ASTR 670: Interstellar medium and gas dynamics

Prof. Benedikt Diemer

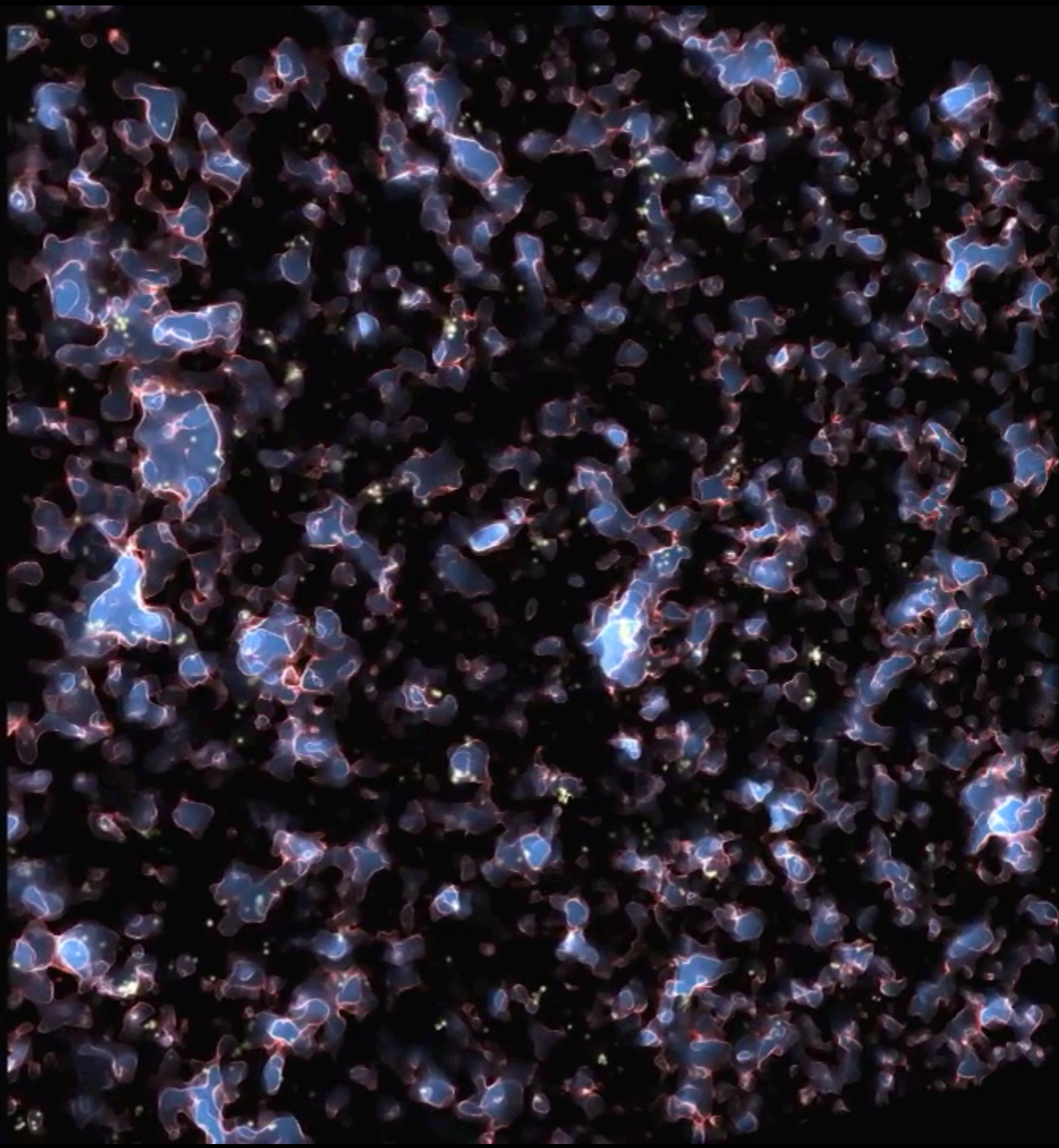
Chapter 10 • Magnetohydrodynamics

