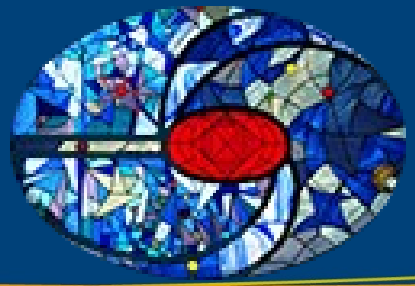
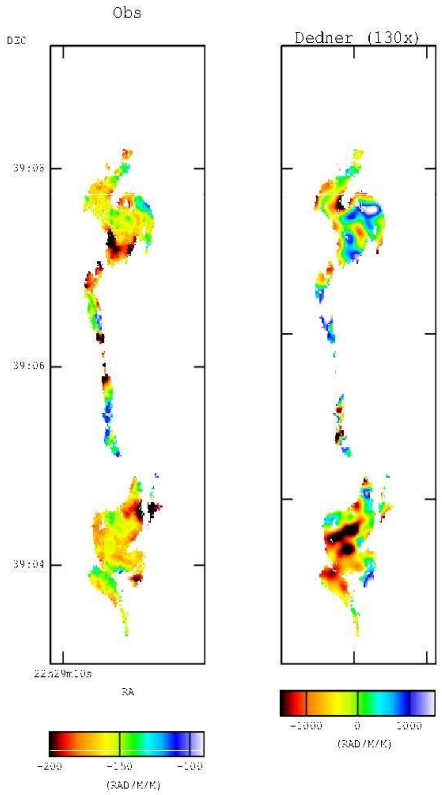
Magnetism footprints in Cosmological environments

Federico A. Stasyszyn

IATE-OAC

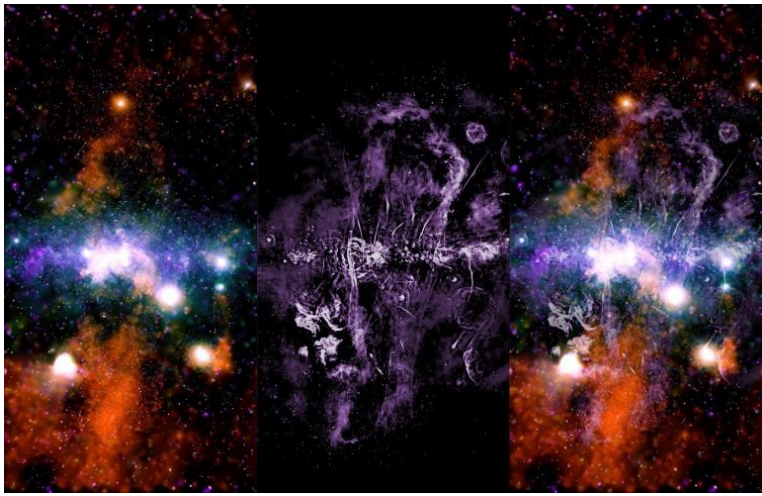


Magnetic Universe

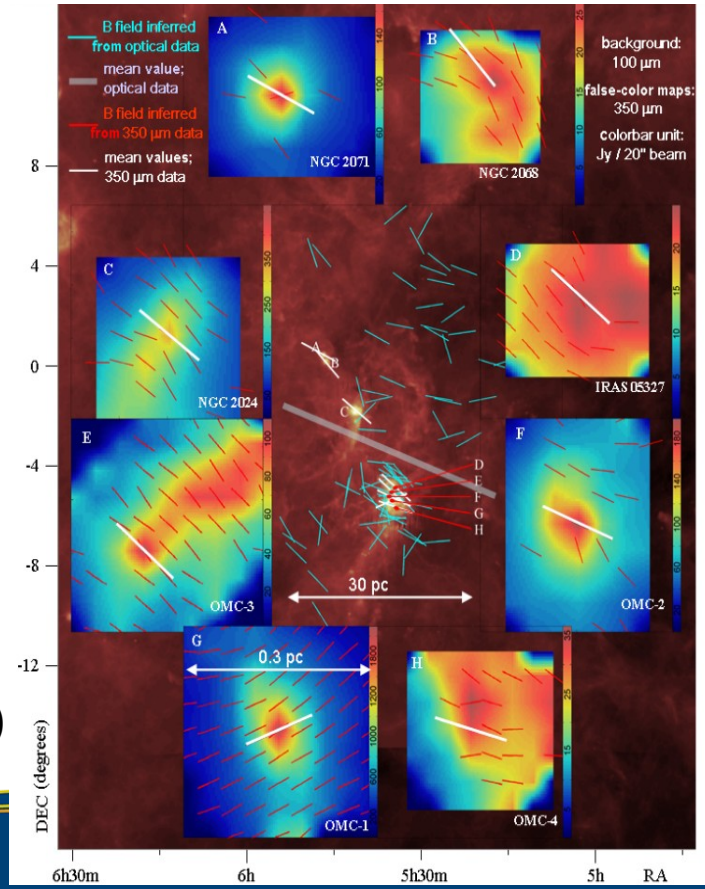


3C449
(Feretti et al 1999)

Galaxies
(Borlaff et al. 2021)

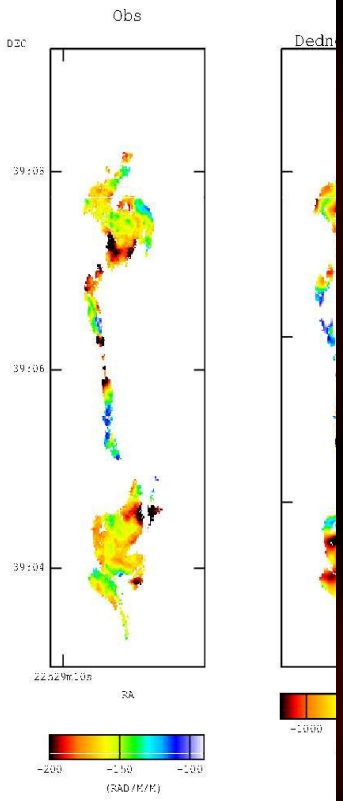


Galactic center
(Wang 2021)

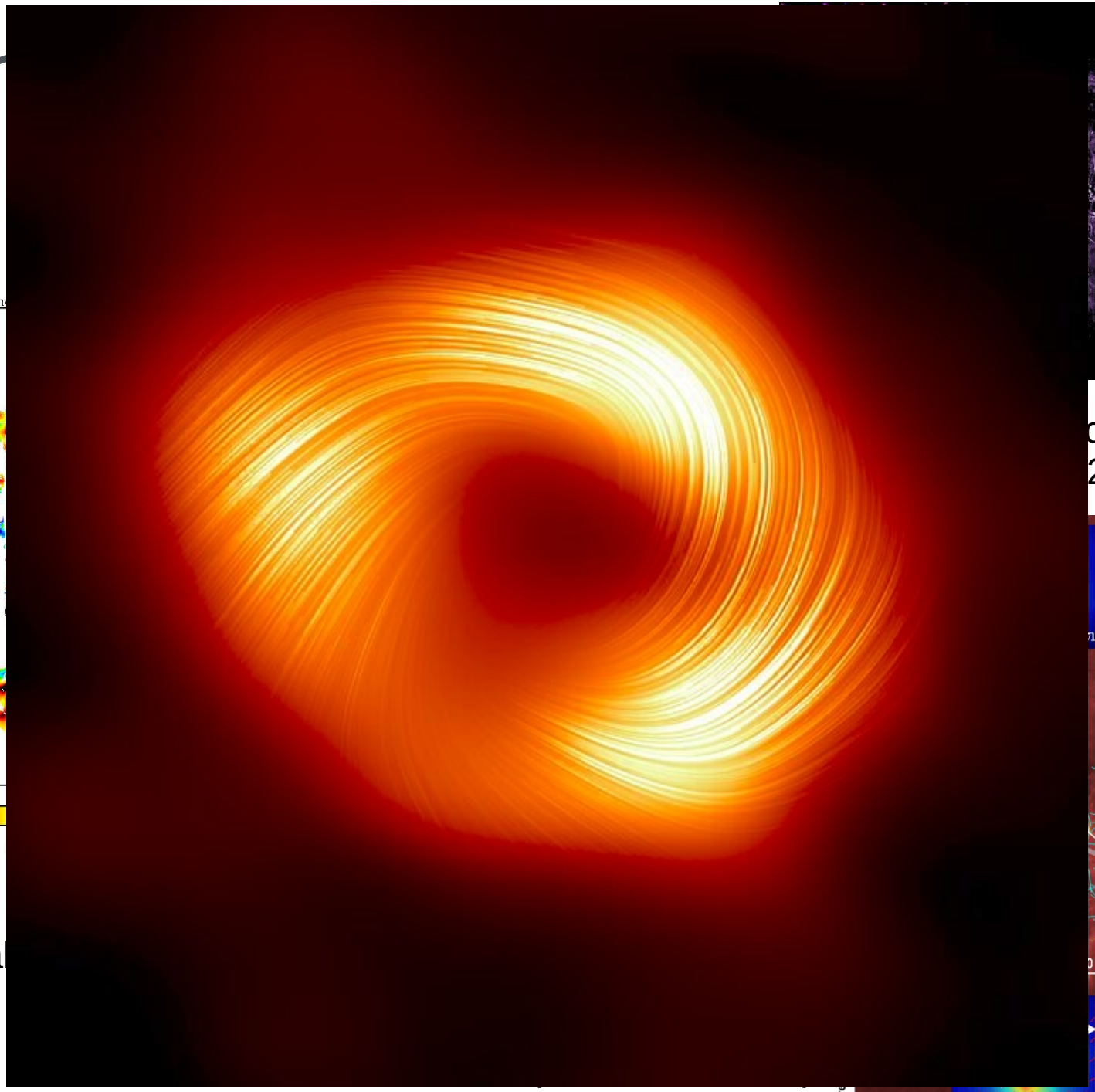


Orion Nebula
(Hua-bai Li 2010)

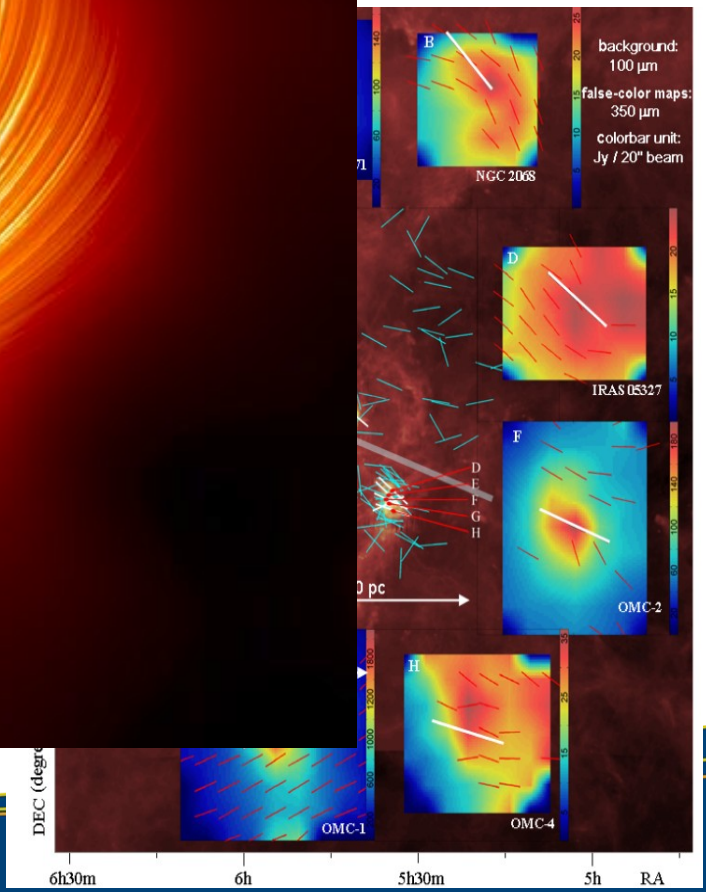
Magn



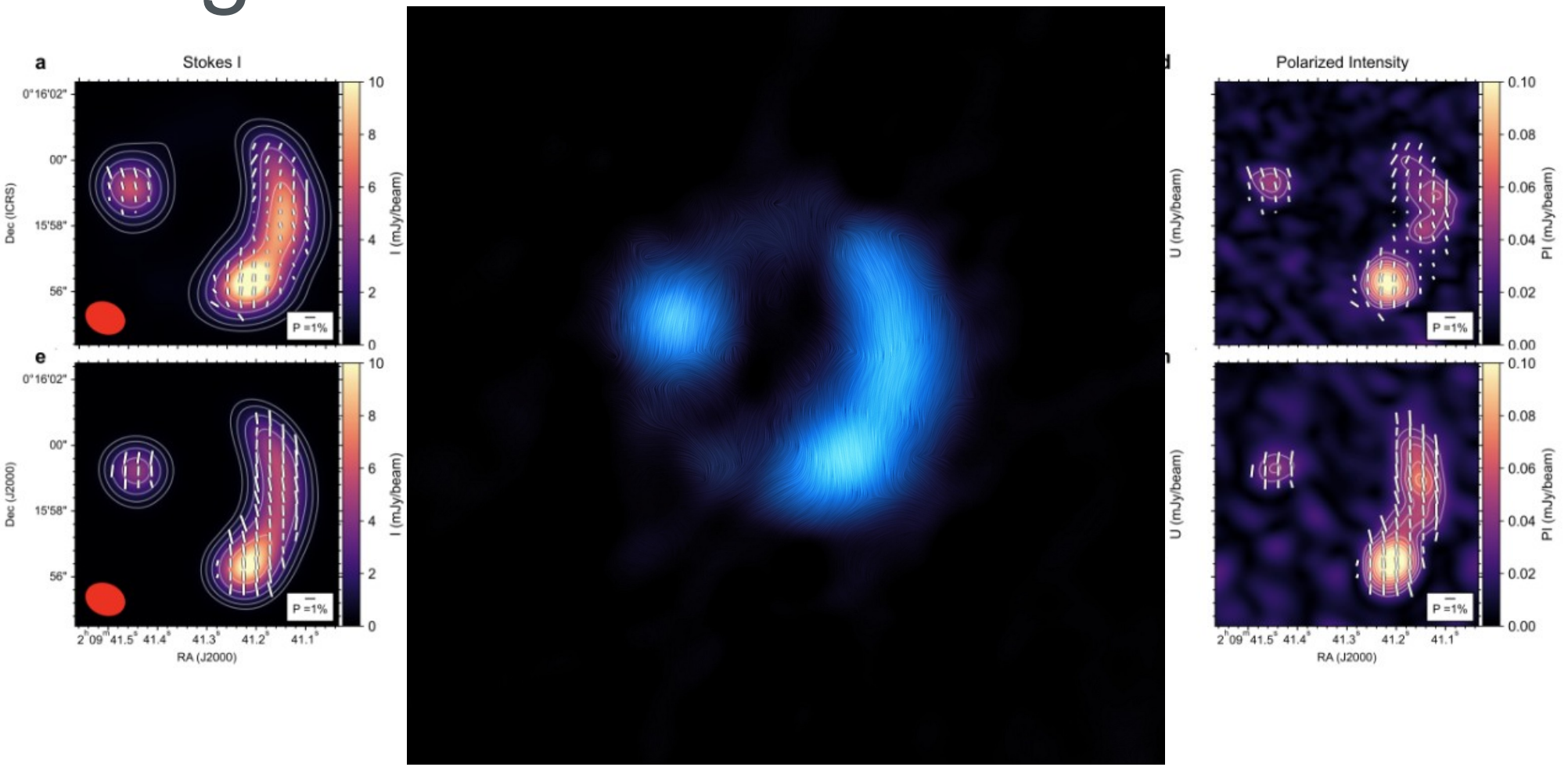
3C449
(Feretti et a



c center
2021)



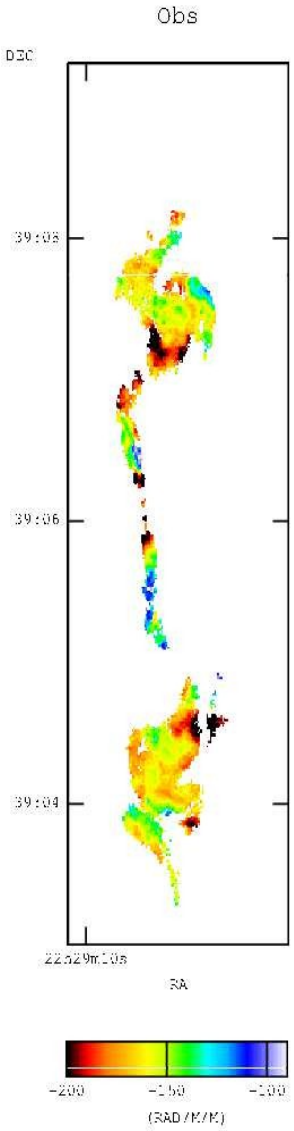
Magnetic Universe



Z~2.6 , ordered magnetic field
500 muG

Geach et al. (2023)
Alma Polarized emission

Magnetic Universe



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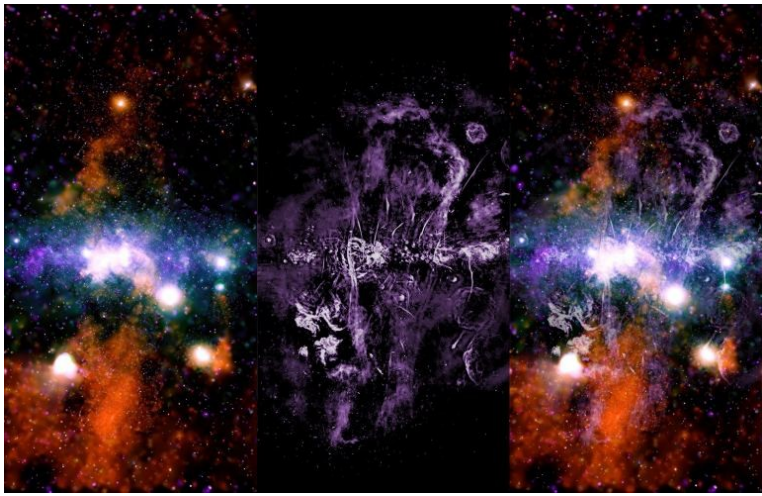

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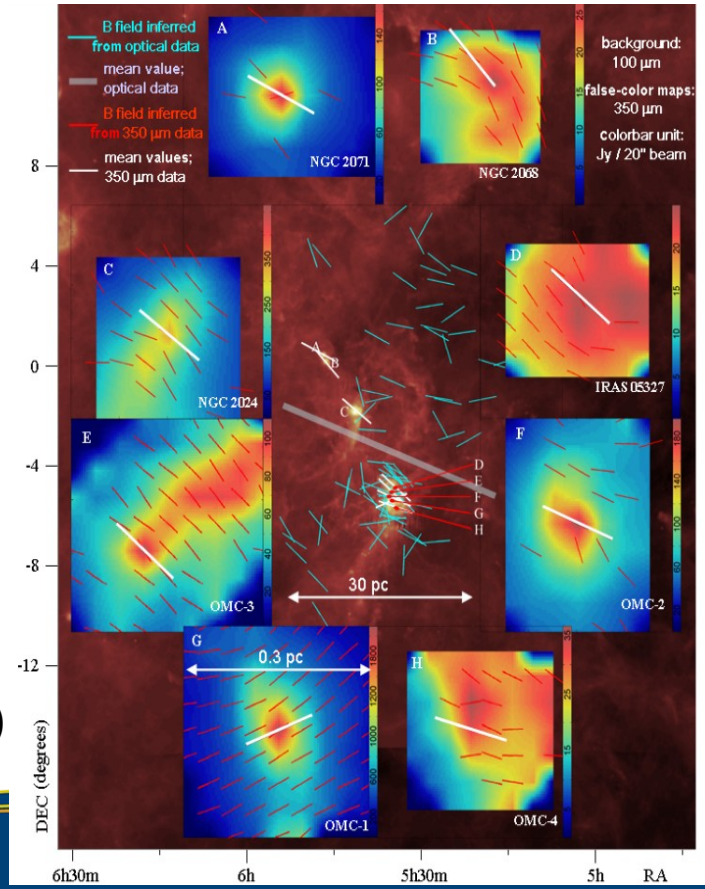

