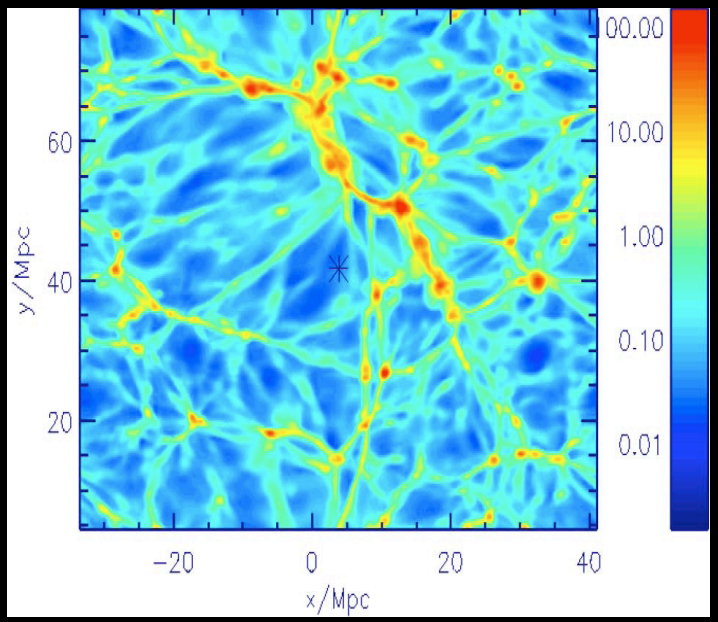
$$\left(\frac{\mathrm{dB}}{\mathrm{dt}}\right)_{\mathrm{src}} \propto \nabla \mathrm{P} \times \nabla \rho$$

- Injected at high redshift by galaxy outflows
- We use the TVD cosmogical code (Ryu et al. 1993)

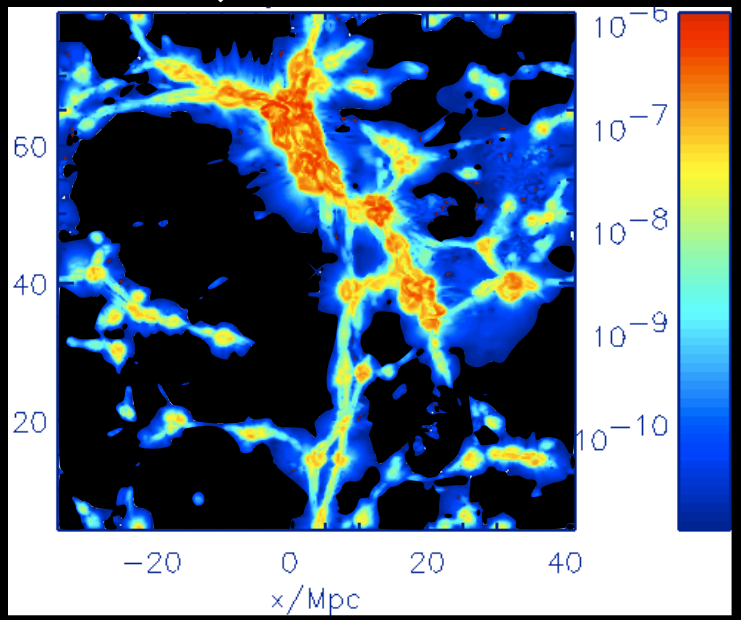
Note: Numerical models generally require some type of normalization to match observed field values in galaxy clusters.