“The larger one's ignorance,

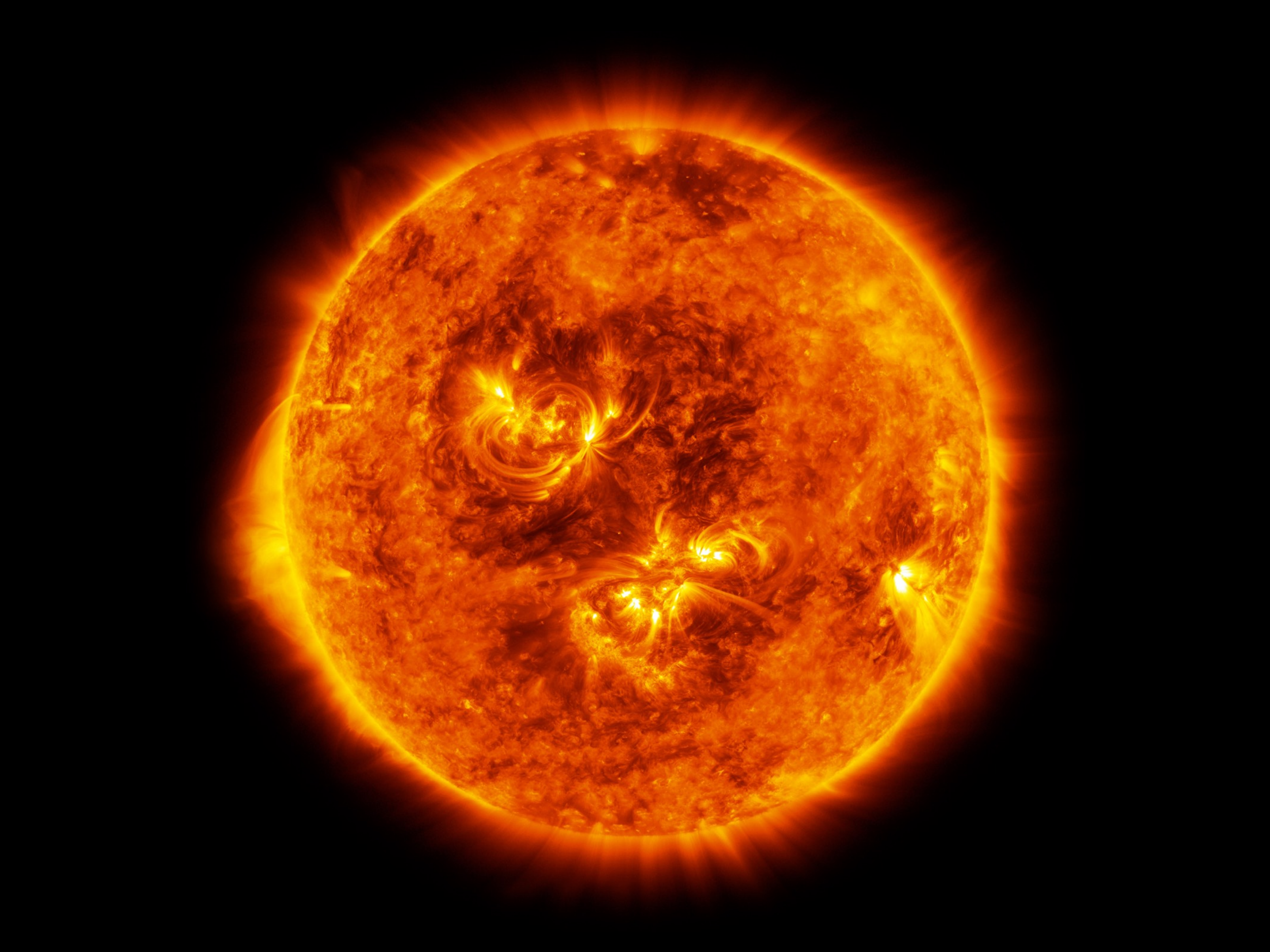
the stronger the magnetic field”

Lodewijk Woltjer

Reionization



Alvarez, Kaehler & Abel (youtube)



