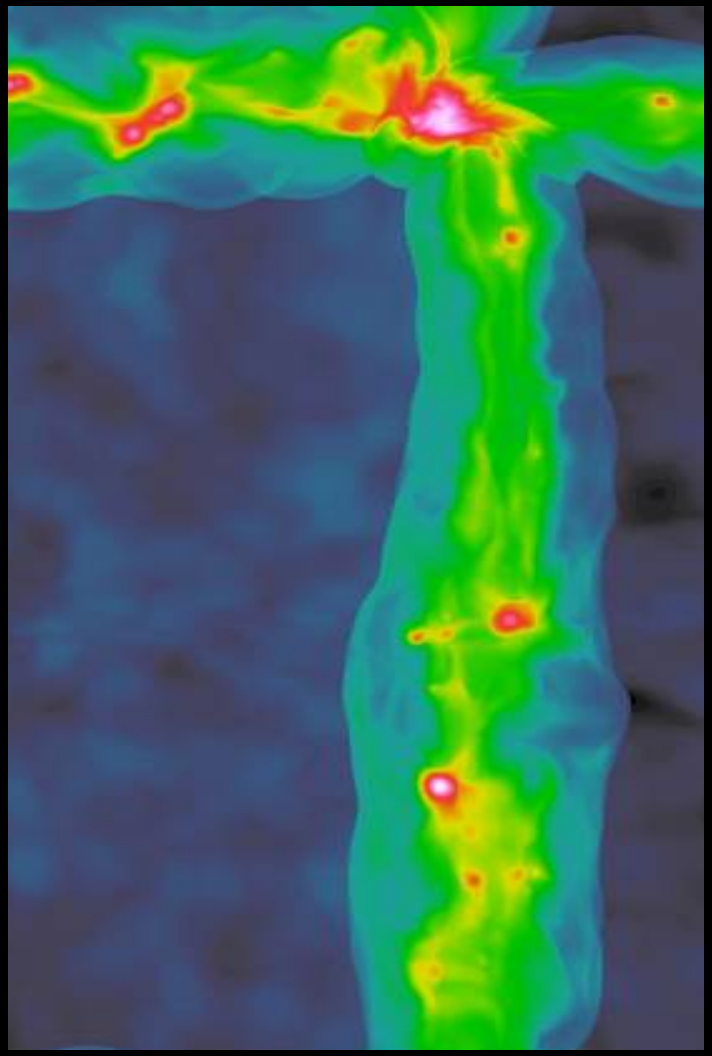
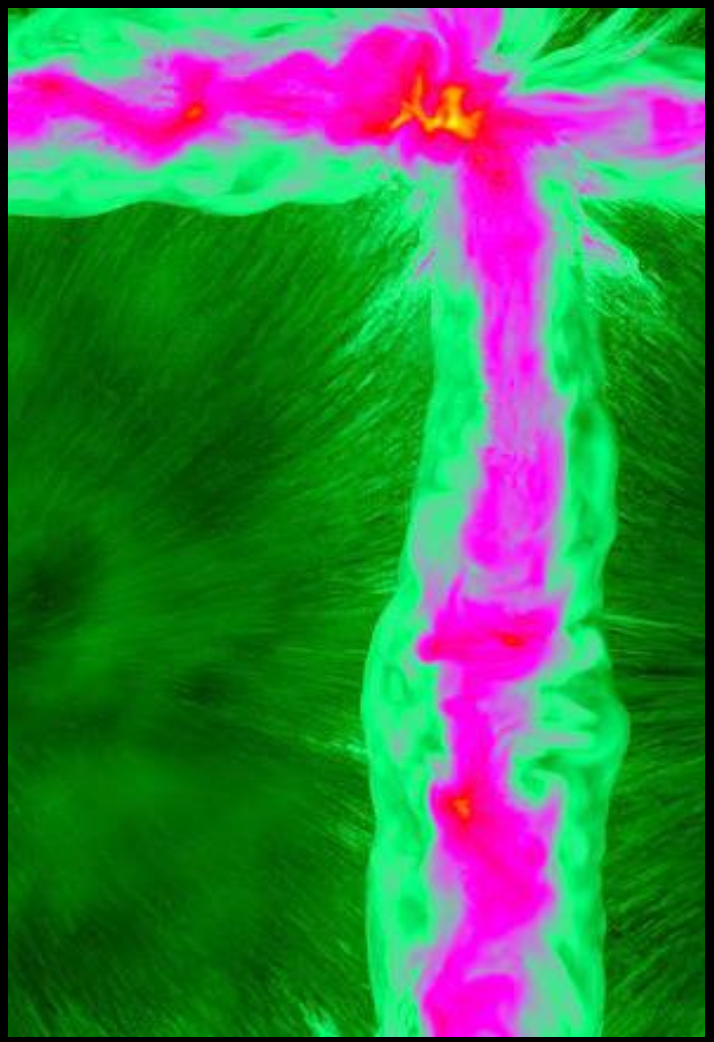
Cosmic magnetic fields and the propagation of UHECR





F.Vazza, 31/01/2014

Scientific case:

Can we "see" the Cosmic Web using its magnetic properties?

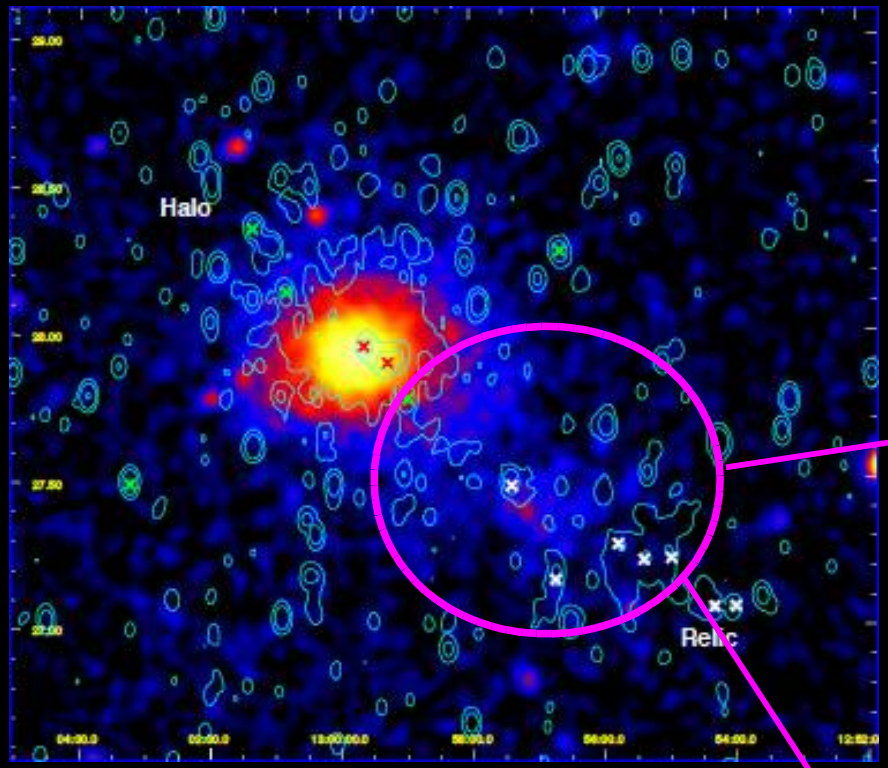
- The magnetic field is a fundamental unknown for many effects:

  - synchrotron emission from relativistic electrons of the WHIM $P \quad \nu_{XP,\varepsilon} \quad B^2$

  - Faraday Rotation measure $RM \quad \nu_{\gamma\alpha\sigma} \quad B(k)/k^{1/2}\, dk$