Orion Nebula
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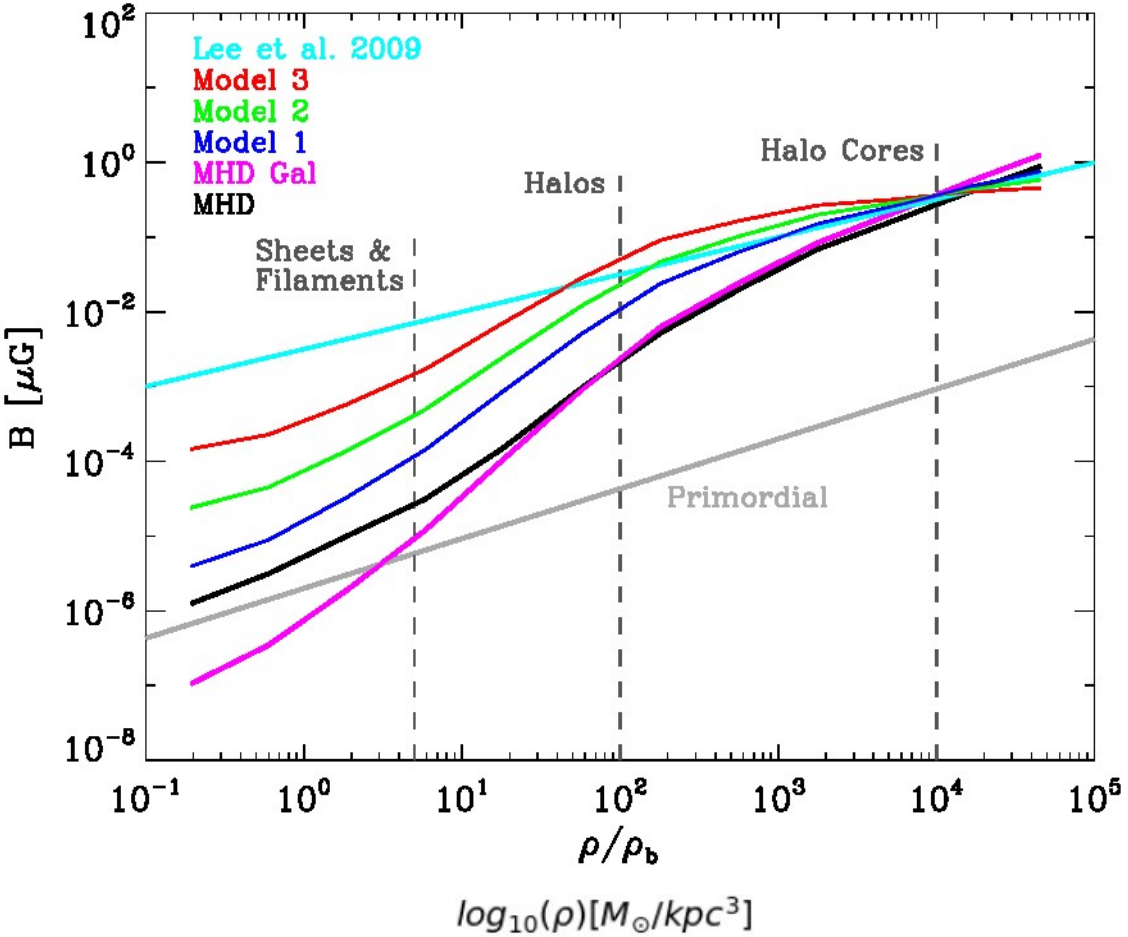


Need Non-Ideal MHD

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{V} \times \vec{B} + \alpha \vec{B}) + \eta \nabla^2 \vec{B}$$

Induction: $\nabla \times (\vec{V} \times \vec{B})$

Diffusion: $\eta \nabla^2 \vec{B}$

$$\eta = \frac{1}{\mu \sigma} = [\Omega m] = [\frac{m^2}{sec}]$$

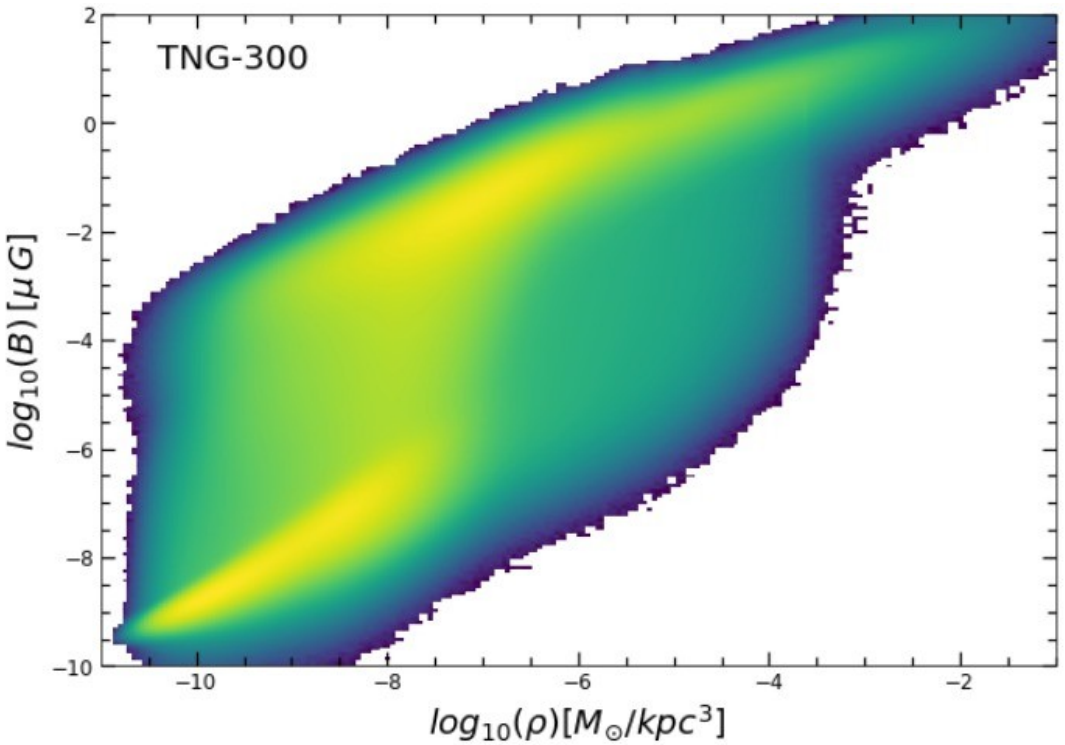
Dynamo: $\nabla \times (\alpha \vec{B})$

$$\alpha = -1/3 \langle \vec{V}_t \cdot \nabla \times \vec{V}_t \rangle$$

Approach?
-Use Simulations and Theory to constrain observations.
-Look for clues of the puzzle in different environments.....

Need Non-Ideal MHD

Rodriguez-Medrano et al. 2023



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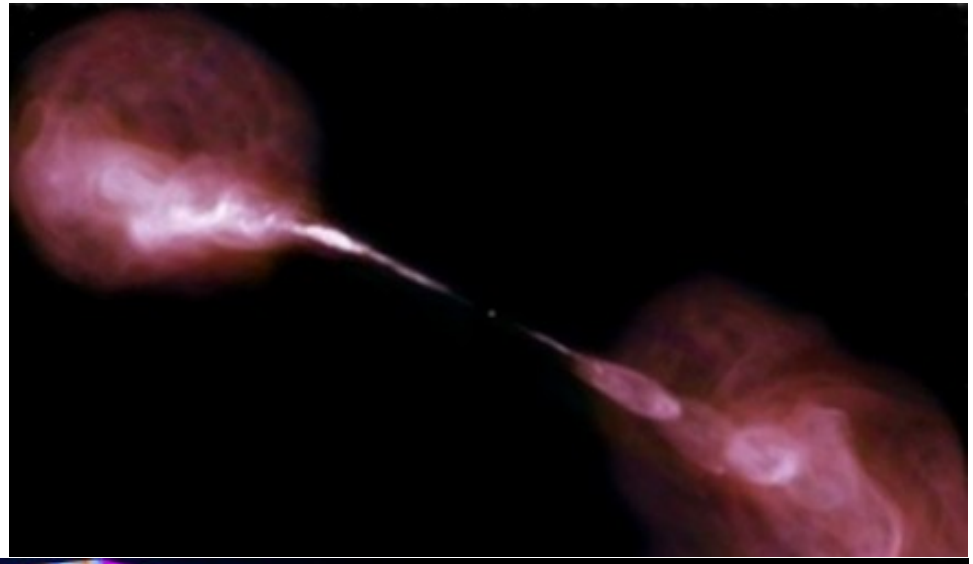
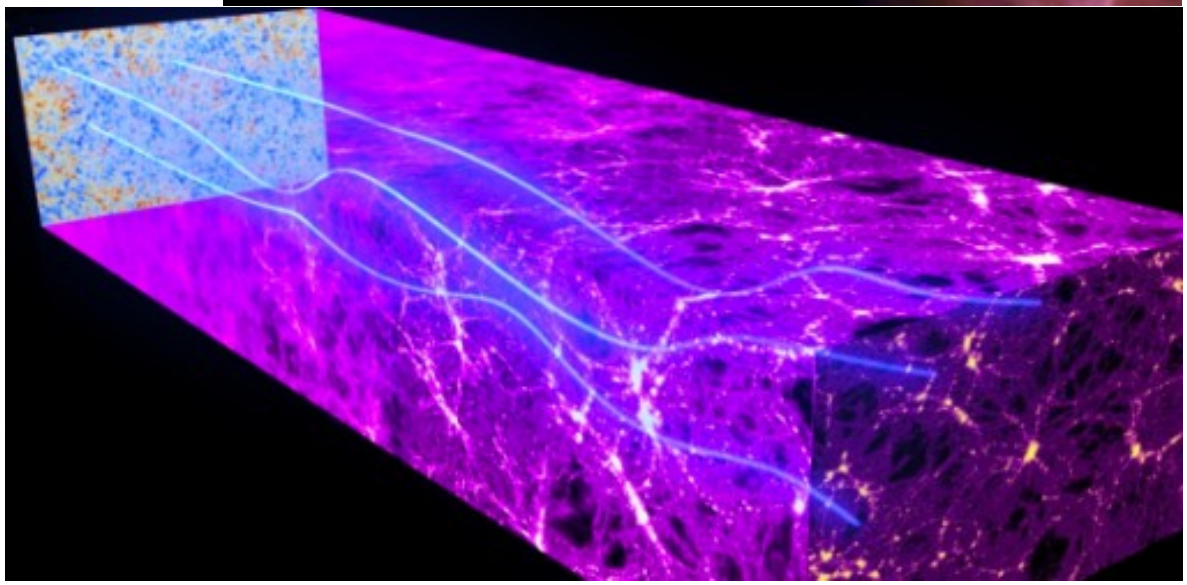
-Use Simulations and Theory to constrain observations.
-Look for clues of the puzzle in different environments.....

Magneto-genesis?

- AstroPhysical
  - Biermann Battery (IGM)
  - Accession Discs (dynamo and battery)
  - Stars and Super Novae
  - Proto-galactic discs



- Cosmological Primordial Origin
  - Inflation
  - Quantum fluctuation
  - Primordial Black Holes



Magneto-genesis?

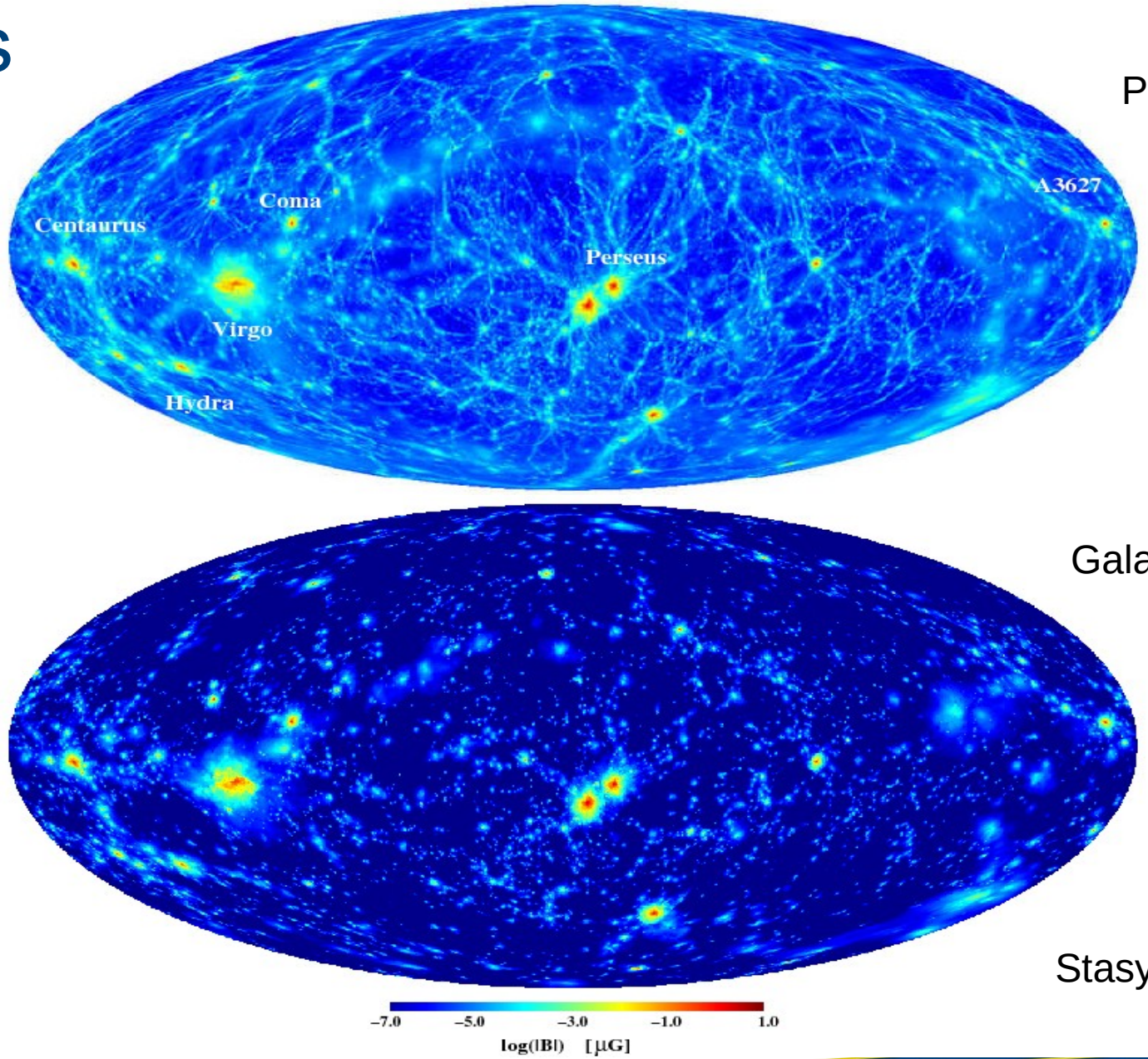
- Bierman Battery / Stellar
  - Accretion Discs
  - Stars and Supernovae

Helps also in Star formation Scenarios, AGN, etc

- Primordial origins
  - Inflation?
  - Quantum?
  - Primordial Black Holes?

Helps explaining Hubble Tension, Primordial Black Holes, Dark Matter?