MHD conservation equations

Ideal MHD equations in conservation-law form

$$\frac{\partial \rho}{\partial t} + \boldsymbol{\nabla} \cdot (\rho \boldsymbol{u}) = 0$$

$$\frac{\partial (\rho \boldsymbol{u})}{\partial t} + \boldsymbol{\nabla} \cdot \left(\rho \boldsymbol{u} \otimes \boldsymbol{u} + \boldsymbol{I} \left[P + \frac{\boldsymbol{B}^2}{2} \right] - \boldsymbol{B} \otimes \boldsymbol{B} \right) = -\rho \boldsymbol{\nabla} \Phi$$

$$\frac{\partial E}{\partial t} + \boldsymbol{\nabla} \cdot \left(\left[E + P + \frac{\boldsymbol{B}^2}{2} \right] \boldsymbol{u} - \boldsymbol{u} \cdot \boldsymbol{B} \otimes \boldsymbol{B} \right) = \rho \frac{\partial \Phi}{\partial t} + \mathcal{H} - \mathcal{C}$$

$$\frac{\partial \boldsymbol{B}}{\partial t} + \boldsymbol{\nabla} \cdot (\boldsymbol{u} \otimes \boldsymbol{B} - \boldsymbol{B} \otimes \boldsymbol{u}) = 0$$

$$E \equiv \rho \left(\frac{\boldsymbol{u}^2}{2} + \varepsilon + \frac{\boldsymbol{B}^2}{2} + \Phi \right)$$

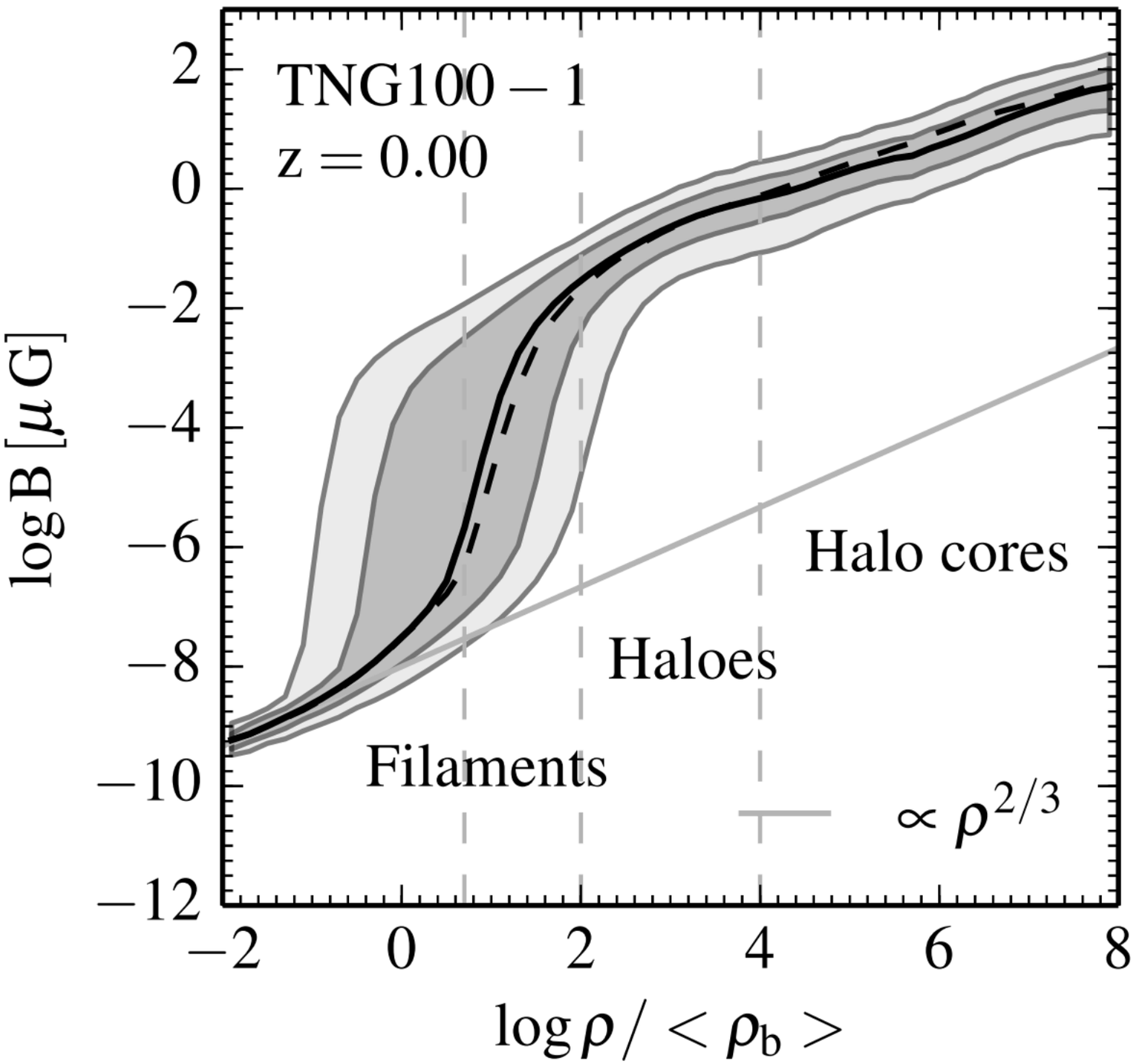
The Riemann problem (1D Euler)