  - Deflection of UHECR $B(k)/k^{1/2}\, dk$

Measurement of B*n along one filament(?) connecting to COMA

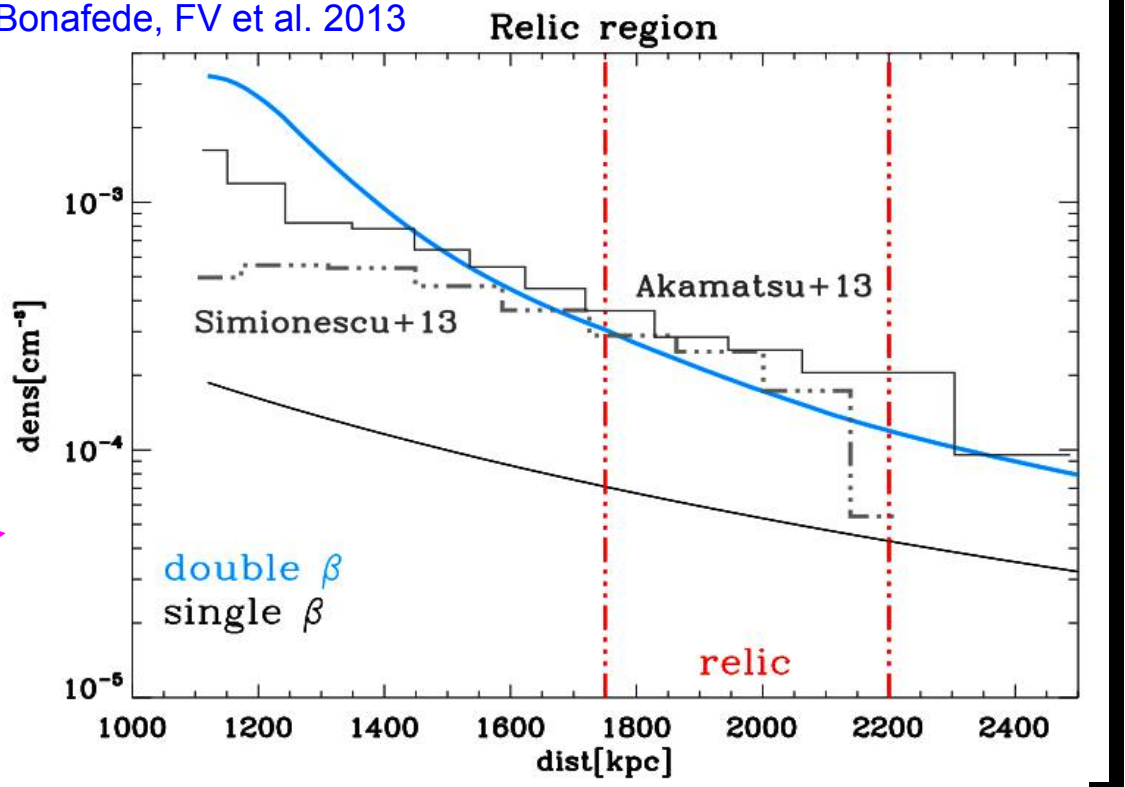


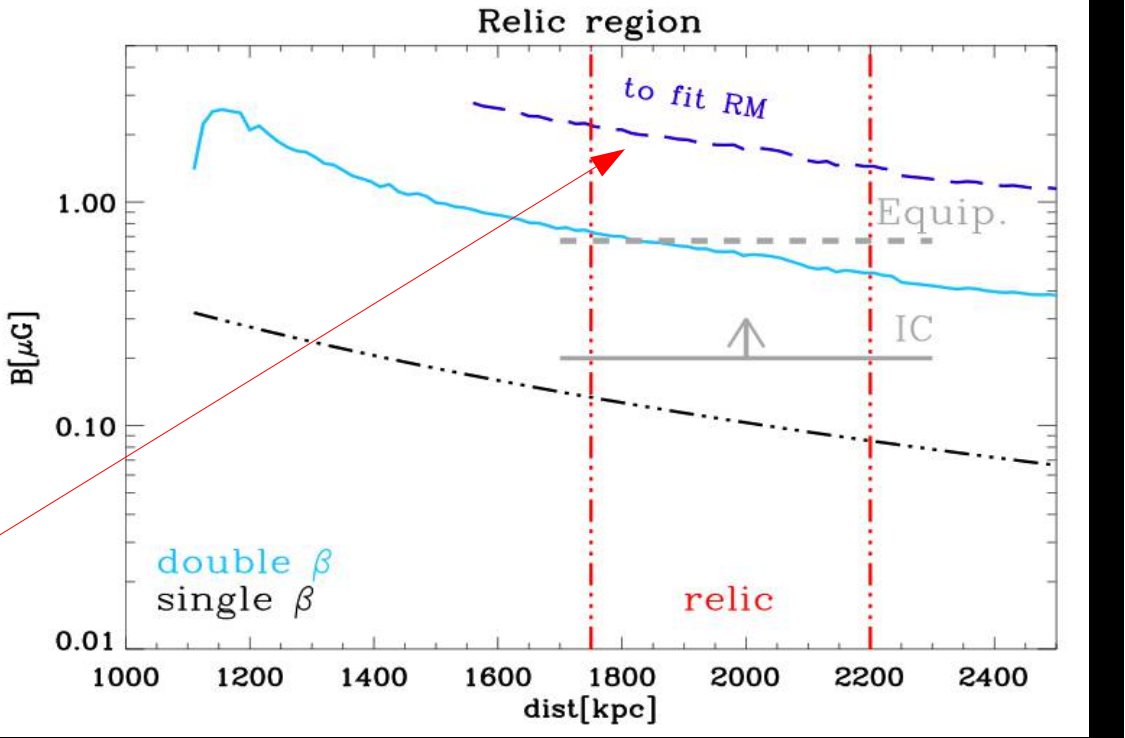
$$RM \equiv \frac{\partial \psi}{\partial \lambda^2} \propto \int_0^d n_e H \cos\vartheta \, dl$$

- Our density model is a factor 2 below the latest X-ray measurements

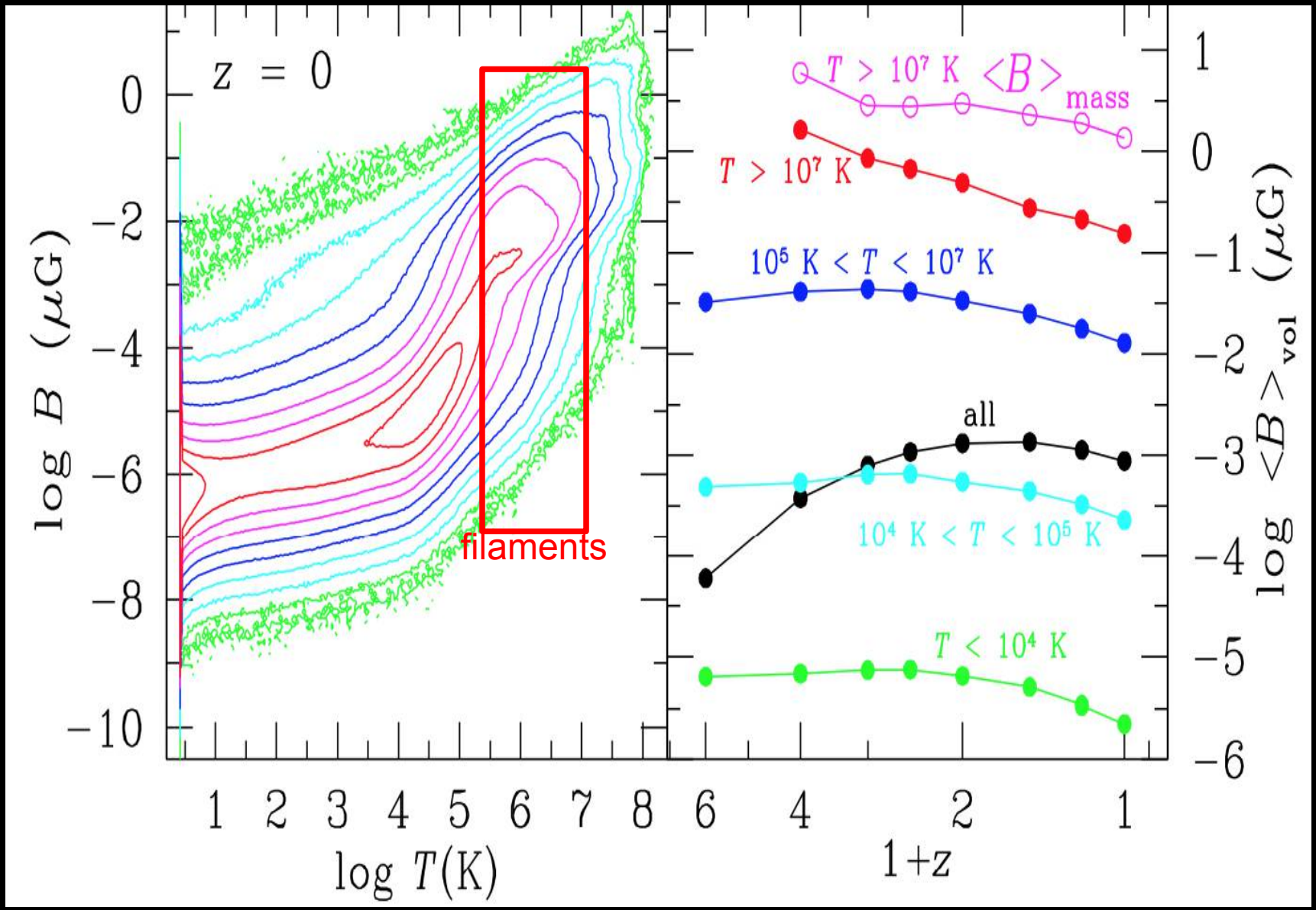
- The magnetic field in the relic region should be 2 Γ

Bonafede, FV et al. 2013





How can we explain 2 Γ in a filament?
Is this a positive bias of observations?