Different Environments & MF Seeds



Primordial

Galactic SF Seeds

Stasyszyn et al. 2011

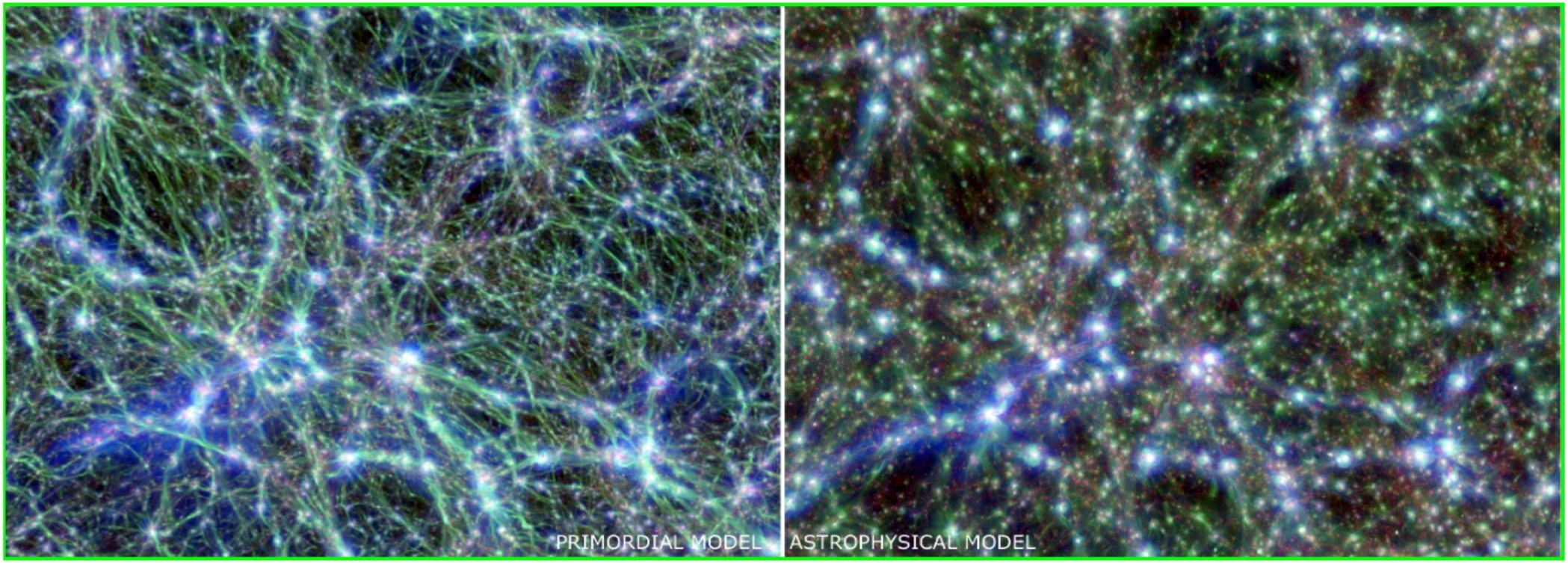
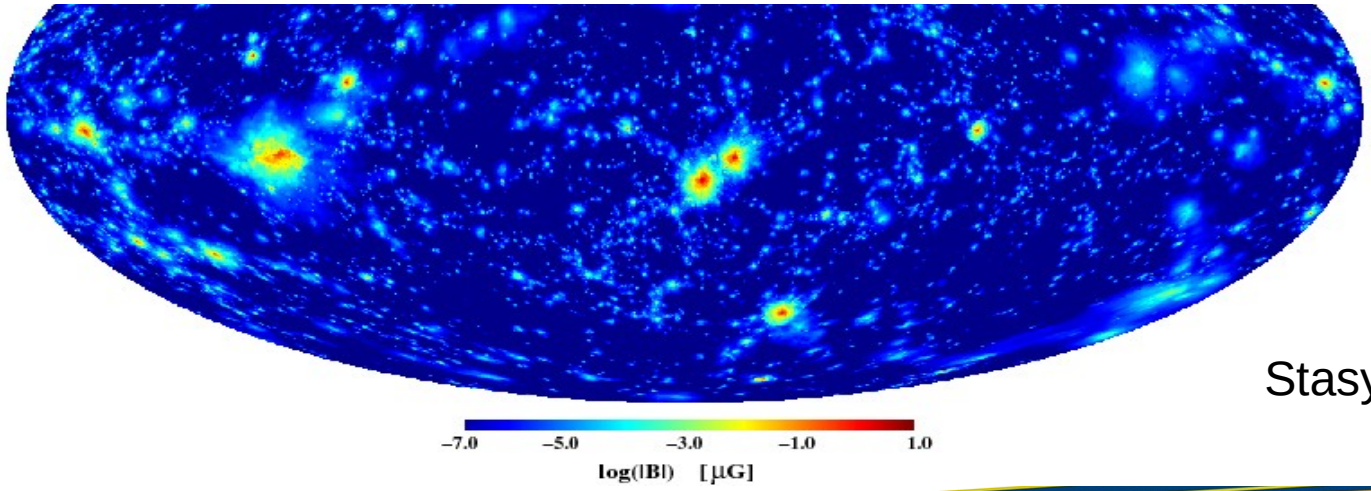
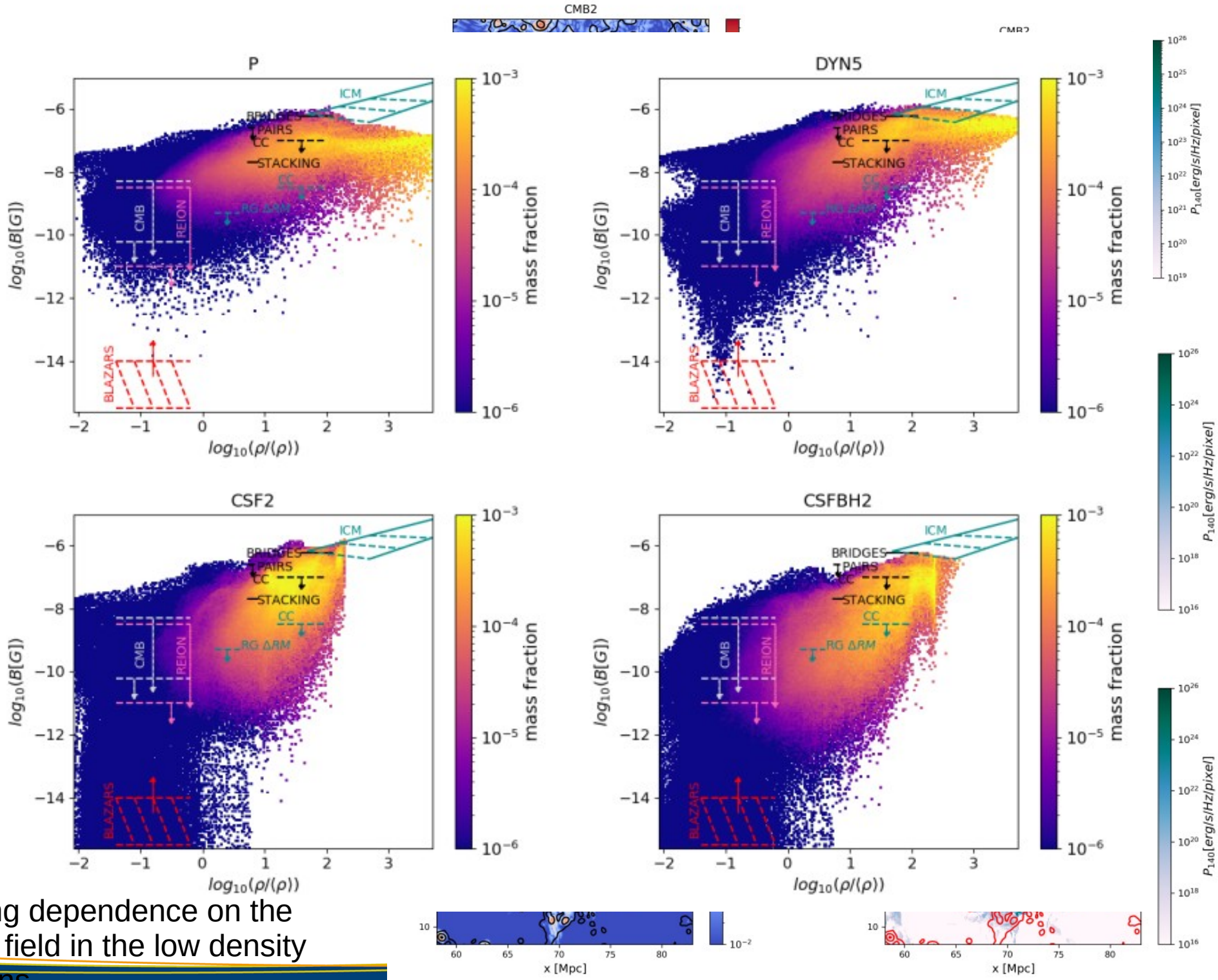


Figure 1. 3-dimensional renderings of the projected distribution of dark matter (red), gas temperature (blue) and magnetic field strength (green) at $z = 0.02$ for the primordial and astrophysical model investigated in this paper. Each panel is 60 Mpc $\times$ 40 Mpc across, and has a depth of 200 Mpc along the line of sight.

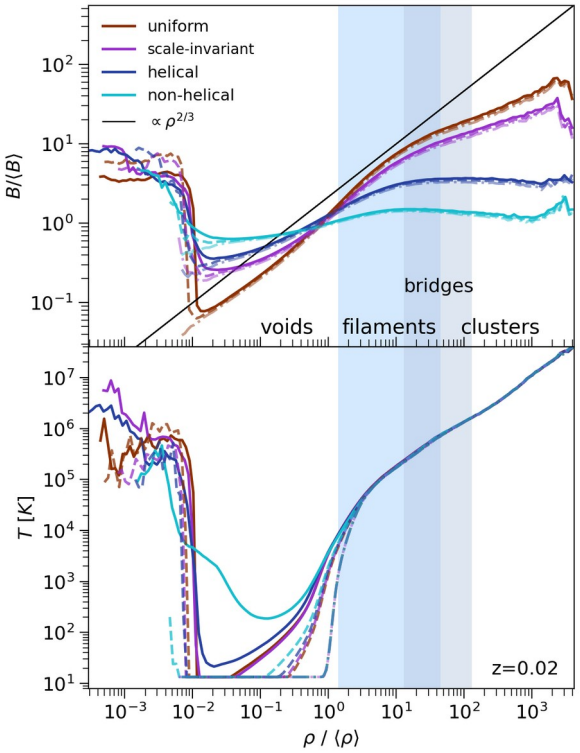
Vazza et al. 2020



Stasyszyn et al. 2011



Strong dependence on the seed field in the low density regions



Vazza et al 2020.
Metcheildize et al 2021.
Dominguez et al 2021.

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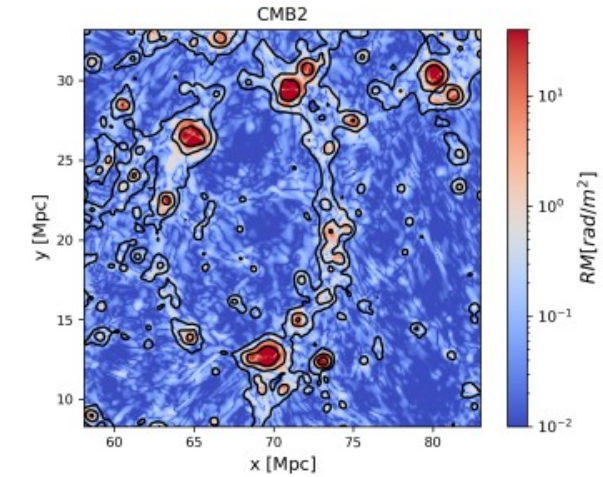
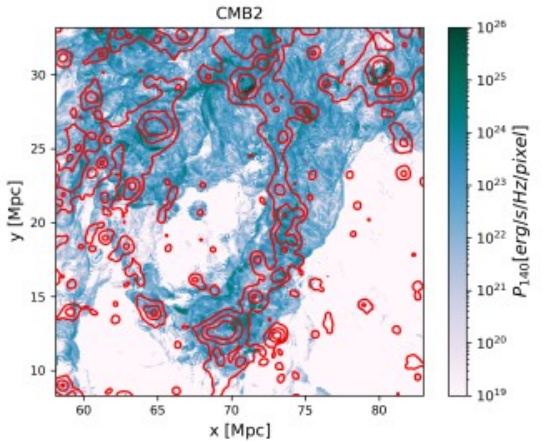
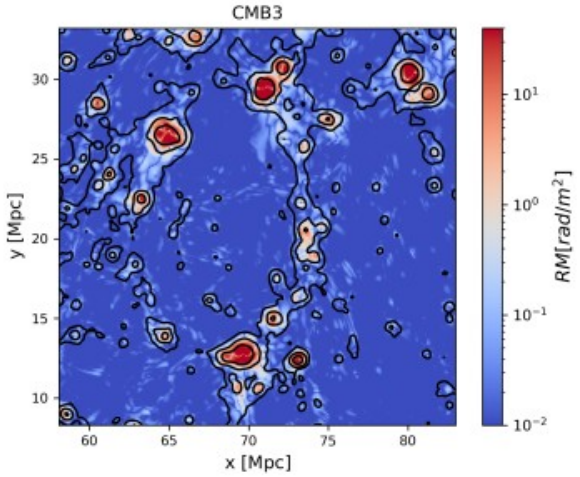
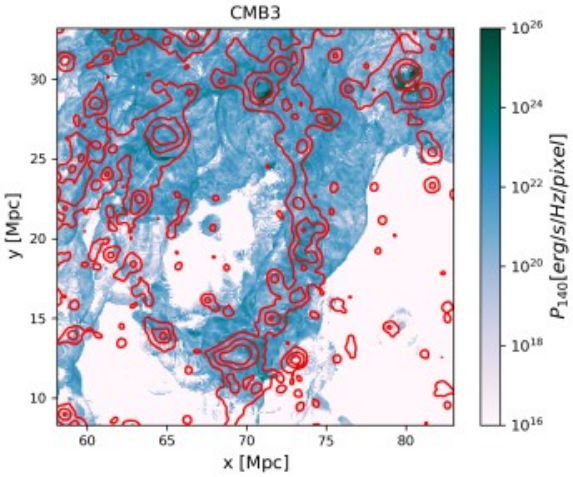
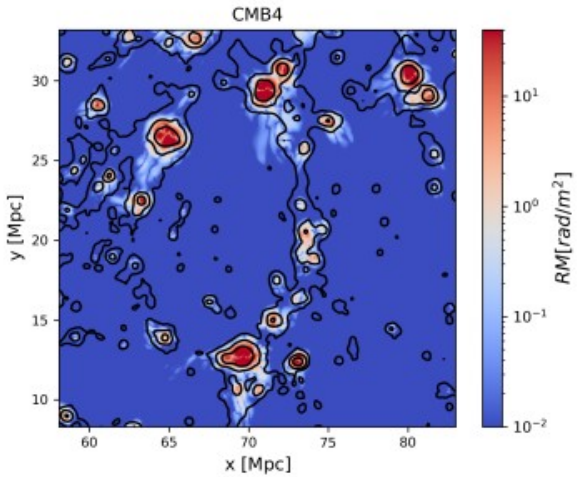
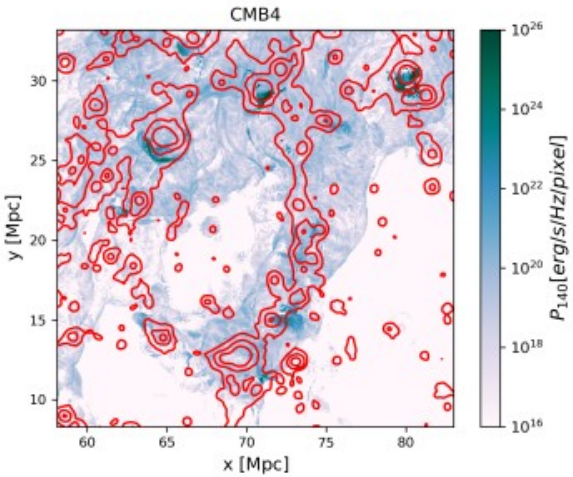