System	$\boldsymbol{n}$ (cm^{-3})	$\boldsymbol{T}$ (K)	$\boldsymbol{B}$ (G)	$\boldsymbol{\beta}$
Magnetosphere of the Earth	10^4	10^4	0.3	4×10^{-6}
Coronal loop in the Sun	10^{10}	10^6	300	0.0004
Solar wind	10	10^5	6×10^{-5}	1
Molecular cloud	100	20	5×10^{-6}	≈ 0.1
Warm HI in interstellar medium	1	10^4	10^{-5}	≈ 0.1
Galaxy cluster	10^{-3}	10^7	$10^{-6} - 10^{-5}$	≈ 1

Magnetic fields in Illustris TNG100

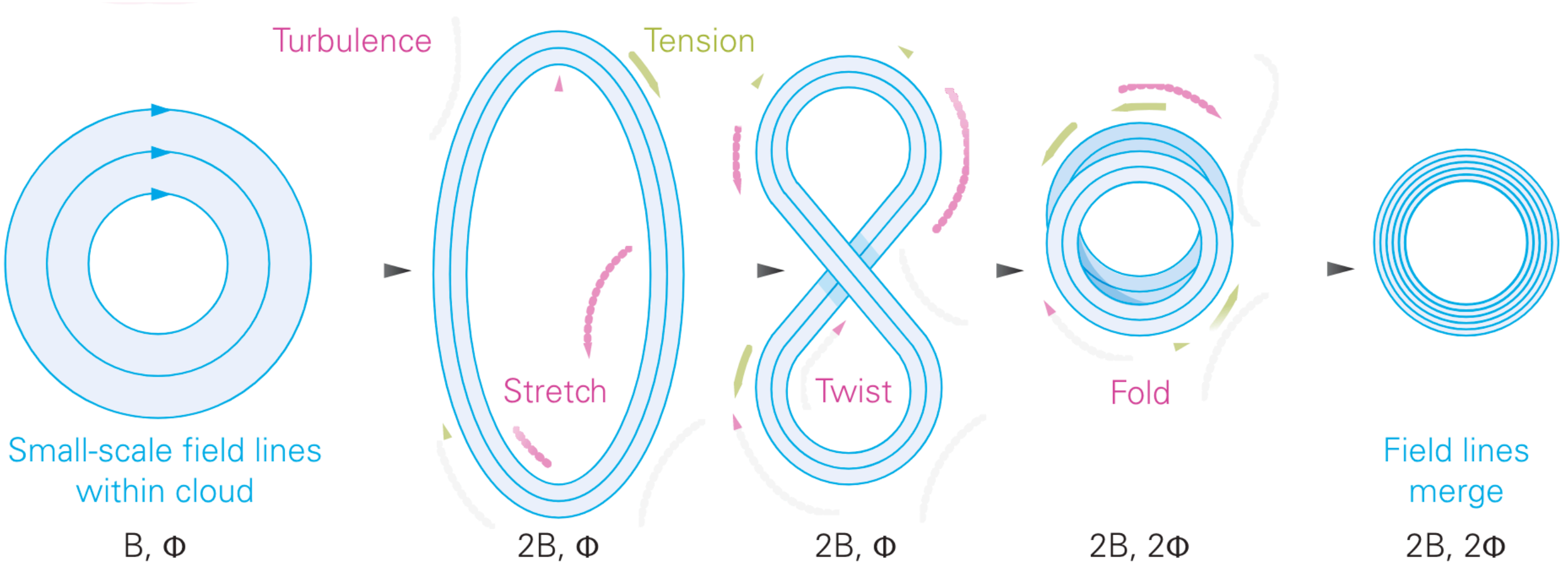
IllustrisTNG team / Mark Vogelsberger (movie page)