Ryu et al.2008 - Estimate of B-field from turbulent dynamo in LSS

Some recent large cosmological simulations (unigrid)

2048^3
ENZO + Cosmic Rays
(no MHD)

FV, Gheller, Brüggen
2014 MNRAS

1.8 Million cpuh

Prace Project:

CURIE @ GENCI
Daint @ CSCS

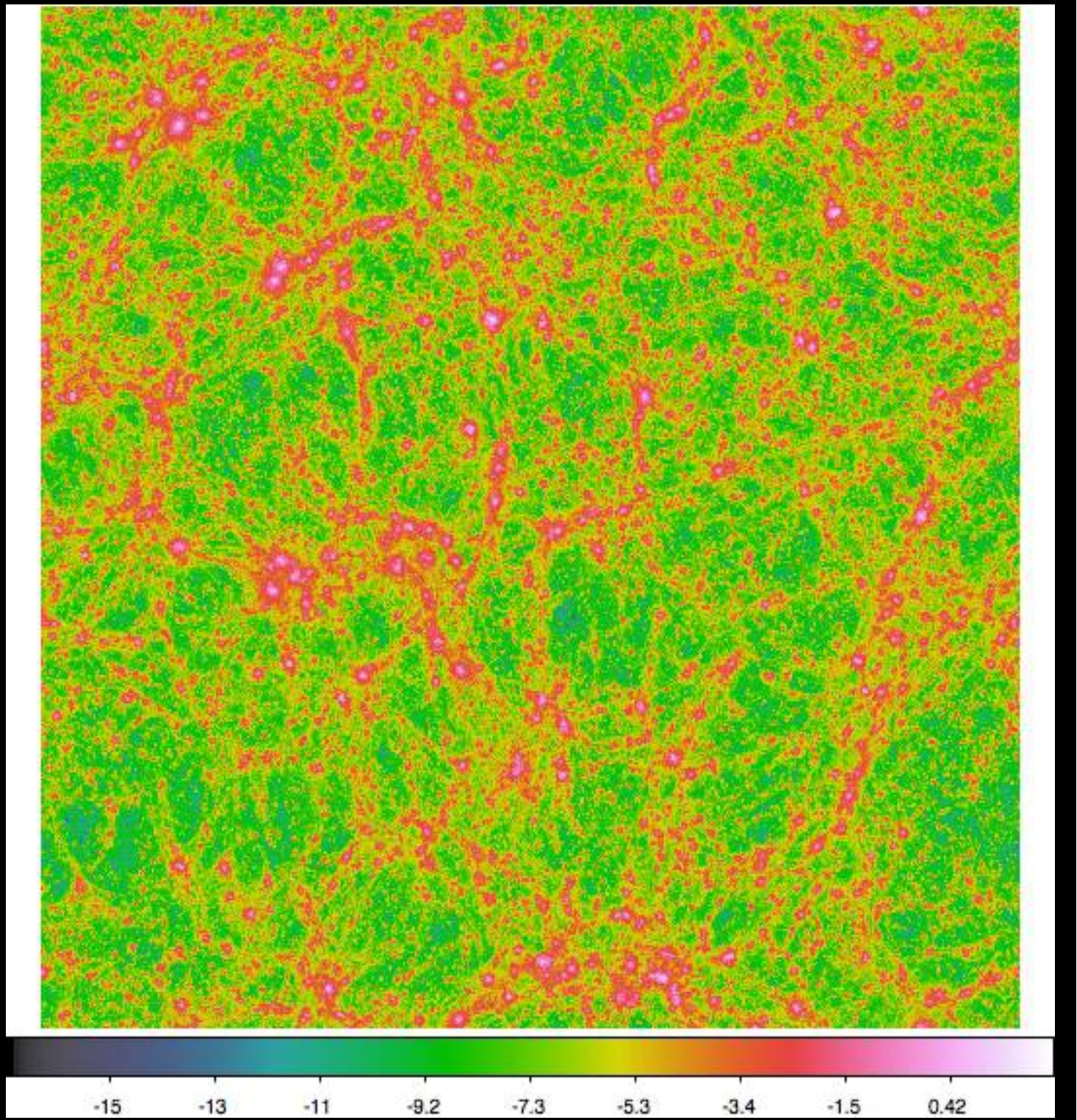
300 Mpc

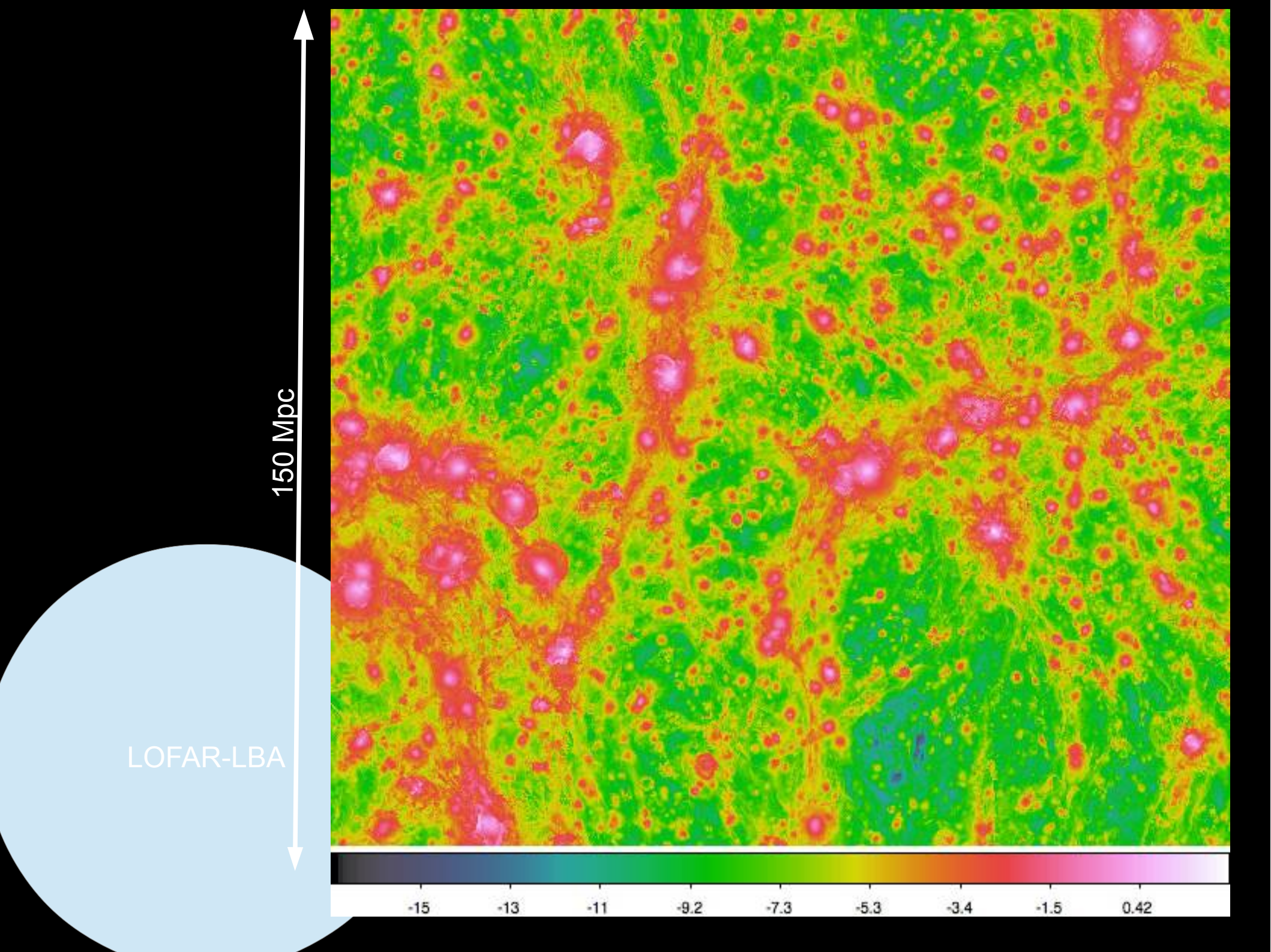
Synchrotron emission from the cosmic web (secondary + primary electrons)

