lecture 3. astroparticle transport in magnetic fields

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Advanced Astroparticle Physics

NPAC M2

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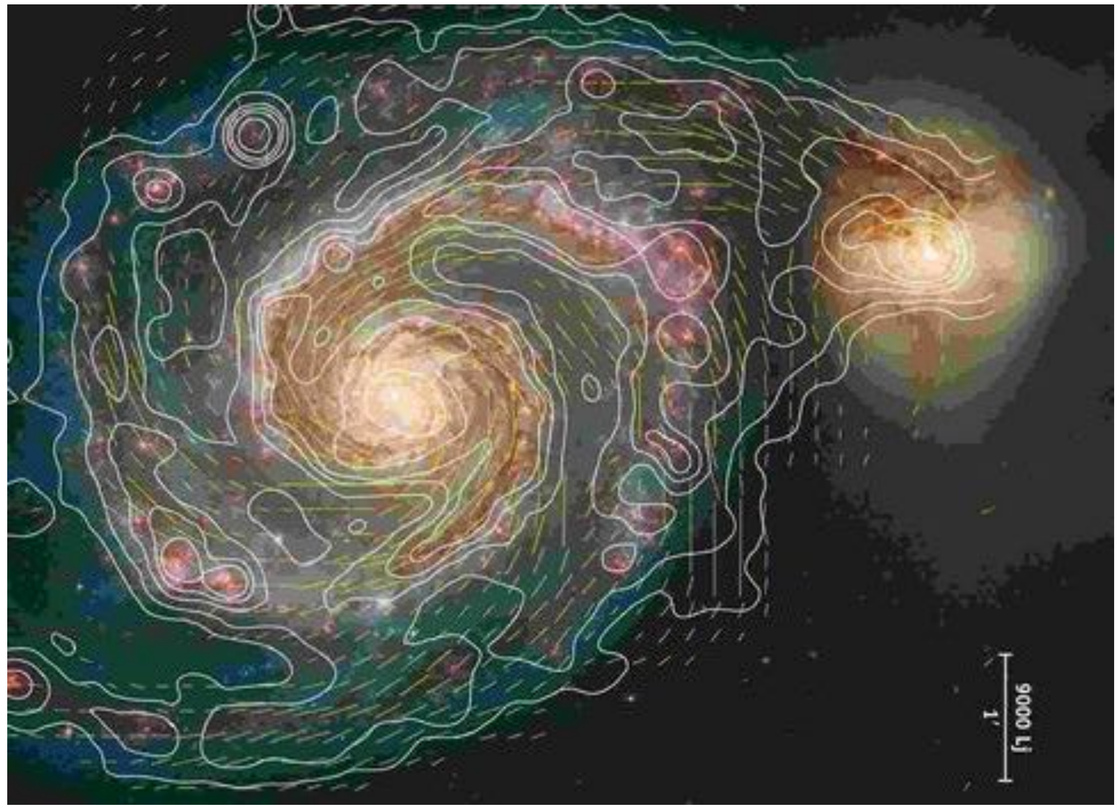
in today's class...

- **cosmic magnetic fields**
- **motion of a single particle in magnetic fields**
- **motion of an ensemble of particles in magnetic fields**