The Riemann problem (1D Euler)



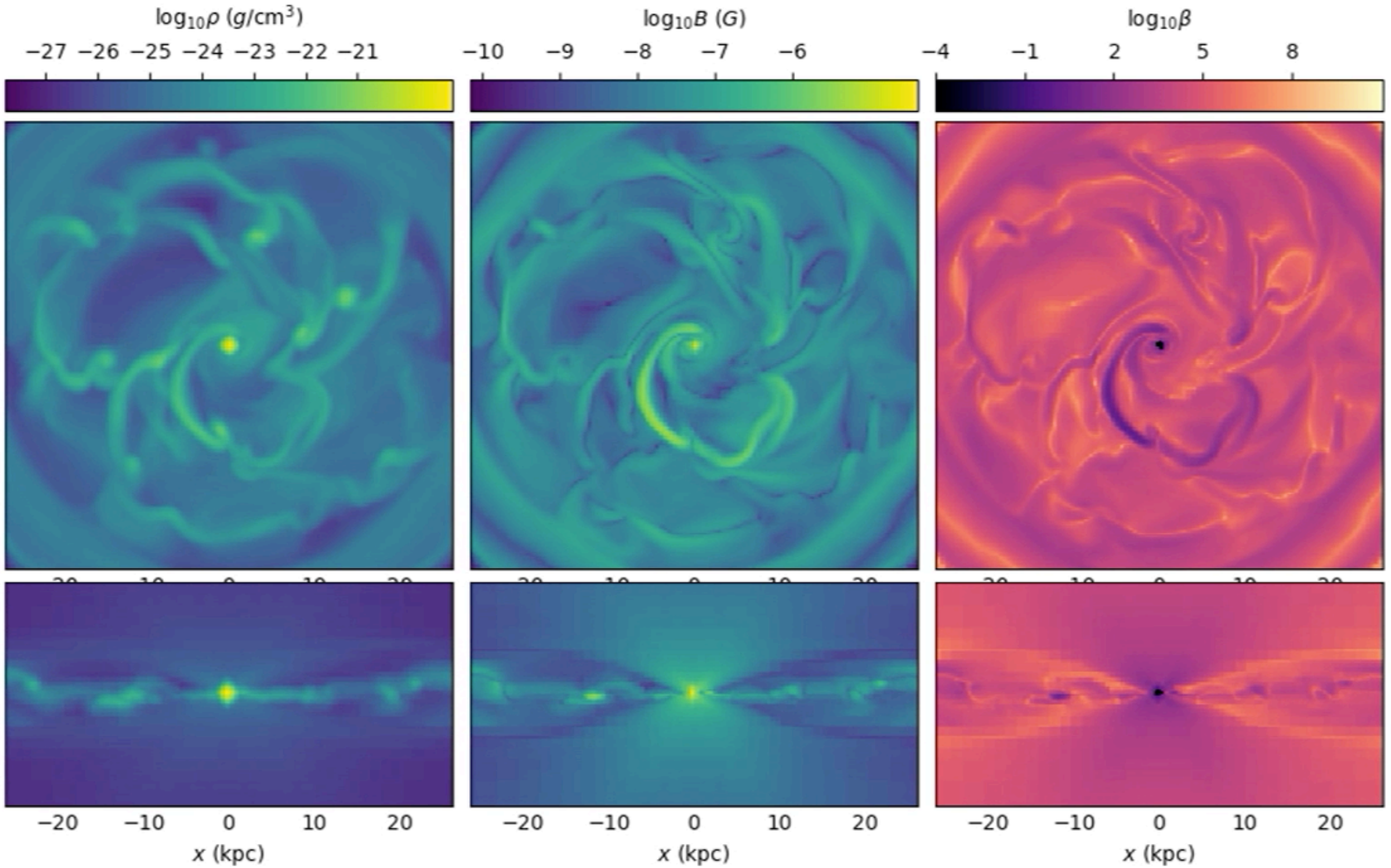
Marinacci et al. 2017 / IllustrisTNG

Galactic dynamo

