Magnetic Field in the Local Universe and the propagation of UHECRs

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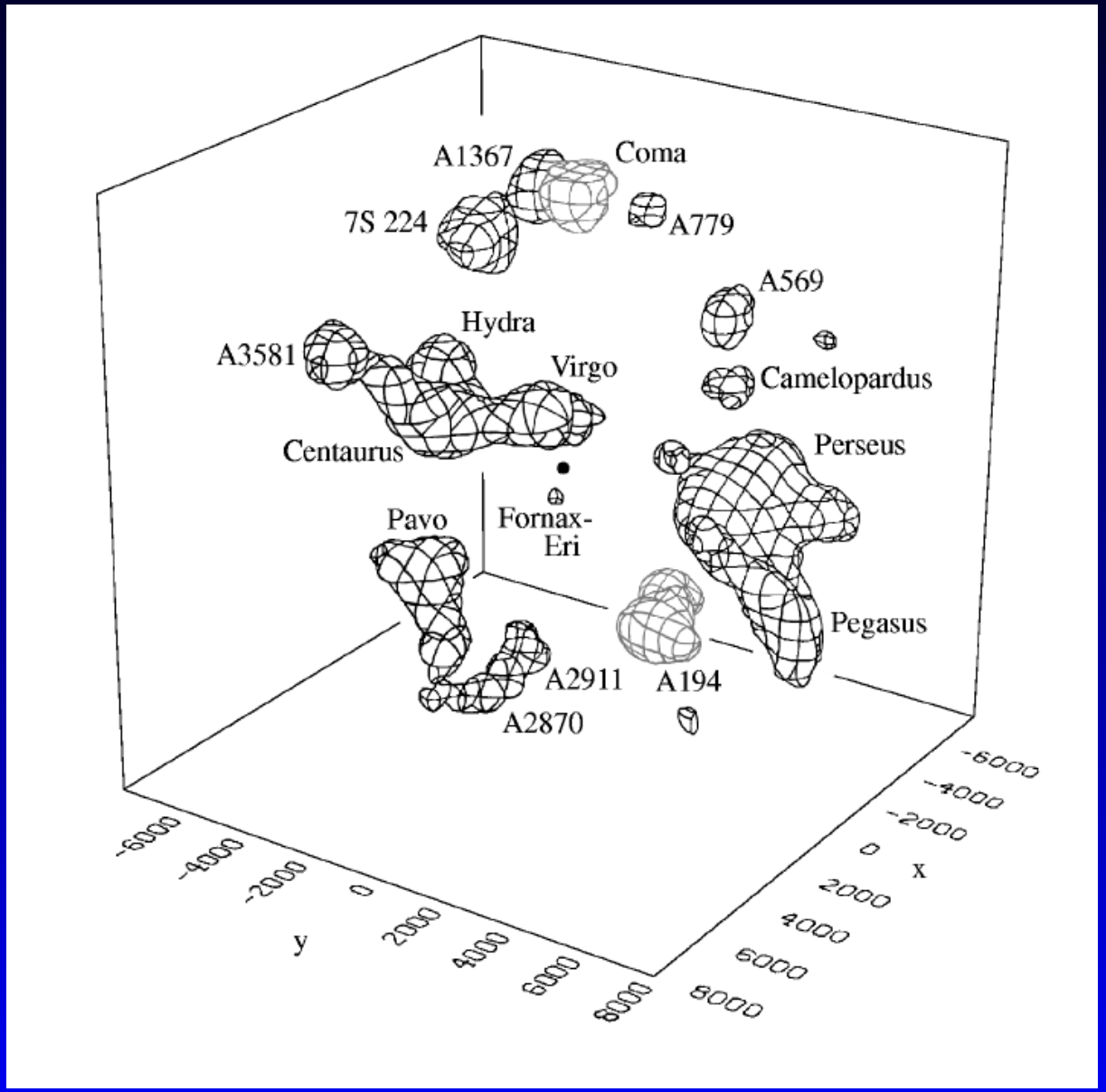
special thanks to all observers for providing their data

The Local Universe

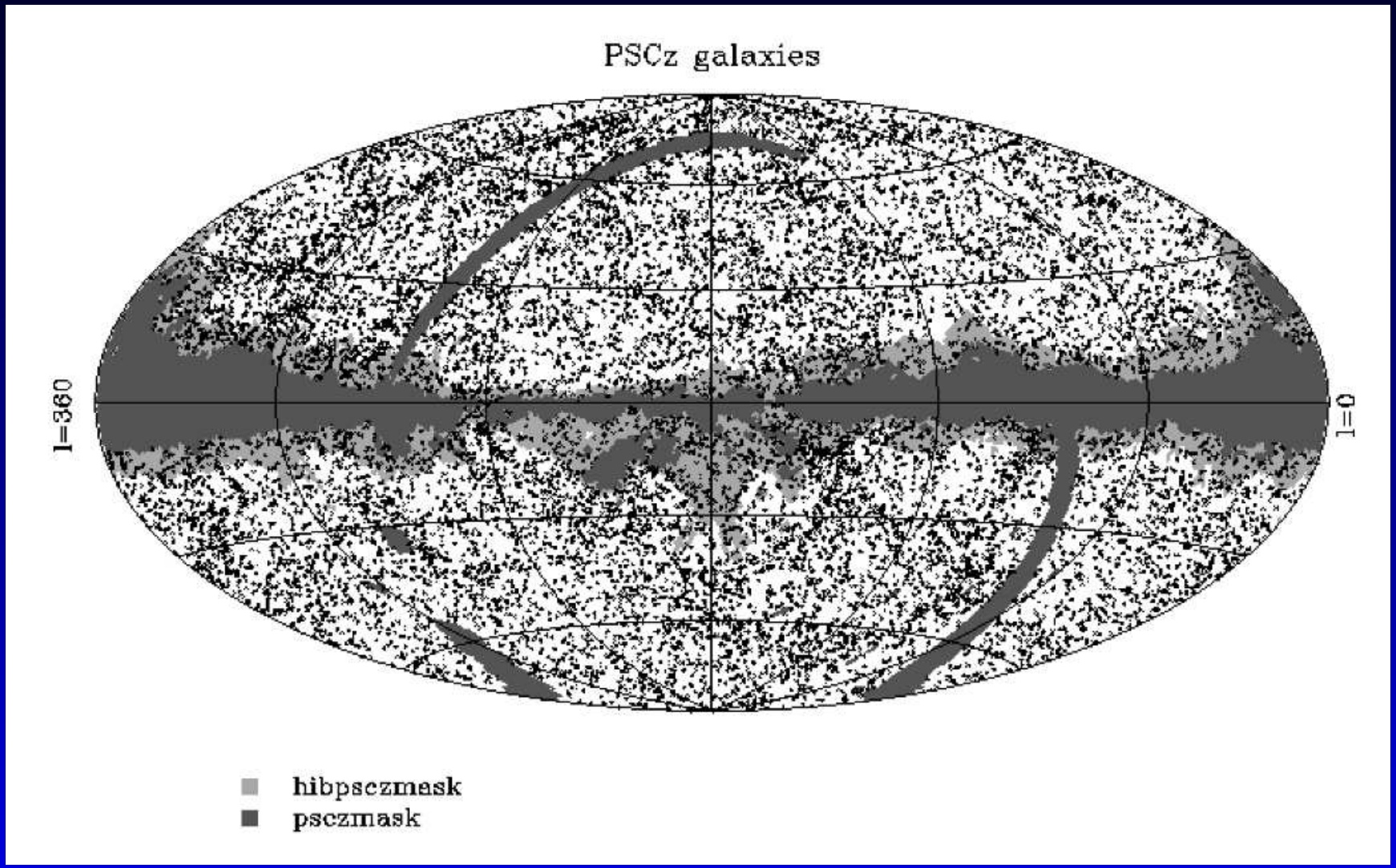


Run movie

Hudson 1993

Magnetic Field structure in Local Universe ? Charged particle astronomy possible ?

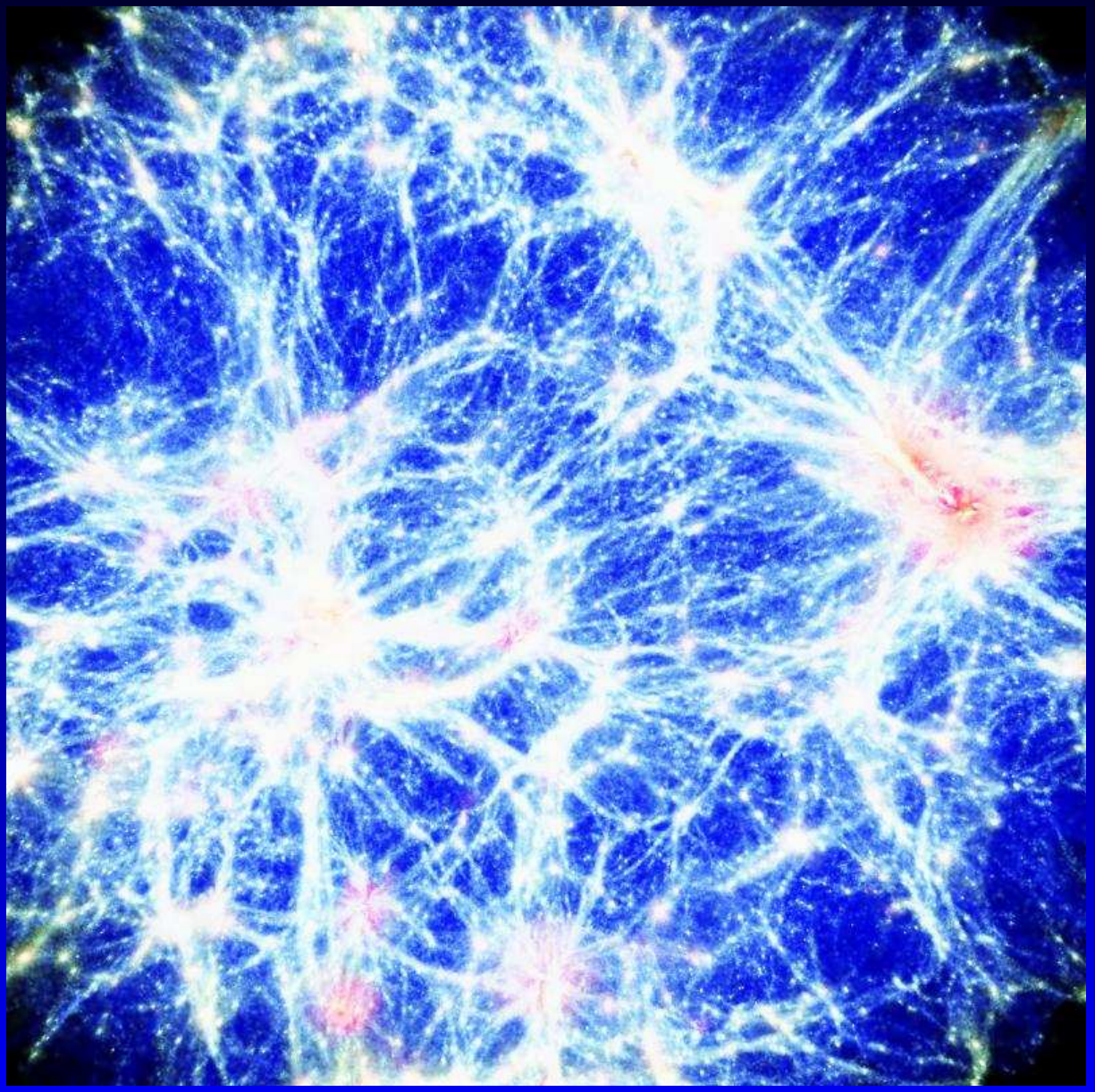
The Local Universe



Saunders et al. 2000

15000 IRAS Galaxies

The Local Universe

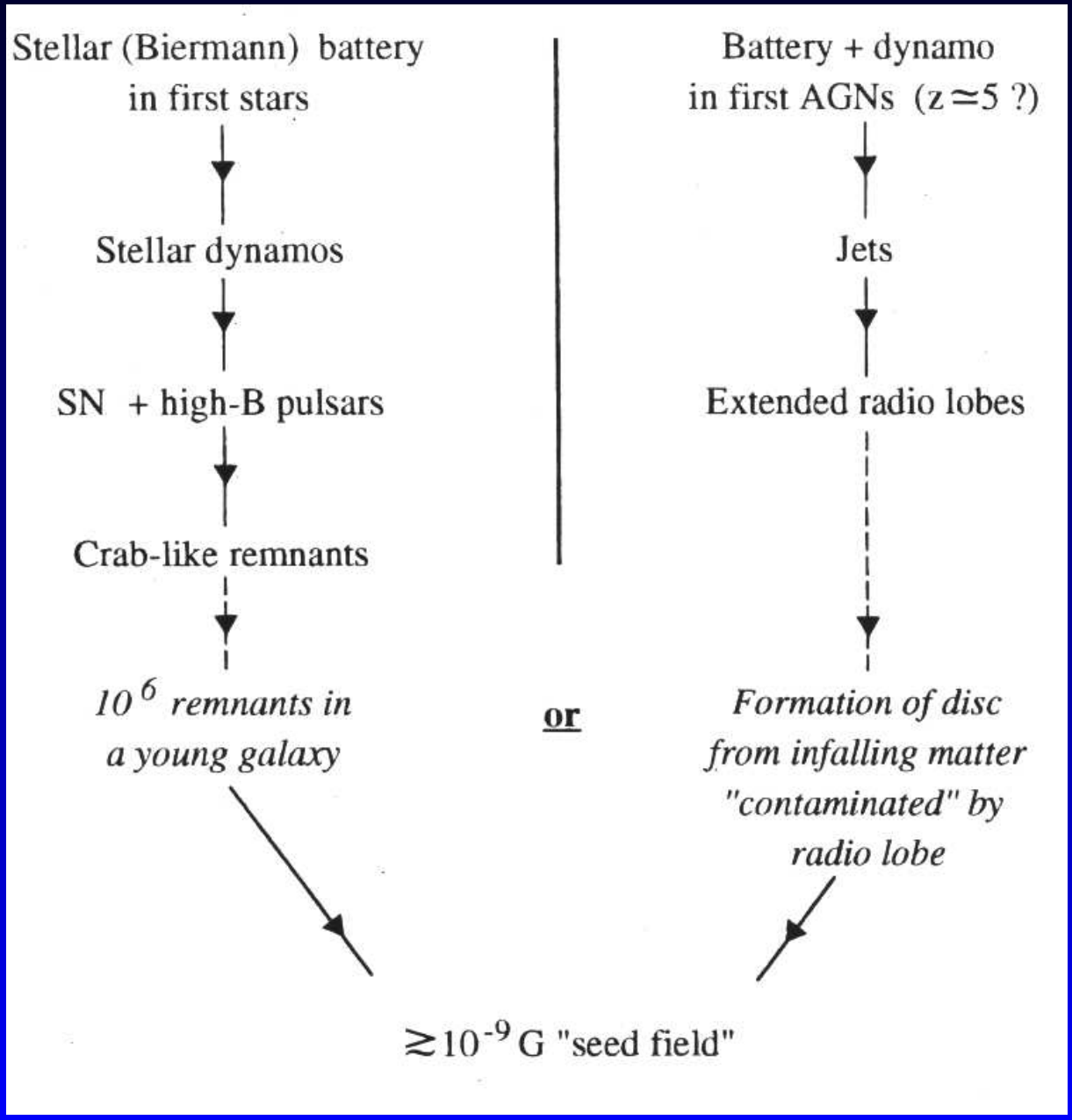


Run movie

$2 \times 50.000.000$

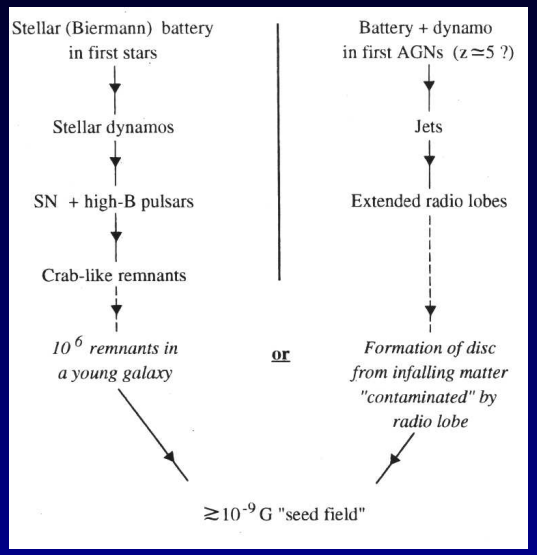
Mathis et al 2002 (DM-Only), Dolag et al 2004 (Gas + MHD)