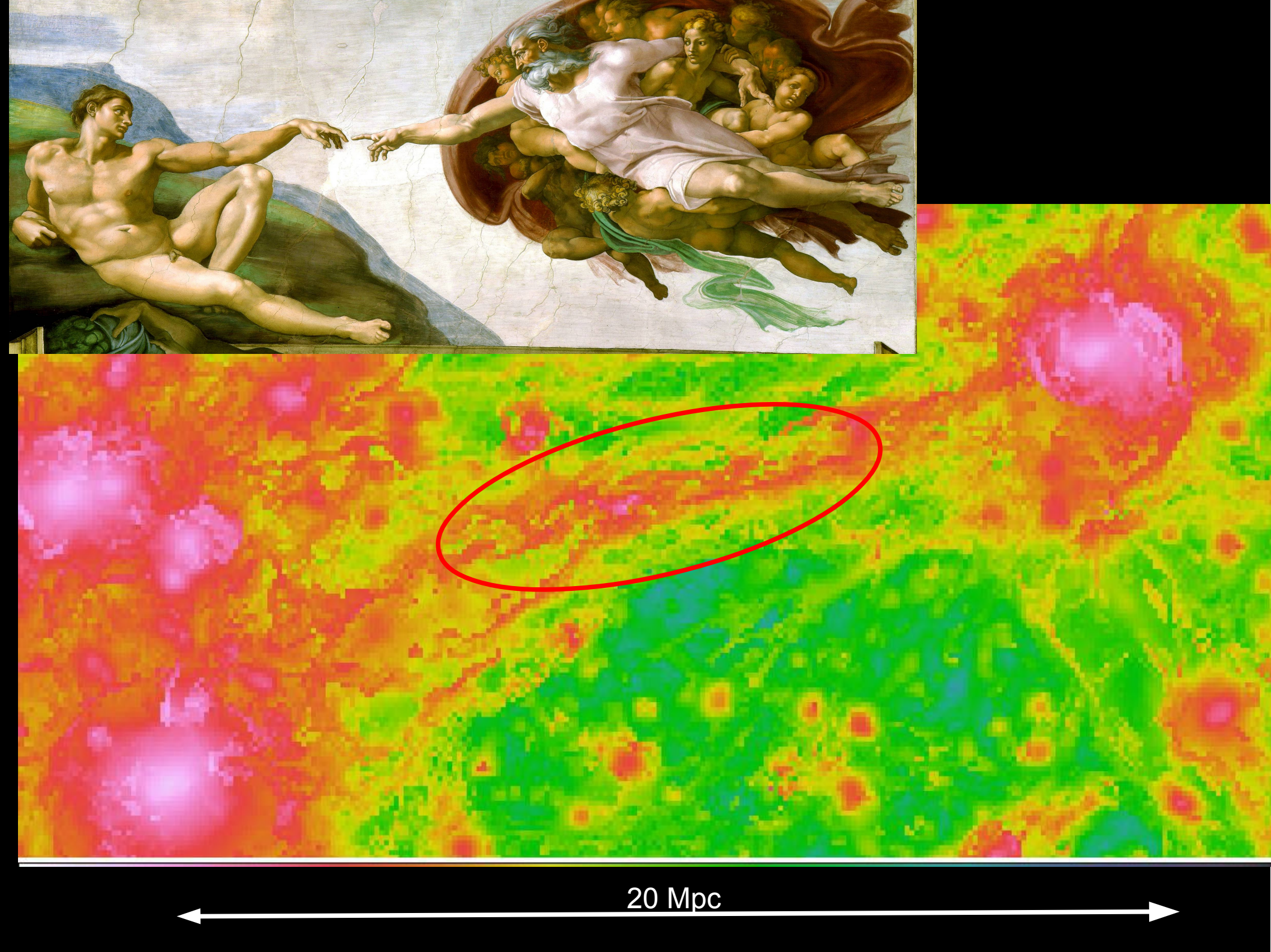
~45° @ z=0.1

300 Mpc

LOFAR-LBA

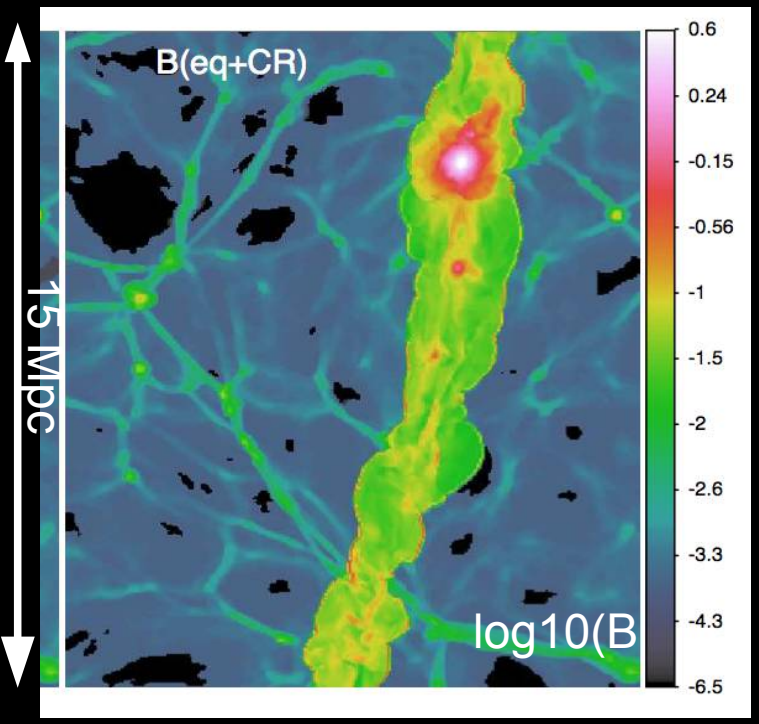



150 Mpc
LOFAR-LBA
-15
-13
-11
-9.2
-7.3
-5.3
-3.4
-1.5
0.42

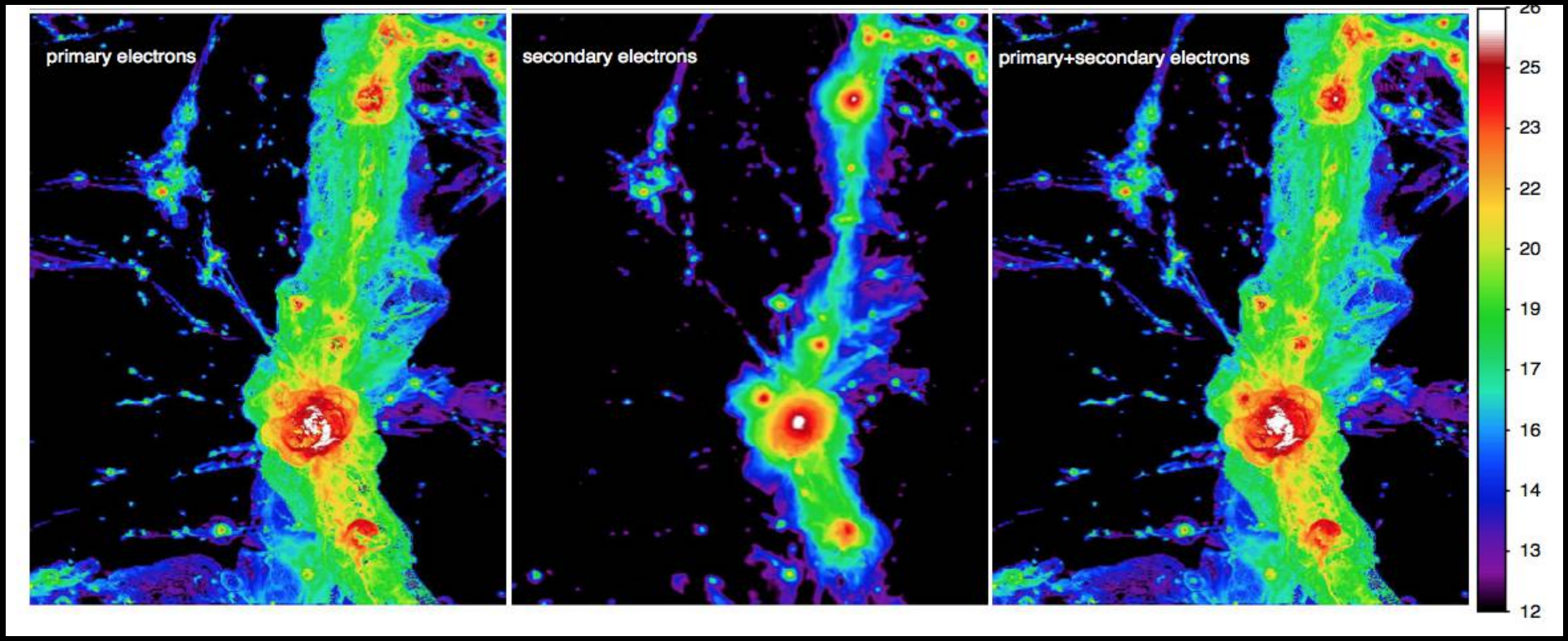

20 Mpc

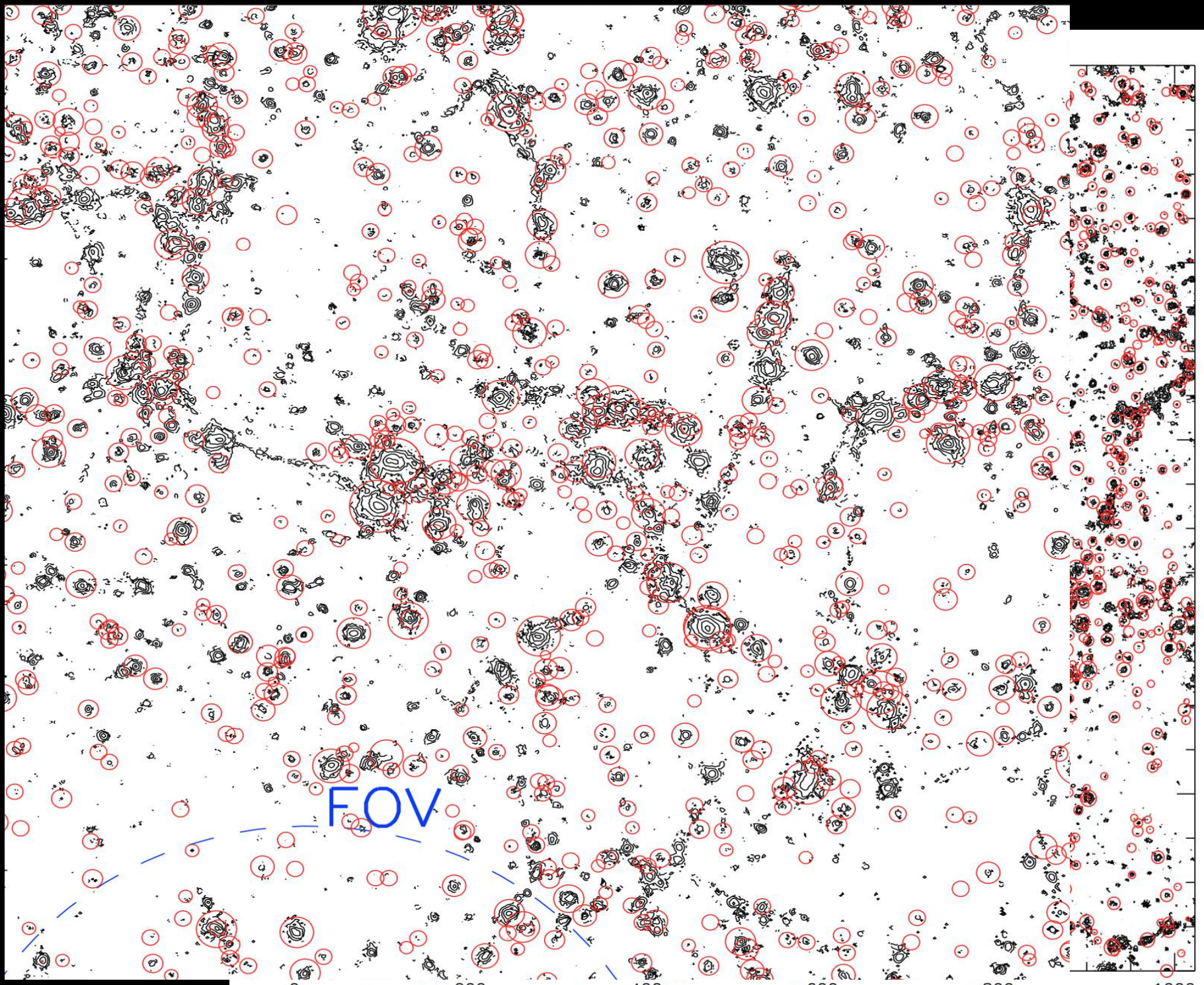
Can we (already) observe filaments in radio (FV,Ferrari,Brüggen,Bonafede...)