Simulated IGMF Model Properties

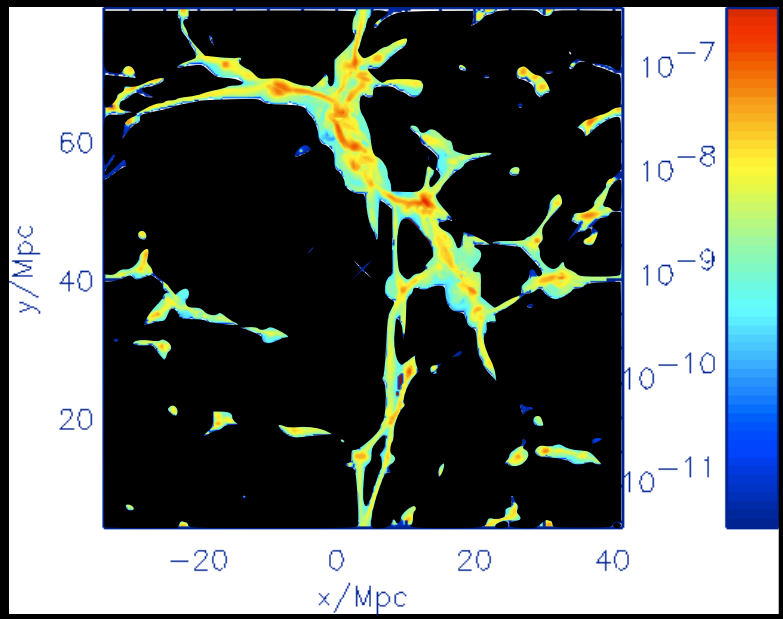
baryon density



B injected at shocks

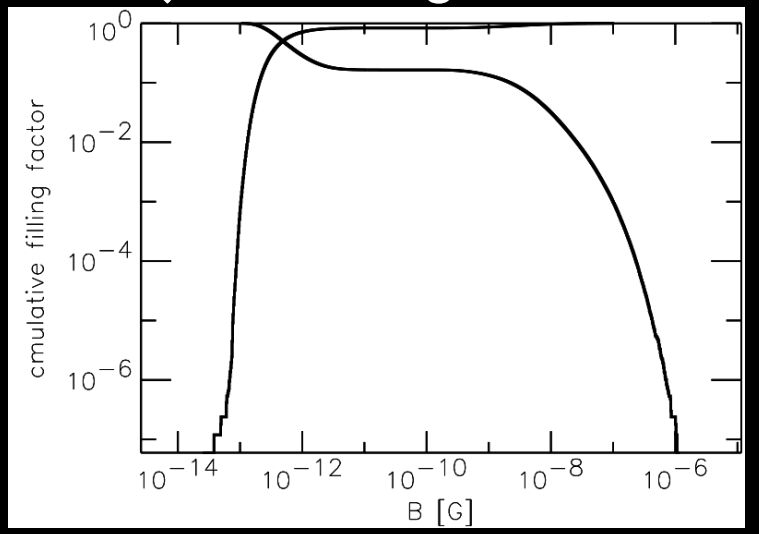


B injected at 'high' redshift



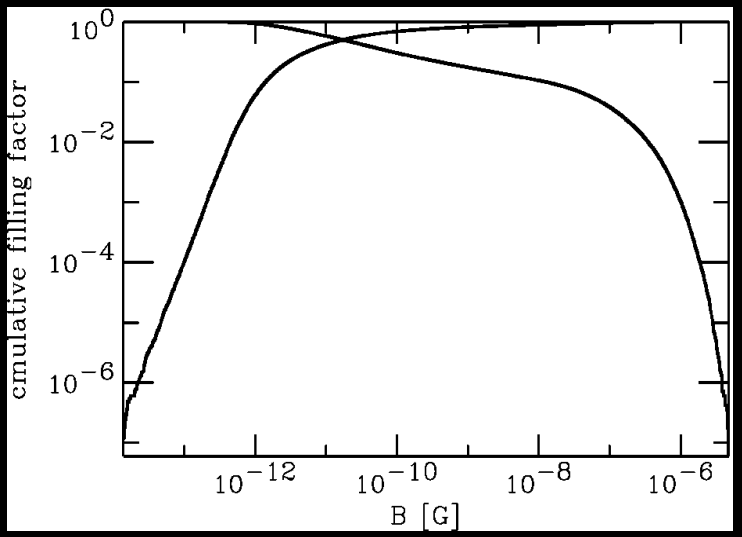
IGMF Filling Factors