Magnetic Field Model



Rees 1994

Magnetic Field Model



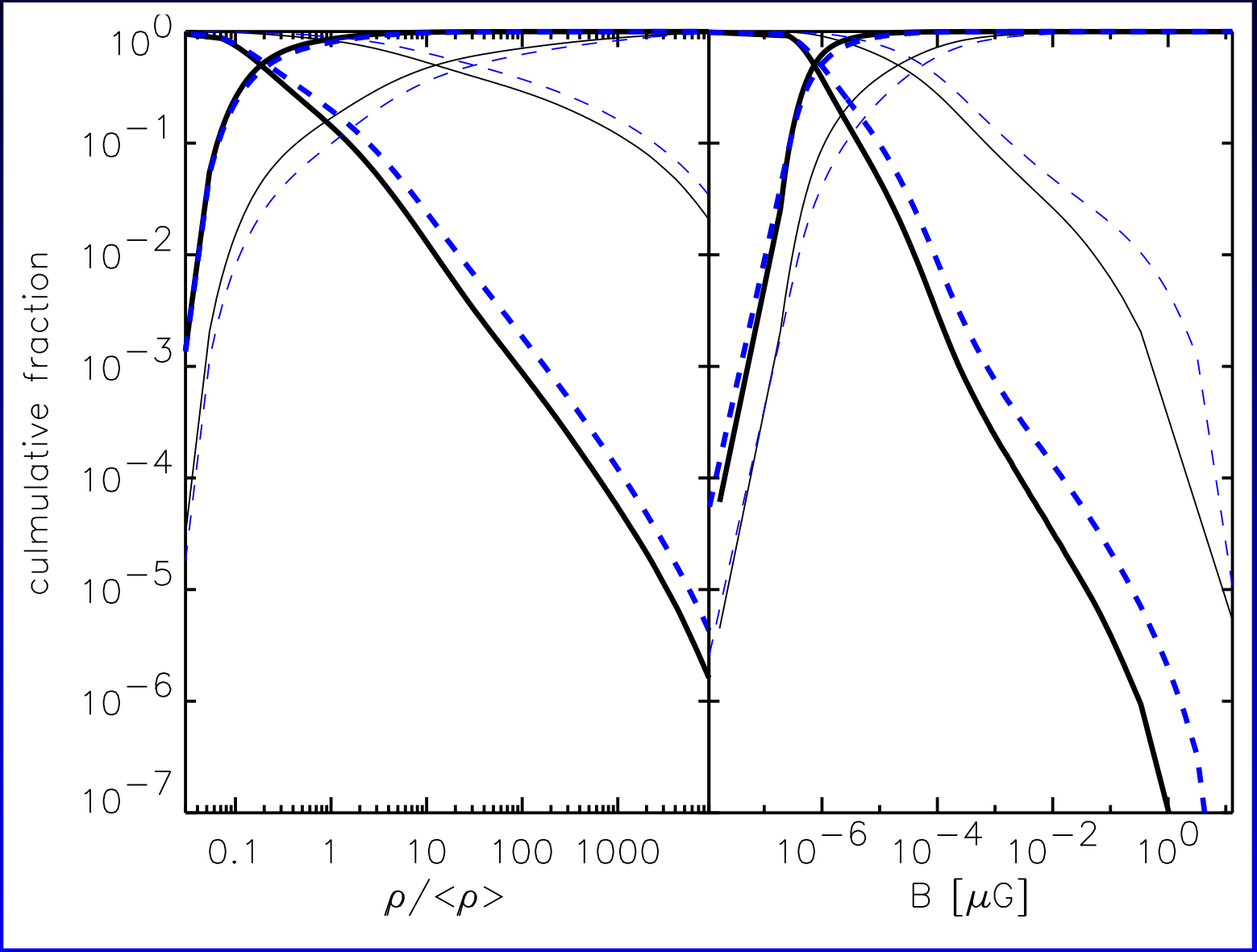
movie

For $B_0 \approx (0.2 - 1) \times 10^{-12} \times (1+z)^2$ Gauss injected at $z > 3$:

- Simulations reproduce the shape, scaling and amplitude of the RM signal caused by observed clusters very well.
- Homogeneous and chaotic initial field configurations can not be distinguished.

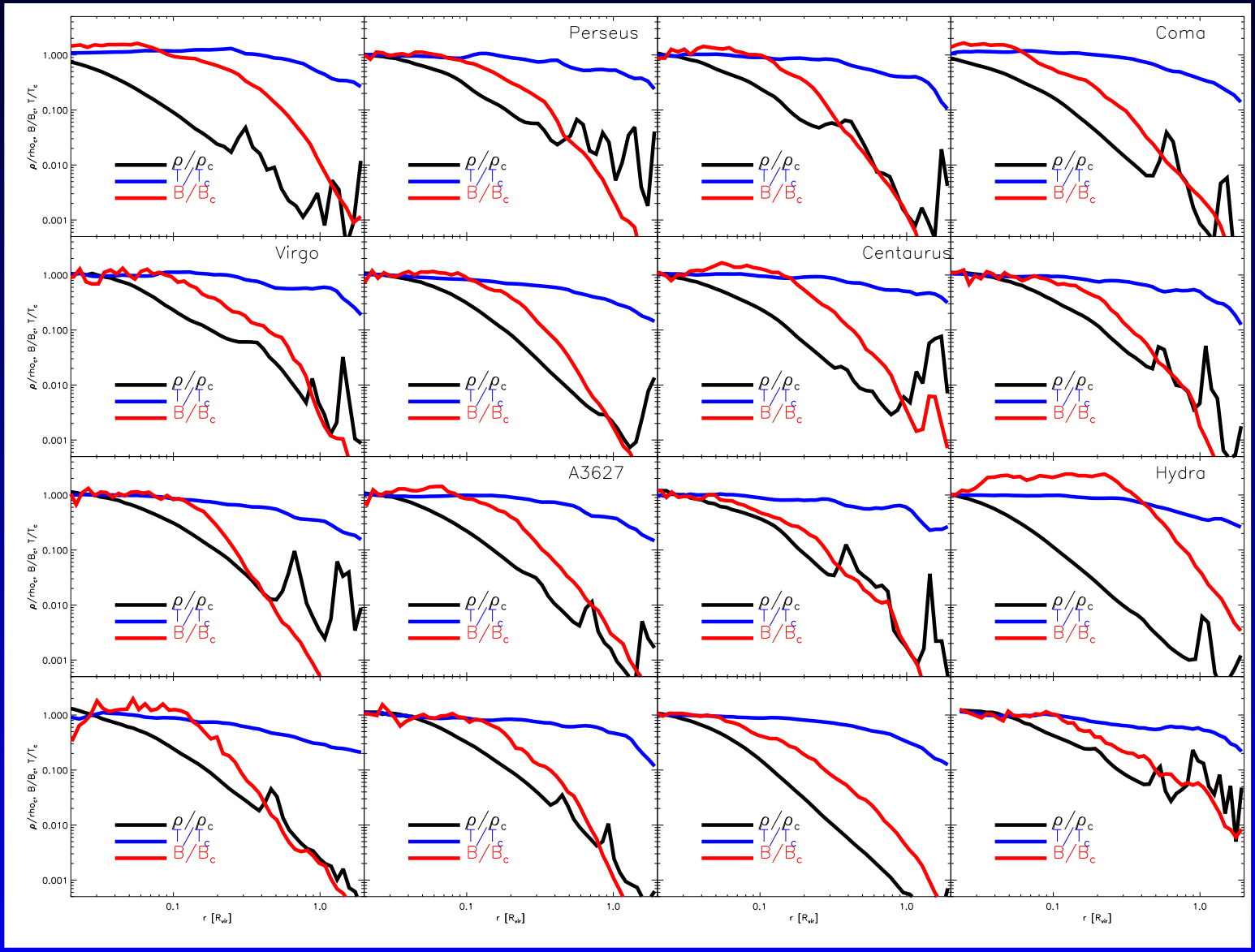
$\Rightarrow$ Almost independent of details of seed creation mechanism.

Model predictions



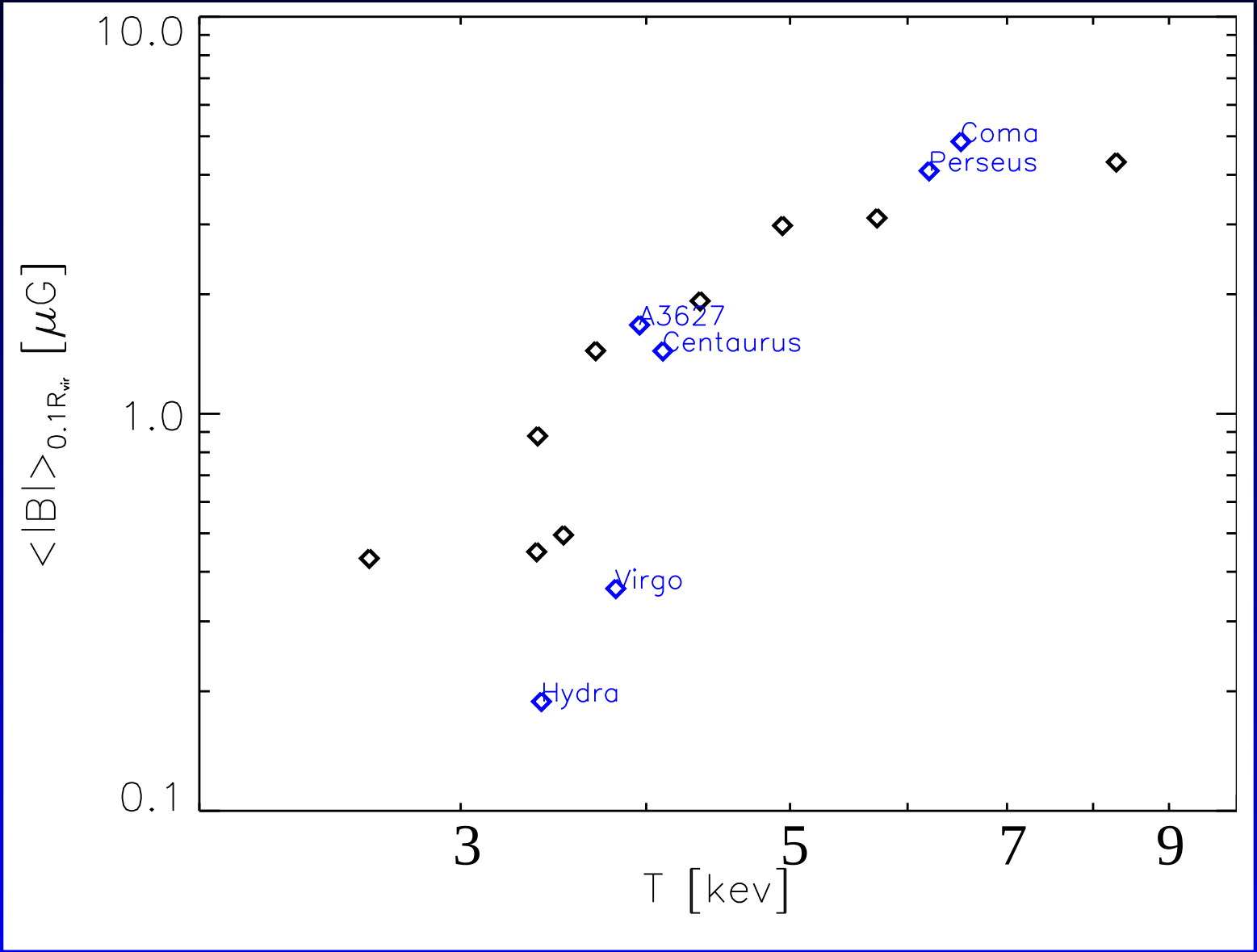
Density and magnetic field distribution within two sub-volumes of $(70\mathrm{Mpc})^3$ each.

Model predictions



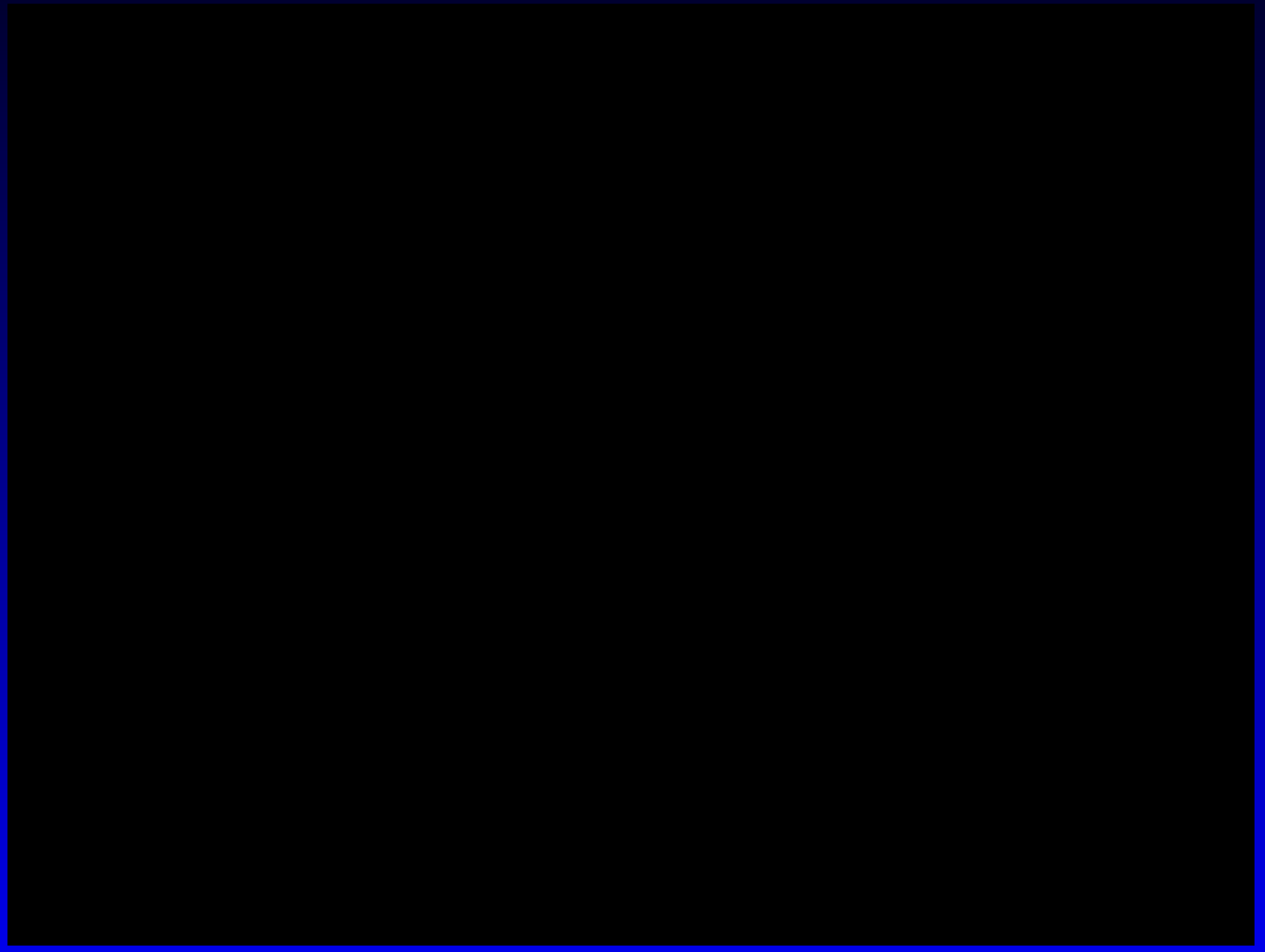
Scaled radial Profiles: Temperature (blue), Gas Density (black) and mean Magnetic Field (red)