magnetic fields

magnetic fields in the universe

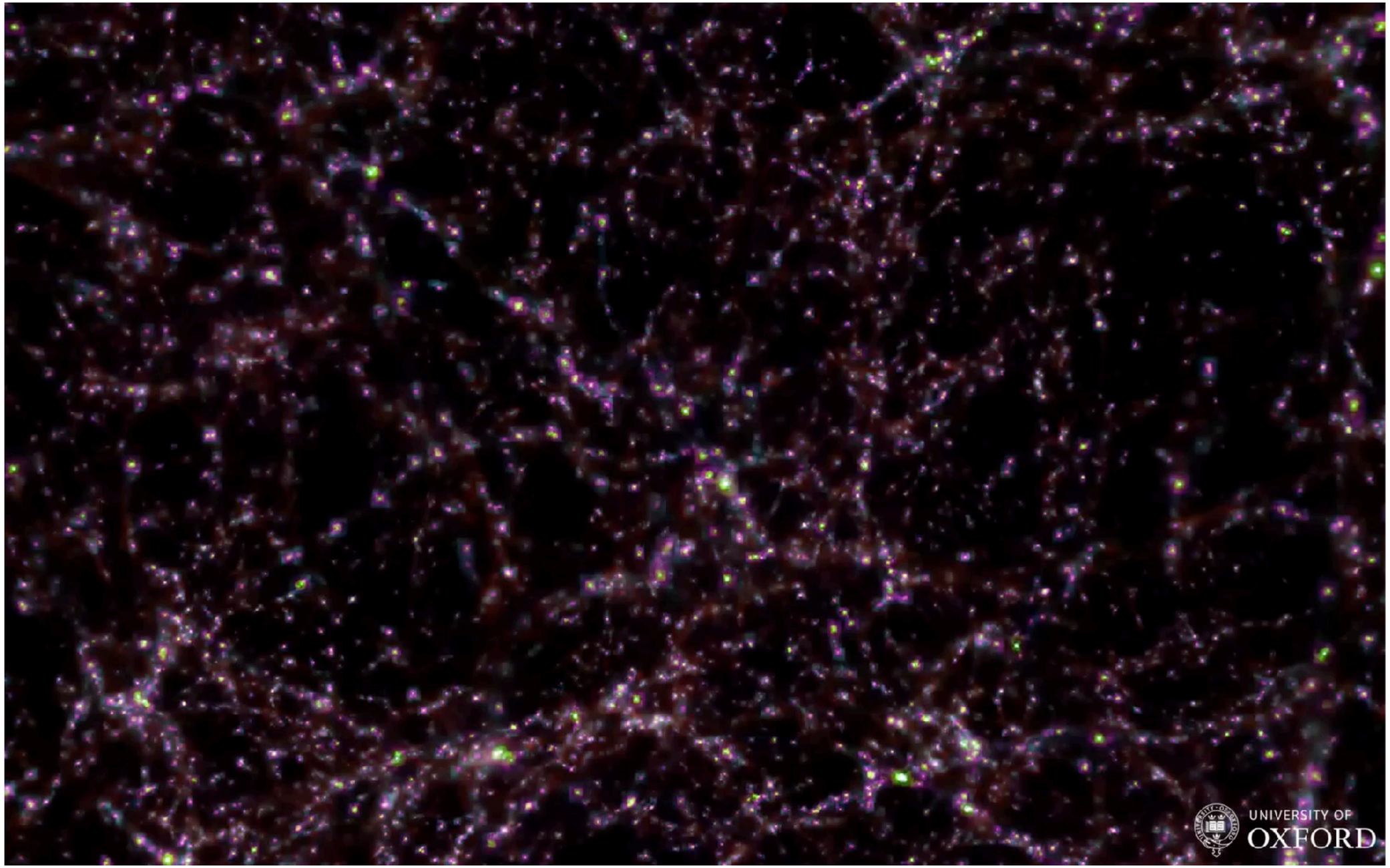
- magnetic fields in galaxies have ~ μG strengths
- to explain these observations, pre-existing **seed fields** are required
- dynamos can amplify (weak) seed fields
- **how did the seed fields originate?**
- but if the seed field is strong (B > 10 pG), adiabatic compression alone explains observations
- MHD induction equation



$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times \left(\vec{v} \times \vec{B} \right) + \eta \nabla^2 \vec{B}$$