B injected at 'high' redshift



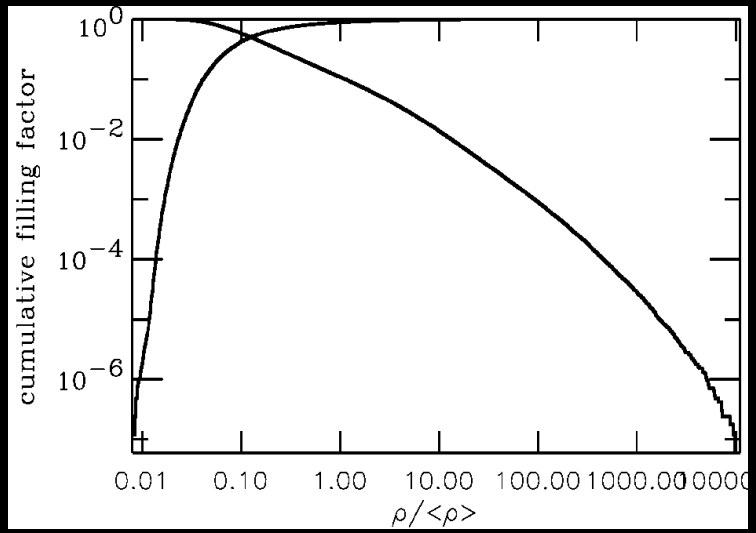
f(B>10^{-9}G) ~10%

B injected at shocks



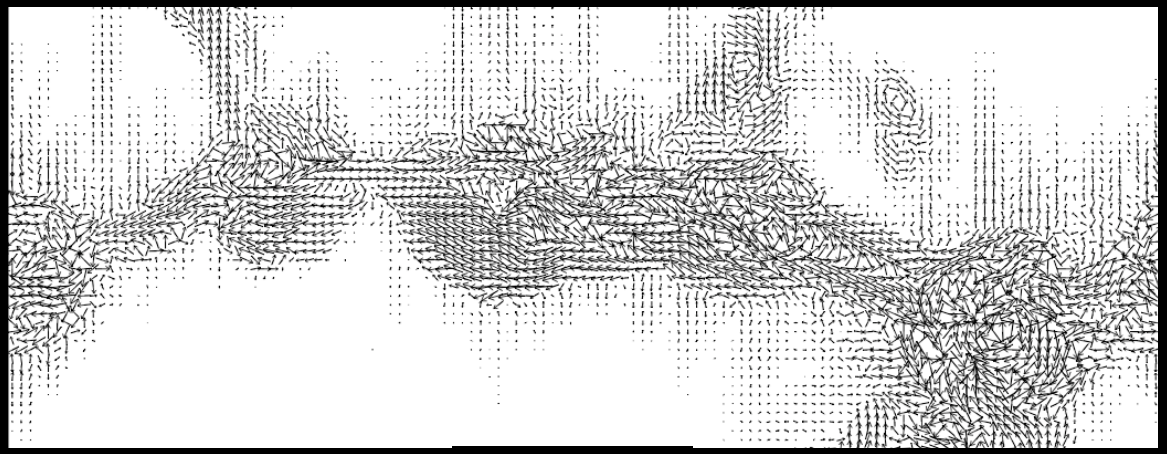
f(B>10^{-8} G)~10%

Baryon Density



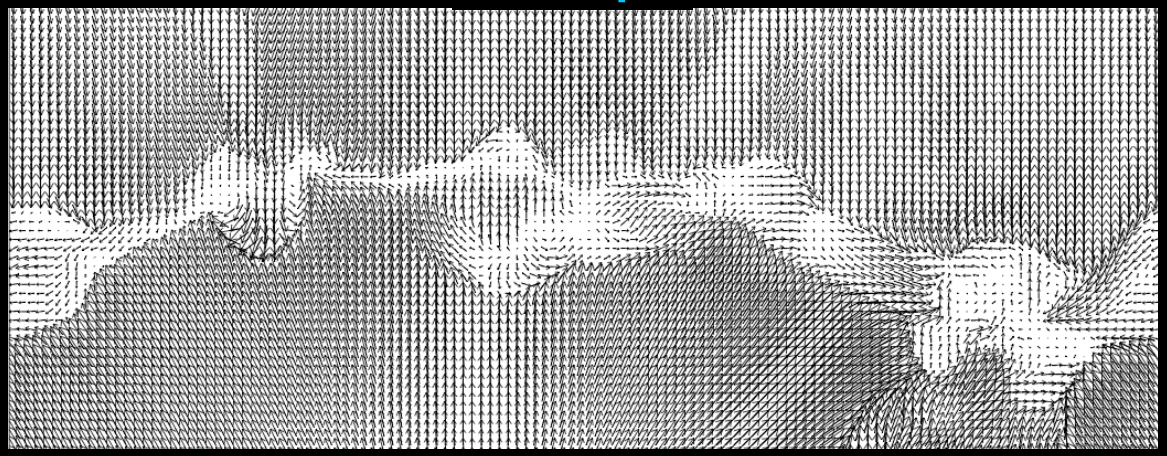
Bulky Structures

B-field