Model predictions



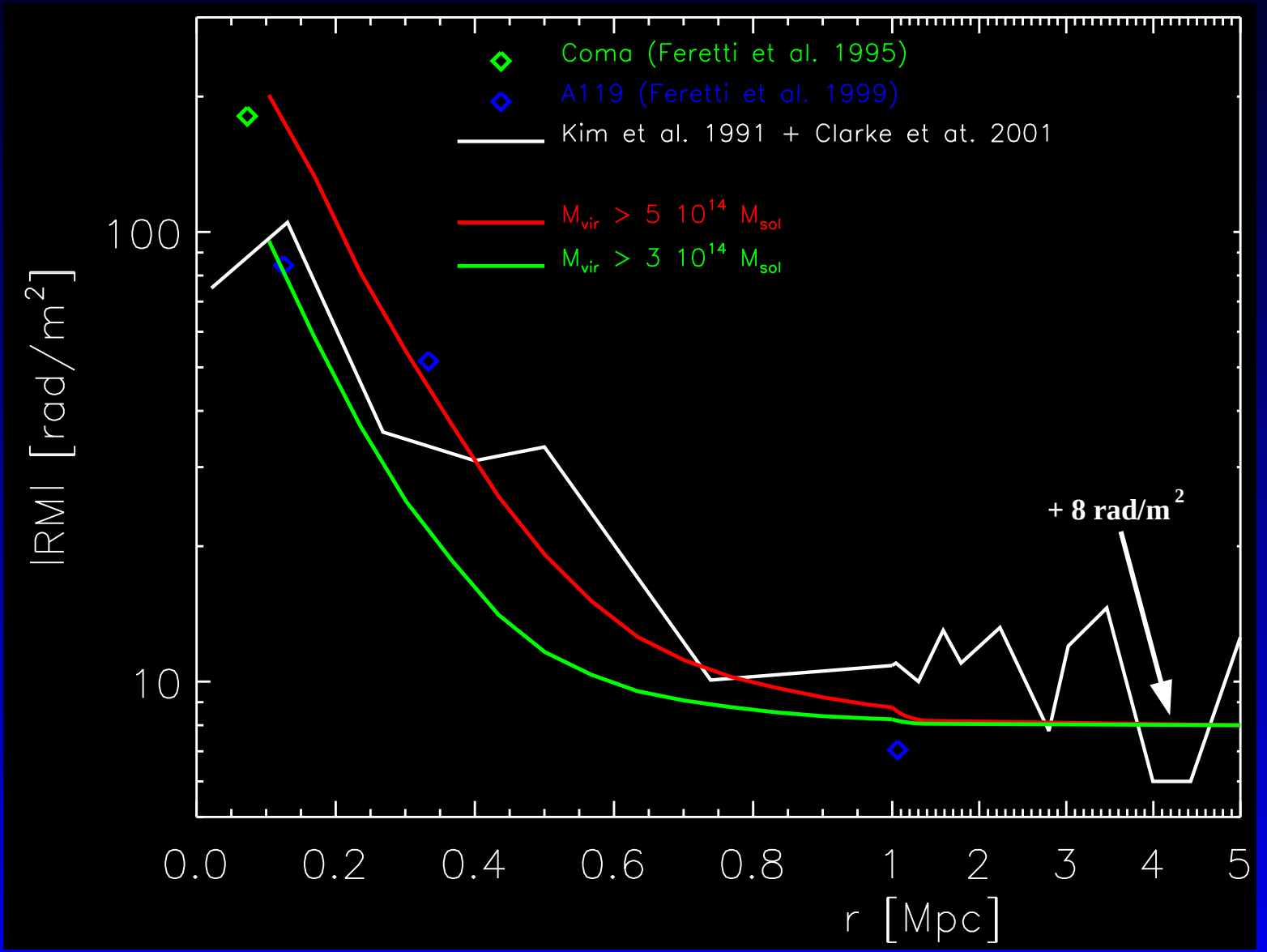
Magnetic Field - Temperature relation

Comparison with Observations



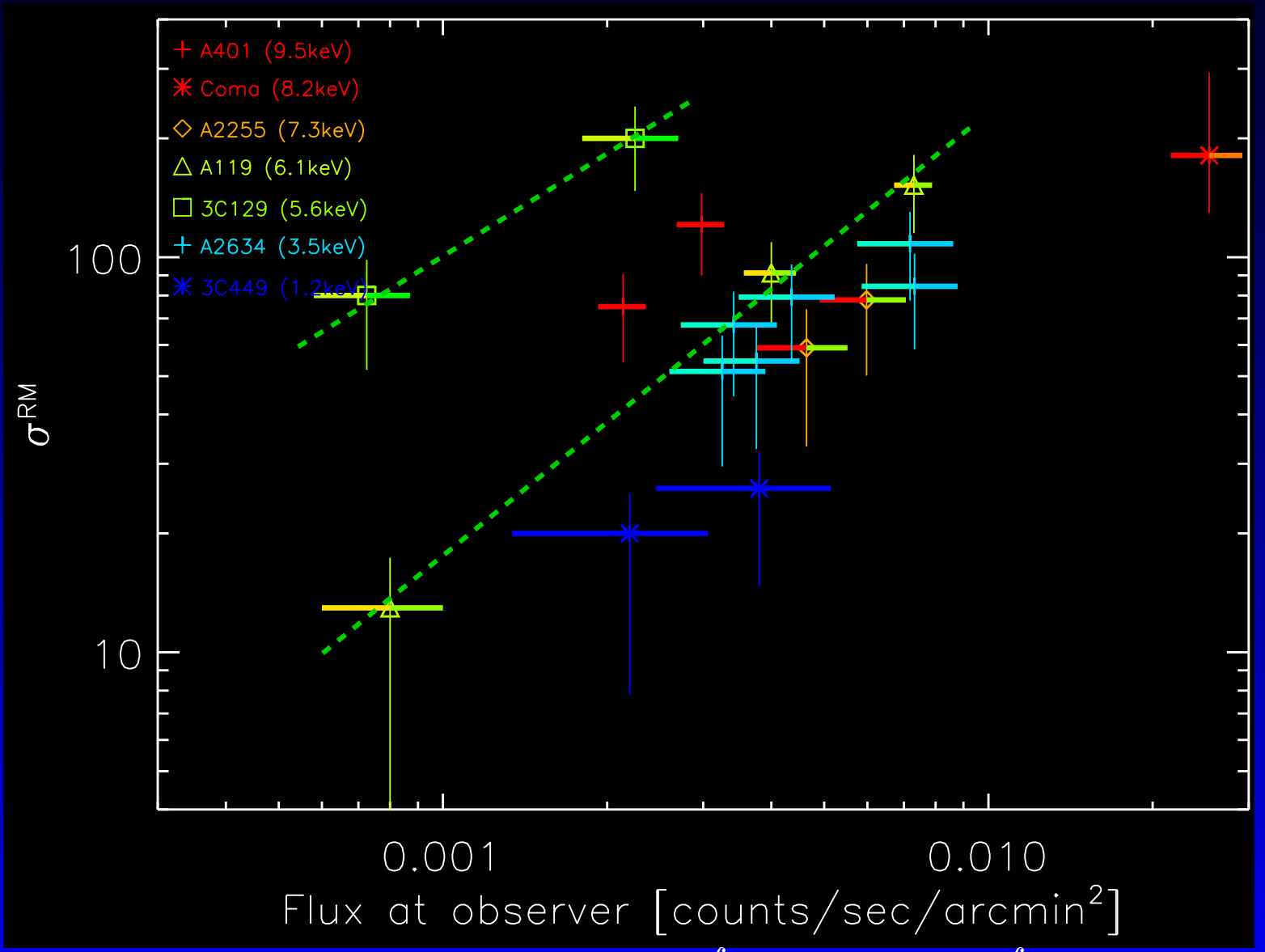
Be carefully, many hidden systematics ! Be scared ?

Comparison with Observations



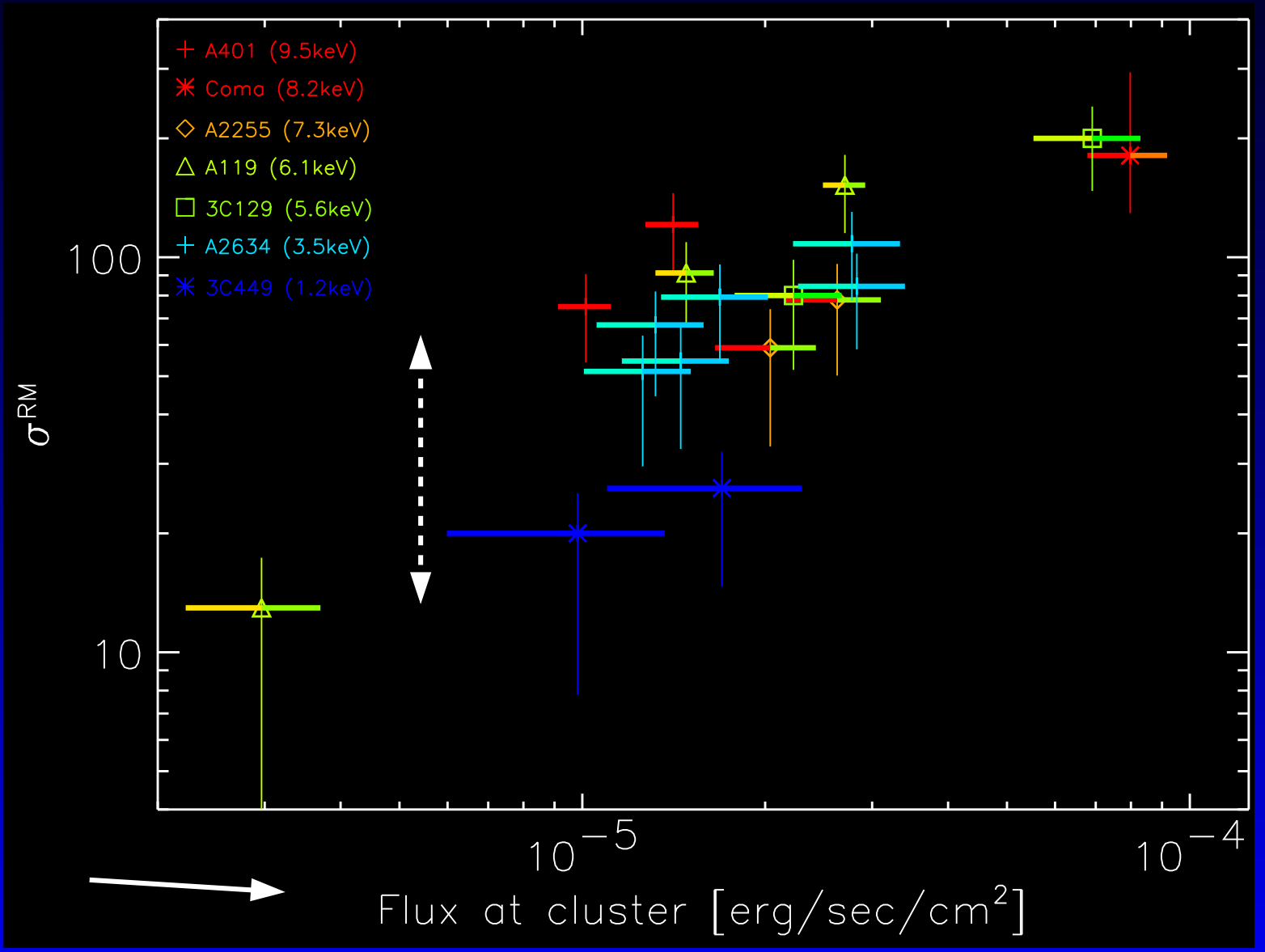
Comparison of radial RM profile.

Comparison with Observations



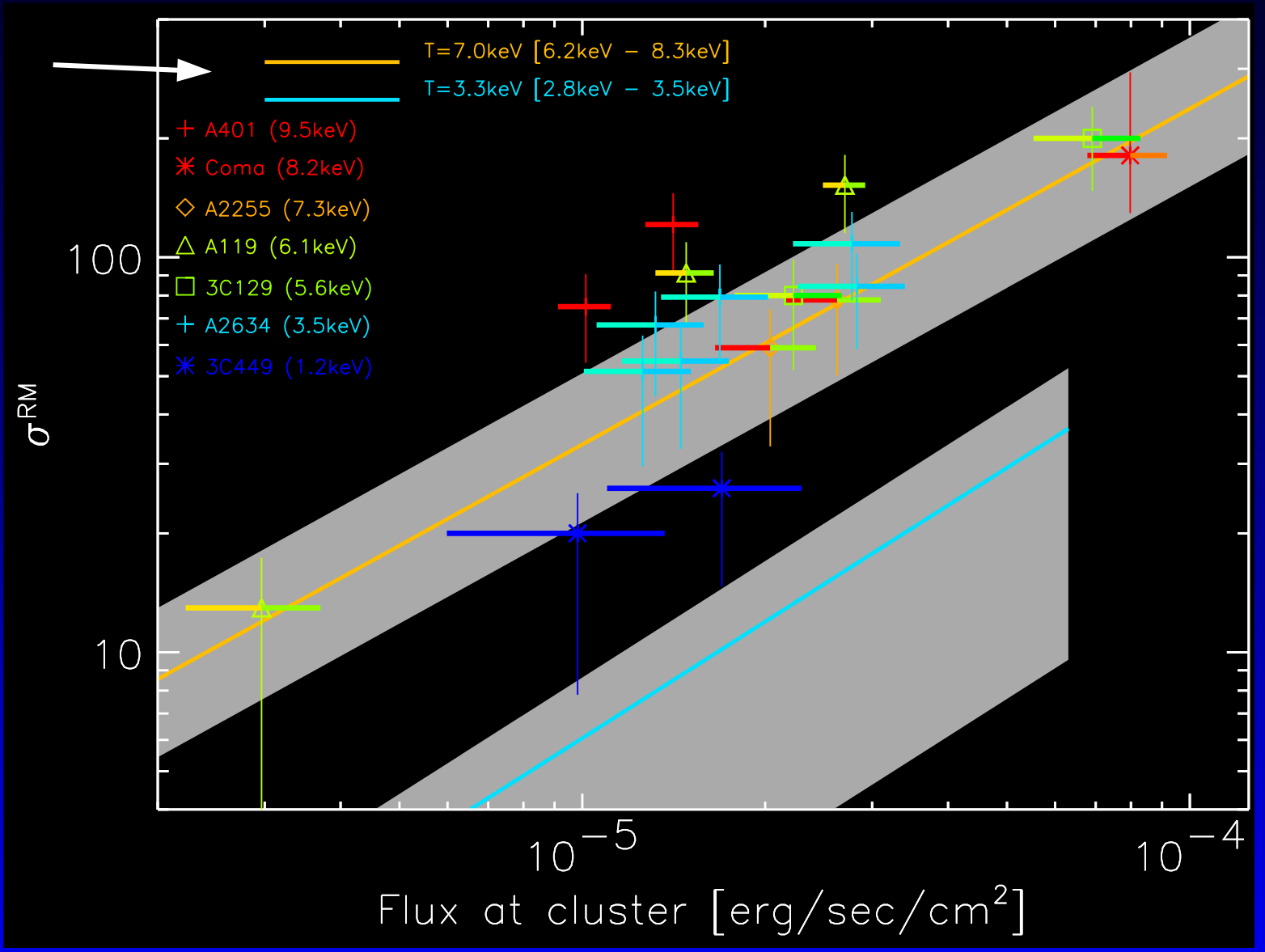
$L_x - \sigma_{RM}$ – Correlation : $\int n_e^2 \sqrt{T}\, dx \Longleftrightarrow \int n_e\, B_{\parallel}\, dx$