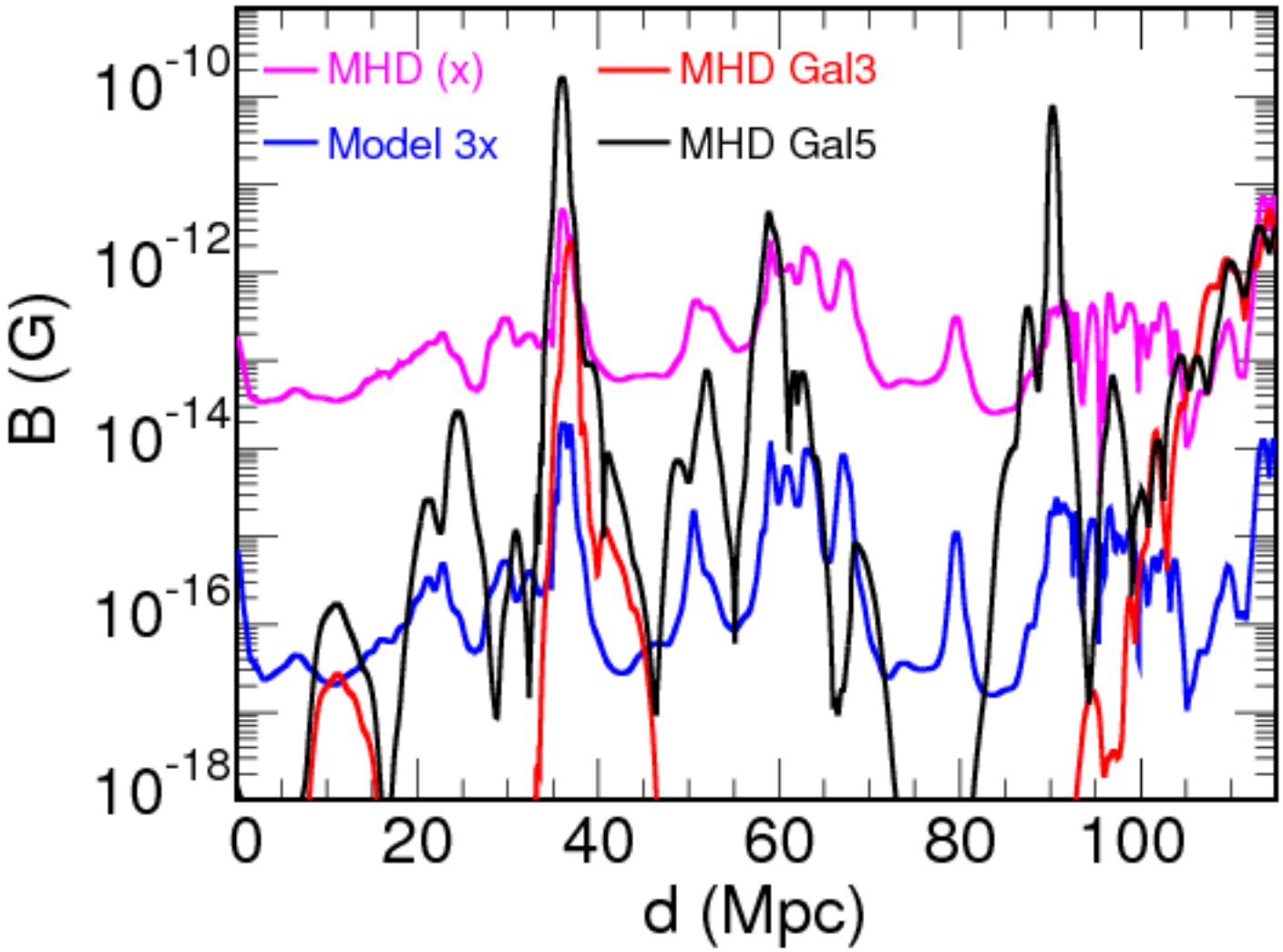






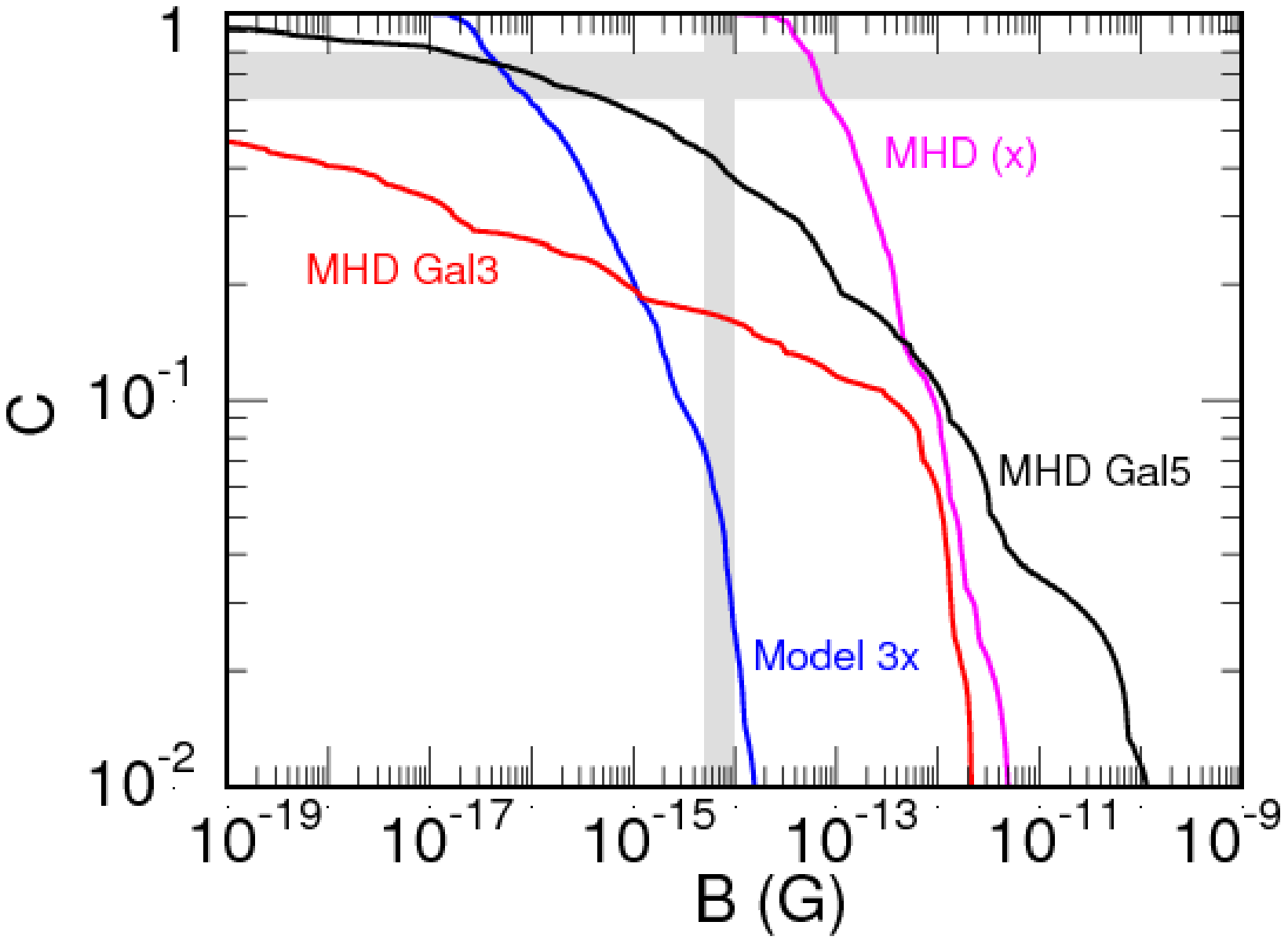






Dolag el al 2010

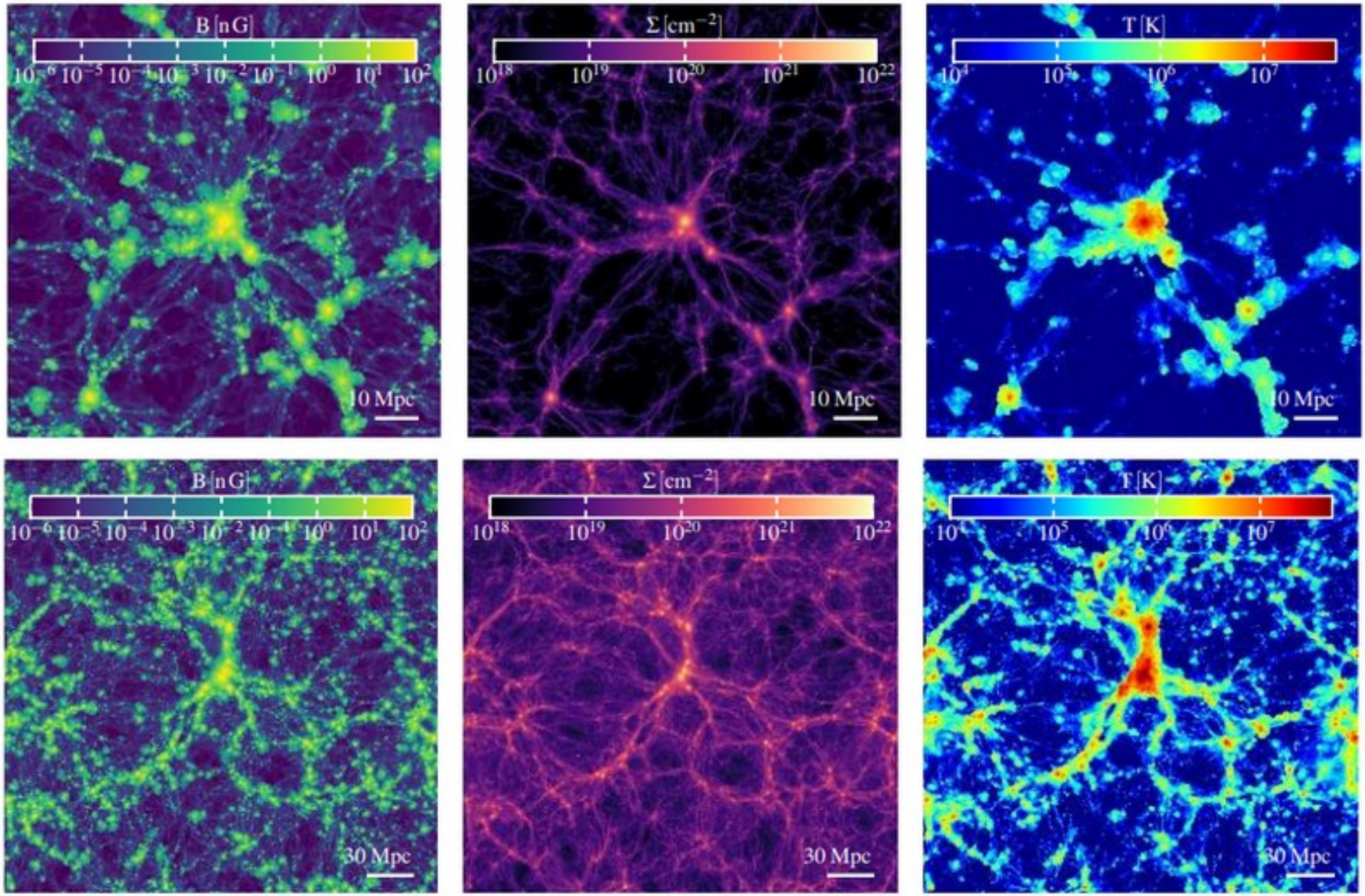
Cumulative filling factors derived from dispersion on Blazar Observations vs Simulations



Dolag 2010

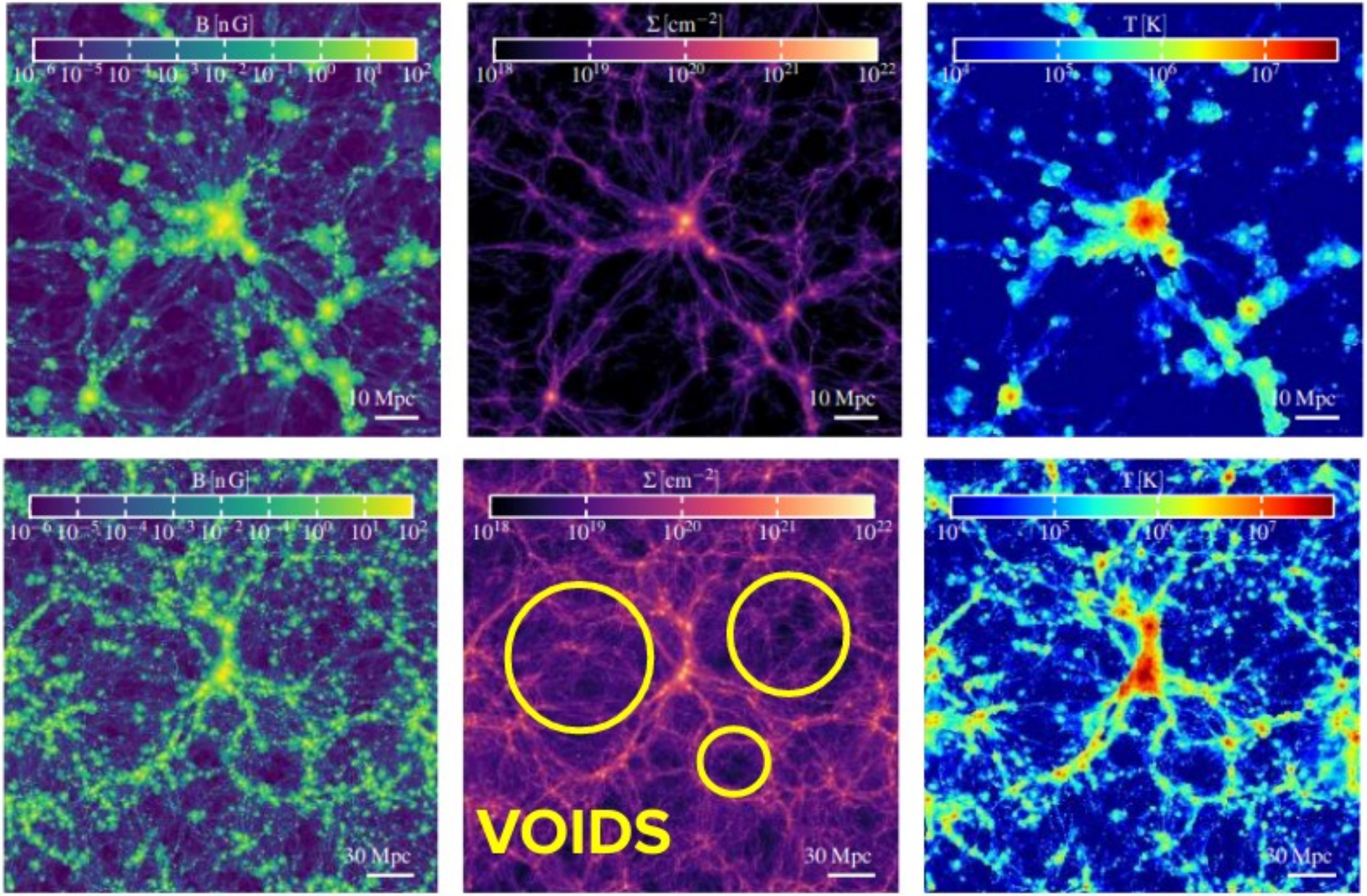
Cumulative filling factors derived from dispersion on Blazar Observations vs Simulations

Illustris TNG



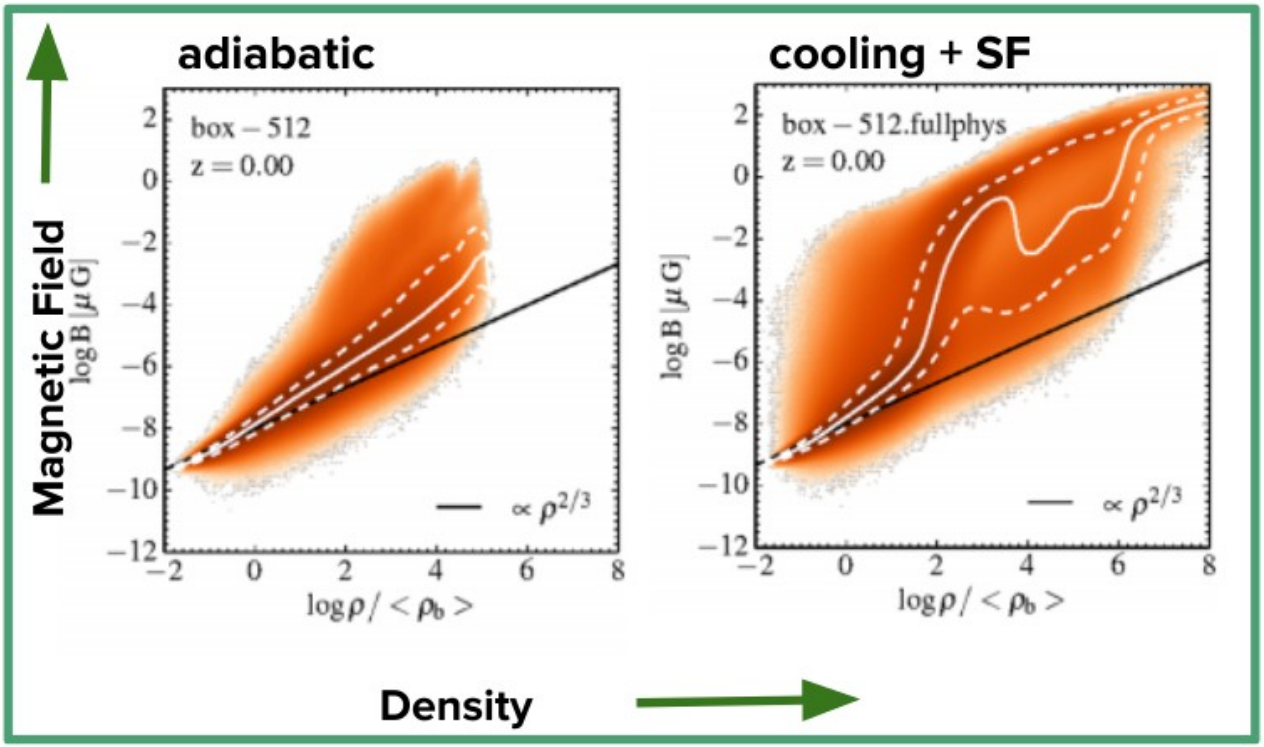
Marinacci et al. (2018)

Illustris TNG

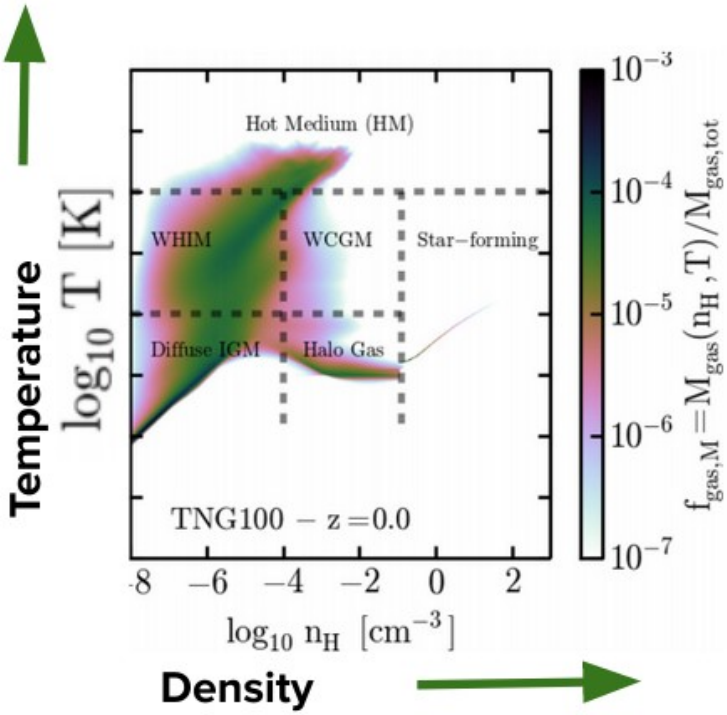


Marinacci et al. (2018)

Illustris TNG



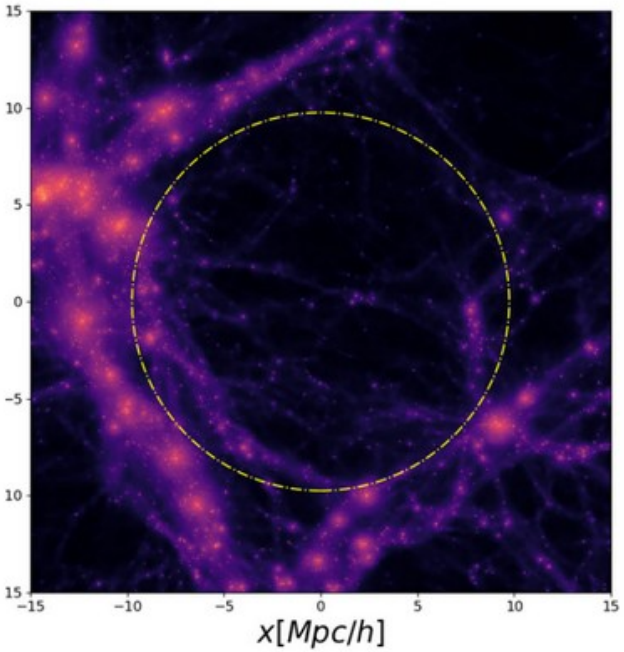
Marinacci et al. (2015)