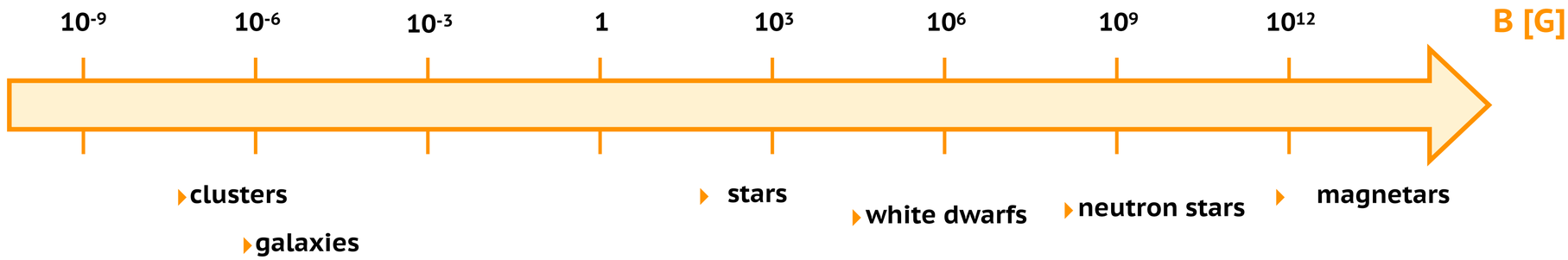
amplification

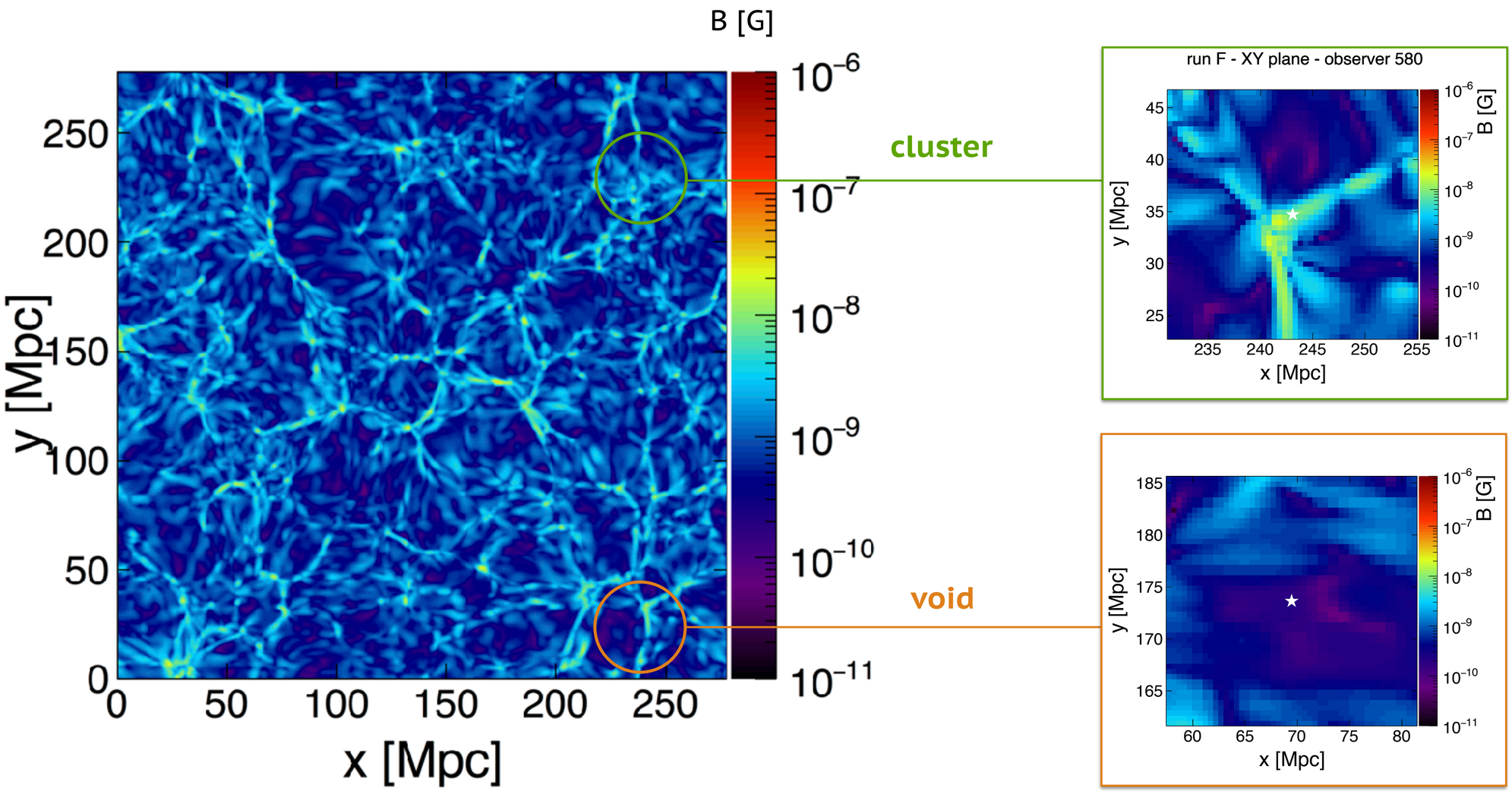
the magnetised cosmic web