25 Mpc

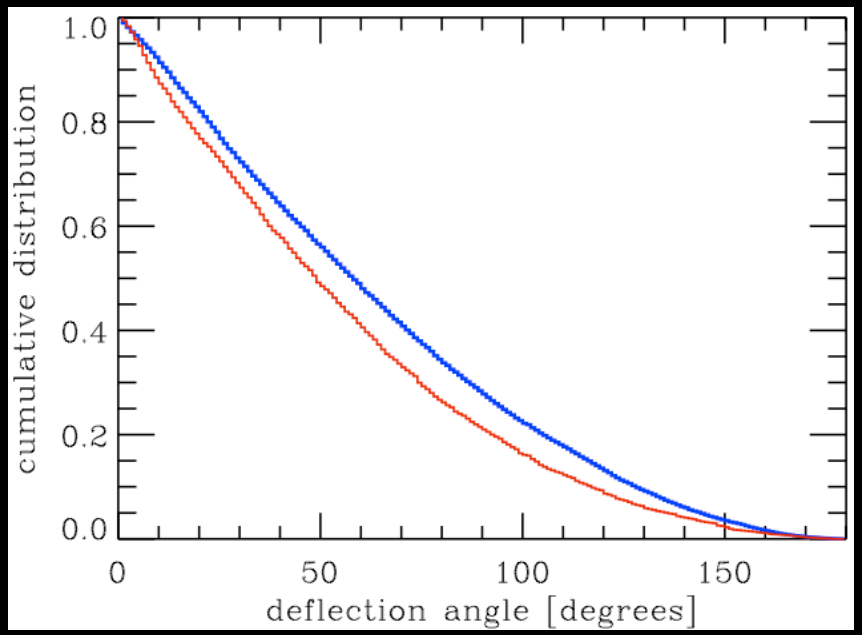
V-field



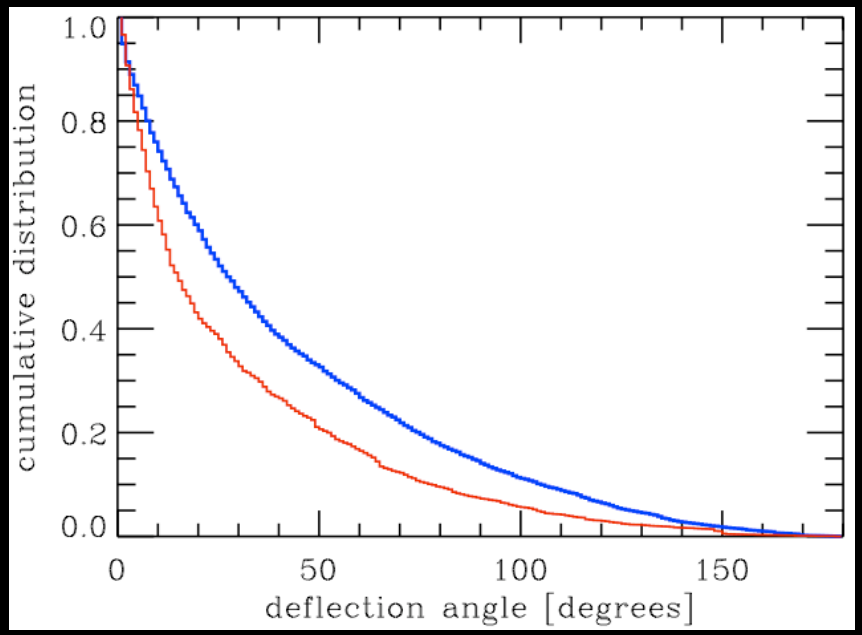
Ryu, Kang & Biermann 1998

Proton Deflection Statistics

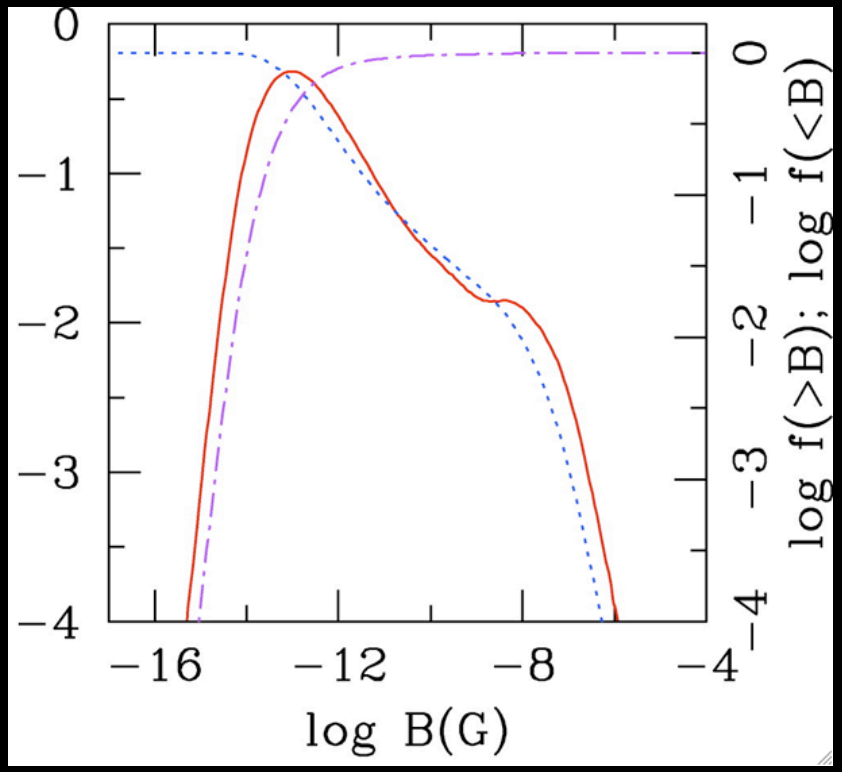
$E \geq 4 \times 10^{19}\,eV$

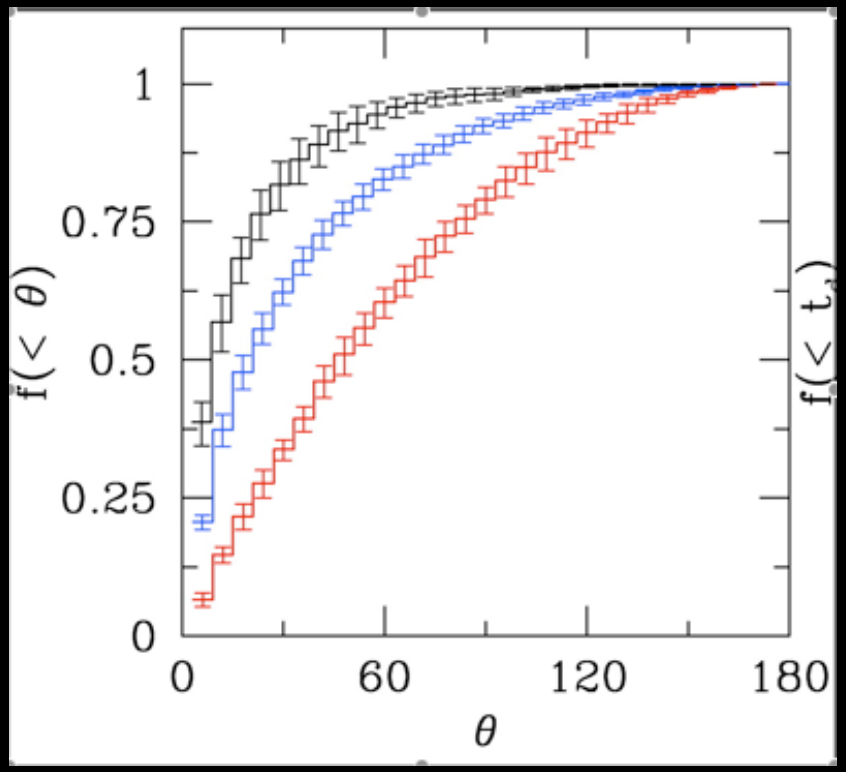