- If B>0.3 Γ we should have already detected filaments with LOFAR
- SKA-LOW – LOFAR-LBA can be near to detect the largest filaments if B is no far from equipartition (0.1 Γ)and the electrons are accelerated as in SNR



Radio emission




FOV
0
200
400
600
800
1000

How efficient is the turbulent dyanmo amplification in filaments?

→ Not a trivial numerical problem: resolution is the issue.

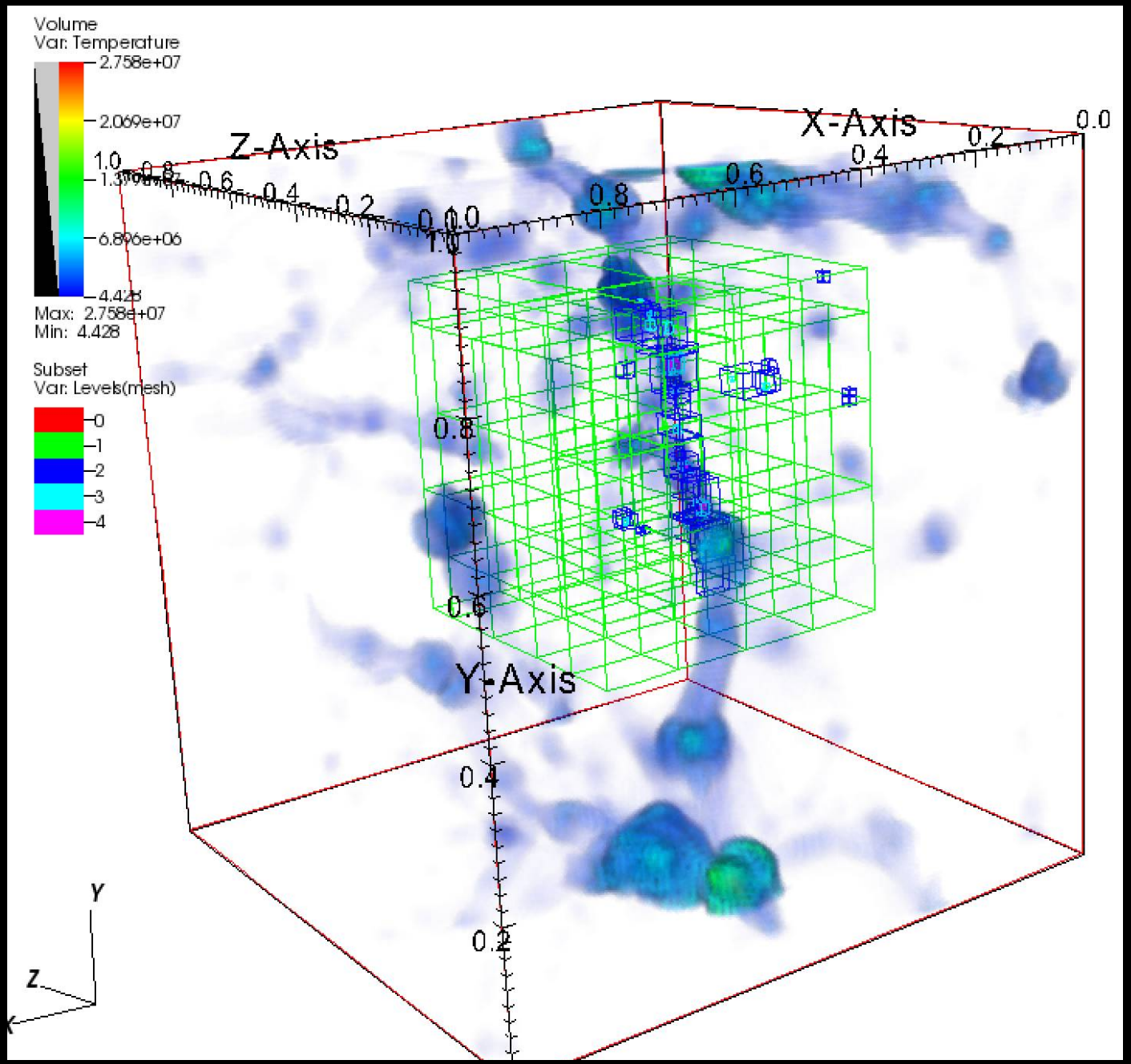
- Some Adaptive Mesh refinement runs with:
- -nested grid