Comparison with Observations



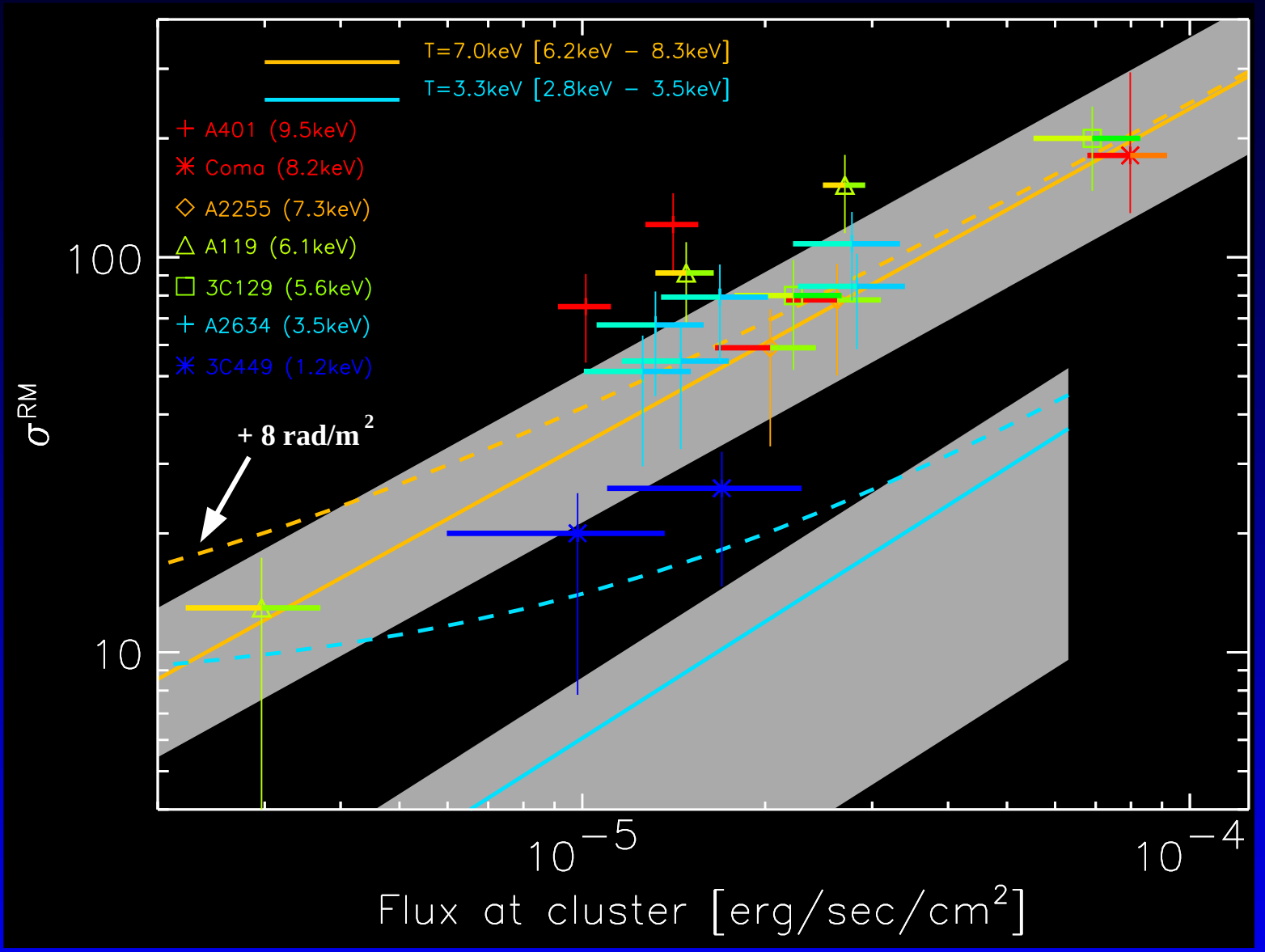
Making different clusters comparable.

Comparison with Observations



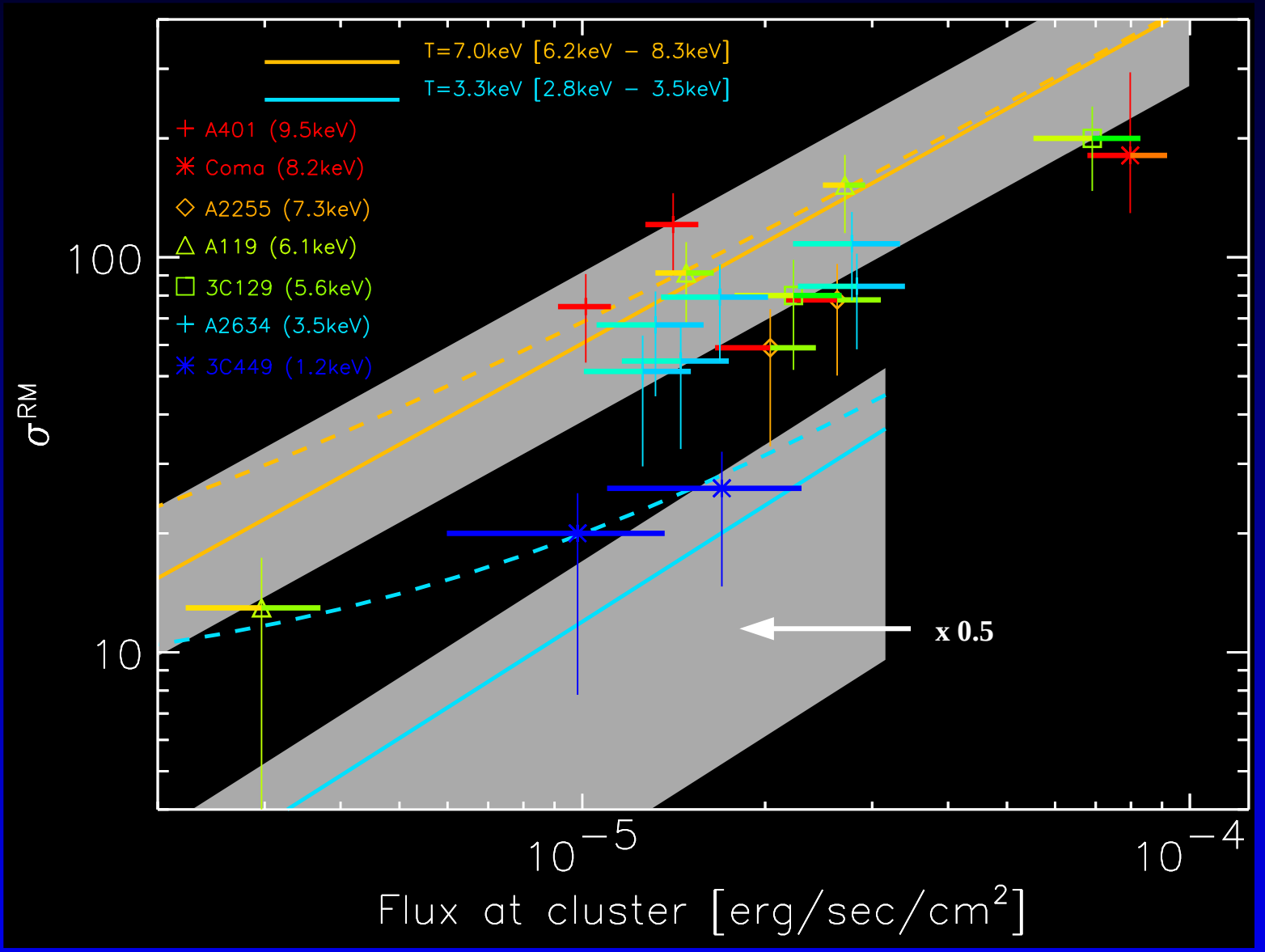
Predictions from the clusters in the simulation.

Comparison with Observations



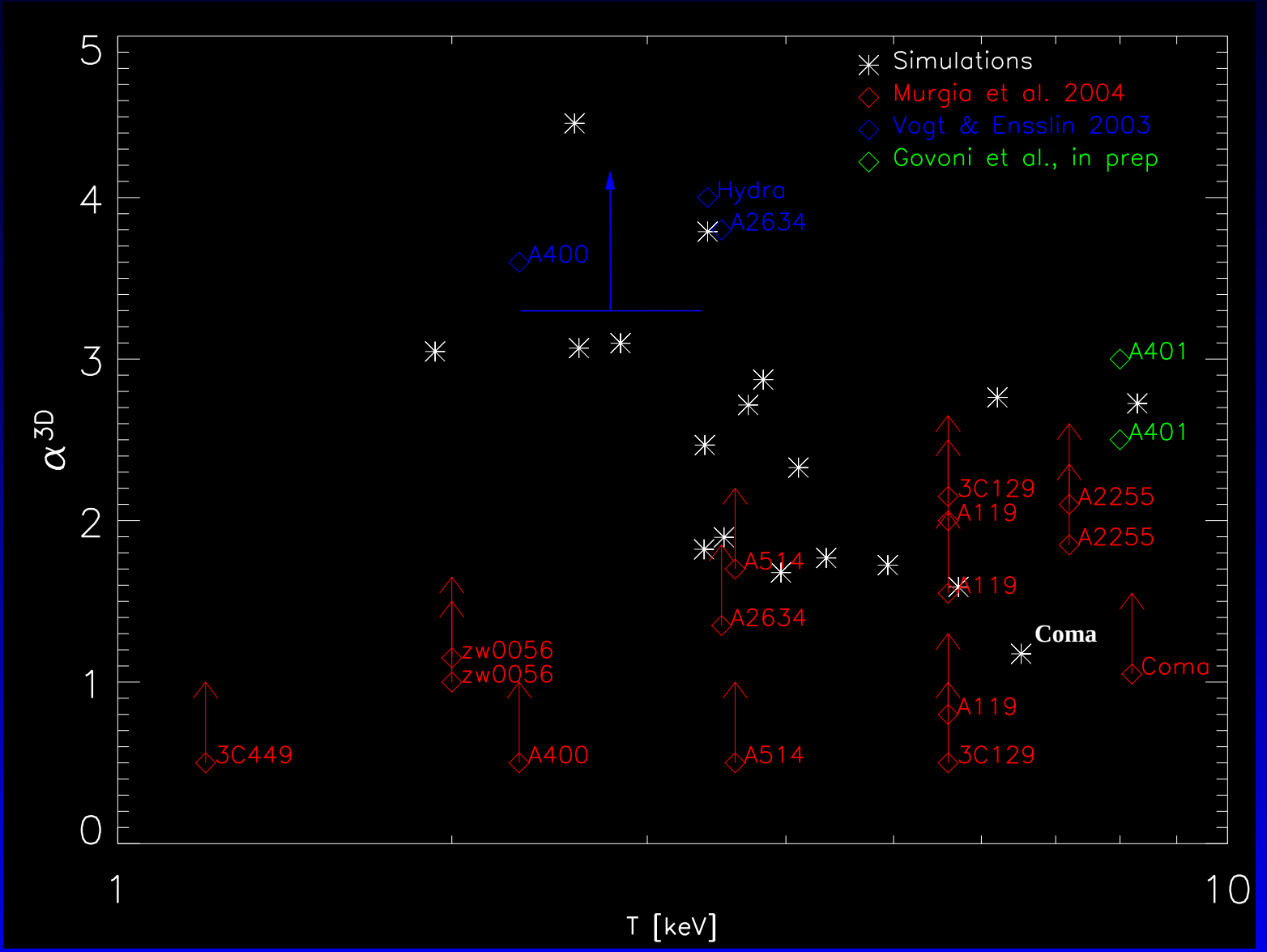
Adding noise is important !

Comparison with Observations



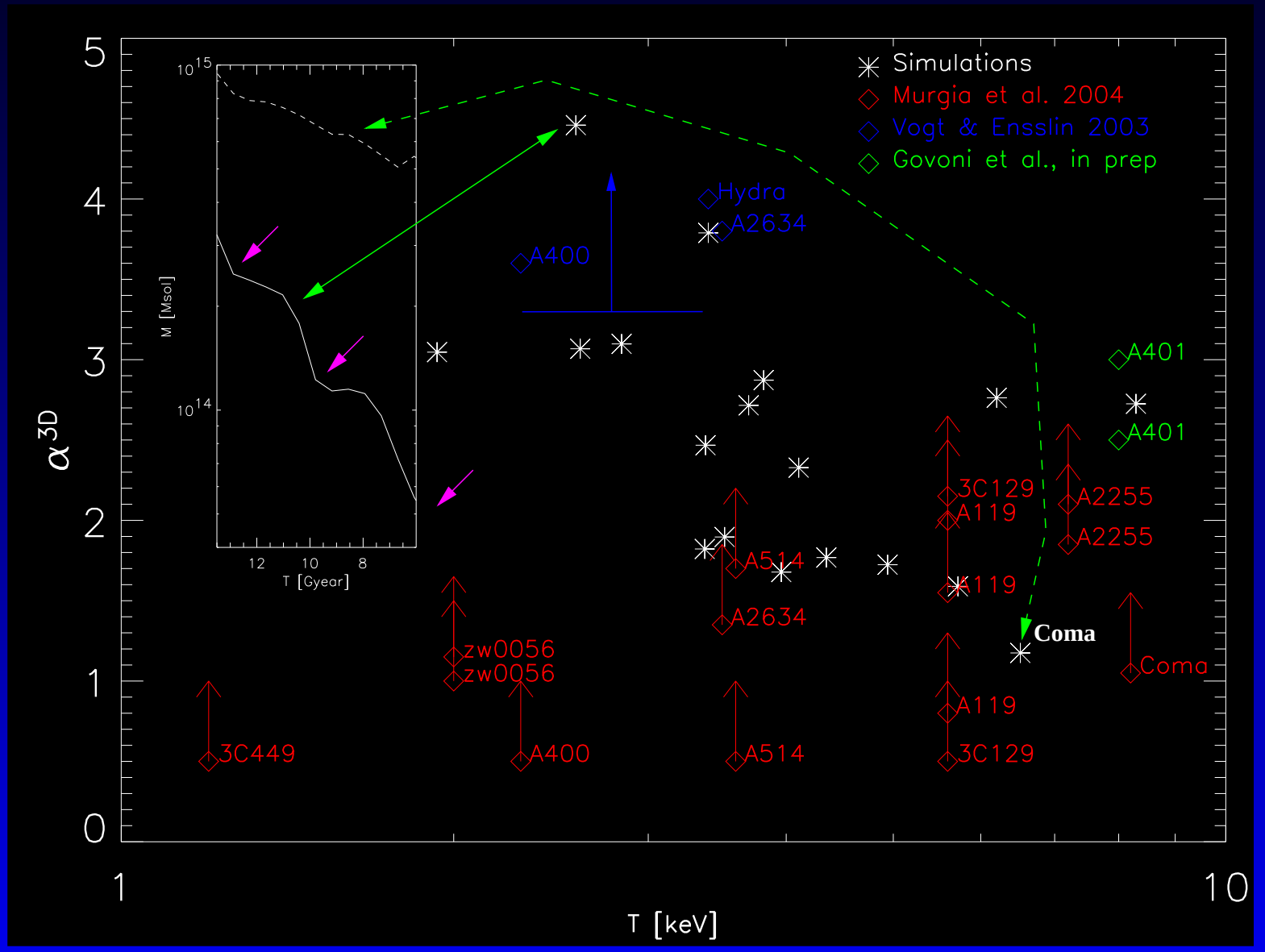
Uncertainties in scaling relations of simulations, specially for x-ray's !

Comparison with Observations



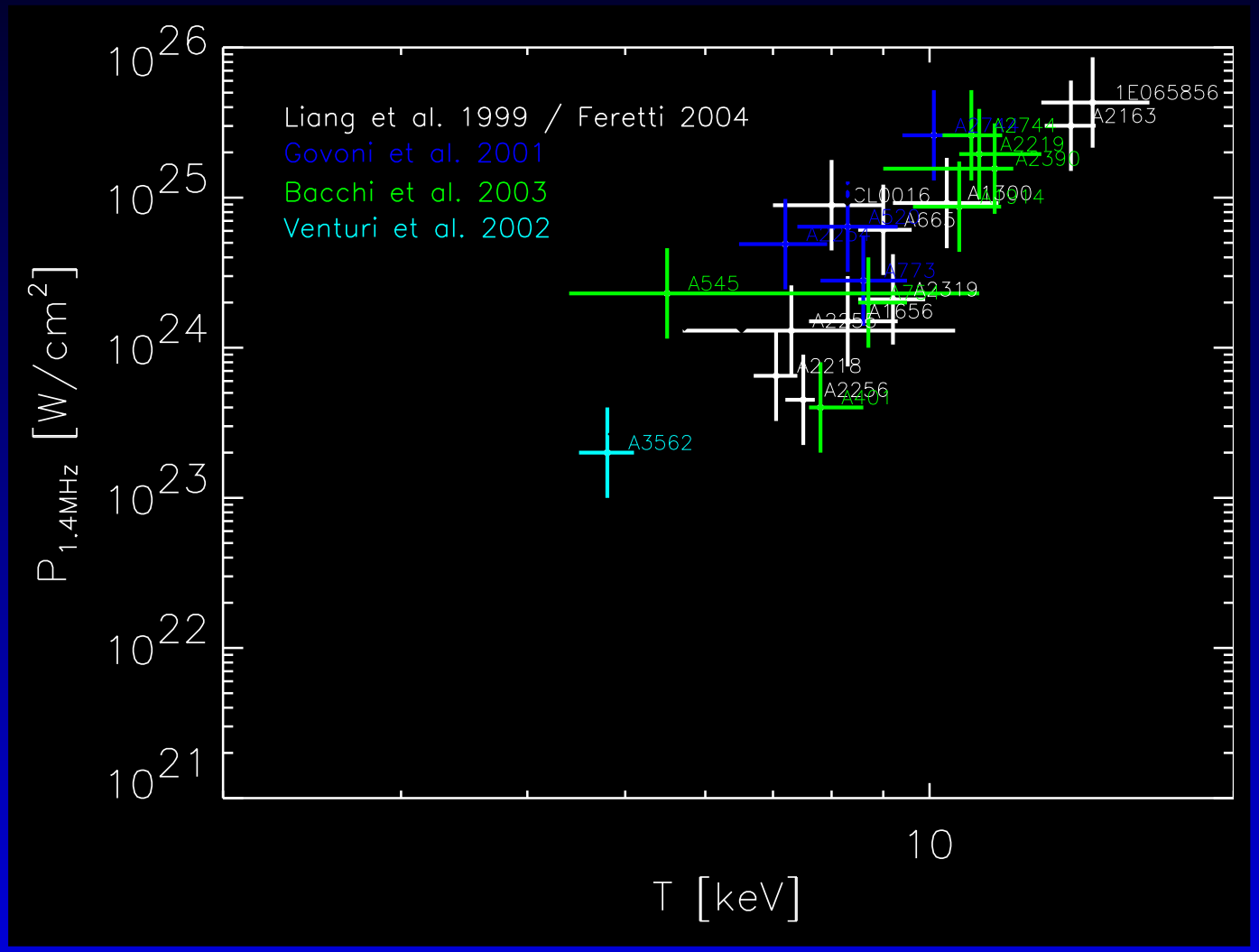
Slope of the (3D) magnetic field power spectra ($k^2 B(k)^2$) !