$E \geq 10^{20}\,eV$



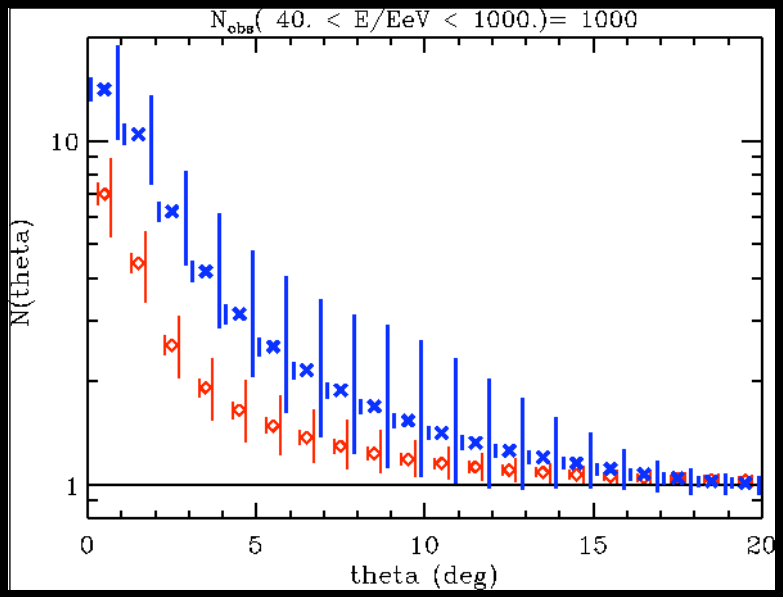
Ryu et al.'s model





Autocorrelations (protons)

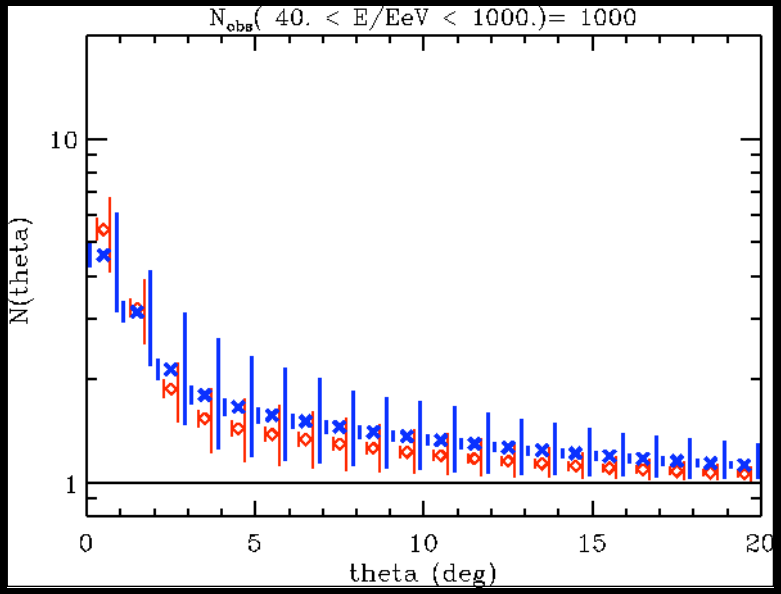
Potential for determining the source number density. E.g. comparison with AGASA data already requires source density is ~ 10^{-5} Mpc^{-3} (Sigl, Miniati & Ensslin 2004, Yoshiguchi et al. 2003, Blasi & de Marco 2004)



Autocorrelations for source density = 2.4×10^{-4} Mpc^{-3} (red) and 2.4×10^{-5} Mpc^{-3} (blue) for an Auger-type exposure.