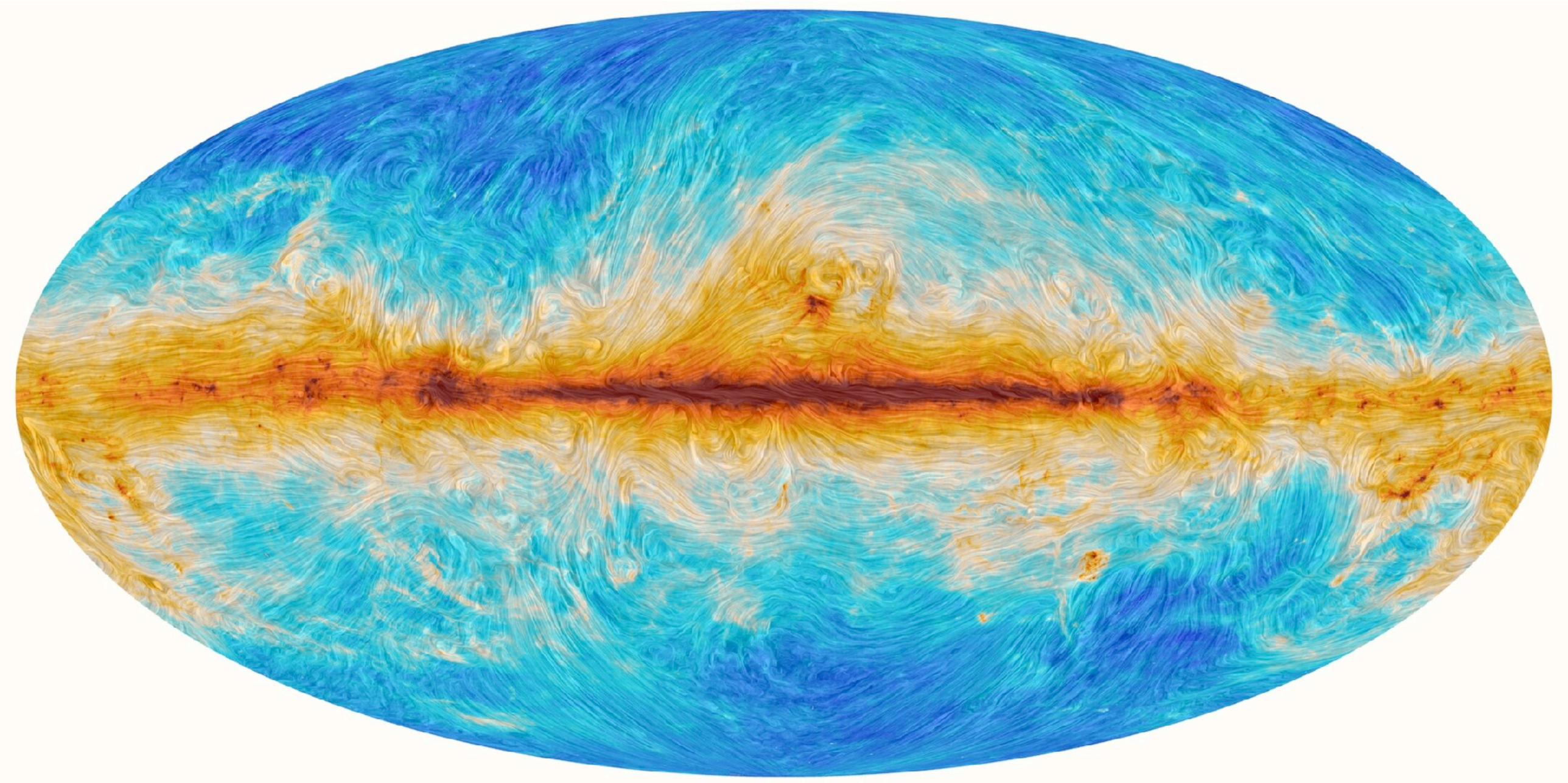
Alves Batista, Shin, Devriendt, Semikoz, Sigl. PRD, 96 (2017) 023010. arXiv:1704.05869