Comparison with Observations



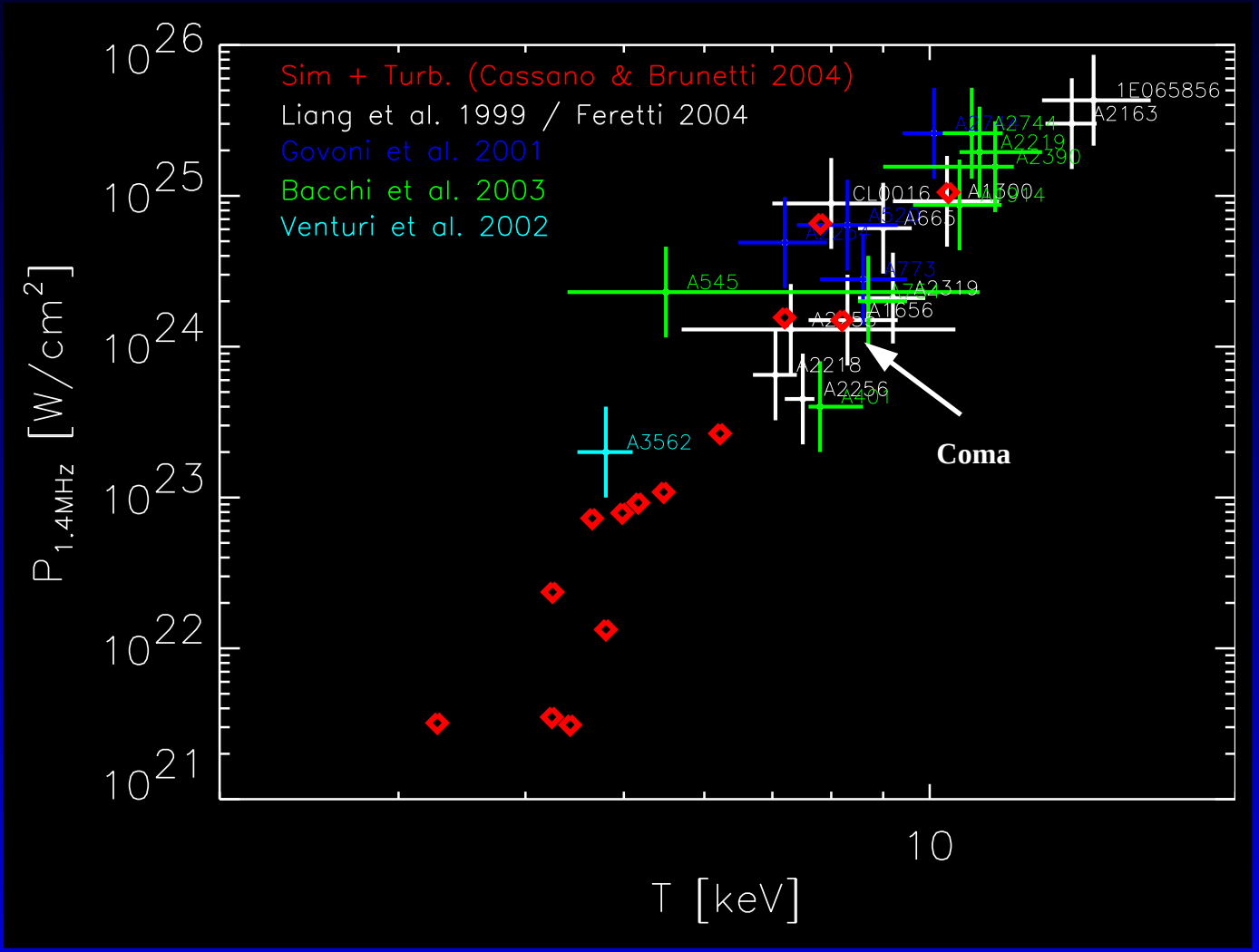
Slope of in simulated clusters reflect (past) dynamics ⇒ injection of turbulence ?

Comparison with Observations



Observed correlation between Radio Power and Cluster Temperature

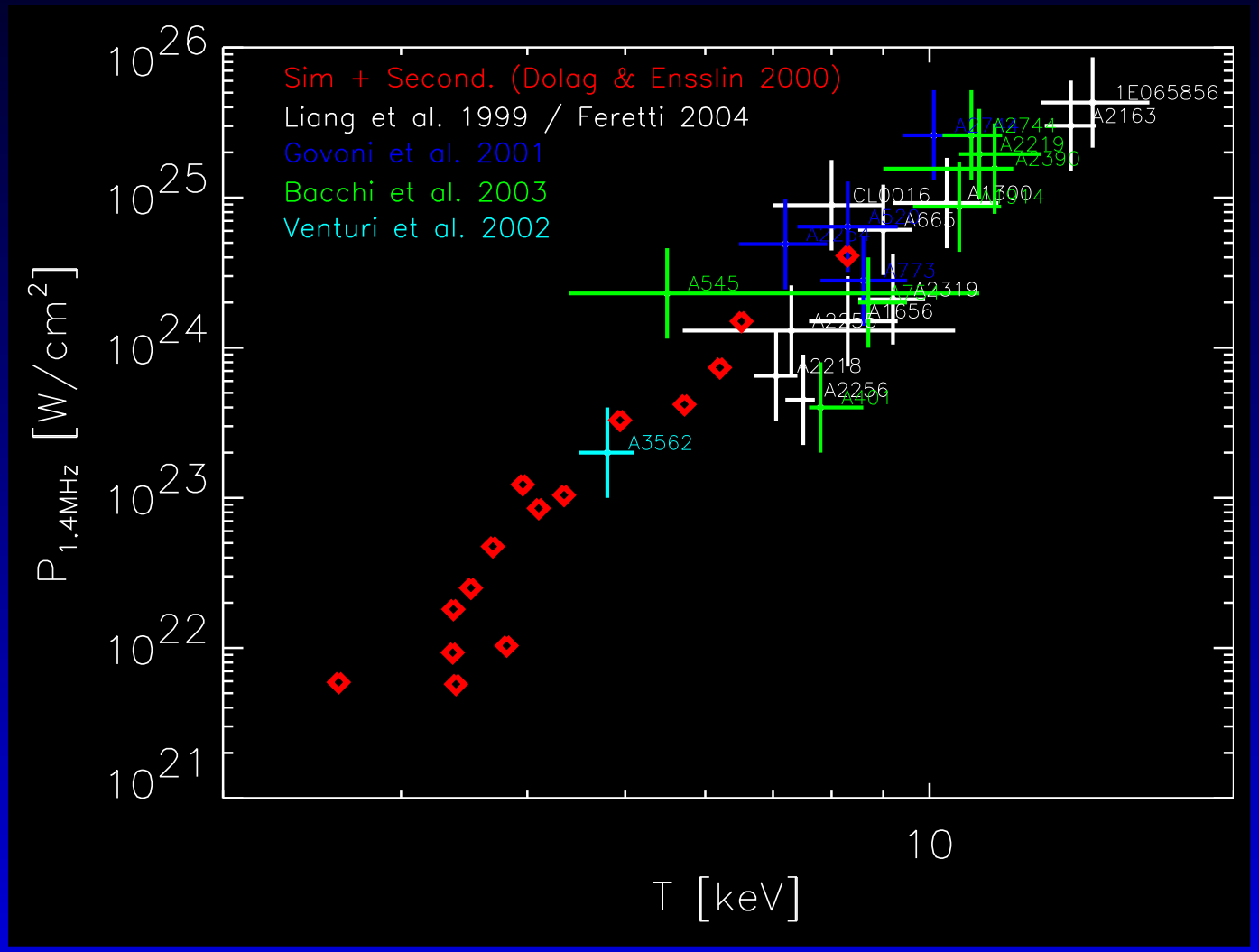
Comparison with Observations



Expected correlation using turbulent acceleration (Cassano & Brunetti 2004)

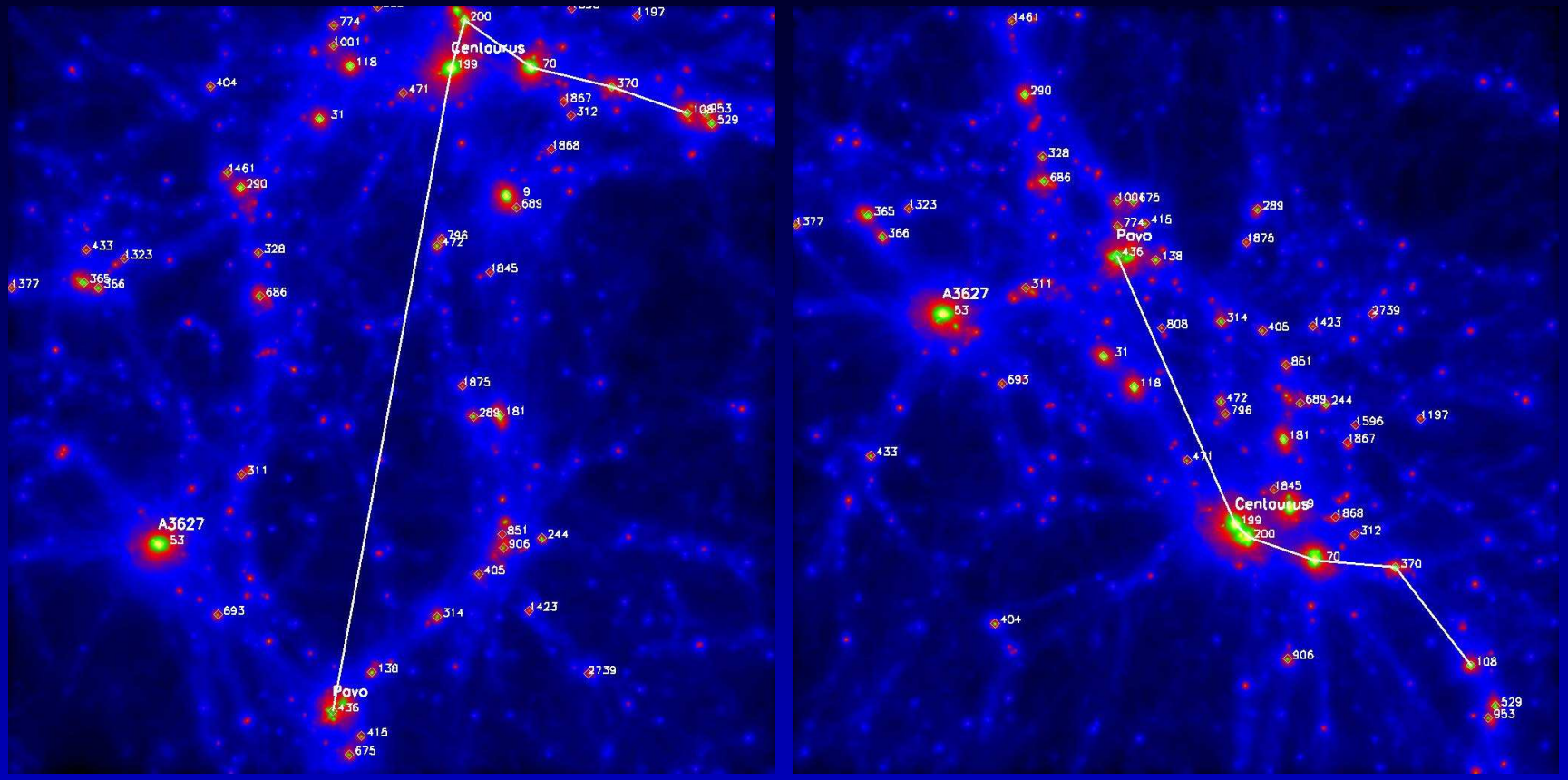
$$P \propto \frac{M_{vir}^3}{\sqrt{T_{vir}}} \frac{B_{core}^2}{B_{CMB}^2 + B_{core}^2}.$$

Comparison with Observations



Expected correlation using hadronic model (Dolag & Ensslin 2000)

Filaments

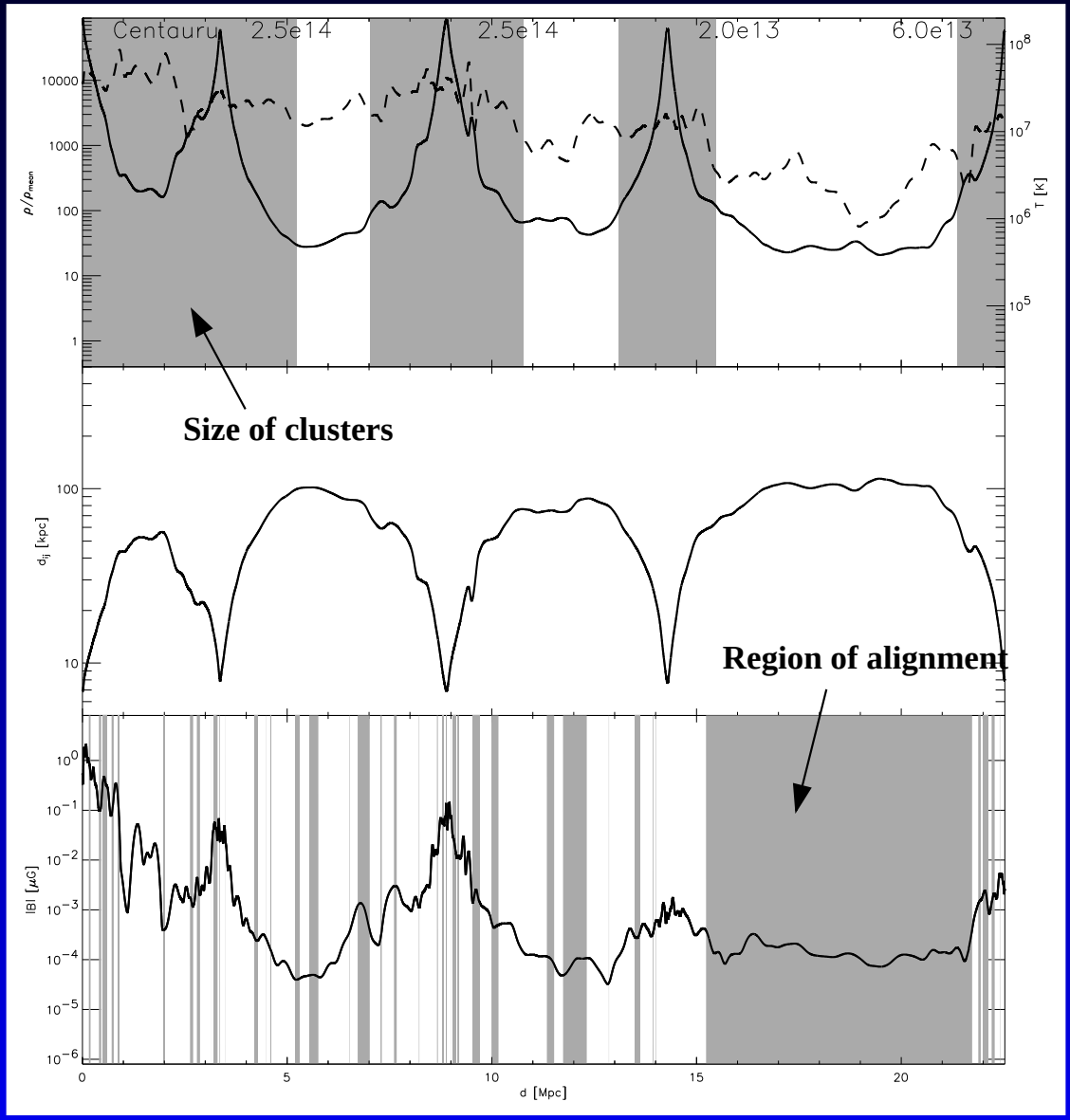


Region shown is $(50\ \mathrm{Mpc})^3$ centered between Centaurus and Pavo

Filaments and bridges between clusters, but be careful:

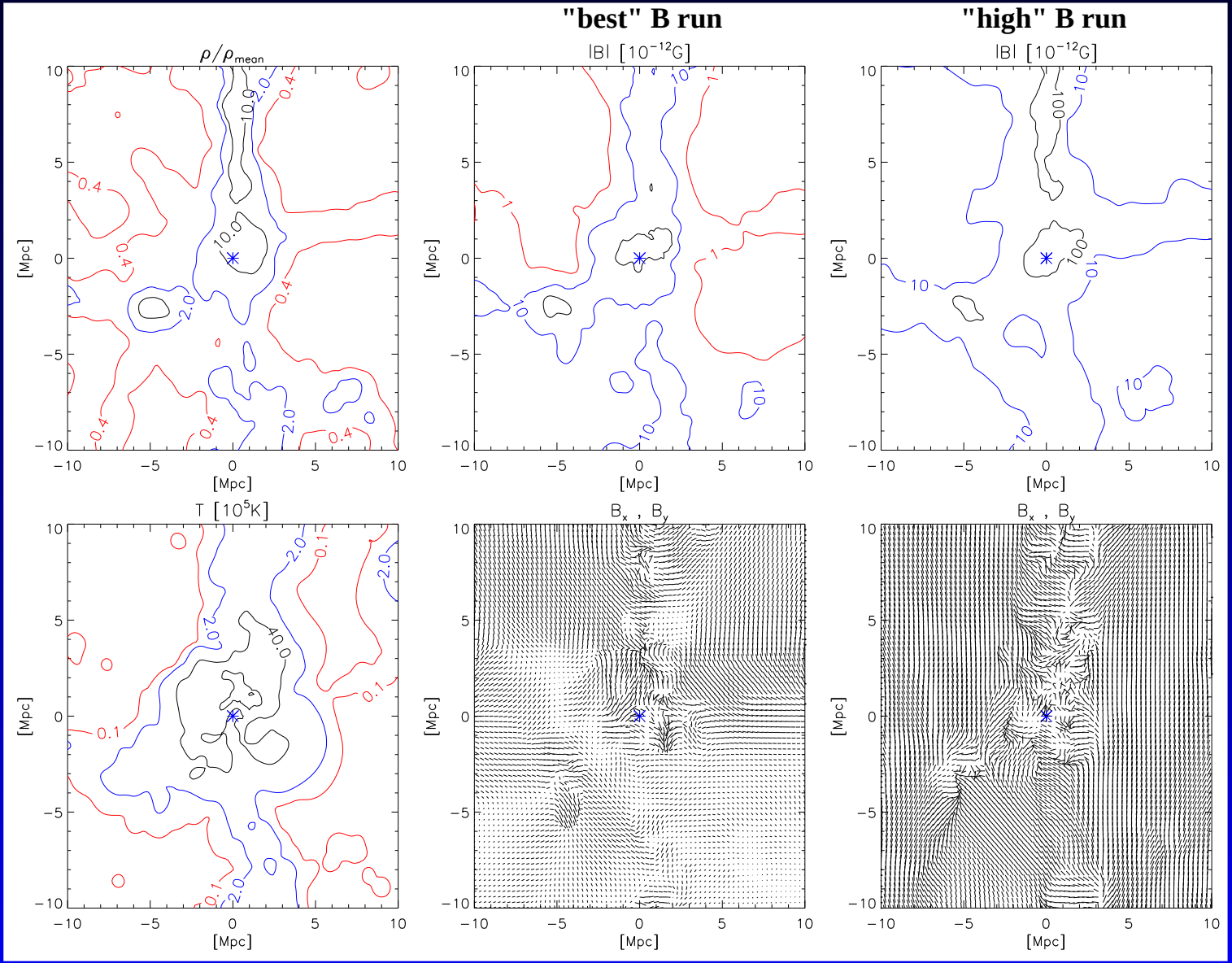
- Never straight lines !
- Always junctions of sheets !
- Sometimes projections of sheets !

Filaments



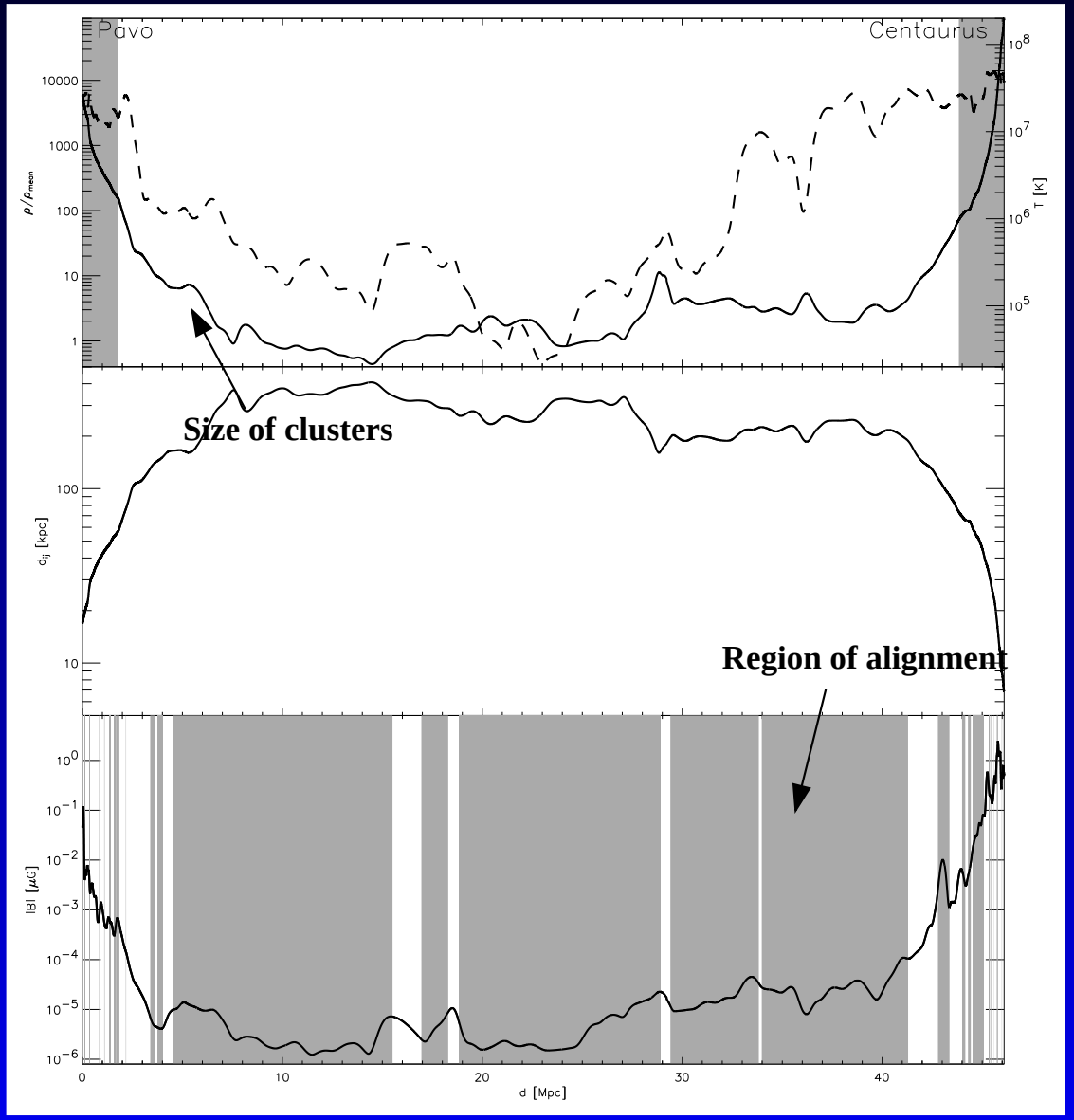
Going along a filament

Filaments



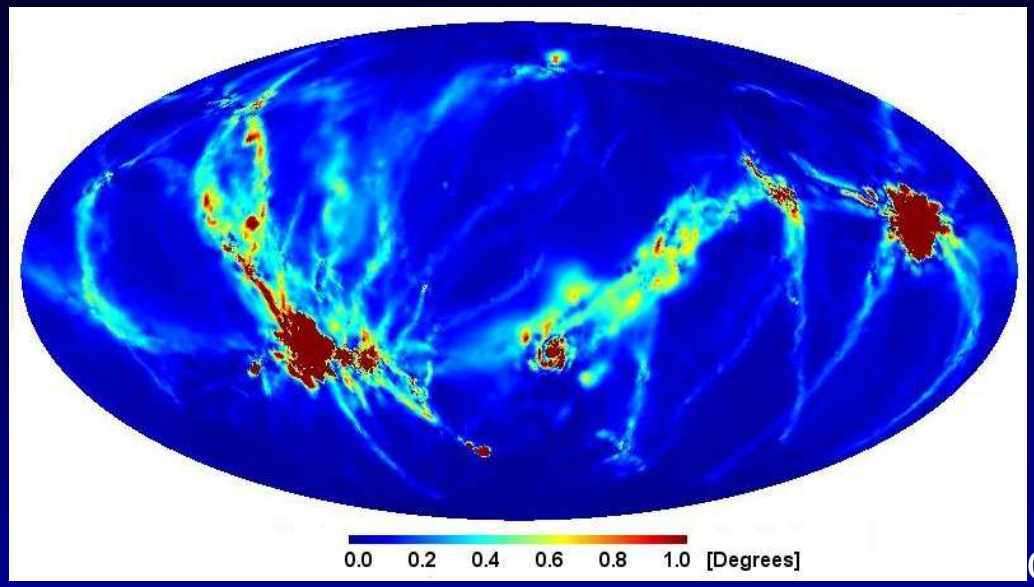
Slice perpendicular to a filament

Filaments

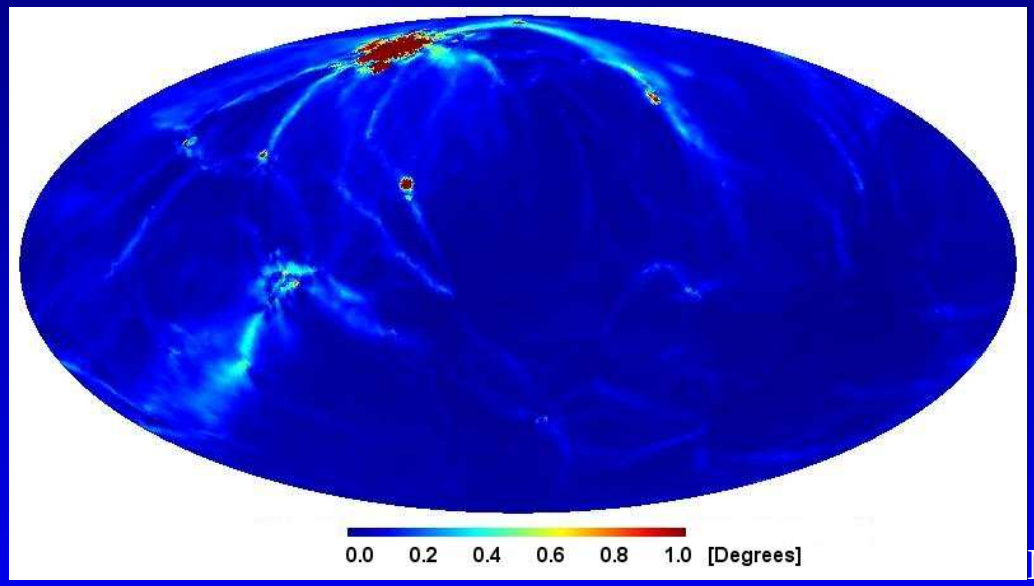


Going through a void

Full Sky Deflection Map



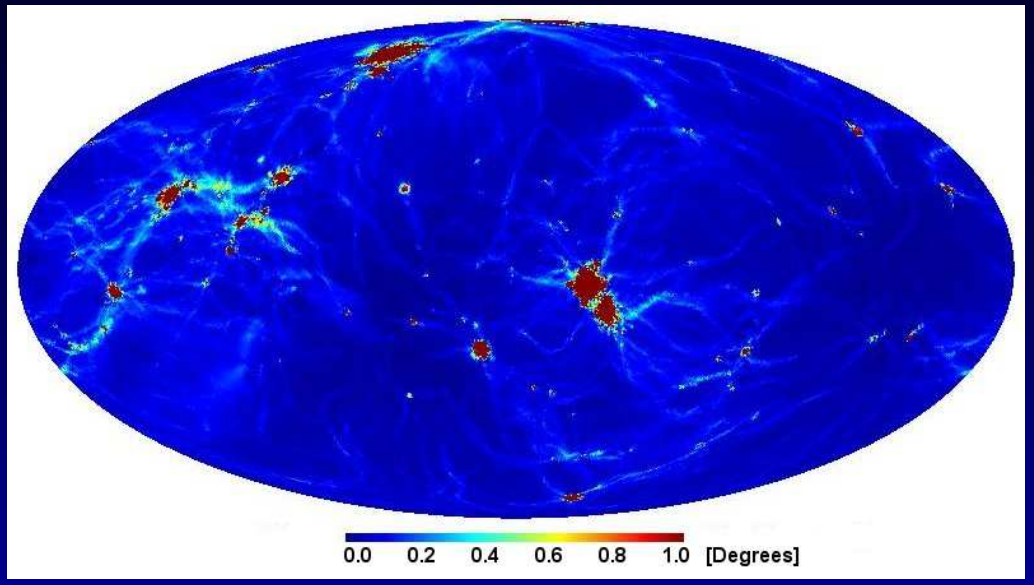
Centaurus



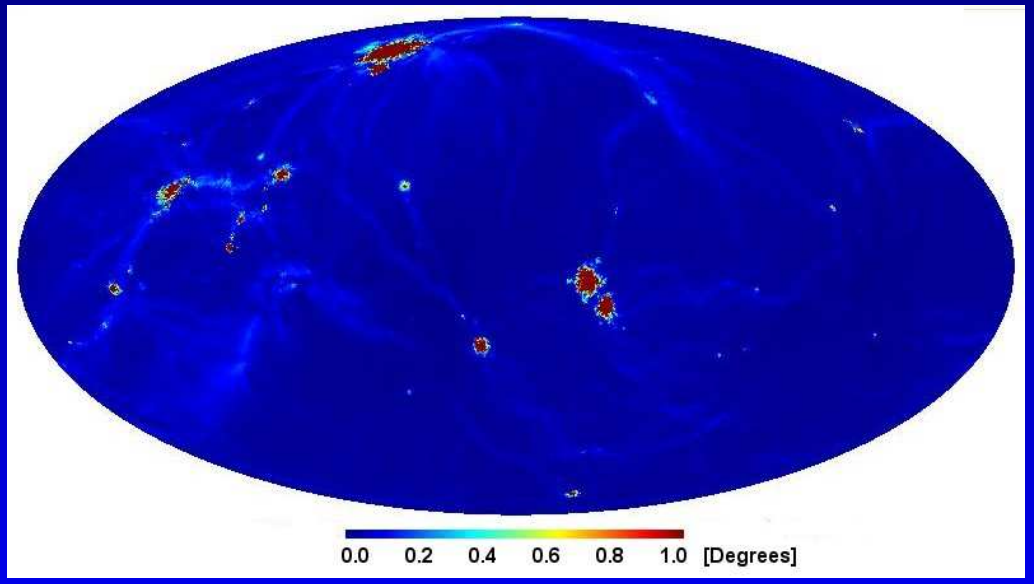
Milky Way

Full sky deflection signal for 4×10^{19}eV Cosmic Rays for two different observer position, using a sphere with radius 35Mpc.