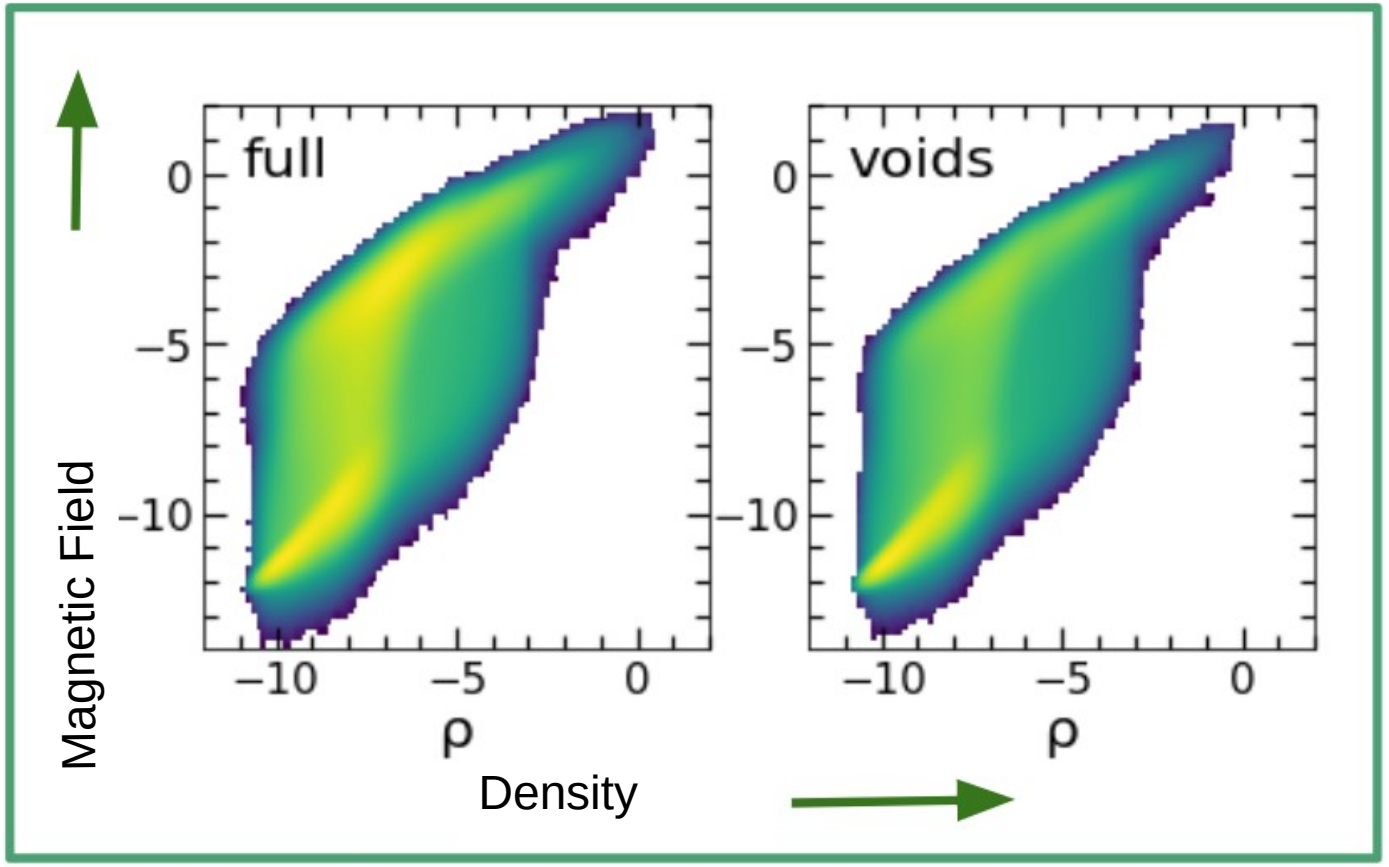


Martizzi et al. 2019

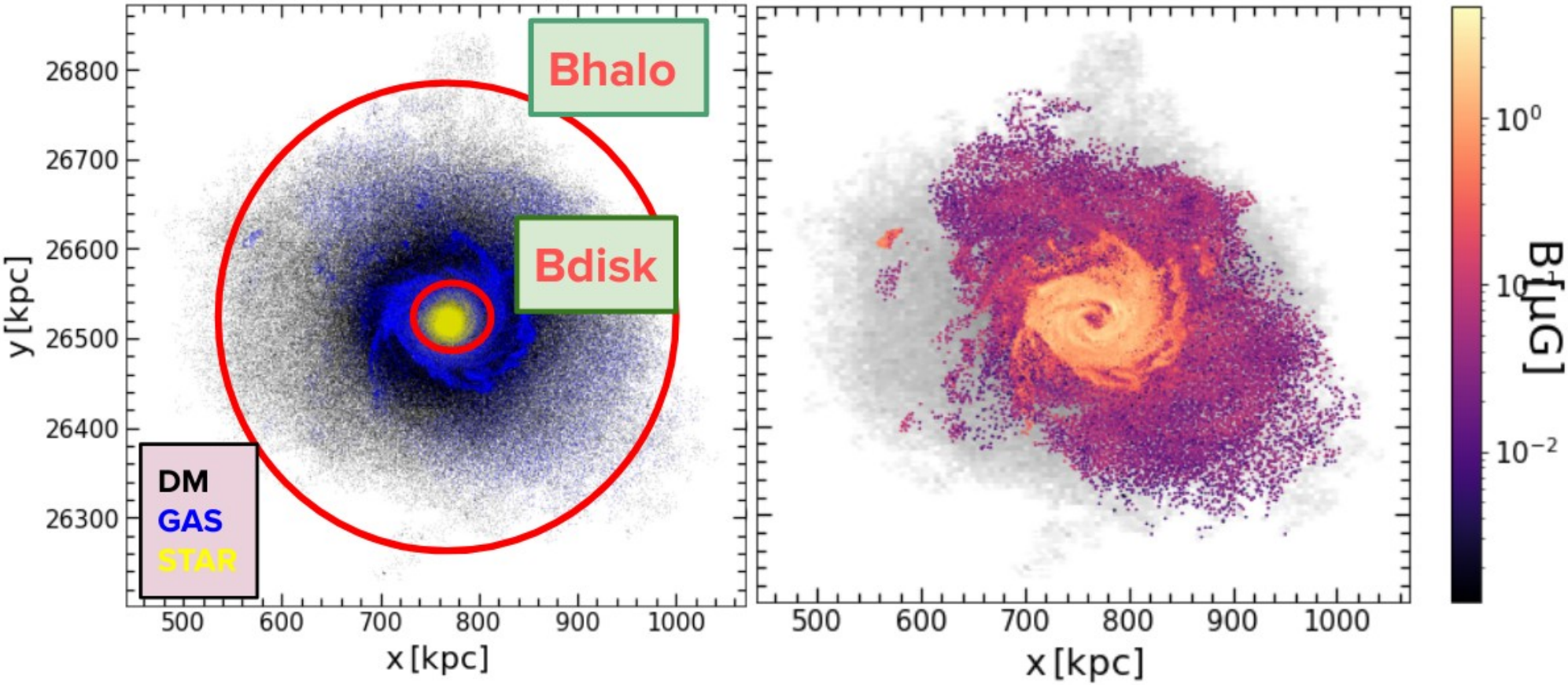
TNG-100/300 simulation: hidro + SF + black hole + magnetic fields

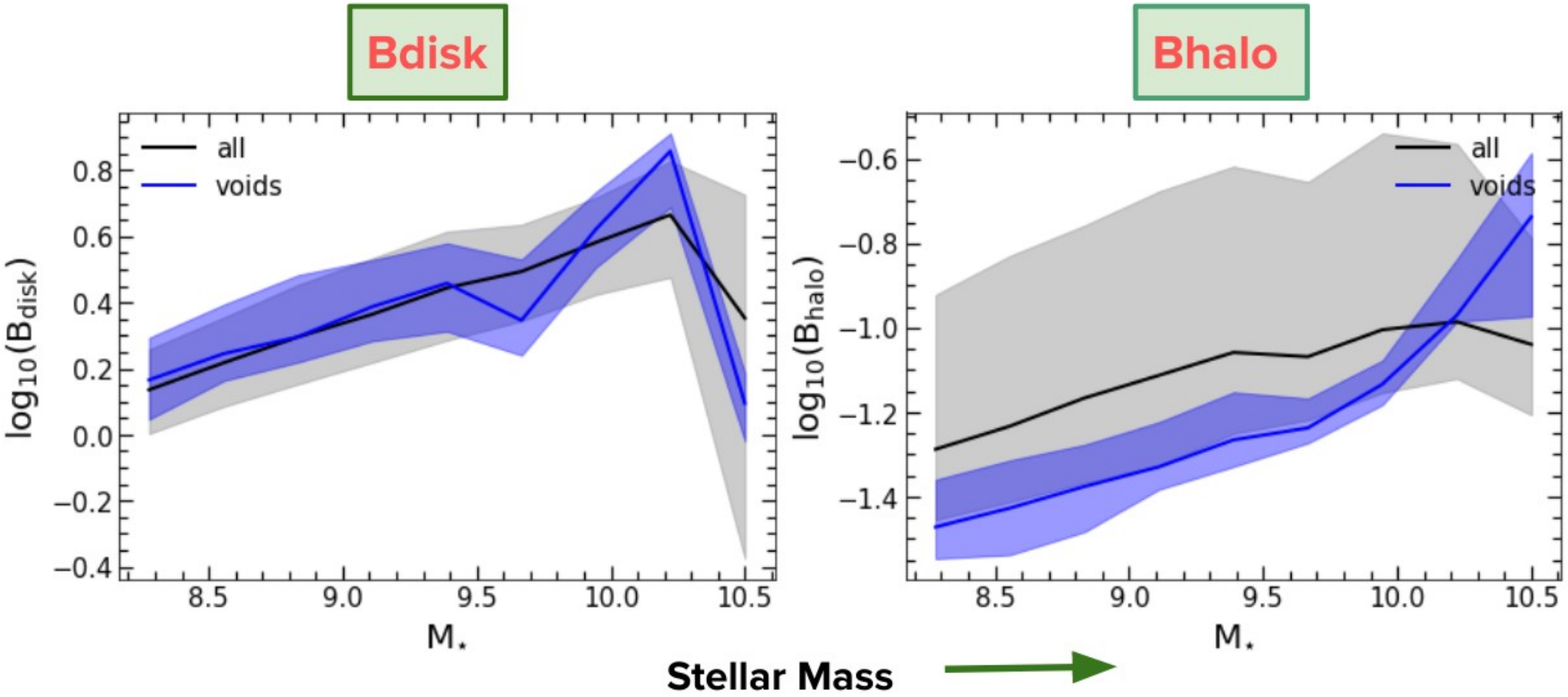
In Spherical voids:





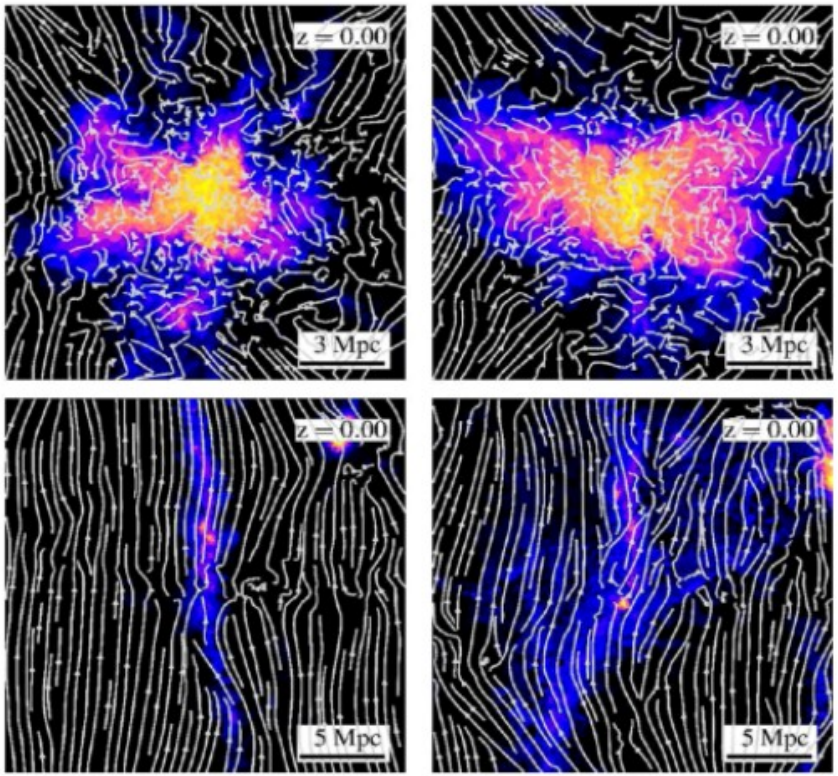
¿ What about the Haloes?





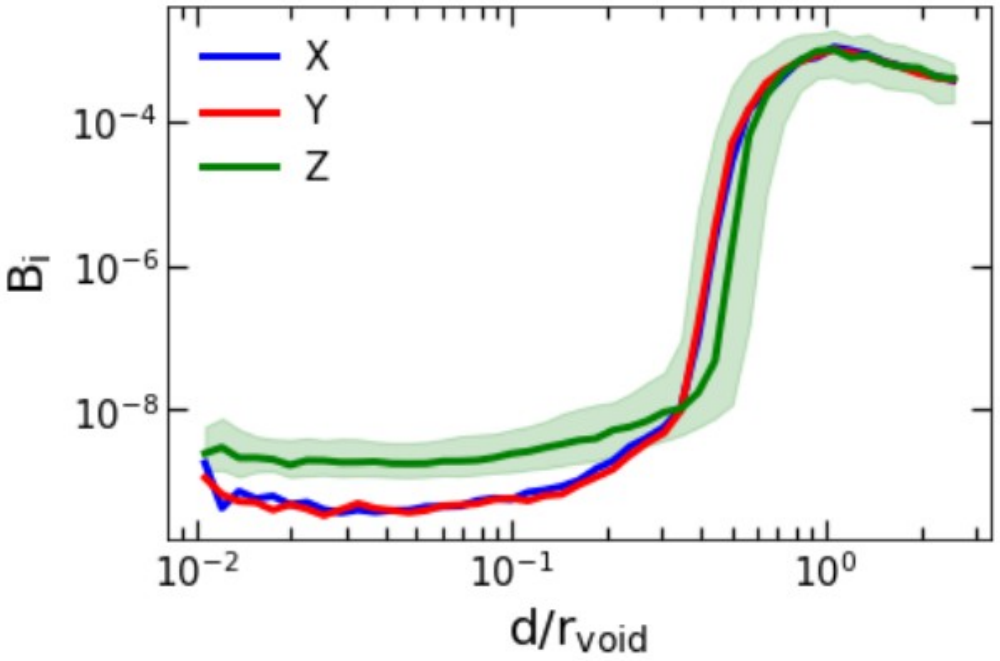
Rodriguez-Medrano et al. 2023

In this simulations the imprints of the original MF are not negligible in void regions



Marinacci et al. (2015)

MF profile in each direction



Need to do better

What do we solve?

$$\frac{d\vec{v}}{dt} = \frac{\nabla \cdot M}{\rho} = \frac{-\nabla P}{\rho} + \frac{(\nabla \times \vec{B}) \times \vec{B}}{\mu_0 \rho}$$

$$\frac{d\vec{v}}{dt} = \frac{\nabla \cdot M}{\rho} - f(\nabla \cdot \vec{B})$$

- When DivB:
  - tensile instabilities arise, but they can be suppressed

Direct Induction

$$\frac{d\vec{B}}{dt} = (\vec{B} \cdot \nabla)\vec{v} - \vec{B}(\nabla \cdot \vec{v})$$

$$\left.\frac{d\vec{B}}{dt}\right|_{Dedner} = -\nabla \phi$$

$$\frac{d\phi}{dt} = -c_s^2 \nabla \cdot B - \frac{\phi}{\tau} - \frac{\phi}{2}(\nabla \cdot \vec{v})$$

Vector Potential

$$\vec{B} = \nabla \times \vec{A}$$

$$\frac{\delta \vec{A}}{\delta t} = \vec{v} \times \vec{B} + \nabla \psi$$

$$\frac{d\psi}{dt} = -\left(c_h^2 \nabla \cdot \vec{A} + c_h \frac{\psi}{h}\right)$$

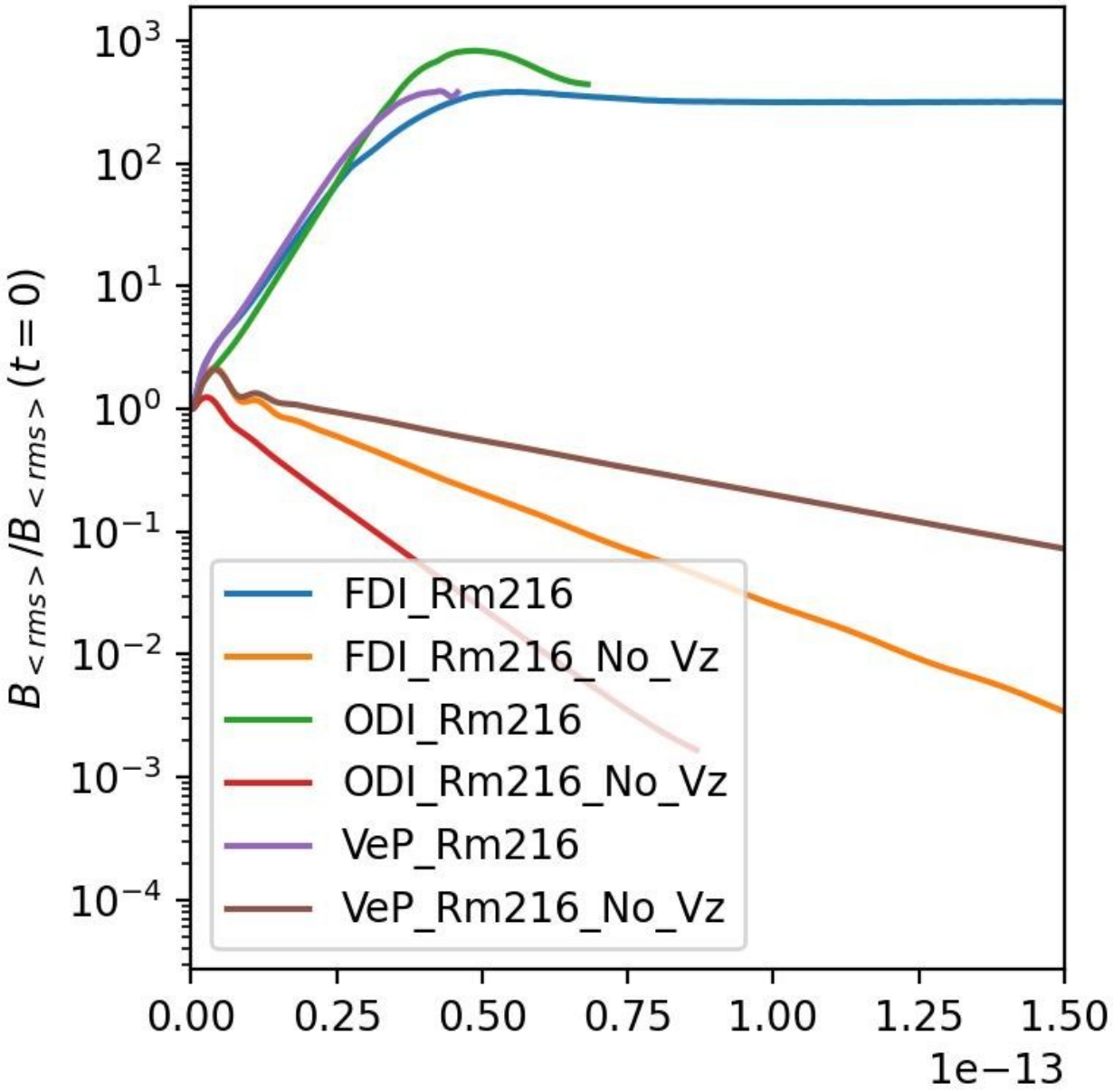
$$\psi = -\vec{v} \cdot \vec{A}$$

- Local Error sources
- Cleaned by:
  - damping
  - dispersion

- DivB errors up to Div Operator
- Vector Potential stabilized by Gauge

- And cosmological Integration!

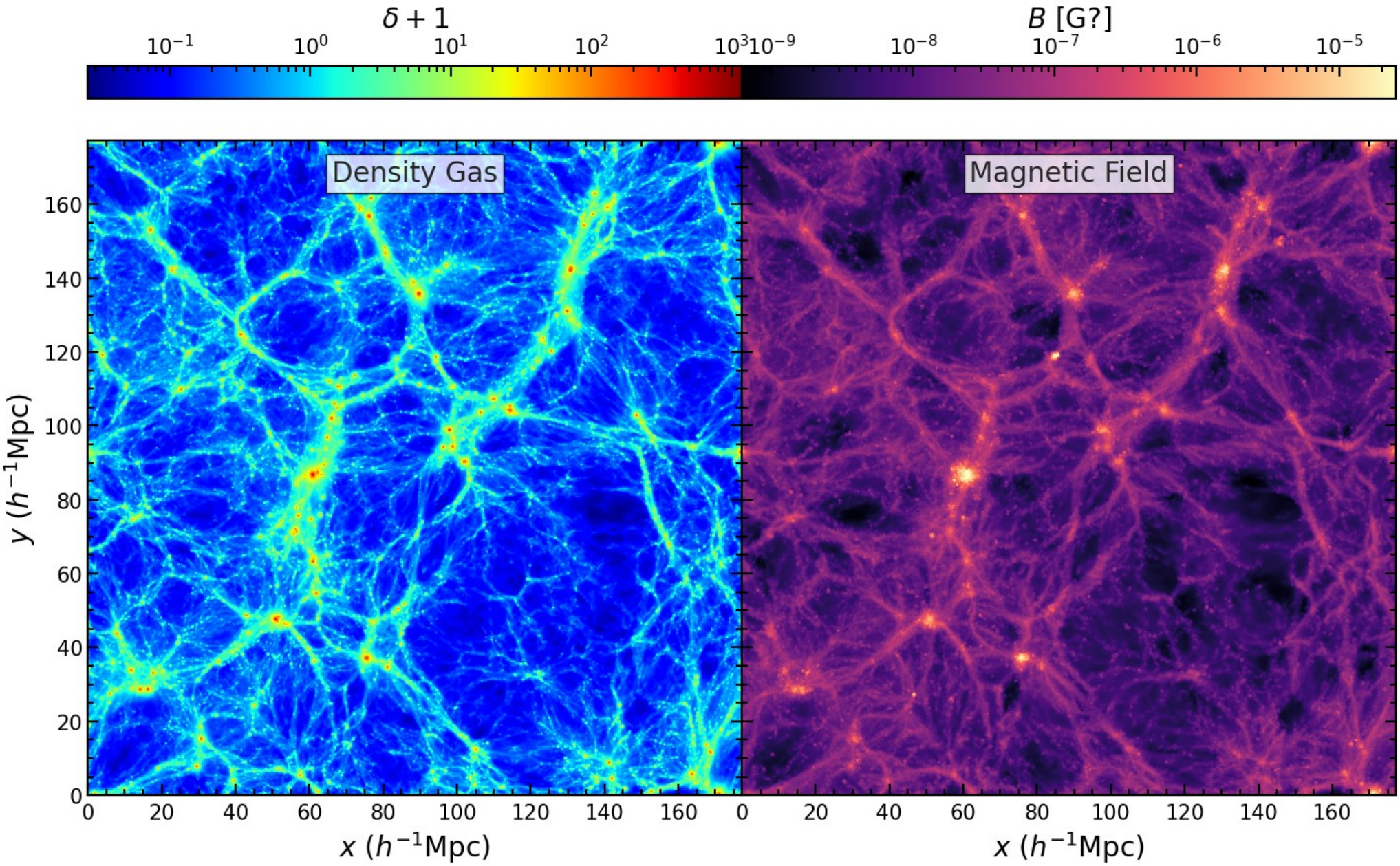
Roberts Flow with SWIFT



We are able to test the regimes in which we know the numerical schemes converge to physical solutions.