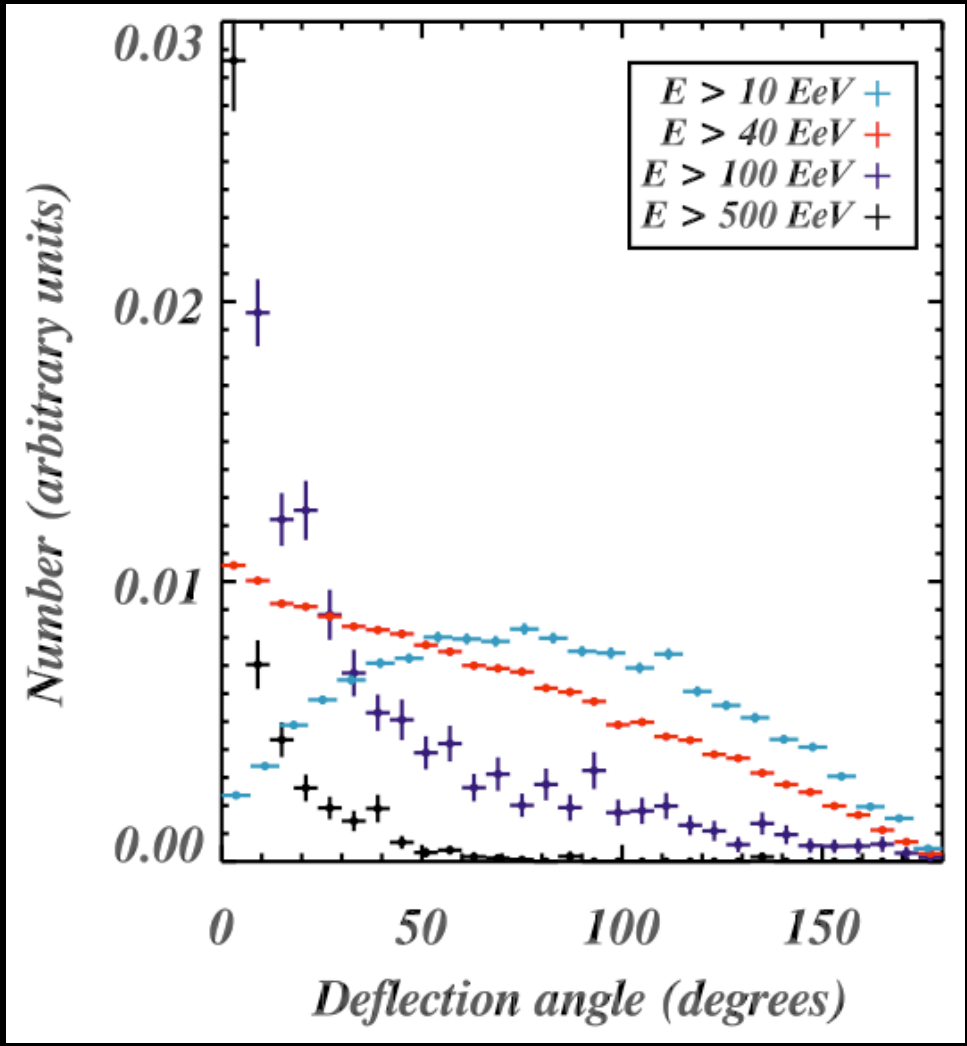
Magnetized Sources

Comparing predicted autocorrelations for source density = 2.4×10^{-4} Mpc^{-3} (red set) and 2.4×10^{-5} Mpc^{-3} (blue set) for an Auger-type exposure.

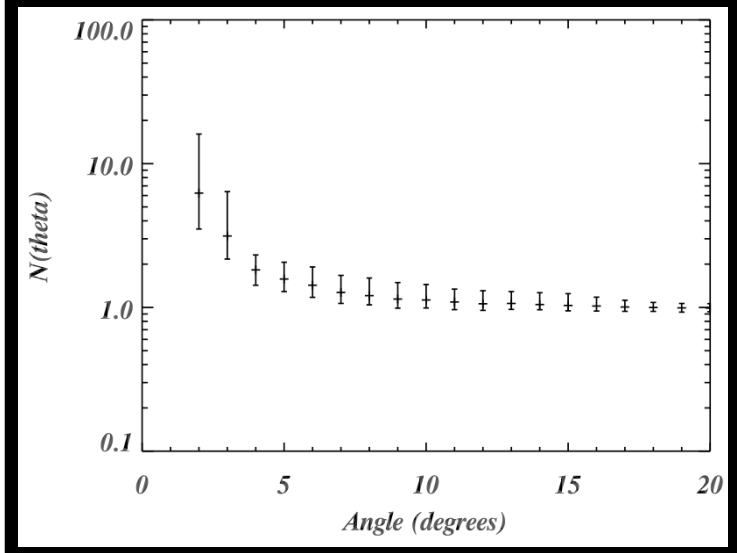


Deflection in magnetic fields makes autocorrelation and power spectrum much less dependent on source density and distribution !