Full Sky Deflection Map



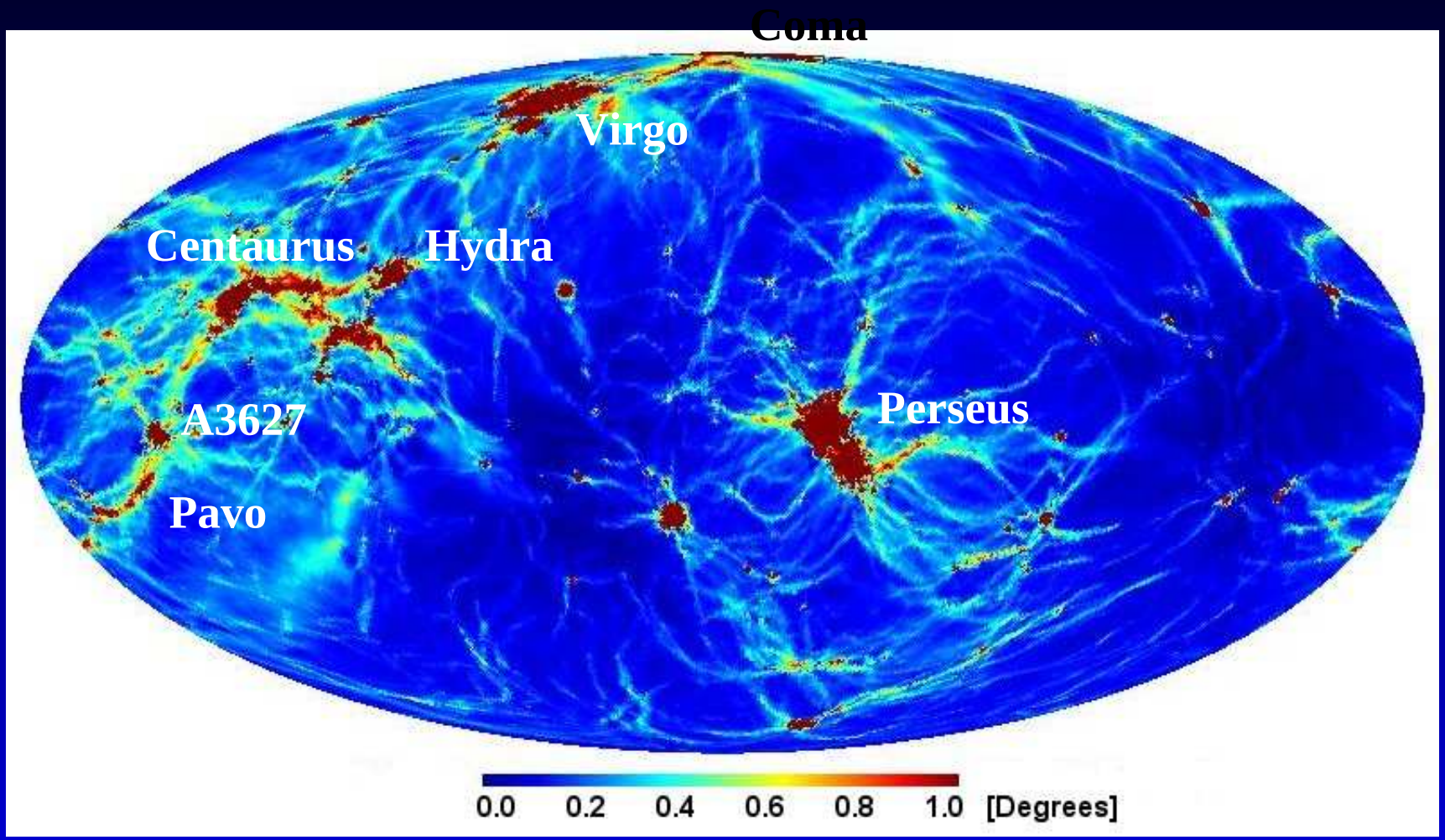
no losses



with losses

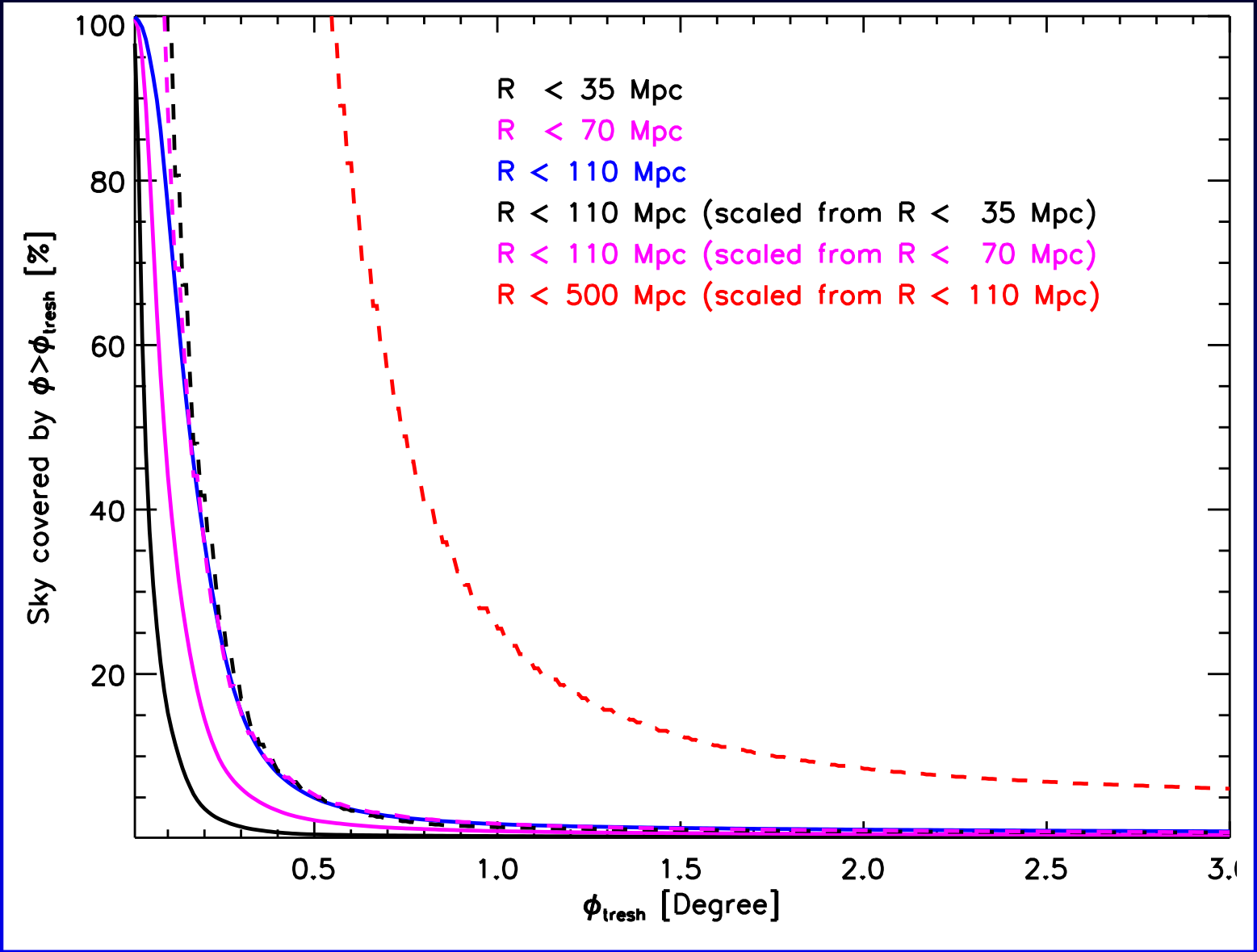
Full sky deflection signal for 1×10^{20}eV Cosmic Rays with and without losses by photo-pion production in collisions with CMB, using a sphere of 100Mpc radius.

Full Sky Deflection Map



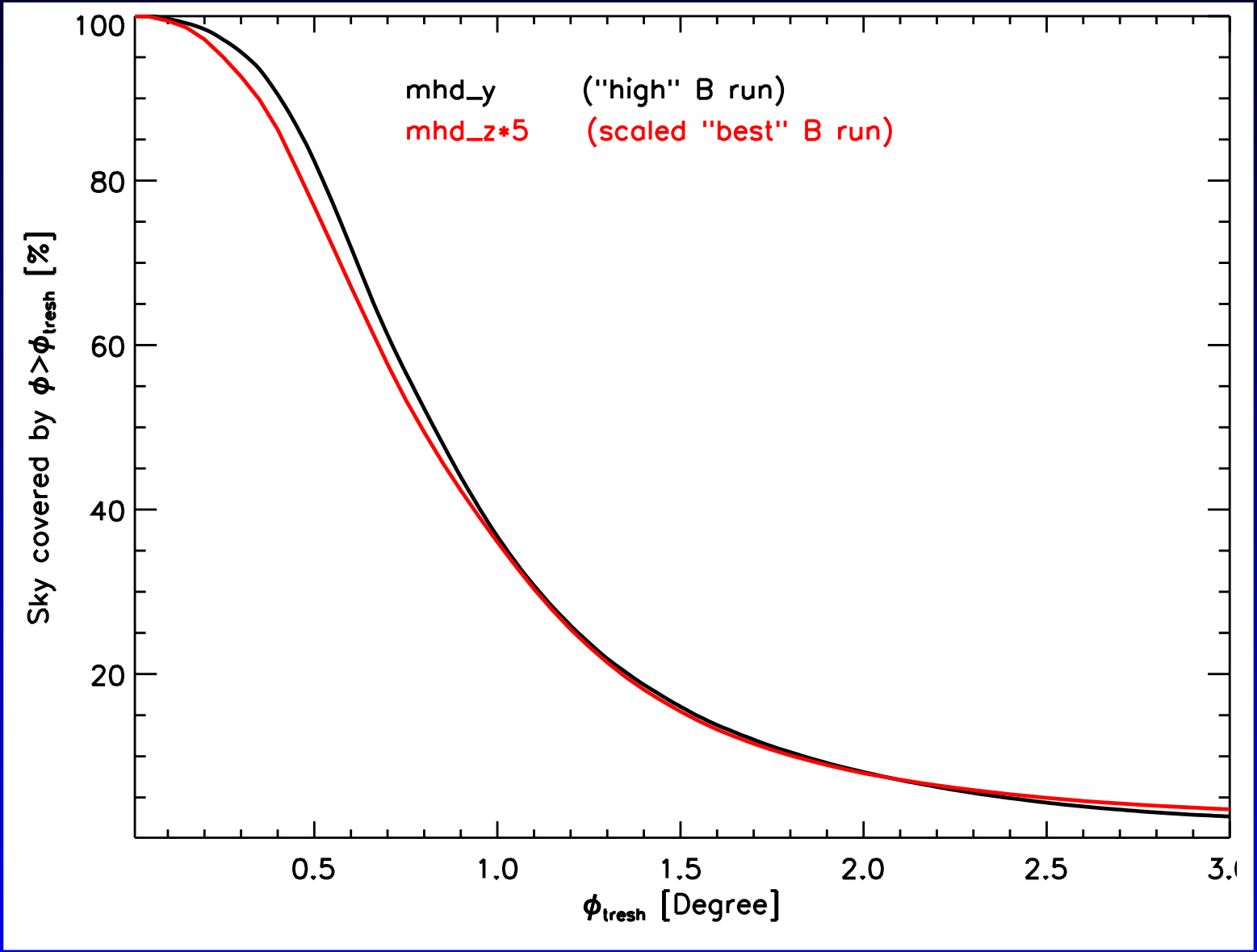
Full sky deflection signal for 4×10^{19}eV Cosmic Rays without losses, using a sphere of 110Mpc radius.

Sky coverage



Extrapolated, assuming self similarity $A(\delta_{\rm th}, d) = x^{-\beta} A_0(\delta_{\rm th} \times x^{\alpha})$,

Sky coverage



Comparing different runs using different initial field setups.

Conclusions

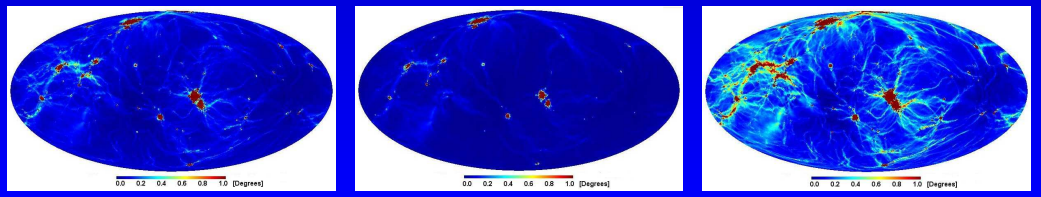
- $B_0 \approx (0.2 - 1) \times 10^{-12} \times (1+z)^2$ Gauss injected at $z > 3$ results in reasonable cluster magnetic fields.
- Simulation predicts scalings and relations which can be observational tested.

! Almost independent of details of seed creation mechanism.

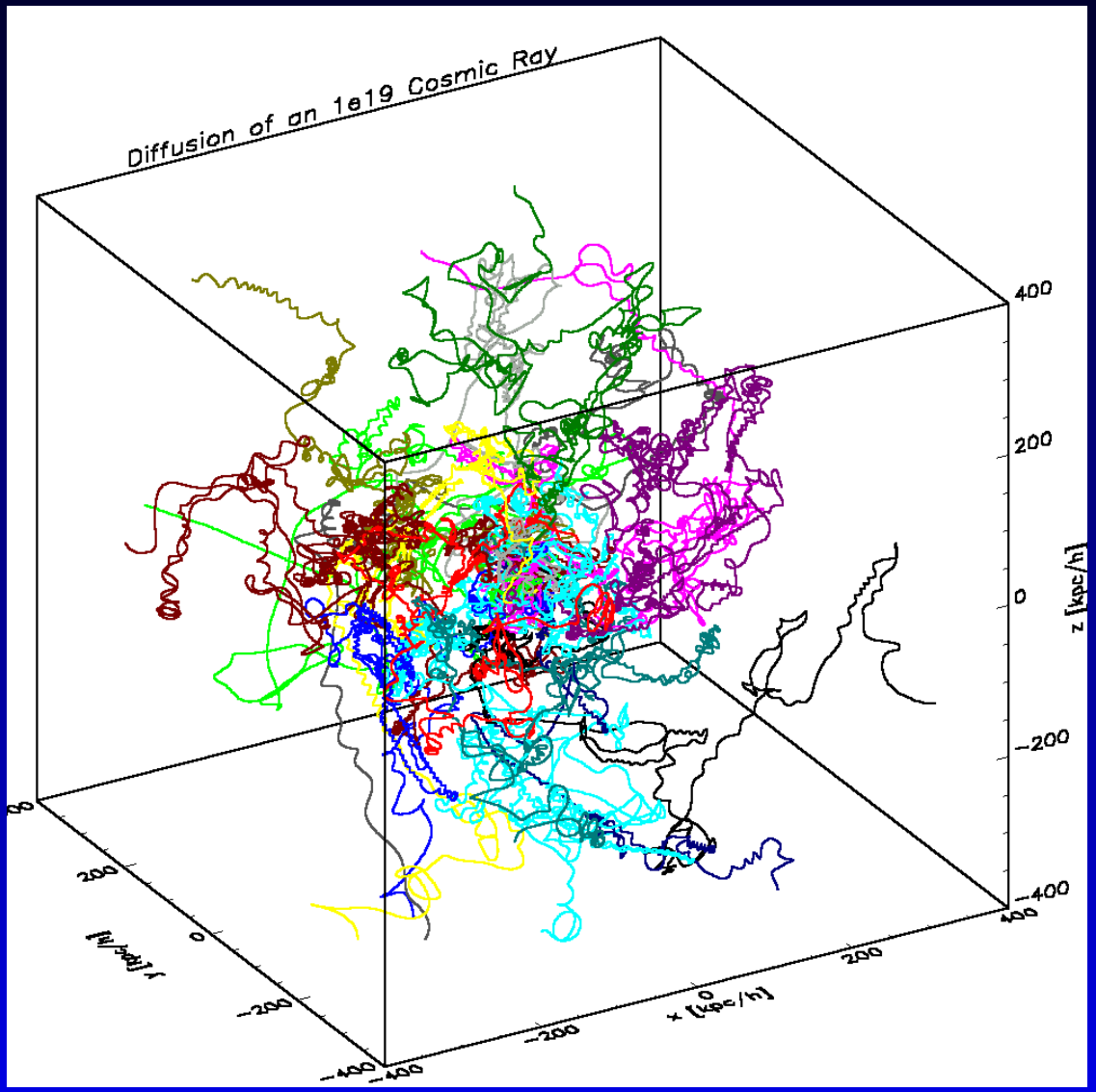
! B_0 is a robust upper limit.