Proof of Concept!

Adiabatic run
150 Mpc - 512**3

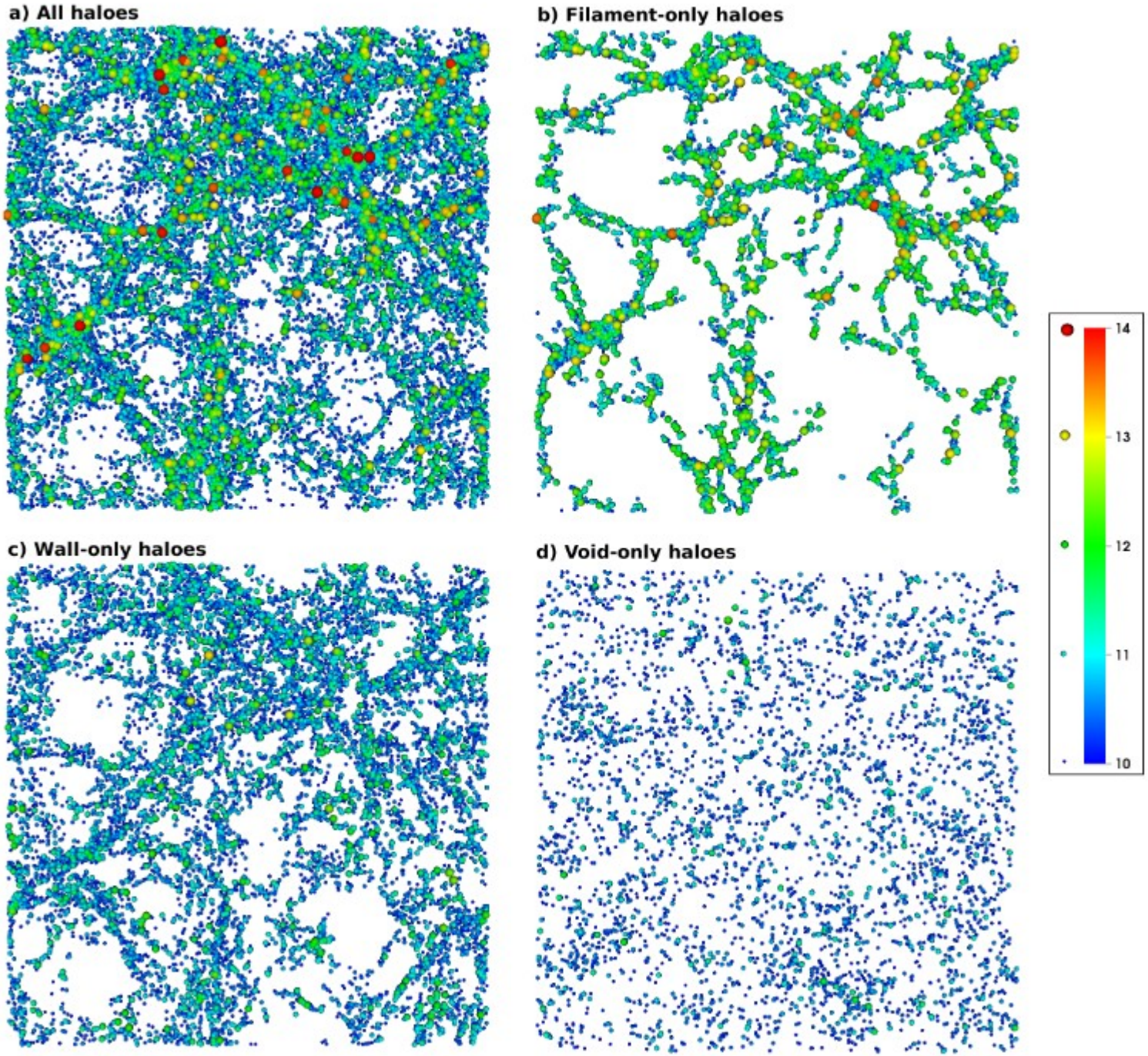


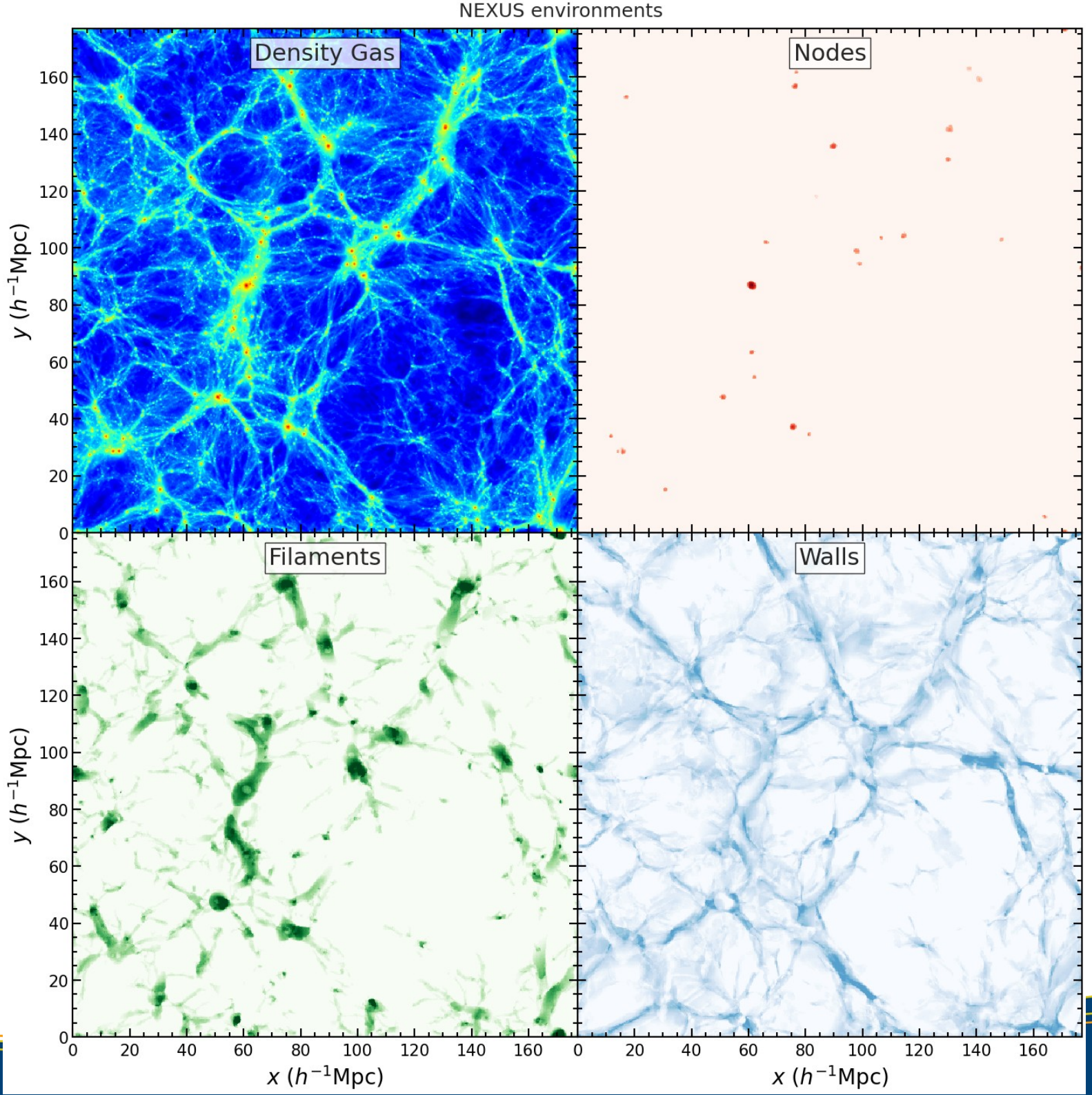
Using Nexus as Environment definition

- Grid and smooth the fields
- Calulate the eigenvalues of the Hessian in each bin
- Characterize the material within

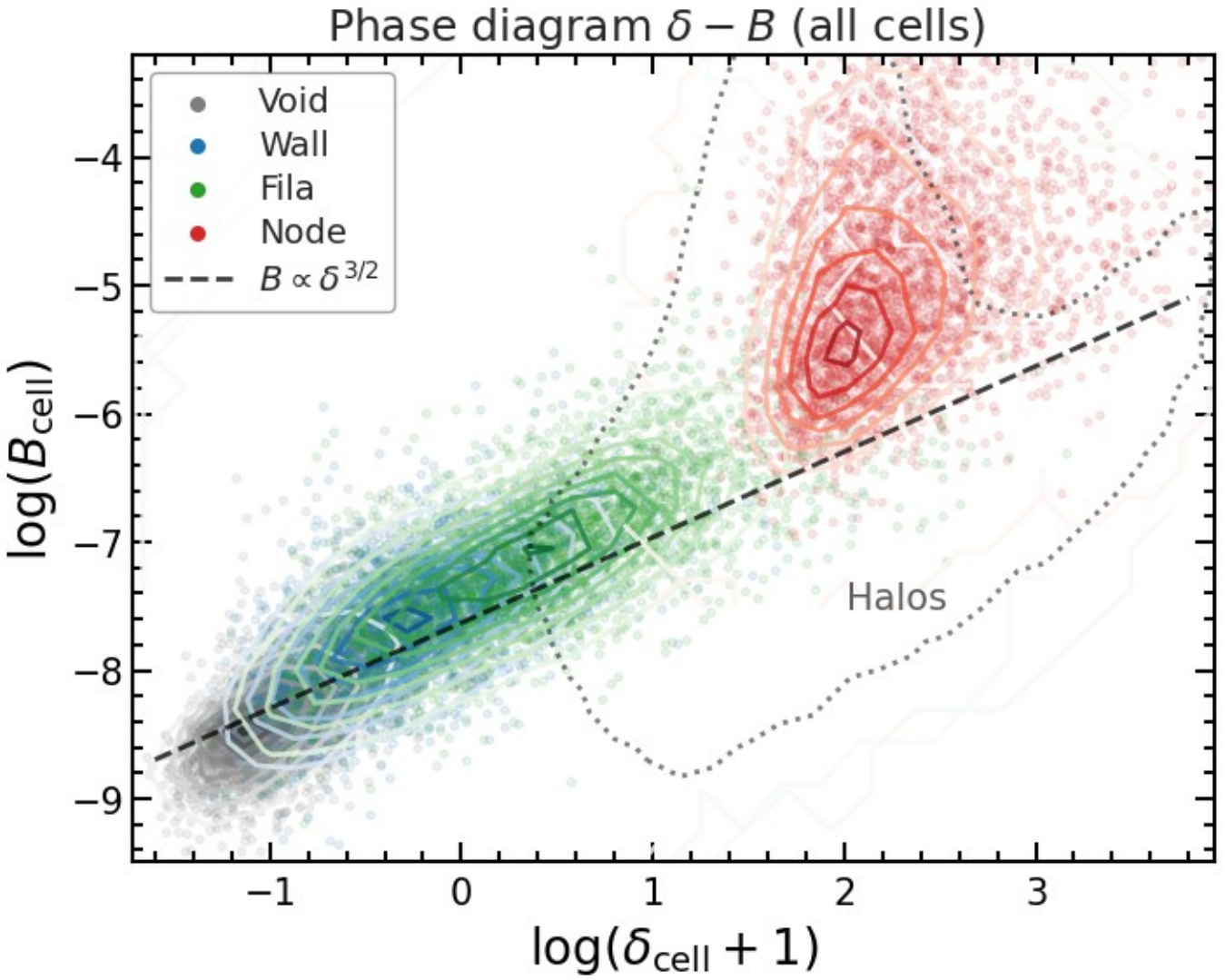
Cautun et al 2012.

Structure	Soft constraints	Strict constraints
cluster	$\lvert\lambda_1\rvert \simeq \lvert\lambda_2\rvert \simeq \lvert\lambda_3\rvert$	$\lambda_1 < 0;\ \lambda_2 < 0;\ \lambda_3 < 0$
filament	$\lvert\lambda_1\rvert \simeq \lvert\lambda_2\rvert \gg \lvert\lambda_3\rvert$	$\lambda_1 < 0;\ \lambda_2 < 0$
wall	$\lvert\lambda_1\rvert \gg \lvert\lambda_2\rvert;\ \lvert\lambda_1\rvert \gg \lvert\lambda_3\rvert$	$\lambda_1 < 0$

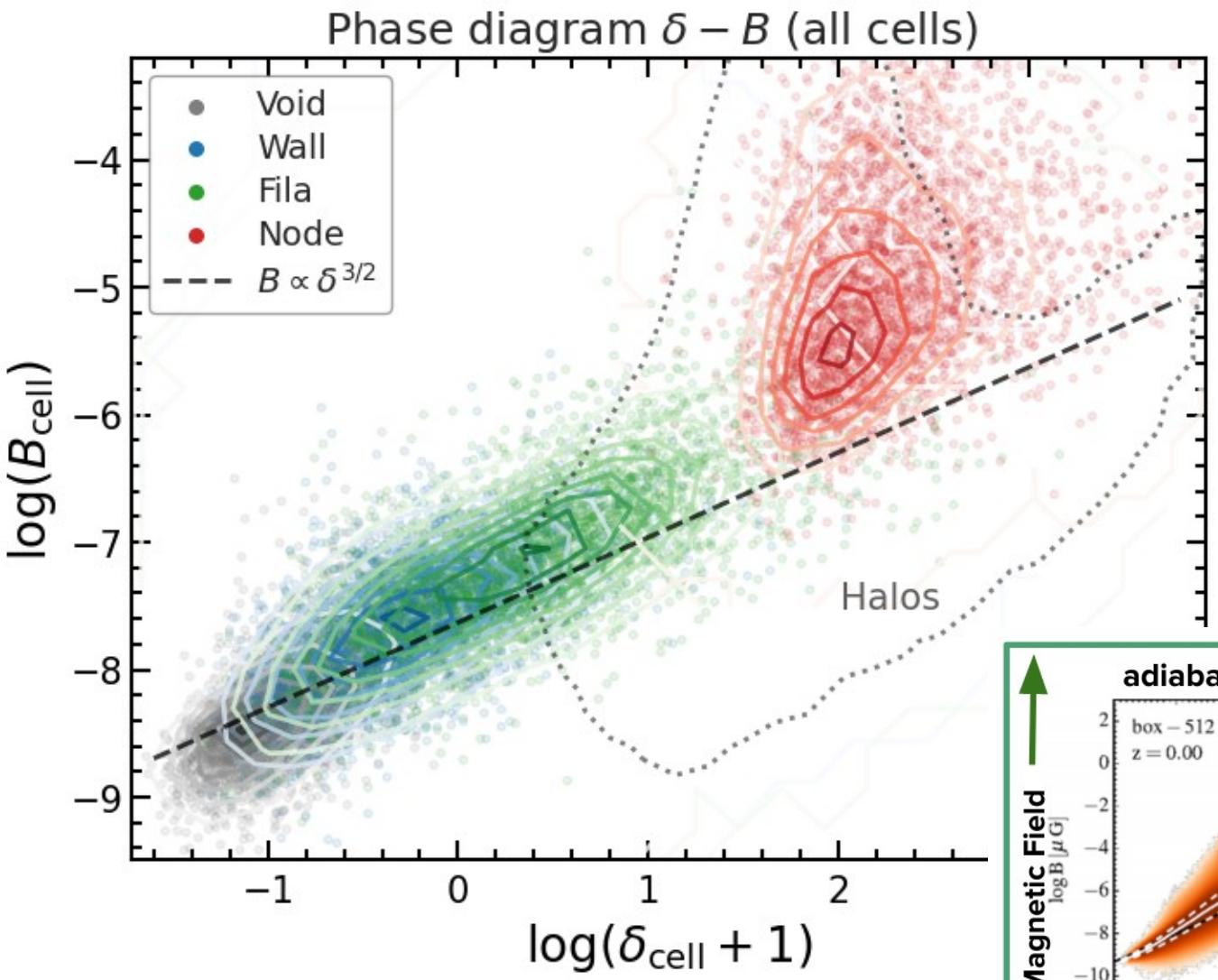


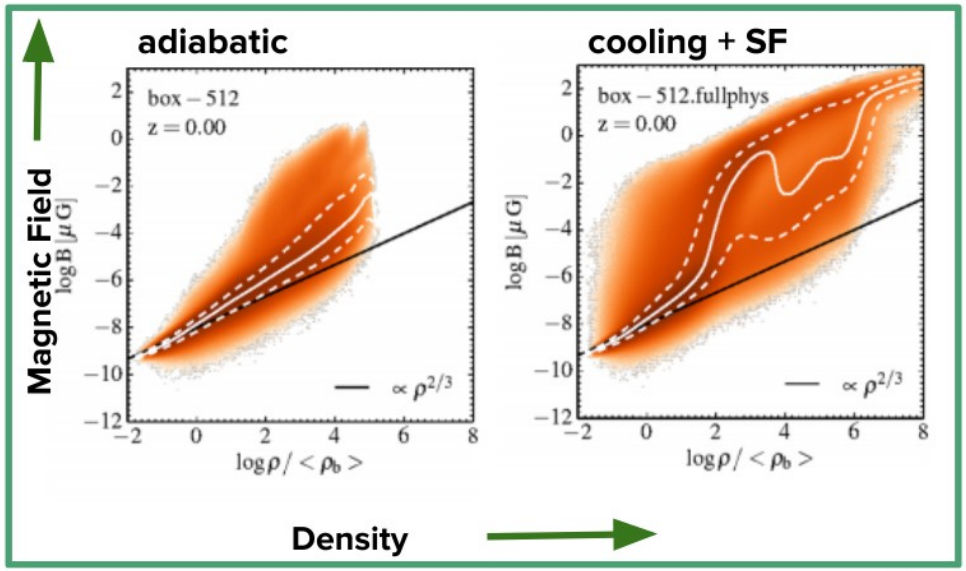

NEXUS environments
Density Gas
Nodes
Filaments
Walls
y (h⁻¹Mpc)
x (h⁻¹Mpc)
0
20
40
60
80
100
120
140
160

Proof of Concept!