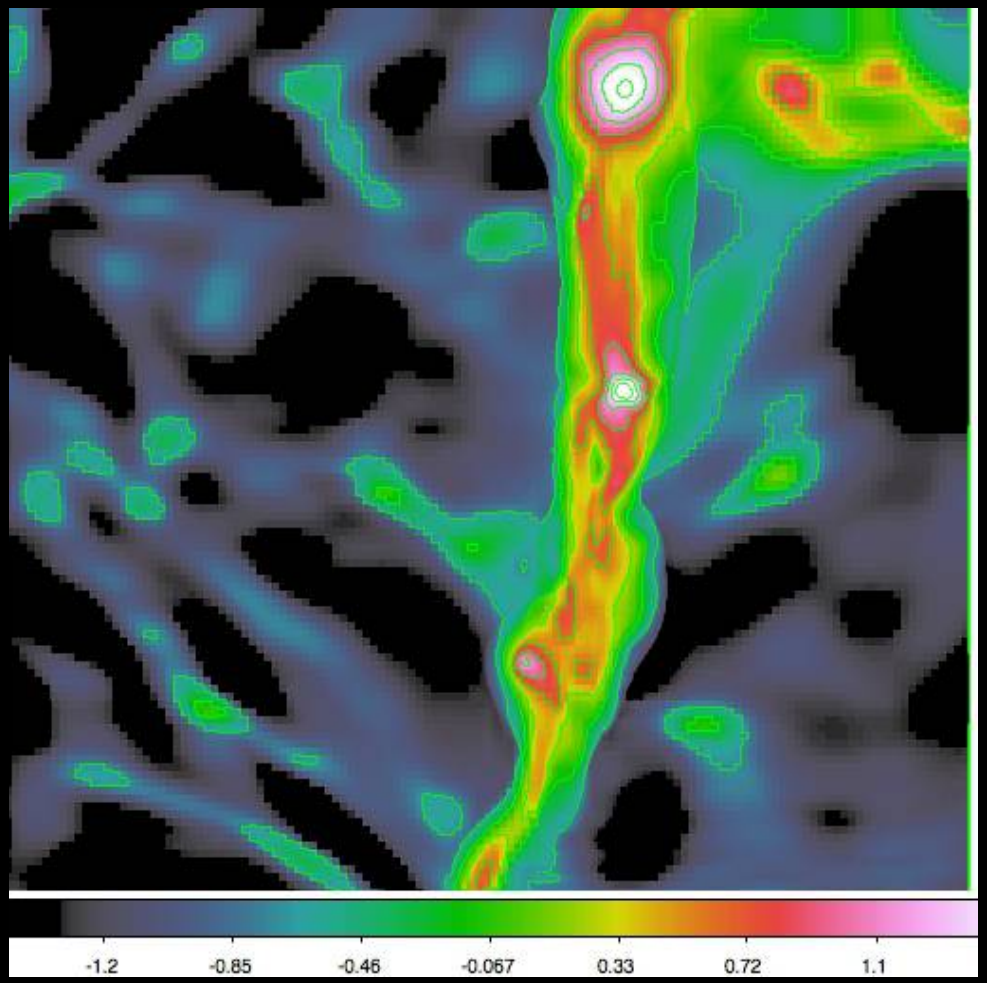
  -MHD,Dedner cleaning

  -4 levels of refinement

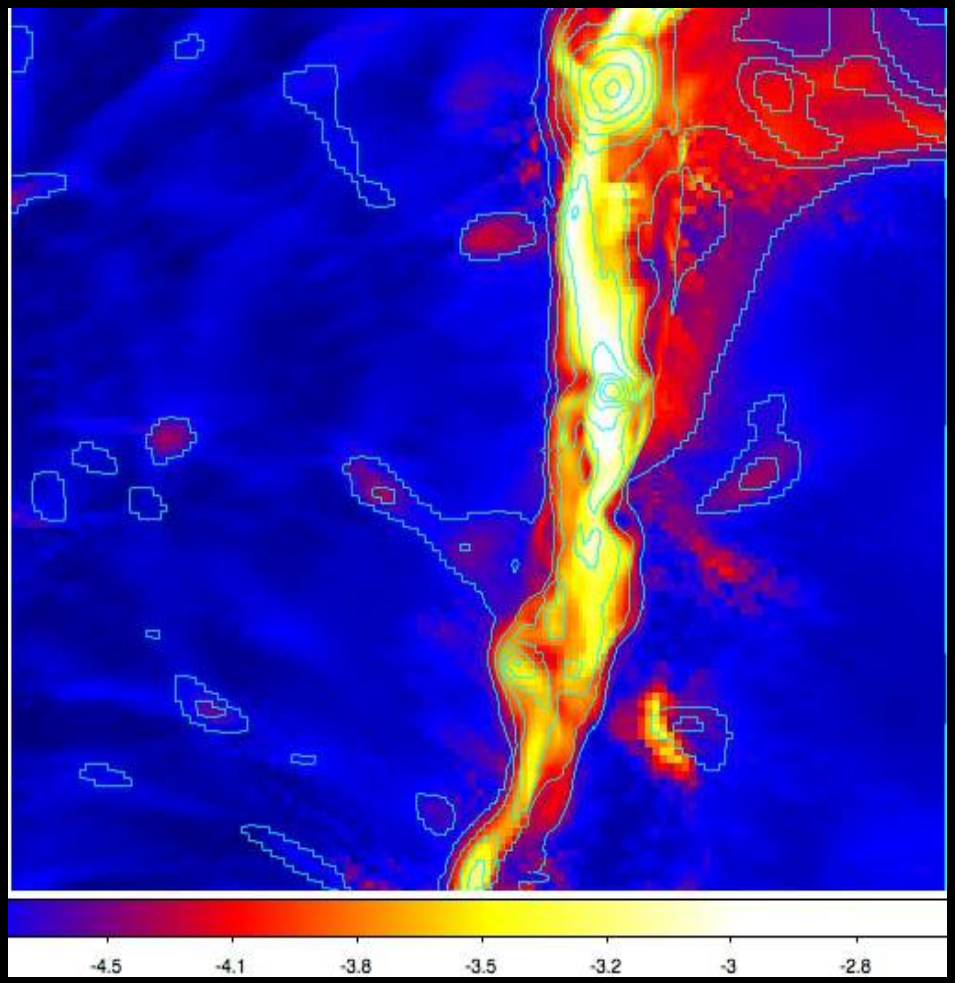
  max res=20kpc

  seed field 10^-10 G at z=30





log10(n) z=0.5



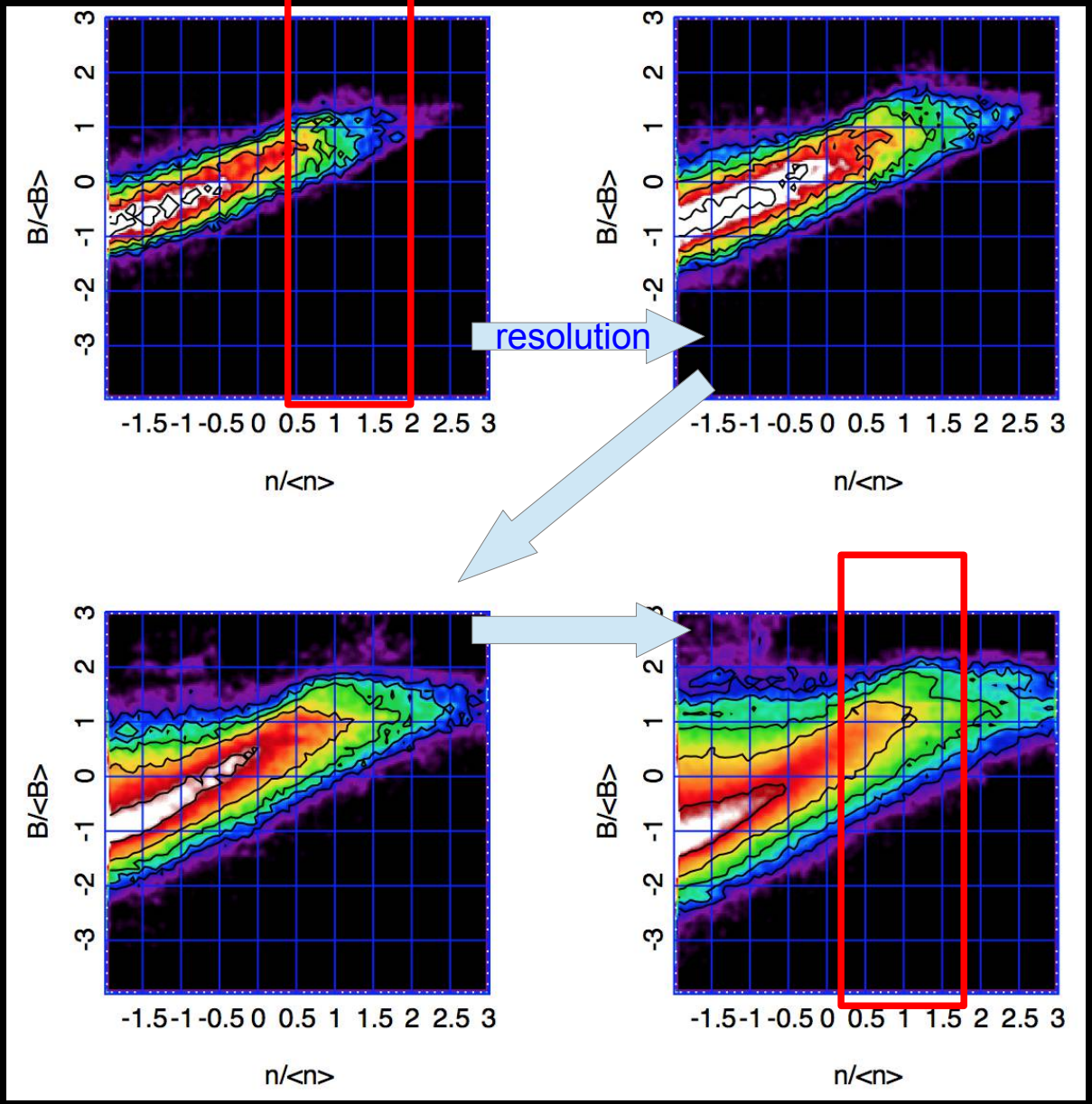
log10(B) z=0.5

The maximum B within the filament is

B 0.005–0.01 Γ, ι.ε. <5% oϕB from equip.

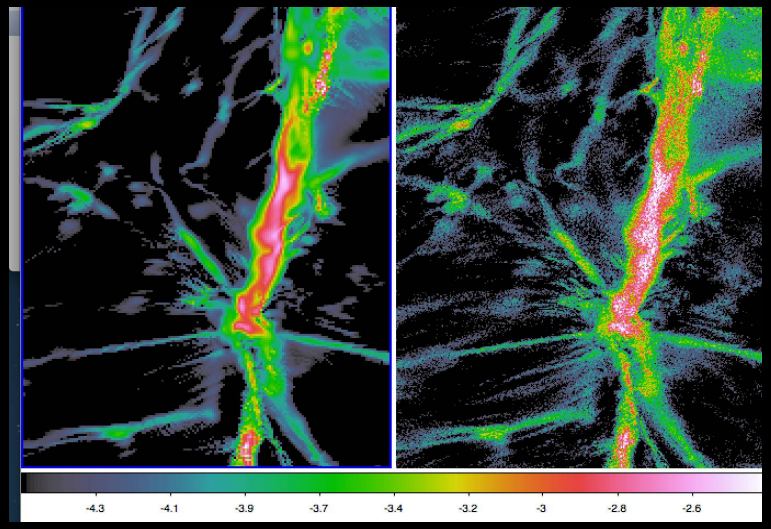
Have we numerically converged?

How far are we from convergence?