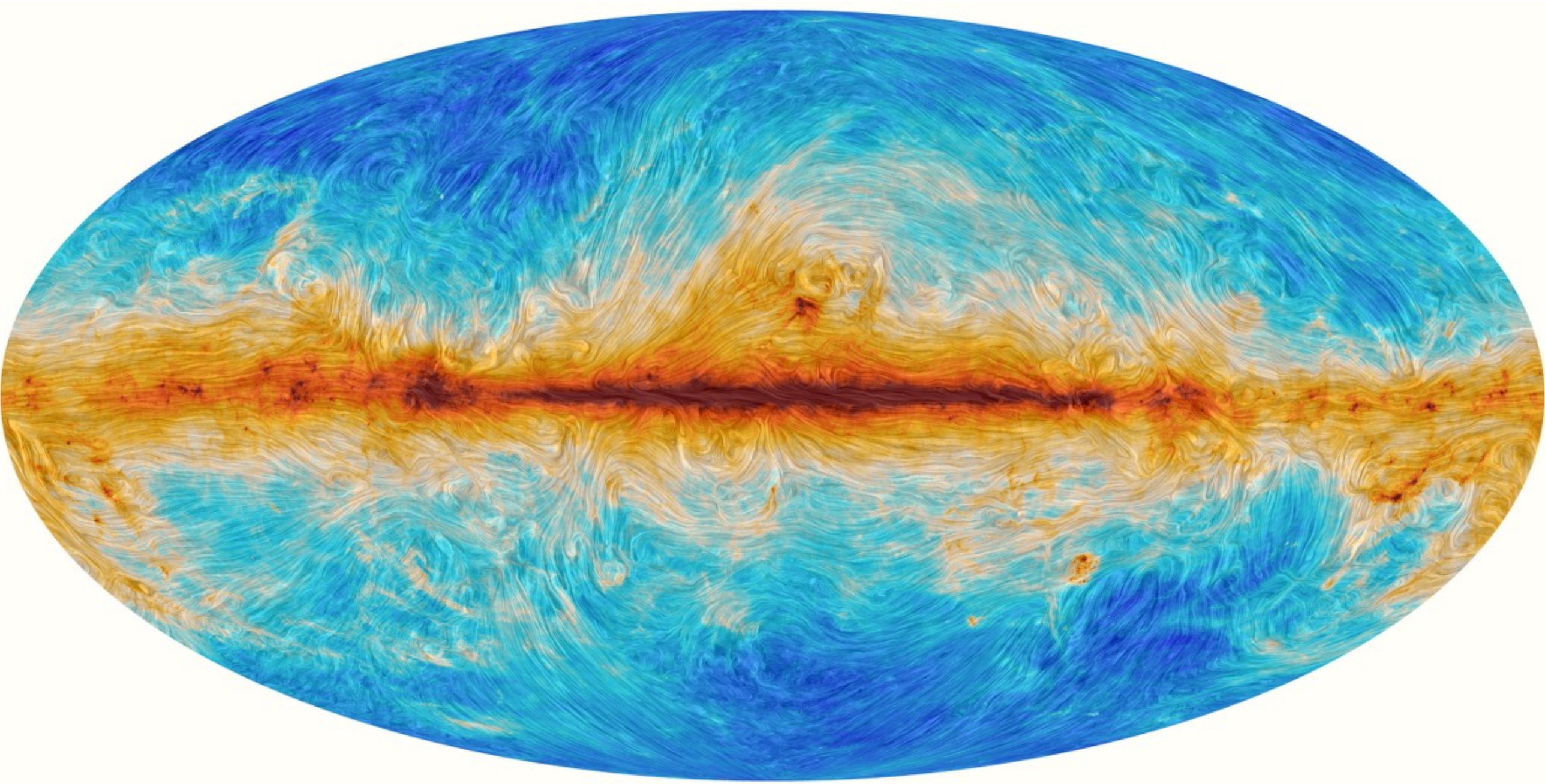


Steinwandel et al. 2023

Galactic dynamo

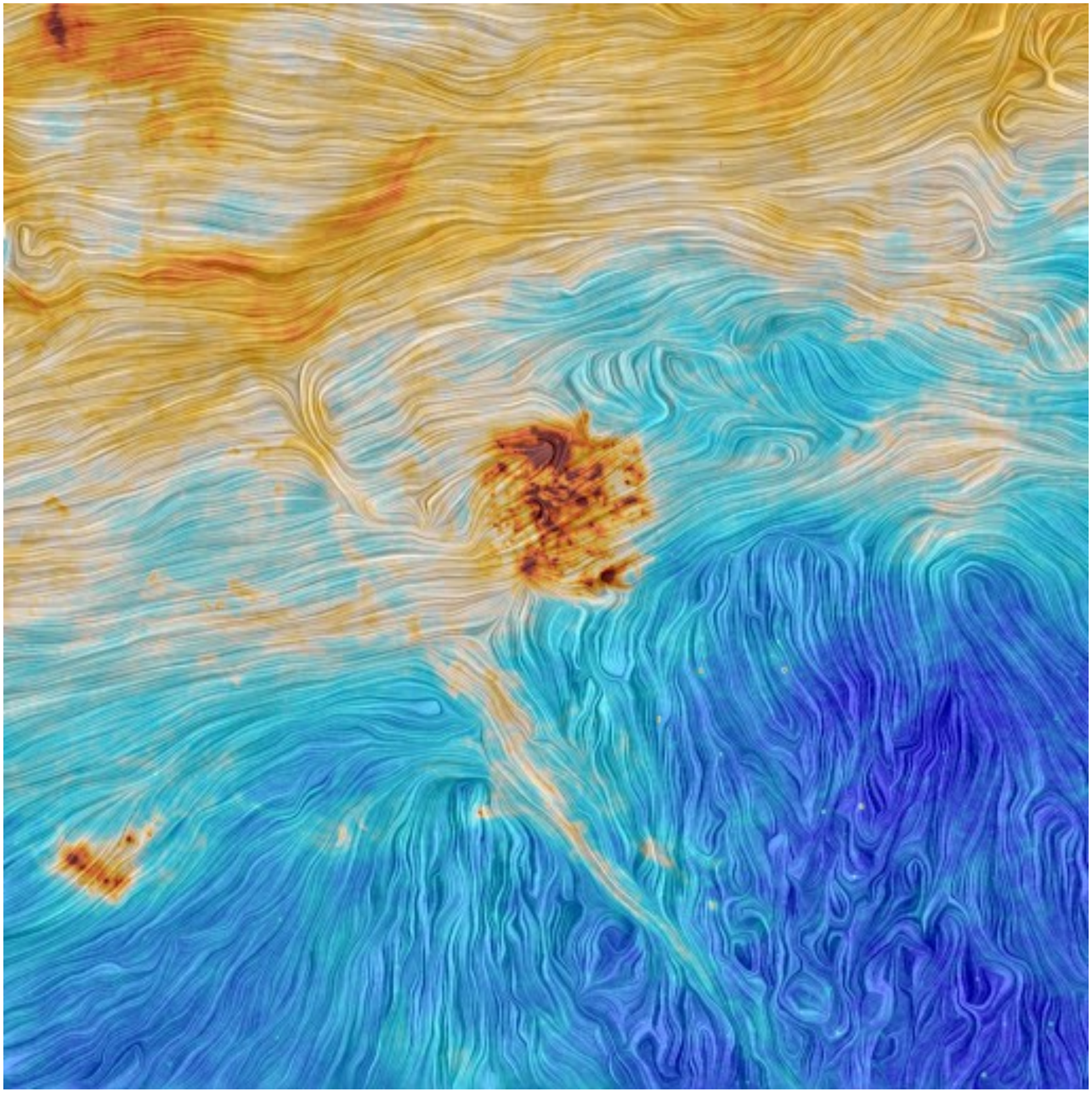


The galactic magnetic field



Planck Collaboration

The galactic magnetic field



Planck Collaboration

Reading

- Recommended: CC §13.1-4
- Additional: Shu §21, §22