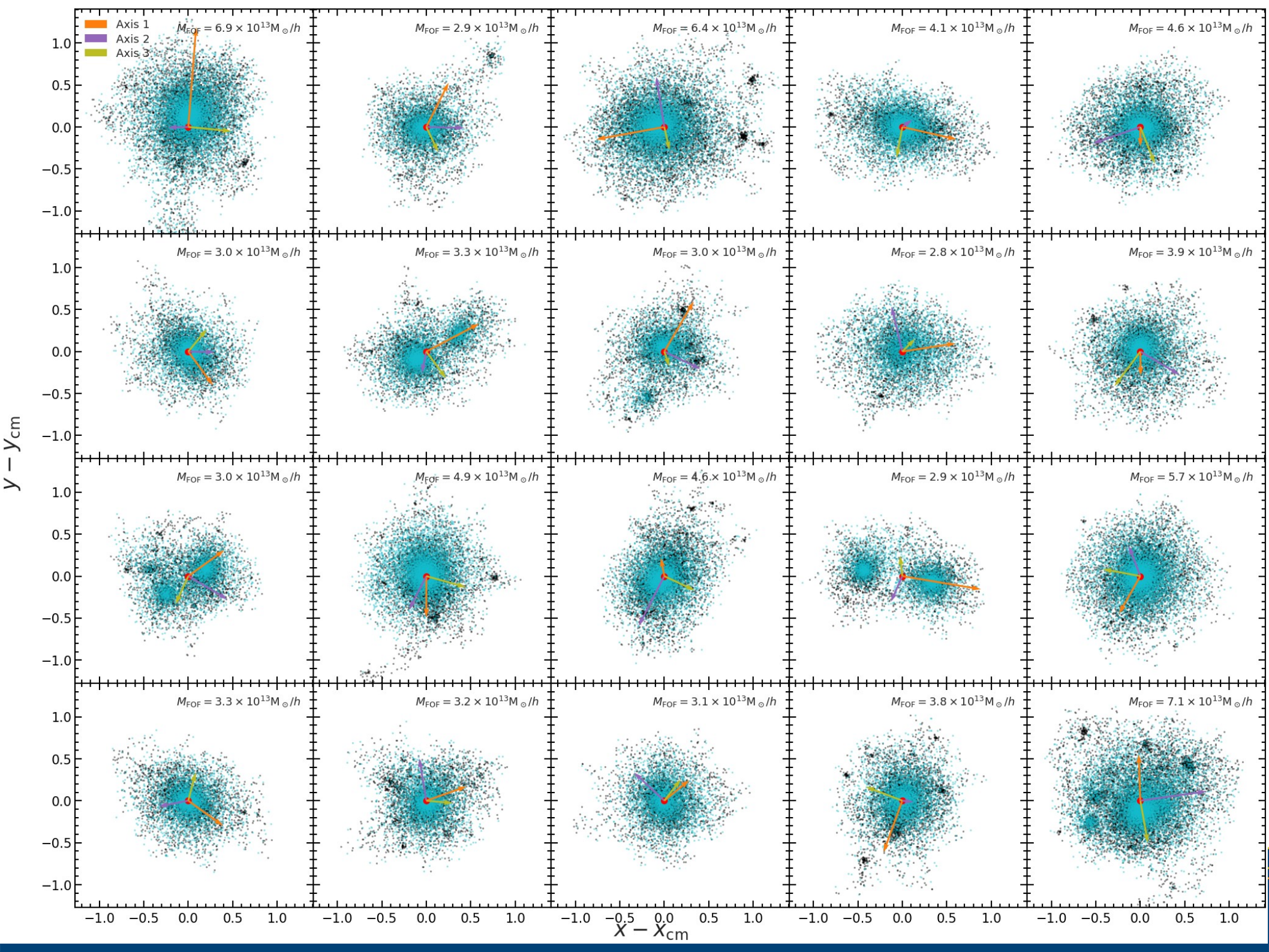


Proof of Concept!

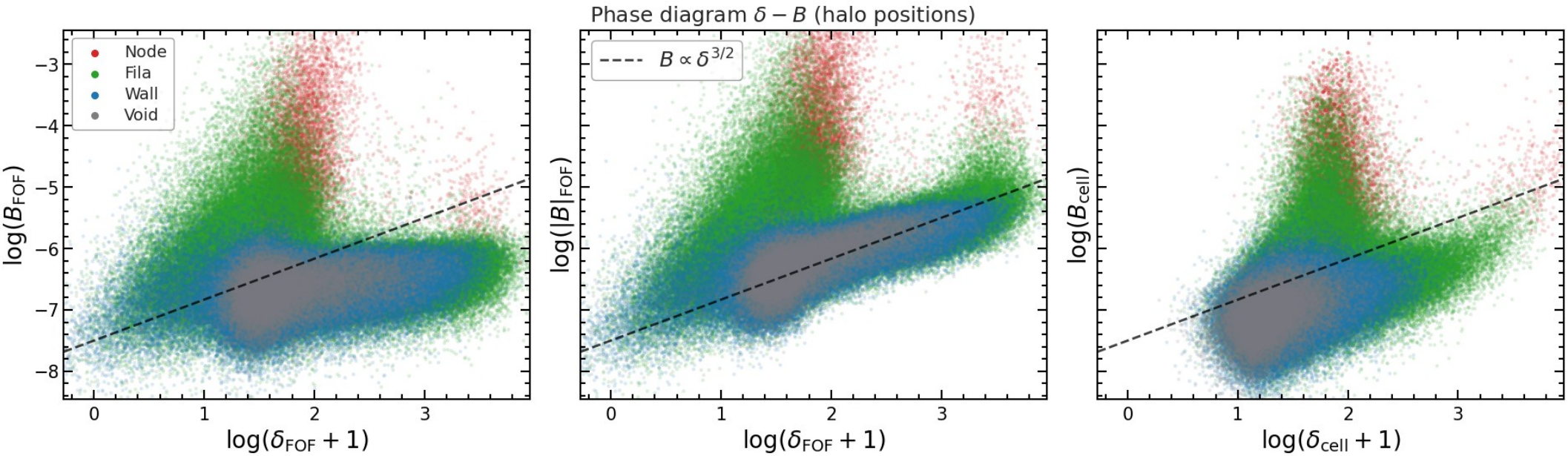




Marinacci et al. (2015)

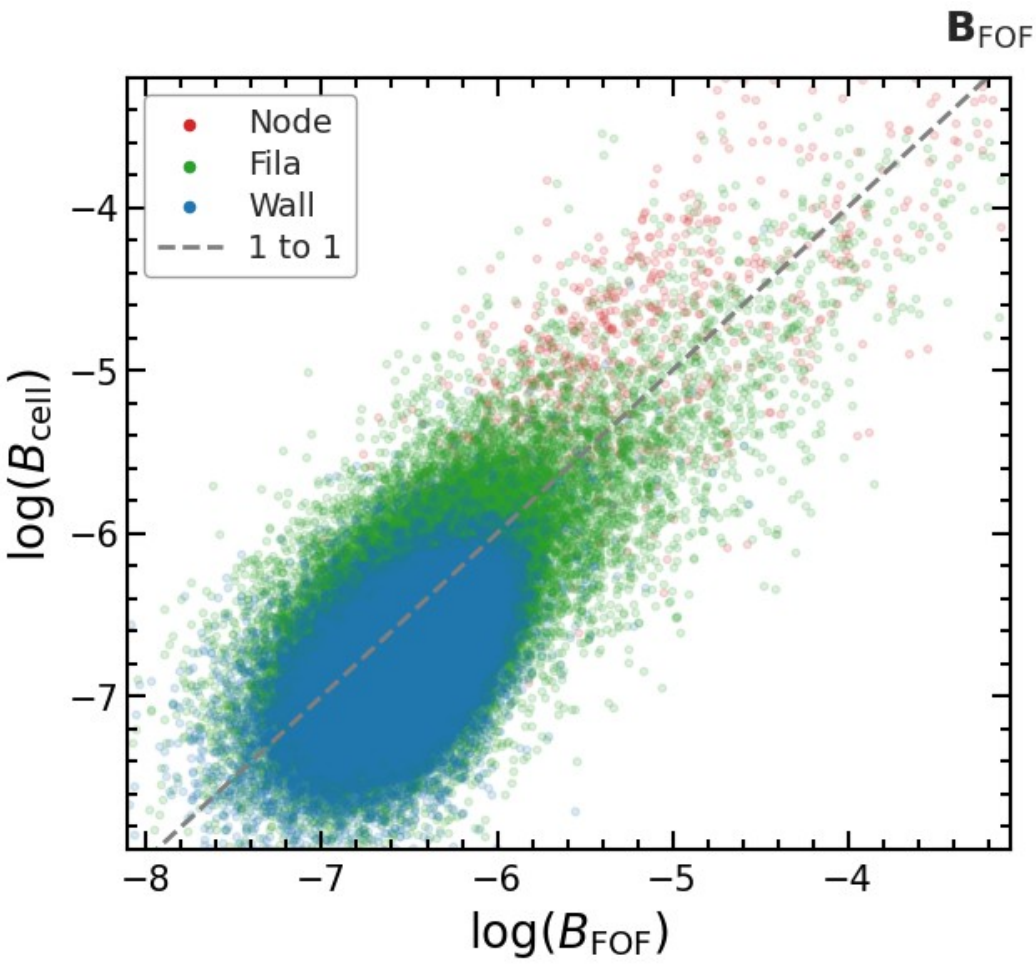

Axis 1
Axis 2
Axis 3
$M_{\rm FOF} = 6.9 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 2.9 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 6.4 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 4.1 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 4.6 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.0 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.3 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.0 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 2.8 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.9 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.0 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 4.9 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 4.6 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 2.9 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 5.7 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.3 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.2 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.1 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 3.8 \times 10^{13} {\rm M}_\odot/h$
$M_{\rm FOF} = 7.1 \times 10^{13} {\rm M}_\odot/h$
$y - y_{\rm cm}$
$x - x_{\rm cm}$
1.0
0.5
0.0
−0.5
−1.0

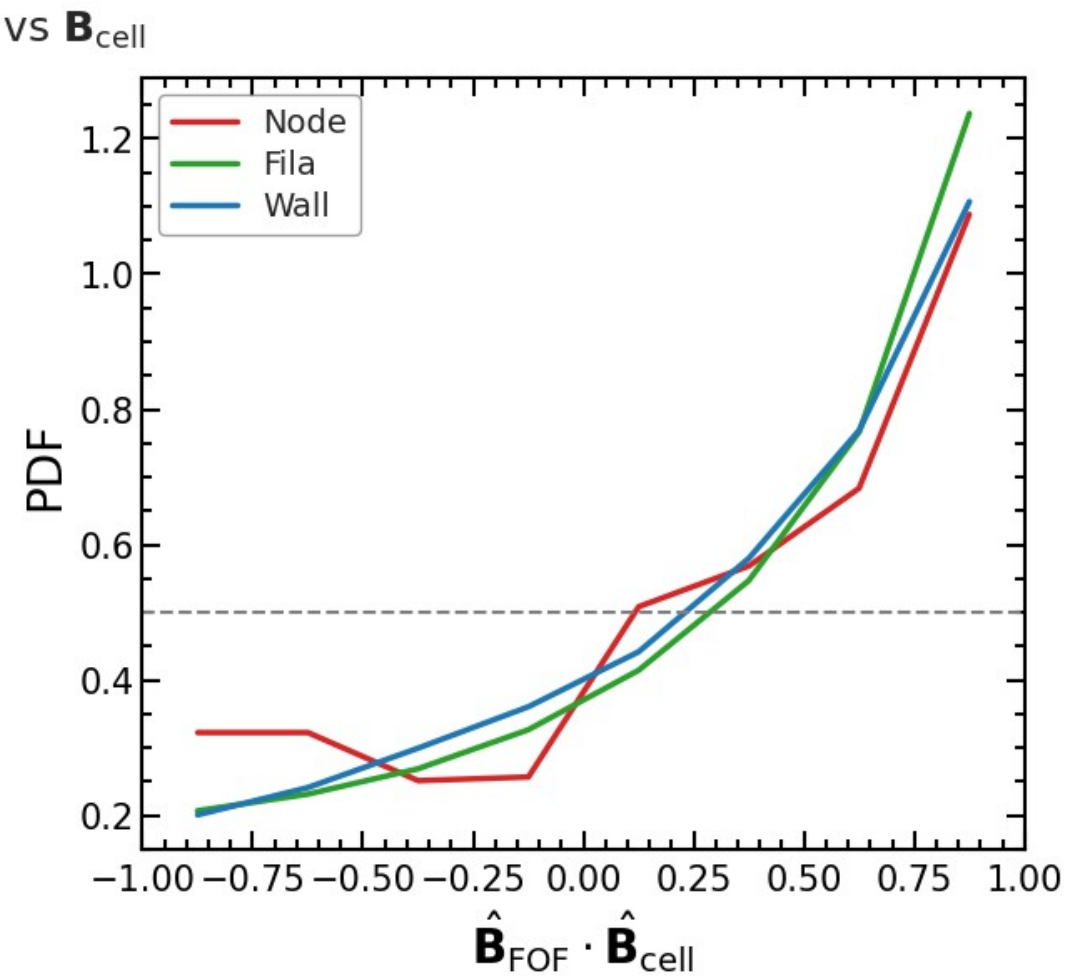
Proof of Concept!



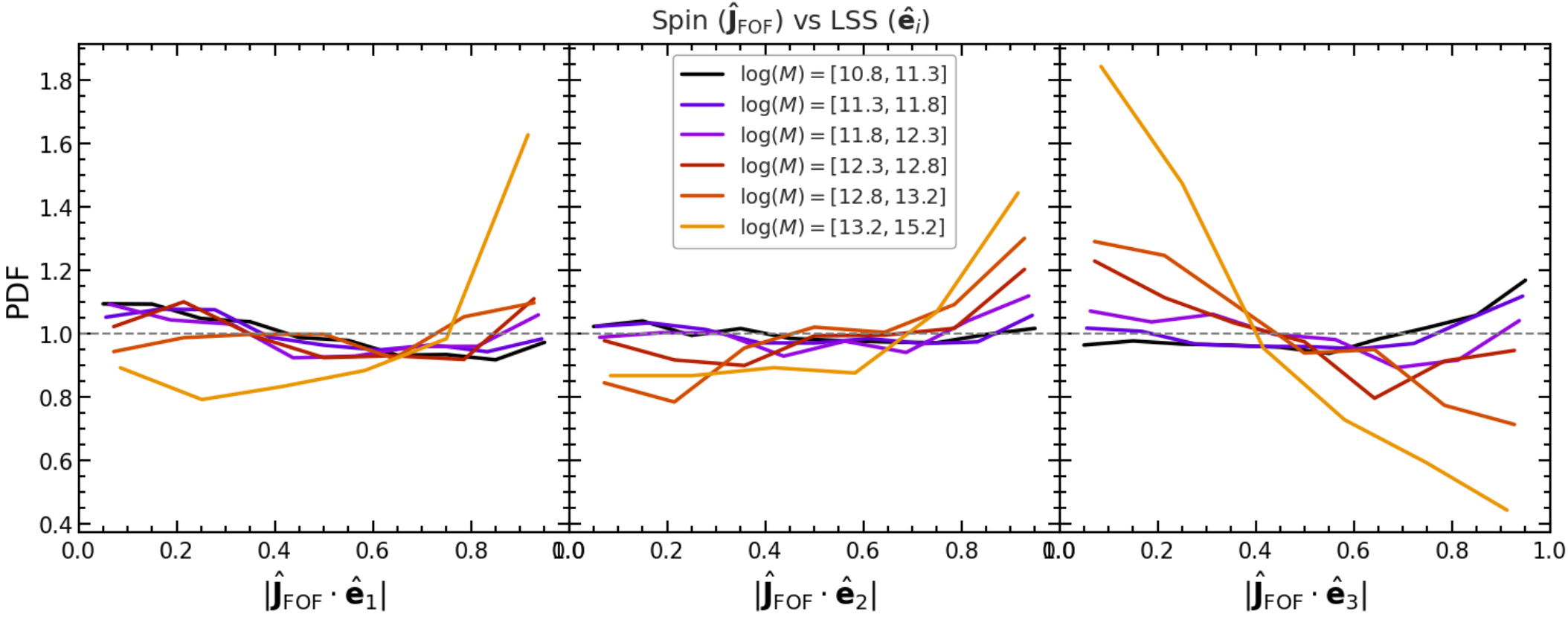
Only cells and halos
-We loose adiabaticity (which should happen)
-This should be close to the thinking about galaxies
-The magnetic field follows different histories, complex, but we can try to summarize them by environments.
-No star-formation, nor cooling, nor feedback!

Proof of Concept!

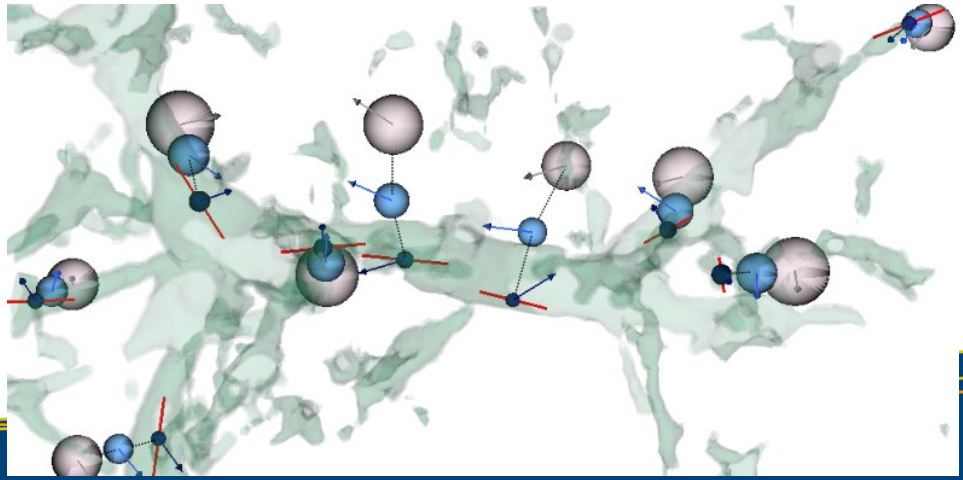




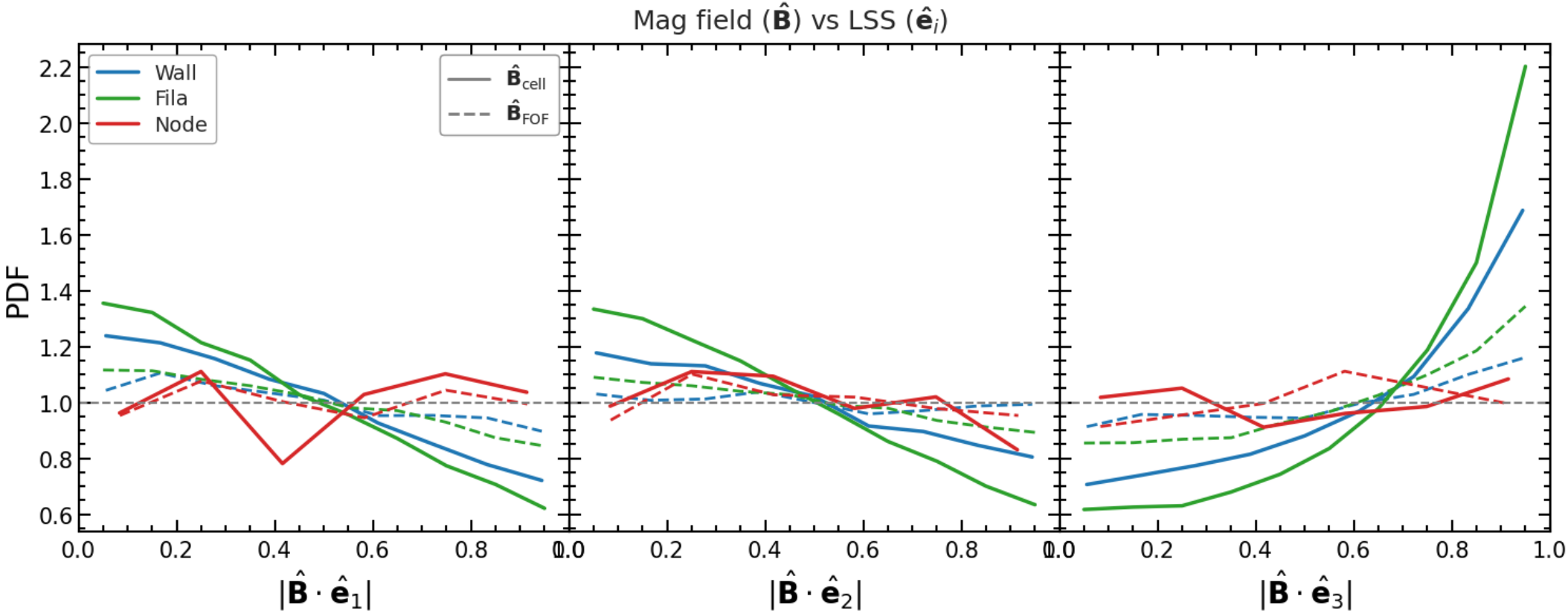
Proof of Concept!