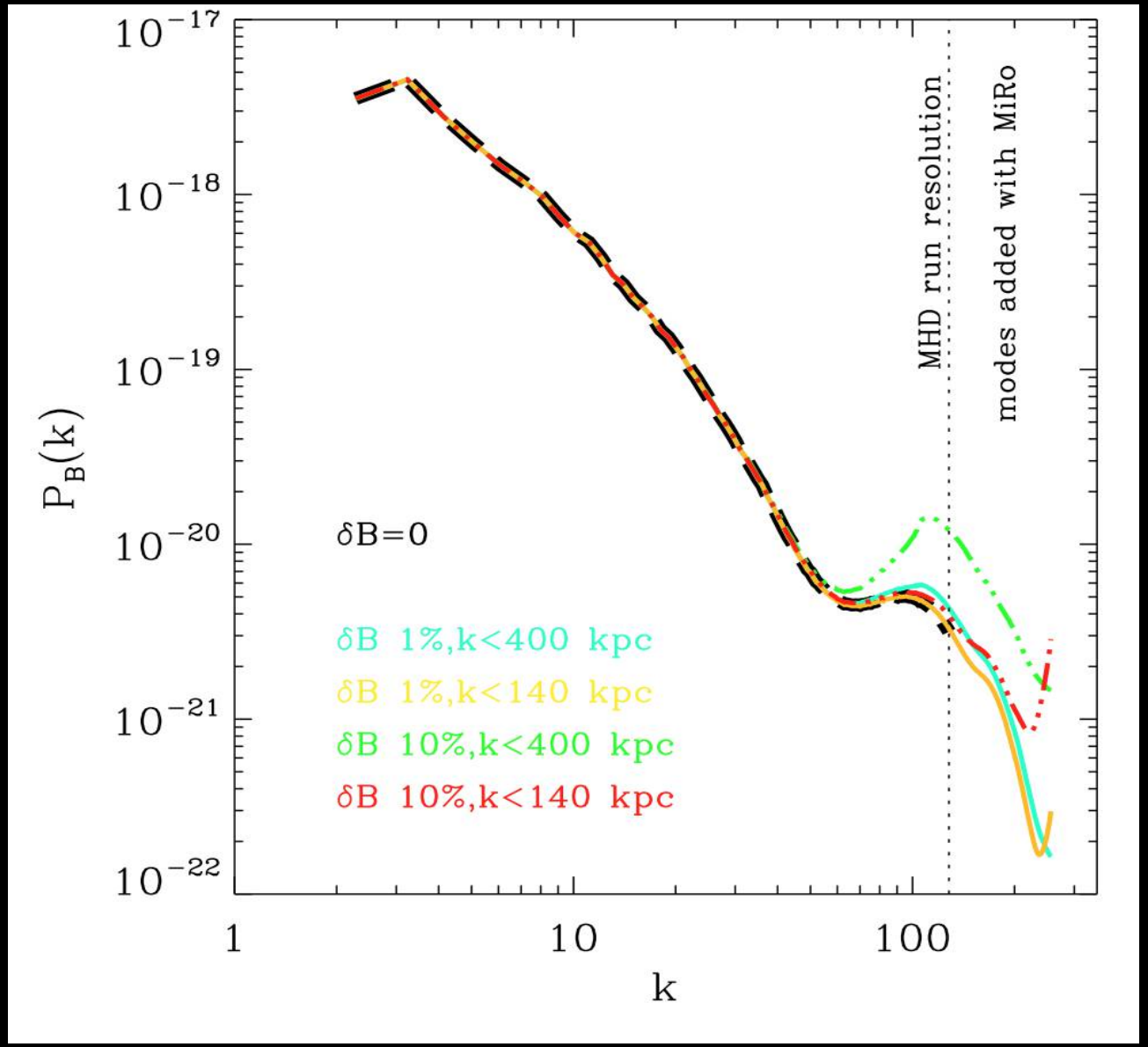


Have we numerically converged?
How far are we from convergence?

-> alternative approaches (beside brute-force)



Power spectra of B for different models



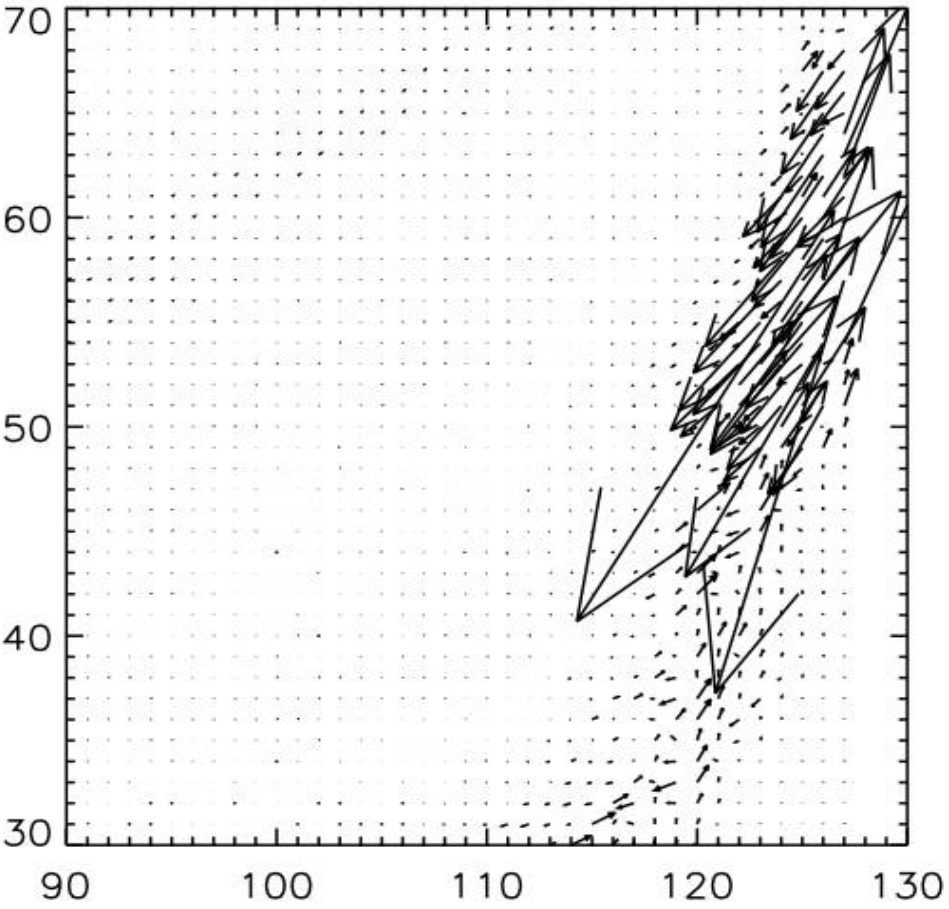
Does the "small scale" B-field topology/strenght matter for the deflection of UHECR?

...some very preliminary test

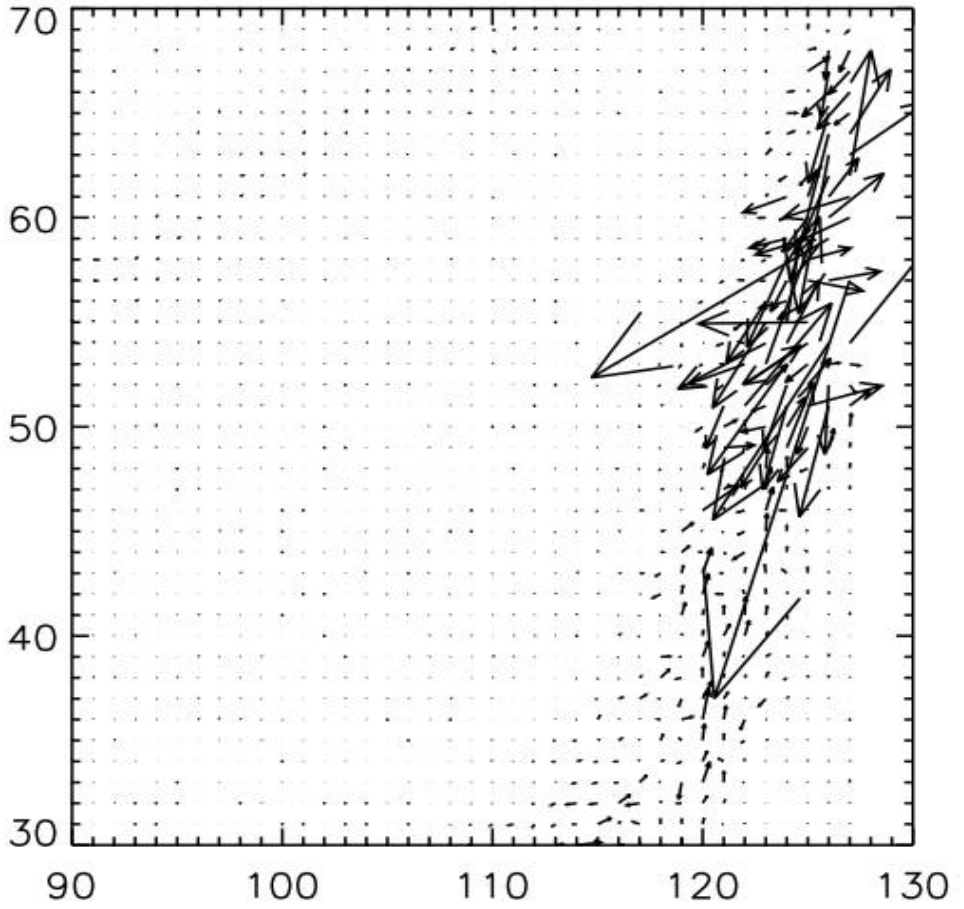
- 3D distribution of B from MHD cosmological run
- Small scale modes added with a divB=0 approach, input scales and spectra
- Ballistic propagation of $E=10^{20}$ eV particles, following the simple Lorentz force with a KDK integrator
- No cosmological effects, energy losses, particle creations etc...