magnetic fields in the large-scale structure of the universe



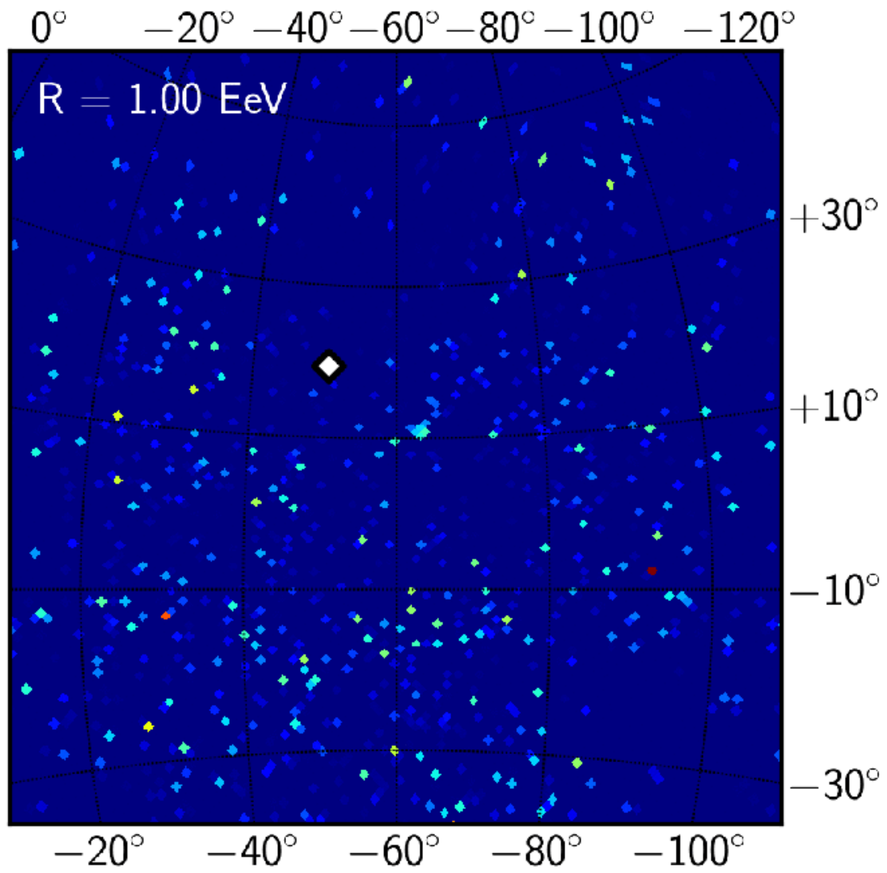


the galactic magnetic field



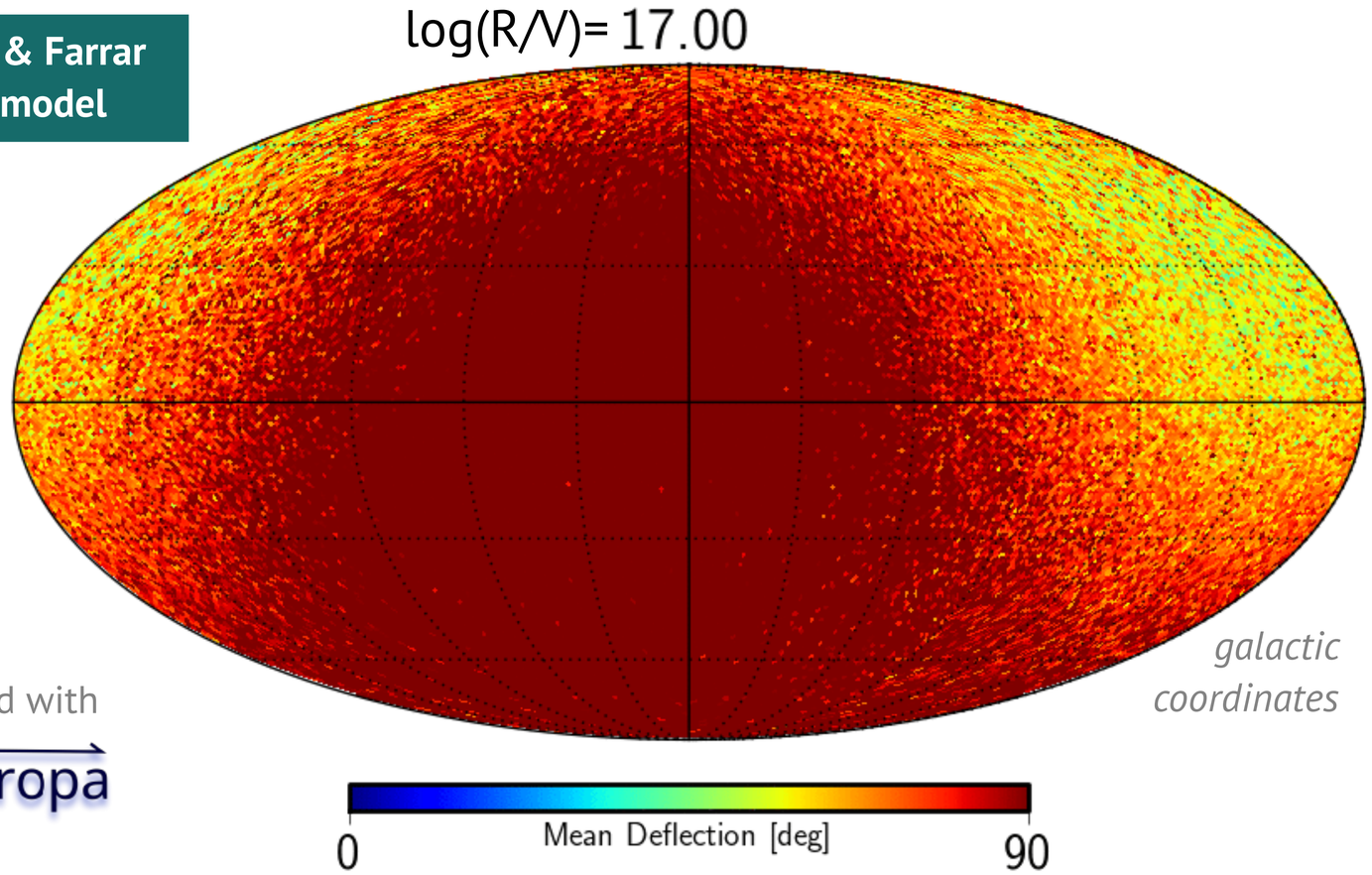
galactic magnetic fields effects on CRs

- the Galactic magnetic field (GMF) → essential for understanding UHECRs
- example 1: average deflection in each direction
- example 2: Centaurus A