Spin flip dependence

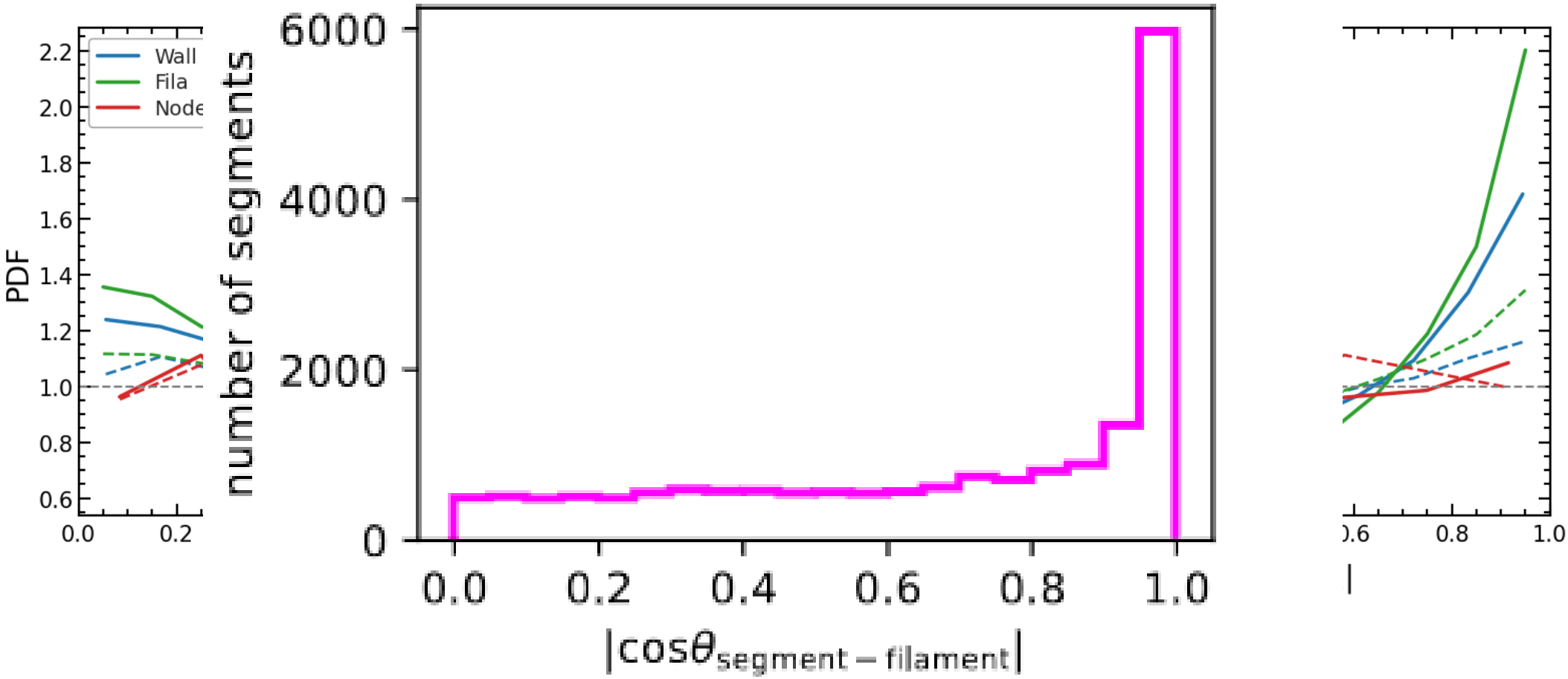


Proof of Concept!



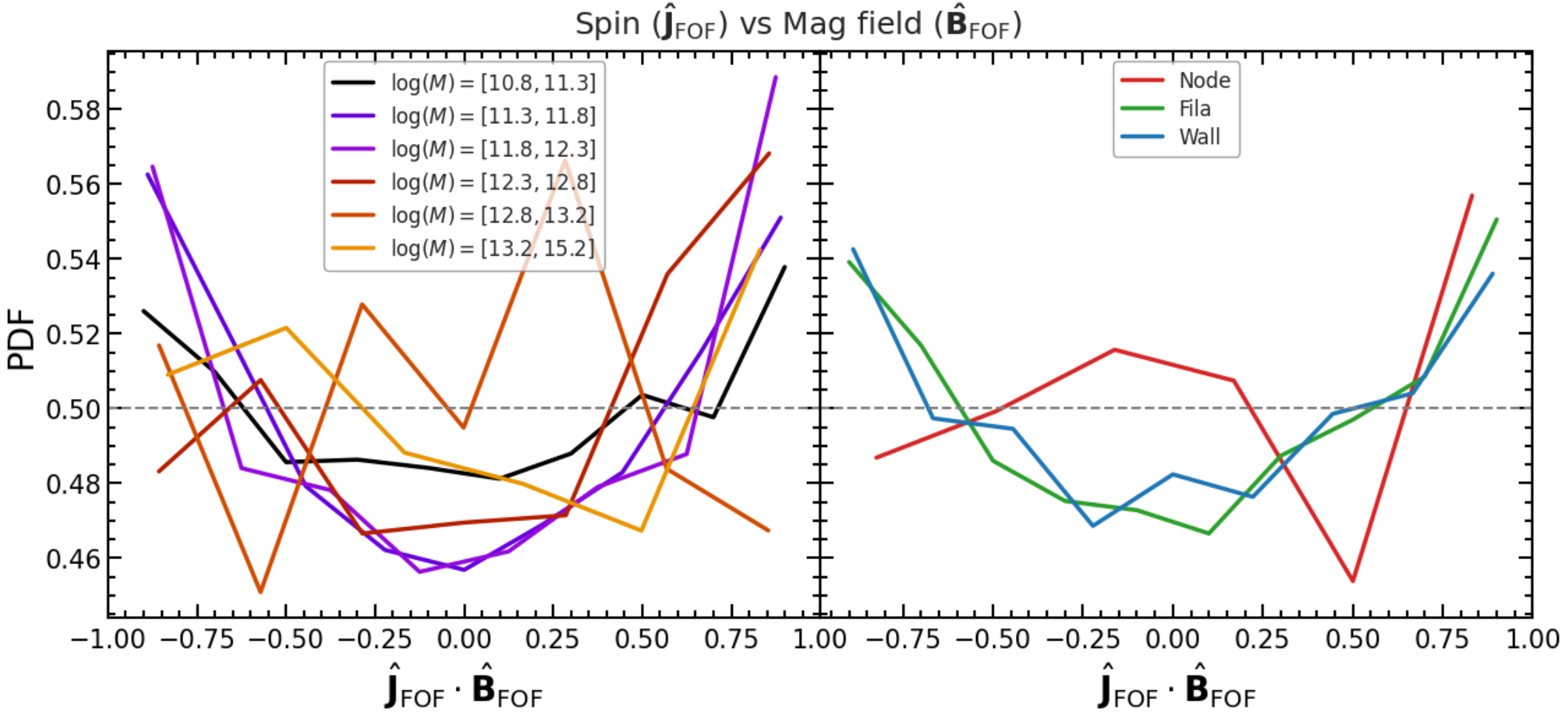
Magnetic fields in filaments tends to be parallel (even the haloes)!

Proof of Concept!



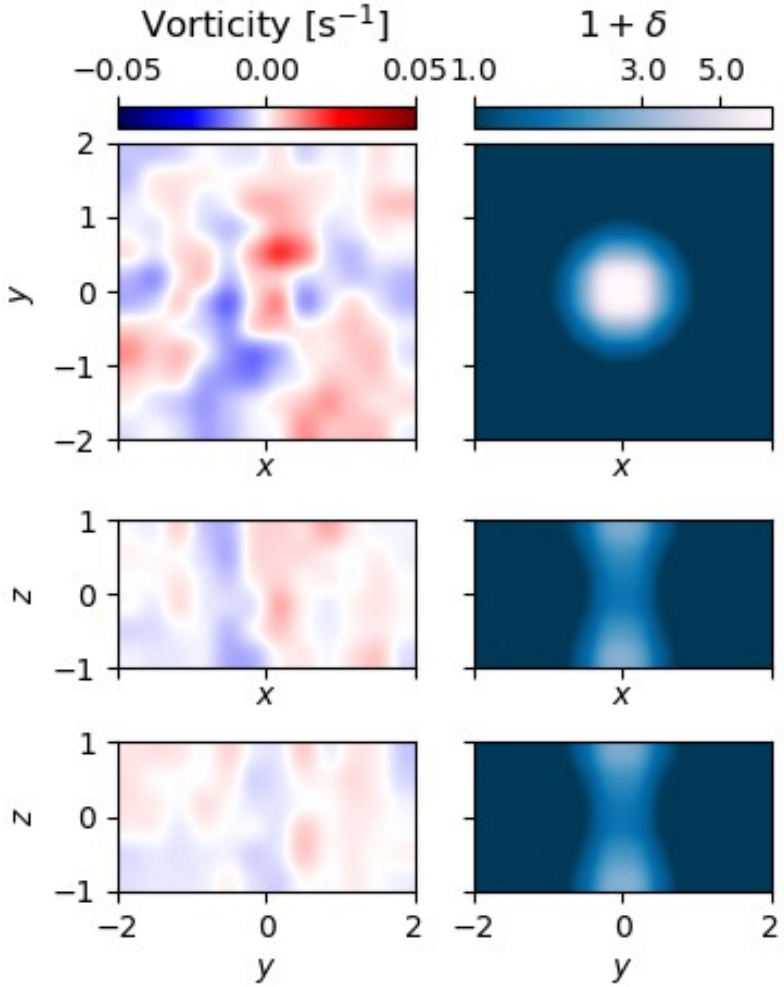
Magnetic fields in filaments tends to be parallel (even the haloes)!
Banfi et al 2021!

Proof of Concept!

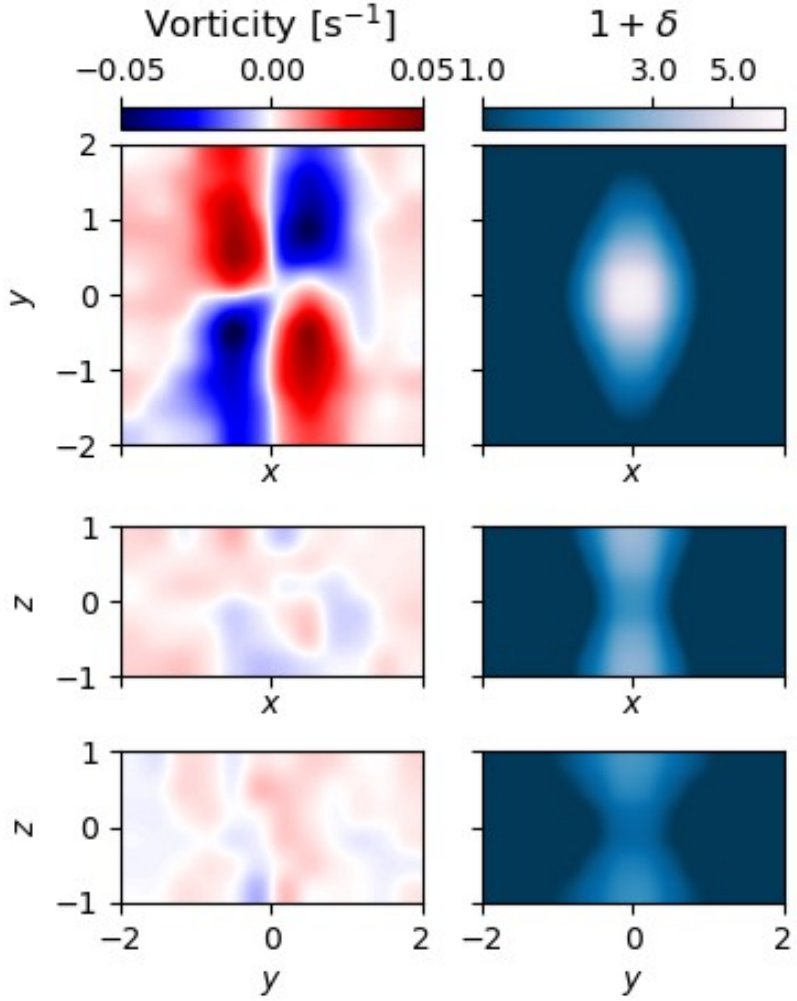


Proof of Concept!

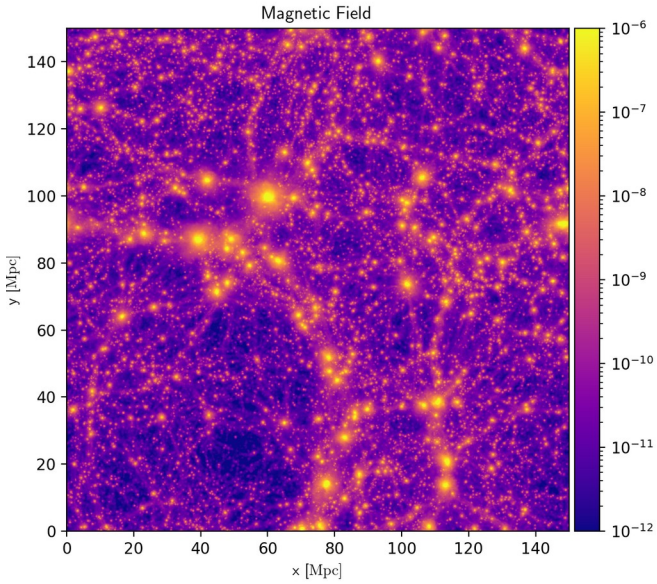
Random stacking of filaments



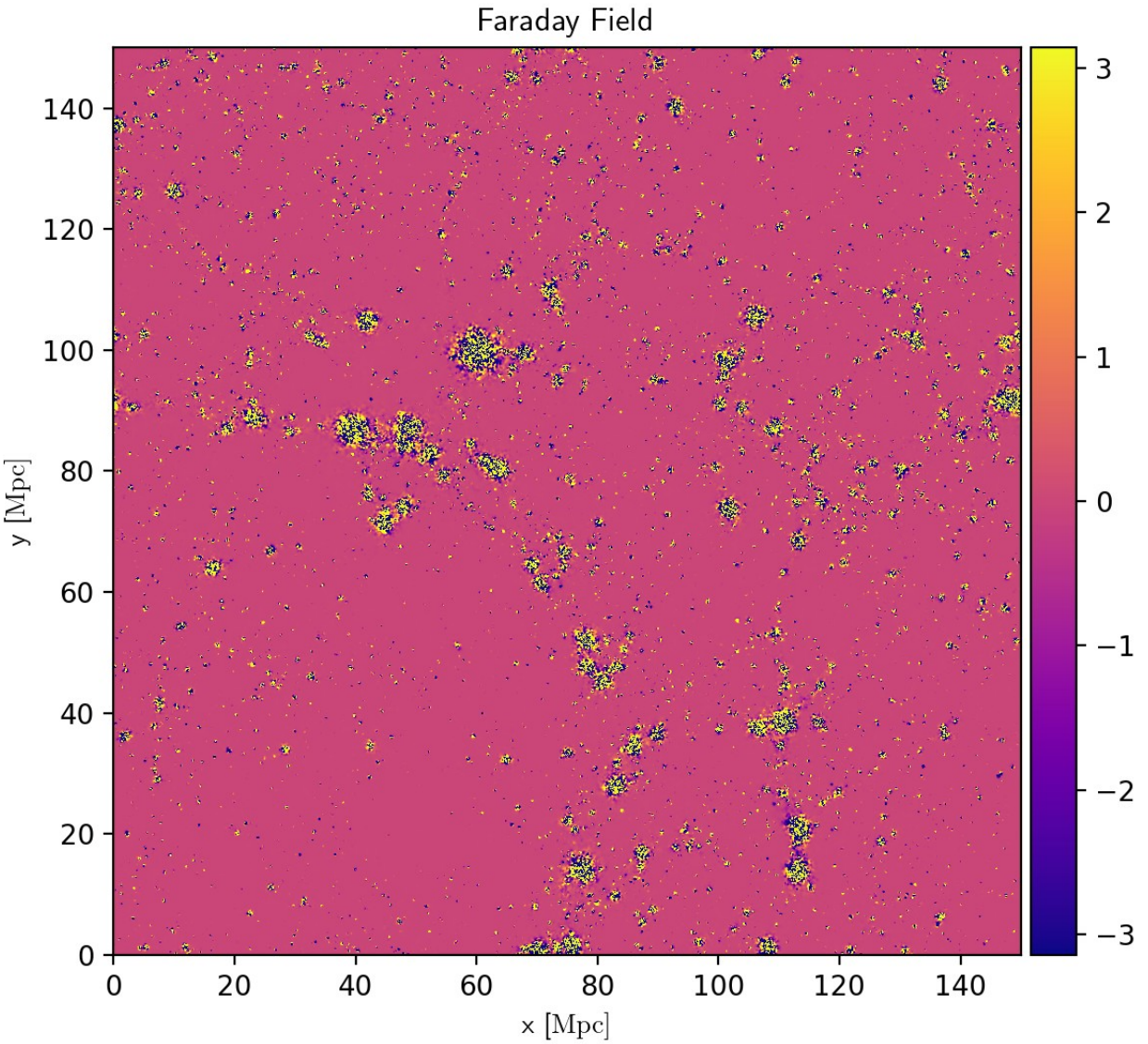
Shape oriented stacking of filaments



And we can build up observables



We start to build up the observable to compare with current observations.



As conclutions

- The interplay between between magnetic fields and galaxy evolution in different environments should be consistent.
- We are in a stage where we can analyze and connect, different ingredients
- We need to use the proper cosmological environmental tools, like void-filament, finders and apply the knowledge in observations.
- We need to do good statistics on those environments, small voids are not the same as big voids, as filemants

Thank you !

Final comments