! Homogenous initial seed results to upper limit in deflections by low density regions.

$\Rightarrow$ Deflections are small enough to allow pointing of sources of UHECRs with energies 4×10^{19}eV over most of the sky.



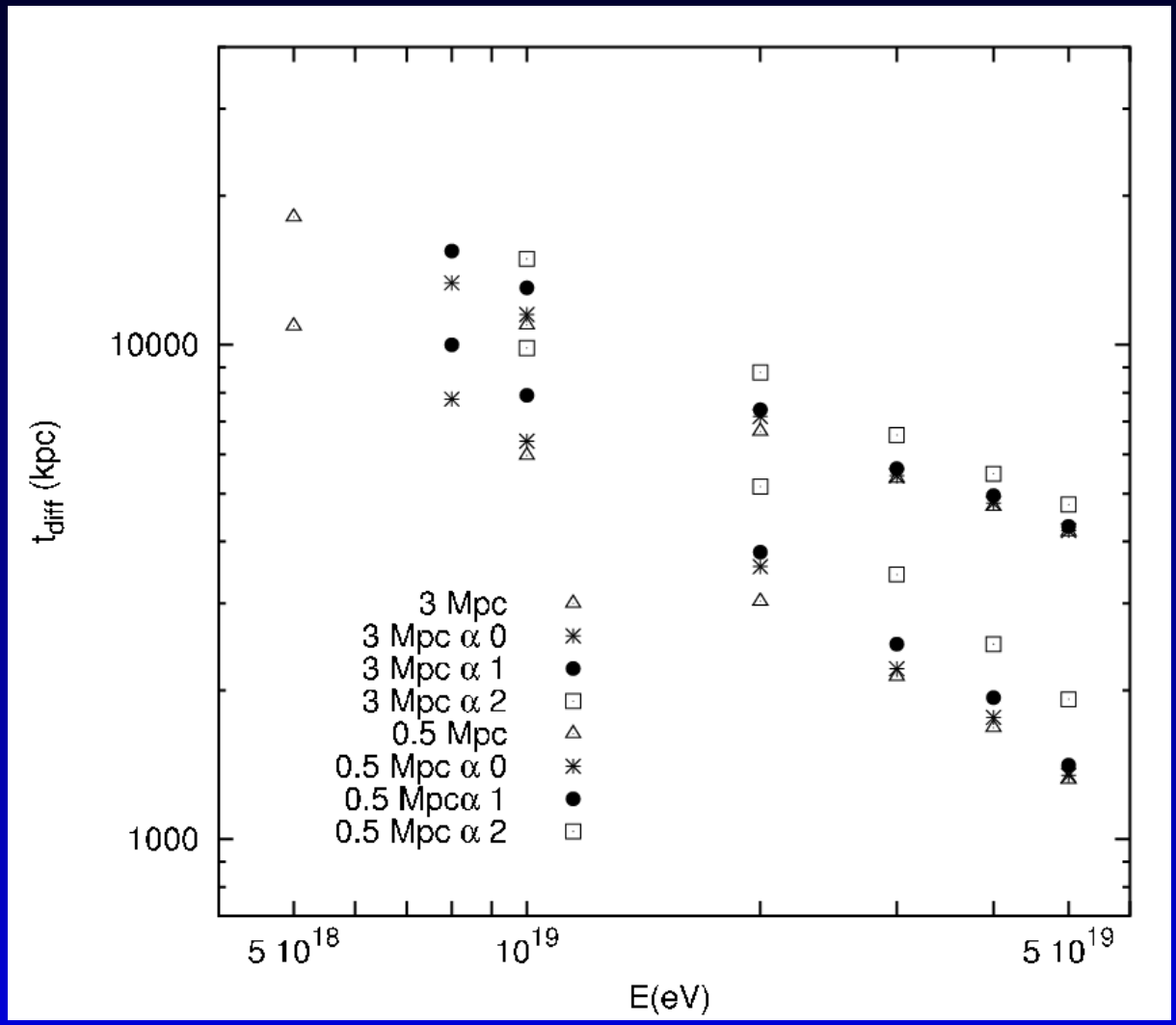
Diffusion within a Cluster



Trajectories of cosmic Rays diffusing through the cluster core.

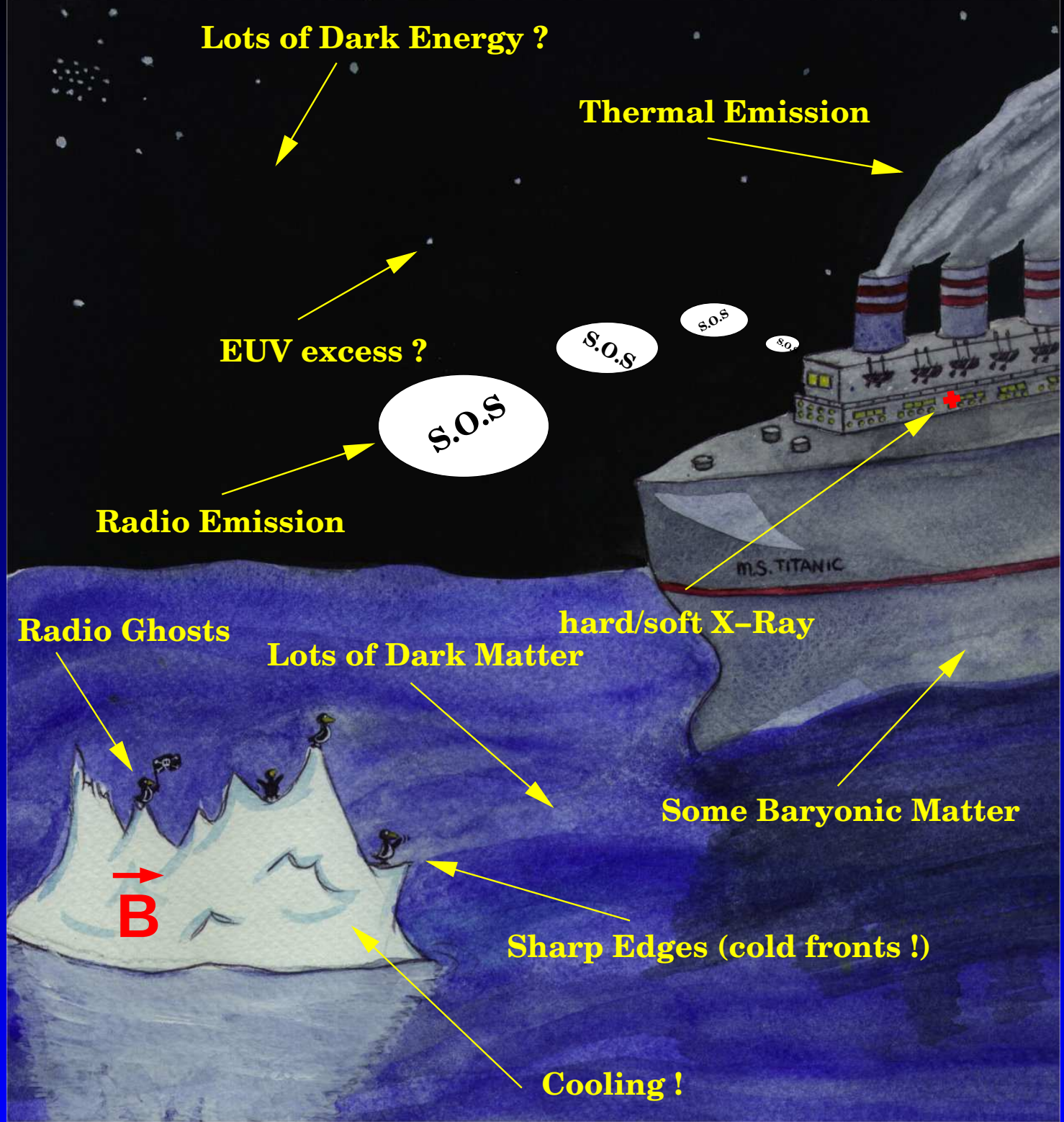
Rordorf et al. 2004

Diffusion within a Cluster

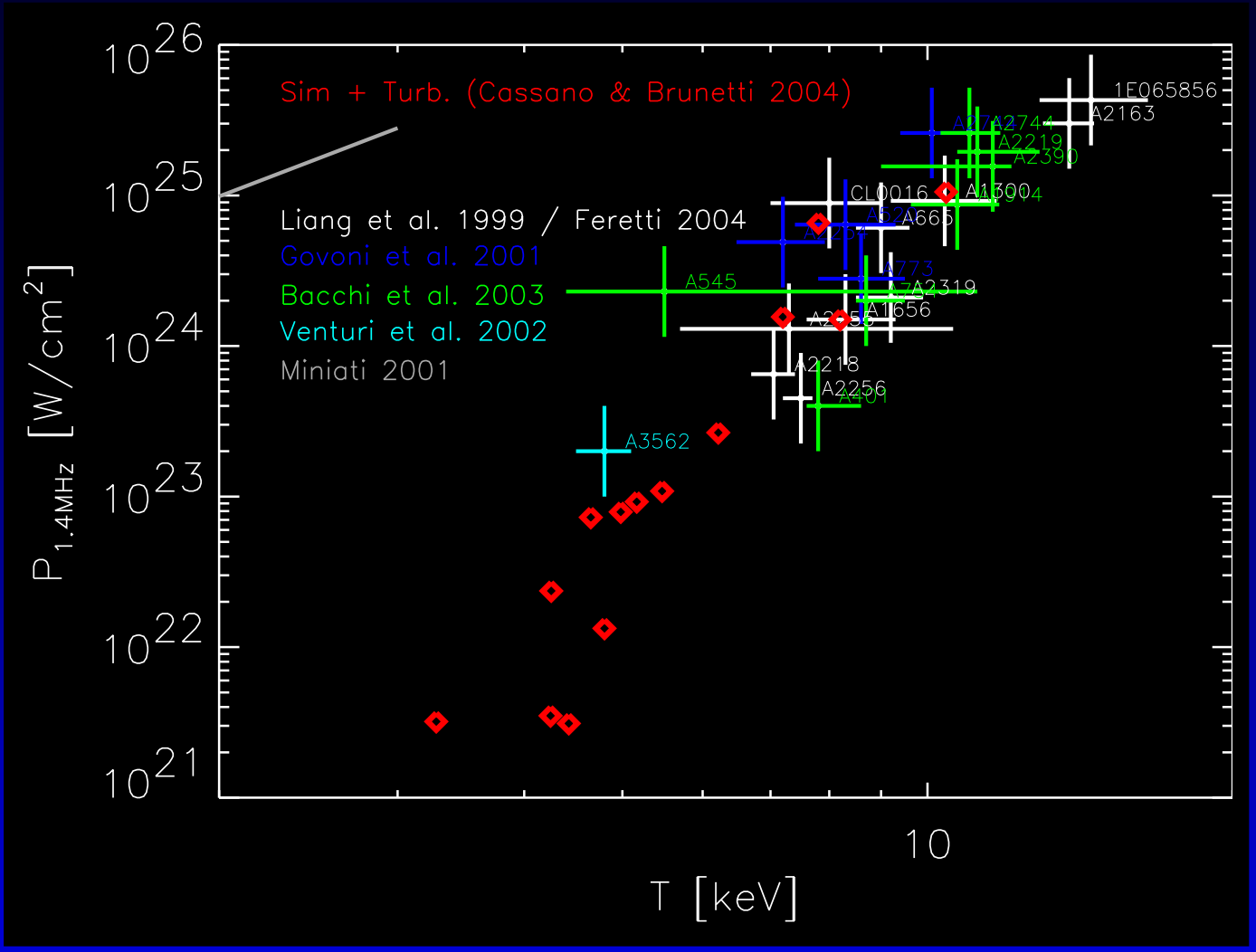


Diffusion time for Cosmic Rays with different energies to reach a distance of 0.5 and 3 Mpc from the cluster center cluster.

Rordorf et al. 2004


Lots of Dark Energy ?
Thermal Emission
EUV excess ?
S.O.S
S.O.S
S.O.S
S.O.S
Radio Emission
M.S. TITANIC
hard/soft X–Ray
Radio Ghosts
Lots of Dark Matter
Some Baryonic Matter
B
Sharp Edges (cold fronts !)
Cooling !

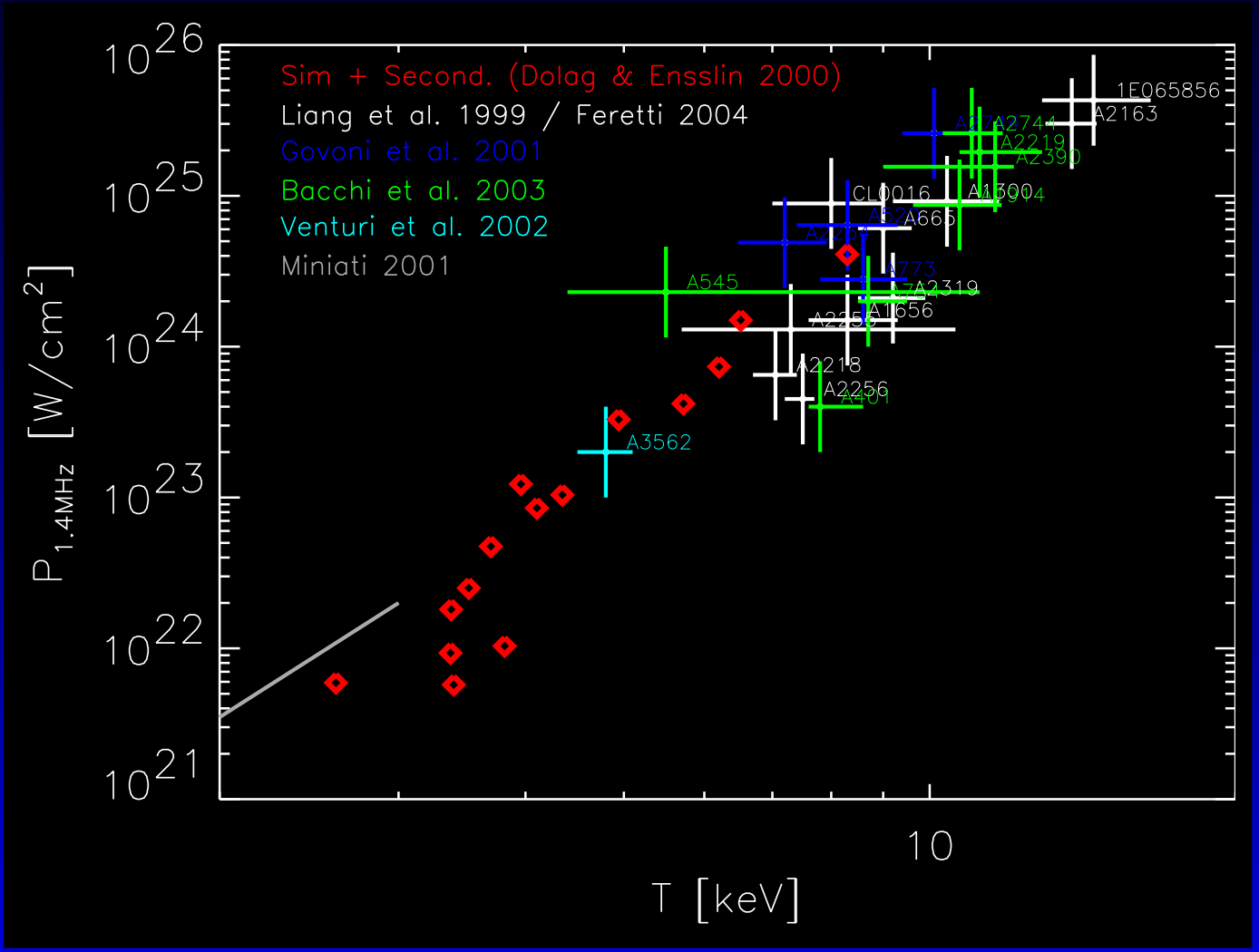
Comparison with Observations



Expected correlation using turbulent acceleration (Cassano & Brunetti 2004)

$$P \propto \frac{M_{vir}^3}{\sqrt{T_{vir}}} \frac{B_{core}^2}{B_{CMB}^2 + B_{core}^2}.$$

Comparison with Observations



Expected correlation using hadronic model (Dolag & Ensslin 2000)