B-vectors

Result from MHD run



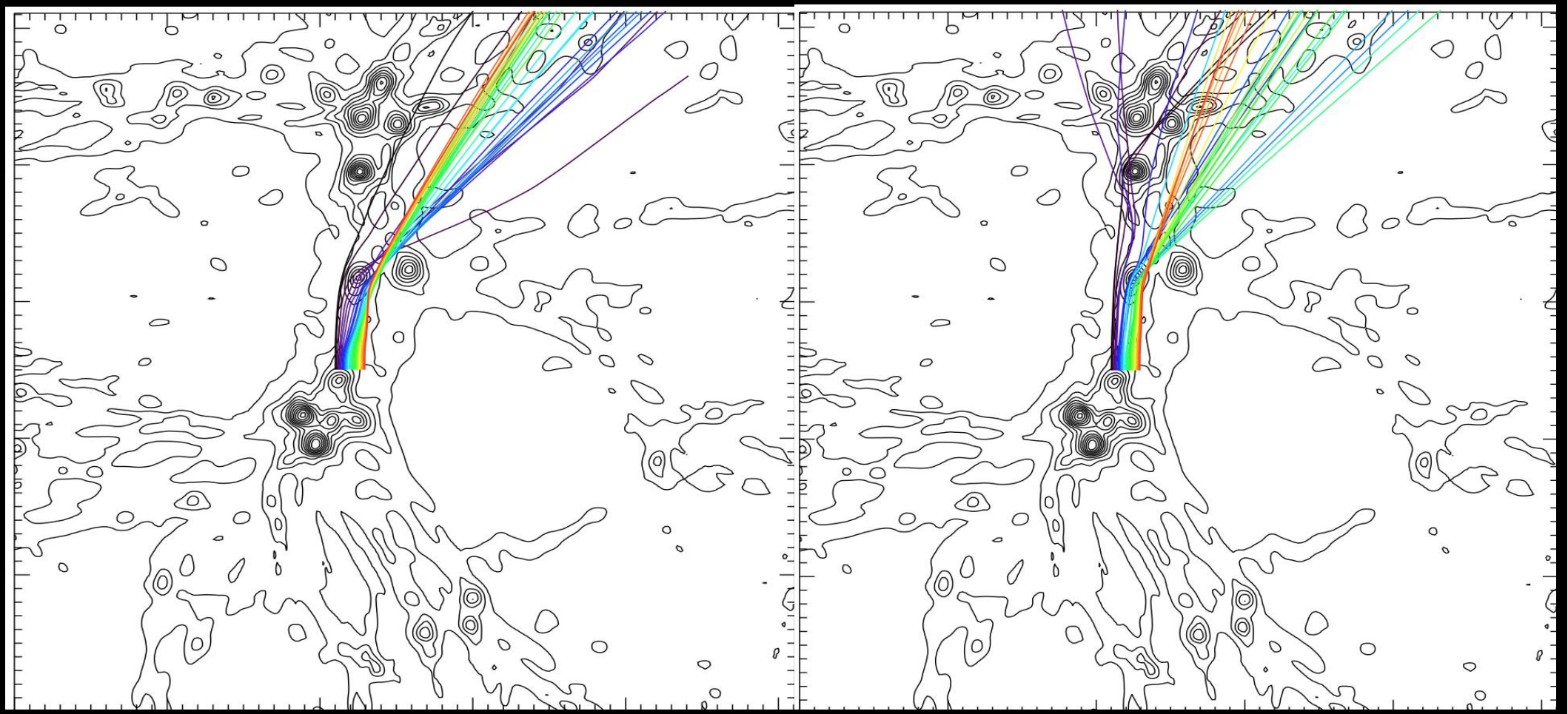
Modes added



Trajectories for 10^20 eV particles

(only 20 samples)

Pure MHD • MHD+k<400kpc modes

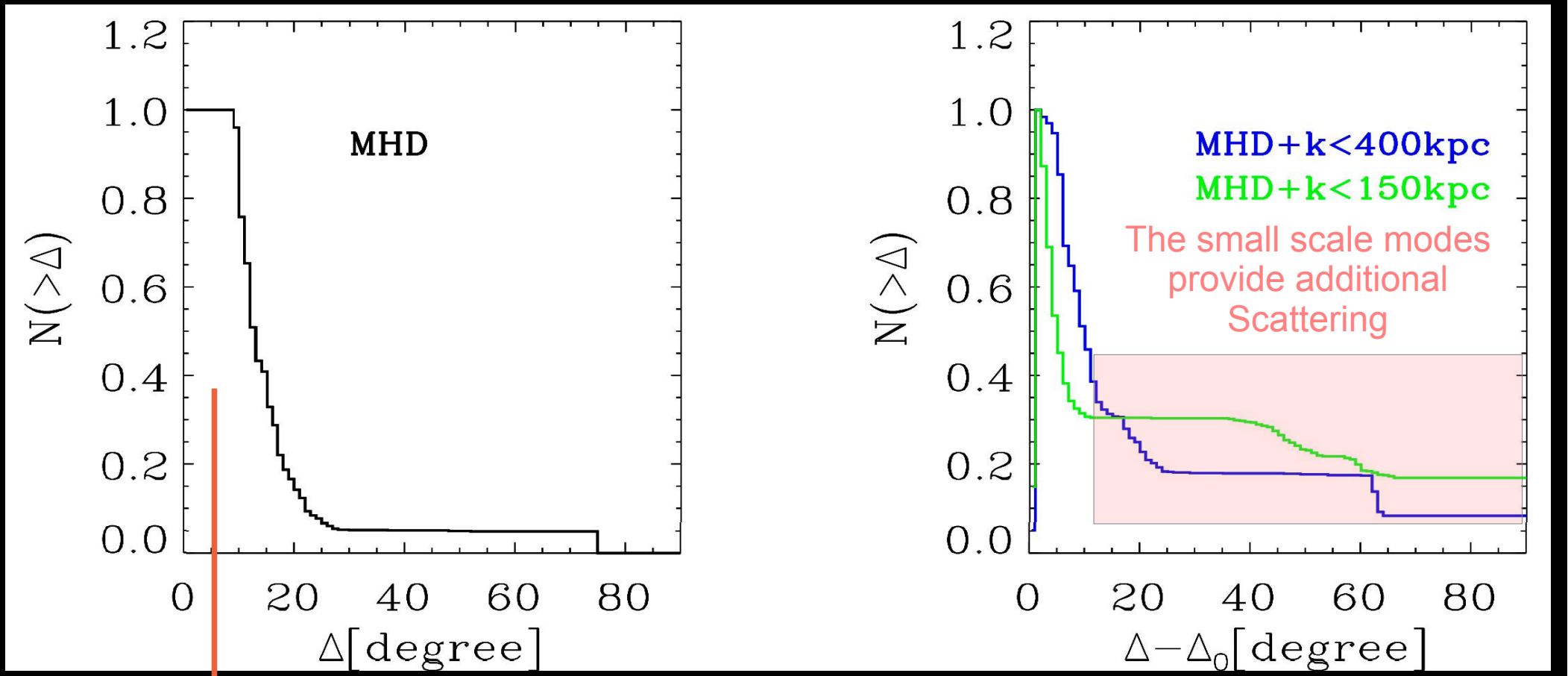


In this case we have 512^3 cells for 35 Mpc,
$\Delta x = 60$kpc

- Deflection angles within 30 Mpc (2000 particles)

Absolute deflection

Deflection relative to MHD



Average deflection by 10°

<B> 10νΓ

$$\theta(E,r) \simeq 0.8^\circ\, Z \left(\frac{E}{10^{20}\,\mathrm{eV}}\right)^{-1} \left(\frac{r}{10\,\mathrm{Mpc}}\right)^{1/2} \times \left(\frac{l_c}{1\,\mathrm{Mpc}}\right)^{1/2} \left(\frac{B}{10^{-9}\,\mathrm{G}}\right),$$

Sigl et al.2003

OPEN QUESTIONS & PROJECTS

Can we bracket the magnetic field in filaments by combining radio data (detection/non-detection) and UHCR science?

CRPropa...

Idea:
- Simulated volumes with simulated+analytic configurations of B

-test radio emission, Faraday Rotation and UHECR spectra together

Problems to solve:
-volume? Scales? seeding ? resolution?
-how much are other physical effects affecting this?

→ In the very next future (<6 months) we will have the largest unigrid and AMR MHD runs ever produced (4800^3, 1024^3+7lev)

→ Can we think to a joint effort towards this direction?
Which constraints are there? Data format? Volume of data? Physics?

COMPUTATIONALLY-INTENSIVE HIGH-IMPACT RESEARCH ON NOVEL OUTSTANDING SCIENCE

CHRONOS

Investigating the origin of cosmic magnetism in large-scale structures: Cosmological simulations with ENZO on the GPU
(FV, Brüggen,Gheller,Wang,Ferrari,Bonafede..)

ENZO 2.3, porting on the GPU (Wang&Abel 2010)
Allotted 32 million CPU hours

What is the distribution of B in large-scale structure?

Which is the seeding mechanism?

Can we fix it observationally?

4800^3

2400^3

1200^3