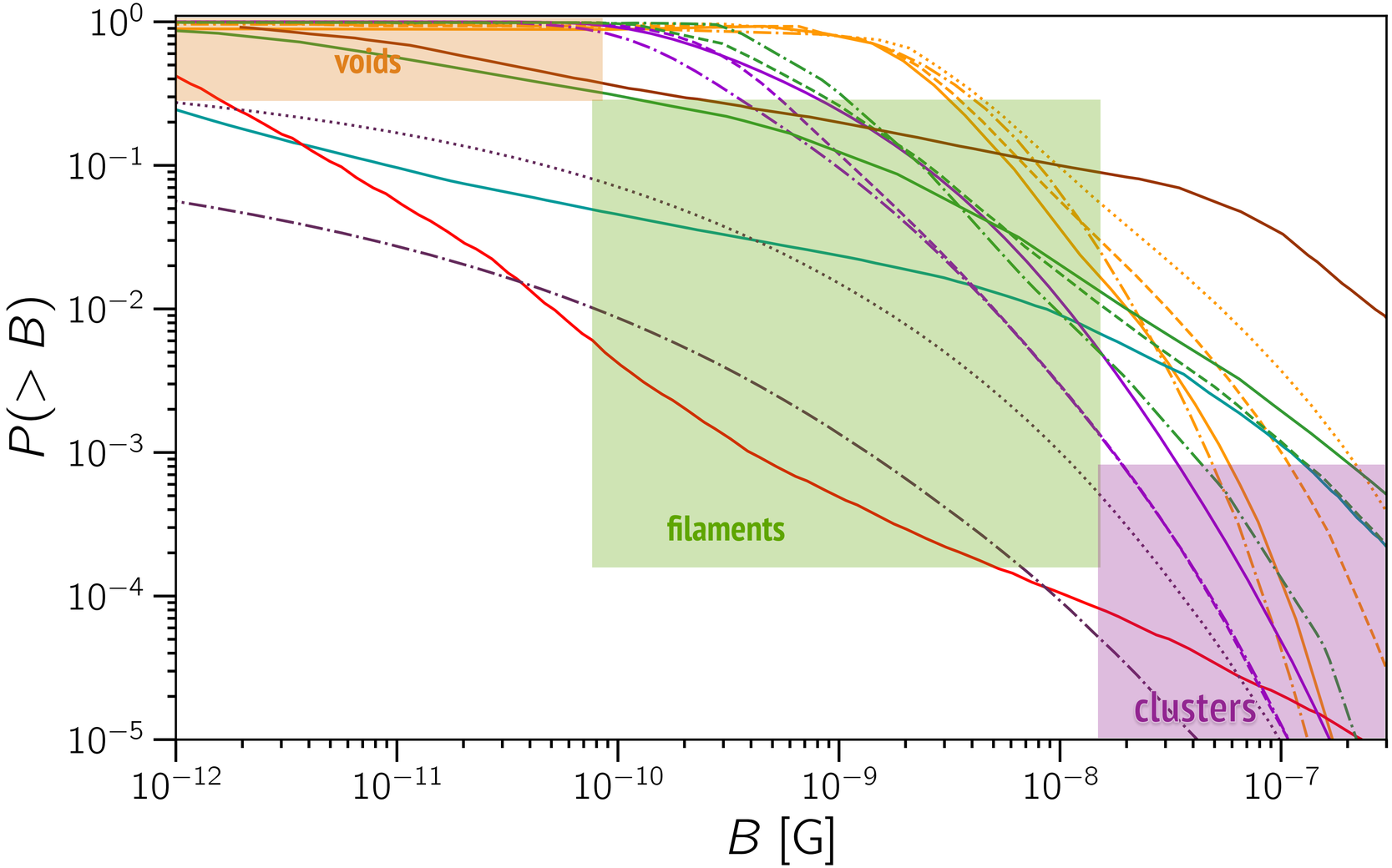


Jansson & Farrar 2012 model

simulated with CRPropa



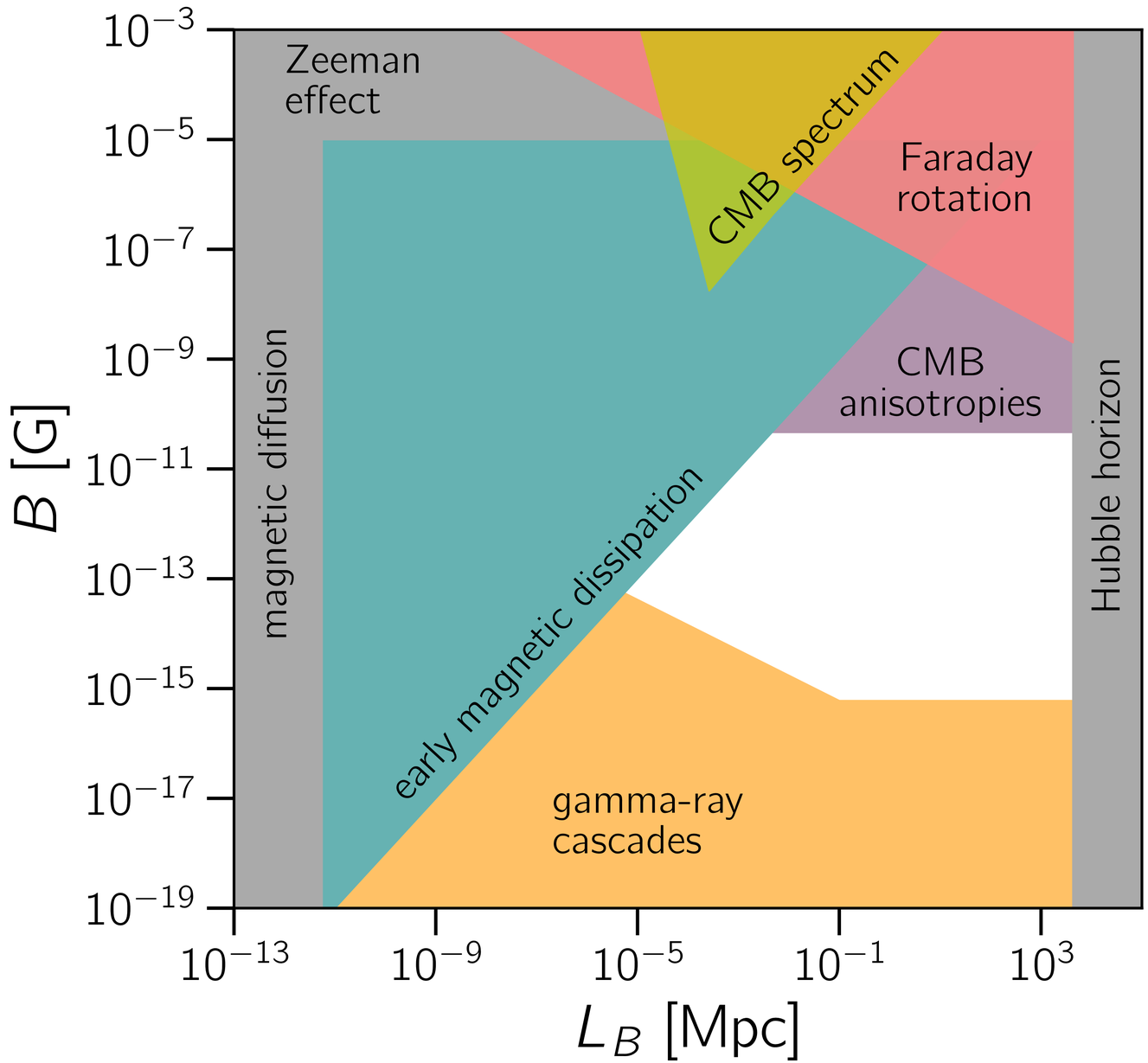
magnetic fields in the cosmic web



- Alves Batista et al. 2017 - model F
- Alves Batista et al. 2017 - model L
- Alves Batista et al. 2017 - model S
- Alves Batista et al. 2017 - model O
- Das et al. 2008
- Dolag et al. 2004
- Hackstein et al. 2018 - primordial
- Hackstein et al. 2018 - primordial2R
- Hackstein et al. 2018 - primordial3R
- Hackstein et al. 2018 - astrophysical
- Hackstein et al. 2018 - astrophysicalR
- Kotera & Lemoine 2009 - $B \propto \rho/(1+\rho^{-2})$
- Kotera & Lemoine 2009 - $B \propto \rho^{0.9}$
- Kotera & Lemoine 2009 - $B \propto \rho^{2/3}$
- Sigl et al. 2003

Alves Batista et al. Front. Astron. Space. Sci. 6 (2019) 23. arXiv:1903.06714

intergalactic magnetic fields



Alves Batista & Saveliev. Universe 7 (2021) 223. arXiv:2105.12020

intergalactic magnetic fields

fundamental questions

- how were they produced?
- what is their role in the evolution of the universe?
- how strong are they?
- what is their power spectrum?
- what are their topological properties?

- **astrophysical mechanisms:** during structure formation (e.g. Biermann battery, …)
- **primordial mechanisms**: large-scale cosmological processes such as inflation, EW phase transition, QCD phase transition, …