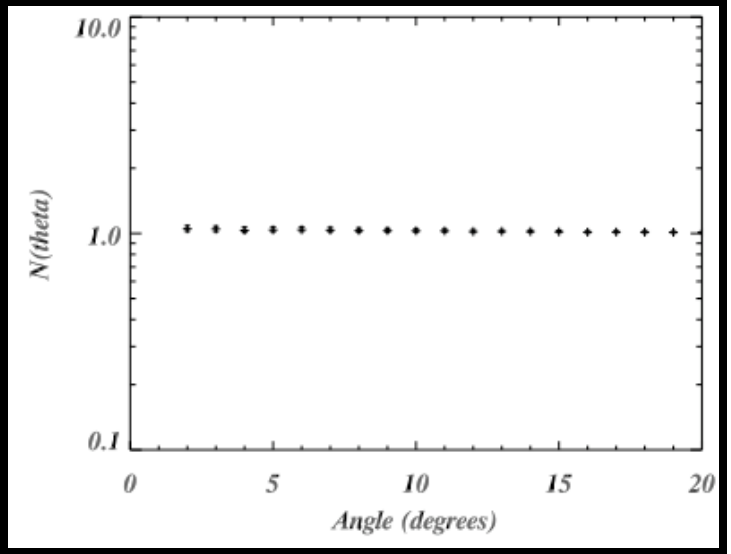
Deflection Statistics (nuclei)



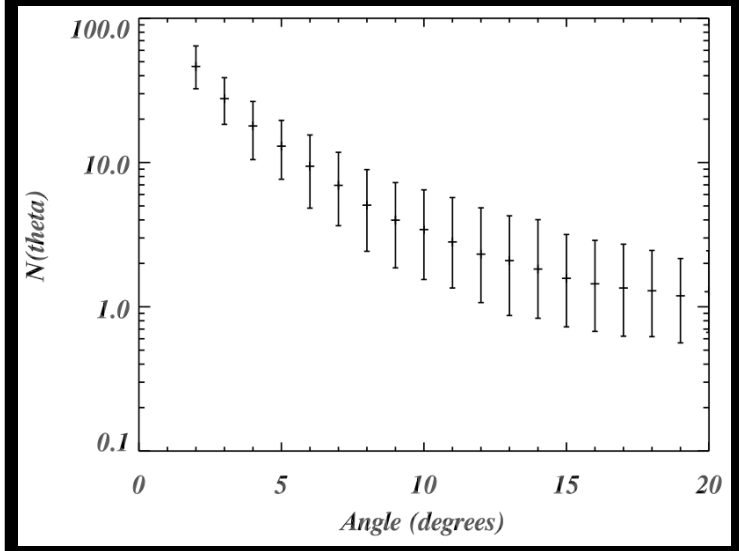
Autocorrelations (nuclei)



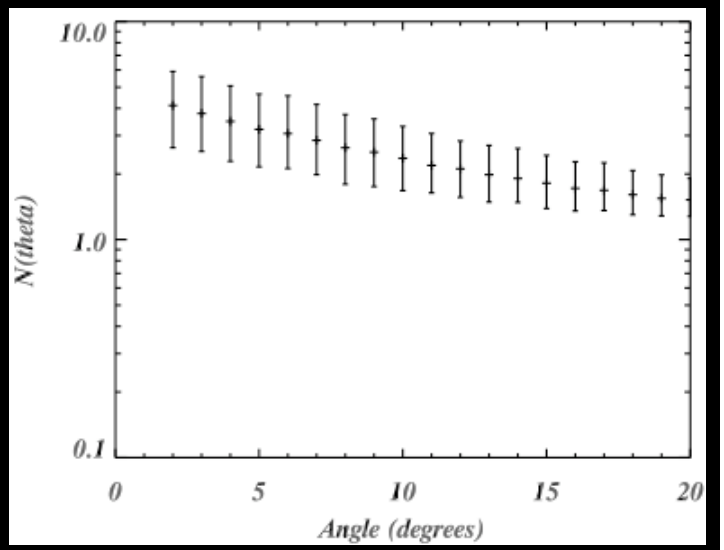
$E \geq 4 \times 10^{19}$ eV



add B



$E \geq 8 \times 10^{19}$ eV



Conclusions

Intergalactic magnetic fields are very difficult to observe and their modeling, therefore, is affected by large uncertainties.

nG strong B-fields ordered on Mpc scales in the low density IGM (f~10%) can cause large deflections.

However this does not necessarily isotropize the arrival directions, not even for nuclei at high enough energy.