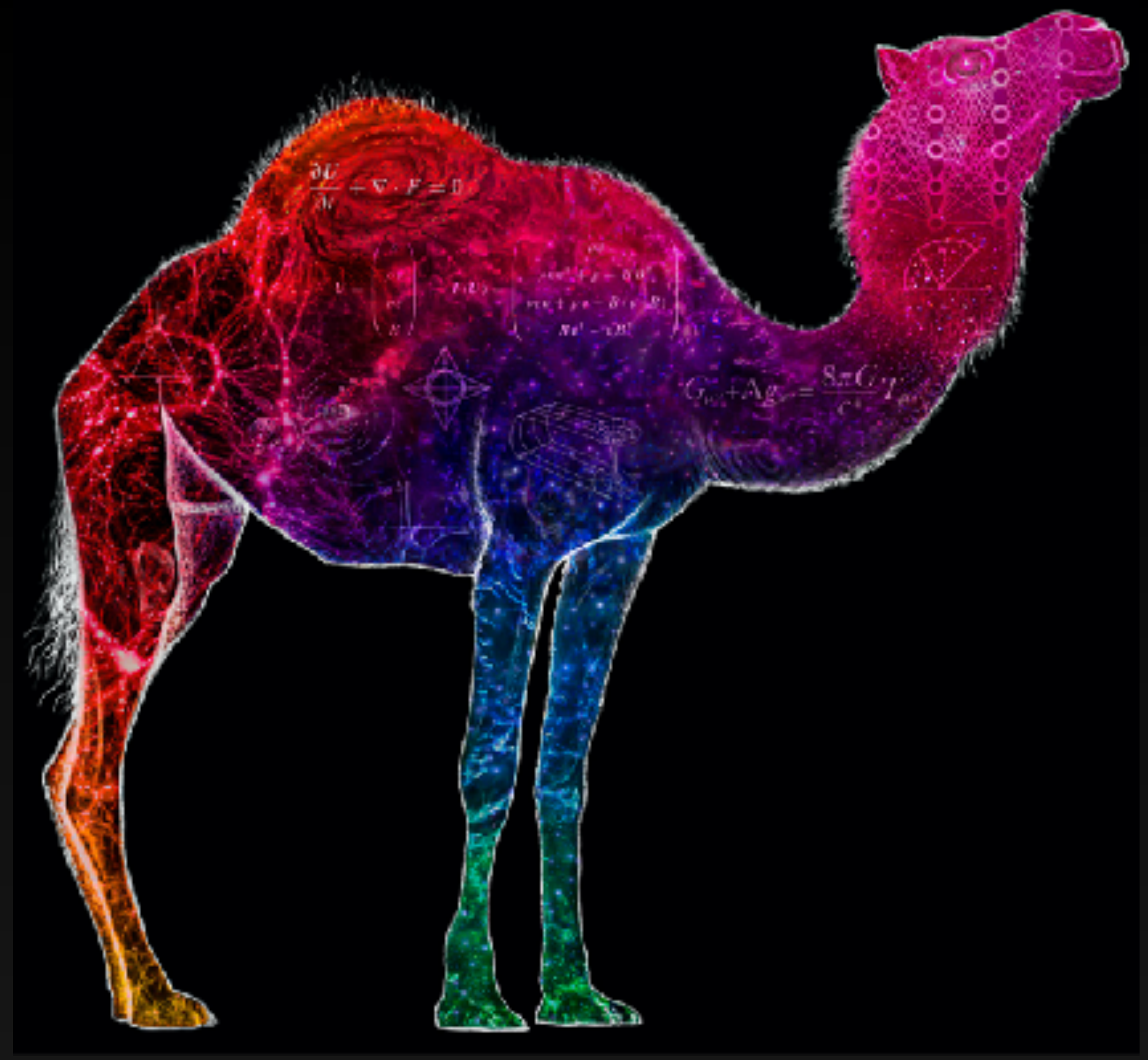

OpenGadget CAMELS

Based on the Magneticum model

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The Magneticum simulations

Magneticum Pathfinder & Magneticum

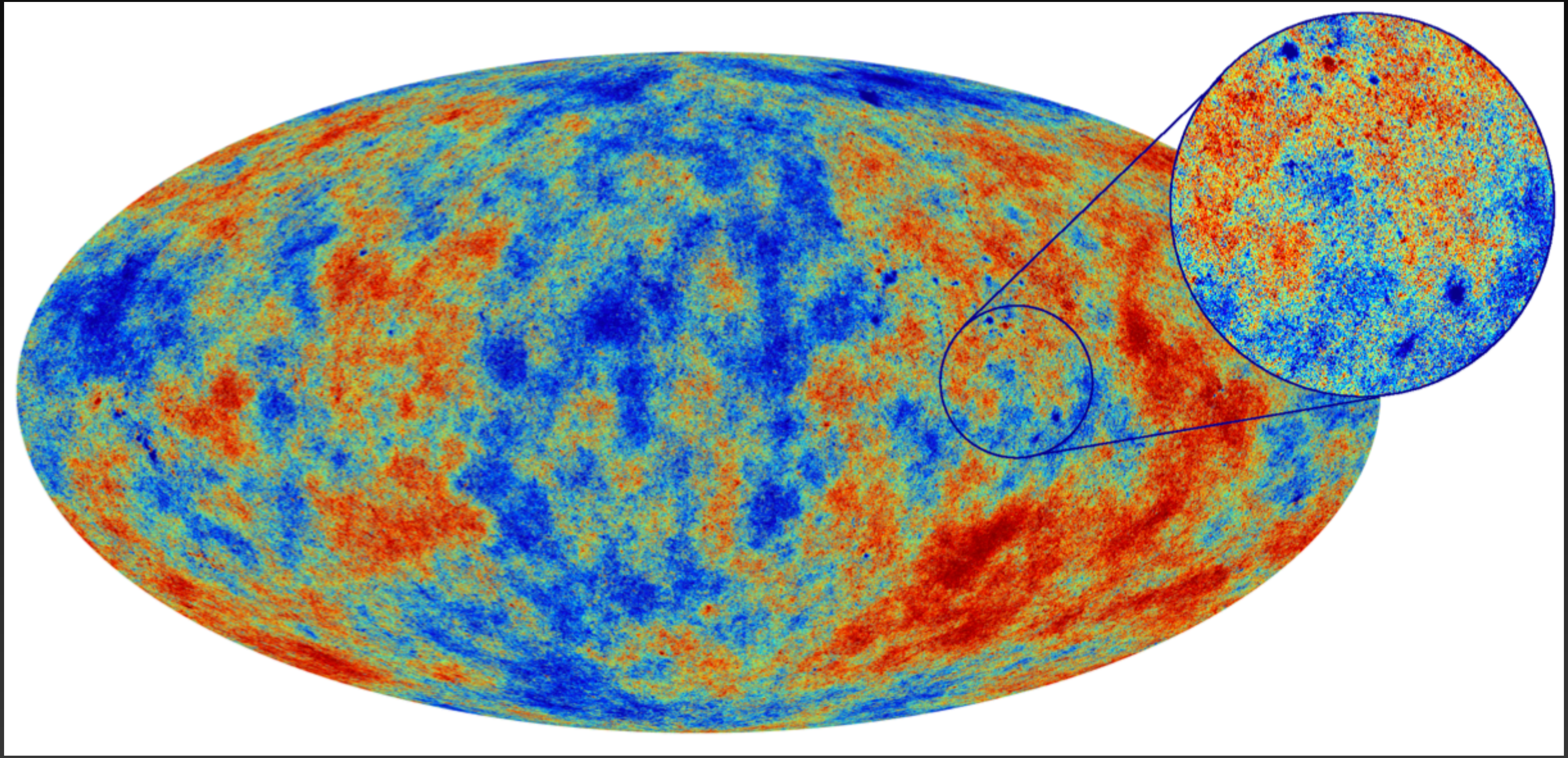
	Box0	Box1a	Box2b	Box2	Box3	Box4	Box5
[Mpc/h]	2688	896	640	352	128	48	18
mr	$2*4536^3$	$2*1512^3$		$2*594^3$	$2*216^3$	$2*81^3$	
hr			$2*2880^3$	$2*1584^3$	$2*576^3$	$2*216^3$	$2*81^3$
uhr					$2*1536^3$	$2*576^3$	$2*216^3$
xhr						$2*1536^3$	$2*576^3$

Table 1: Number of particles used in the *Magneticum Pathfinder* and *Magneticum* simulations for the different resolution levels *mr*, *hr*, *uhr* and *xhr*. The blue entries mark simulations which have been stopped before reaching z=0. *Box2b/hr* has been stopped very close to z=0 (e.g. z~0.2). The gray entries mark future, planned simulations.

	m_{dm}	m_{gas}	eps_{dm}	eps_{gas}	eps_{stars}
mr	1.3e10	2.6e9	10	10	5
hr	6.9e8	1.4e8	3.75	3.75	2
uhr	3.6e7	7.3e6	1.4	1.4	0.7
xhr	1.9e6	3.9e5	0.45	0.45	0.25

Table 2: Mass of dm and gas particles (in Msol/h) at the different resolution levels and the according softenings (in kpc/h) used.

Why the large boxes?

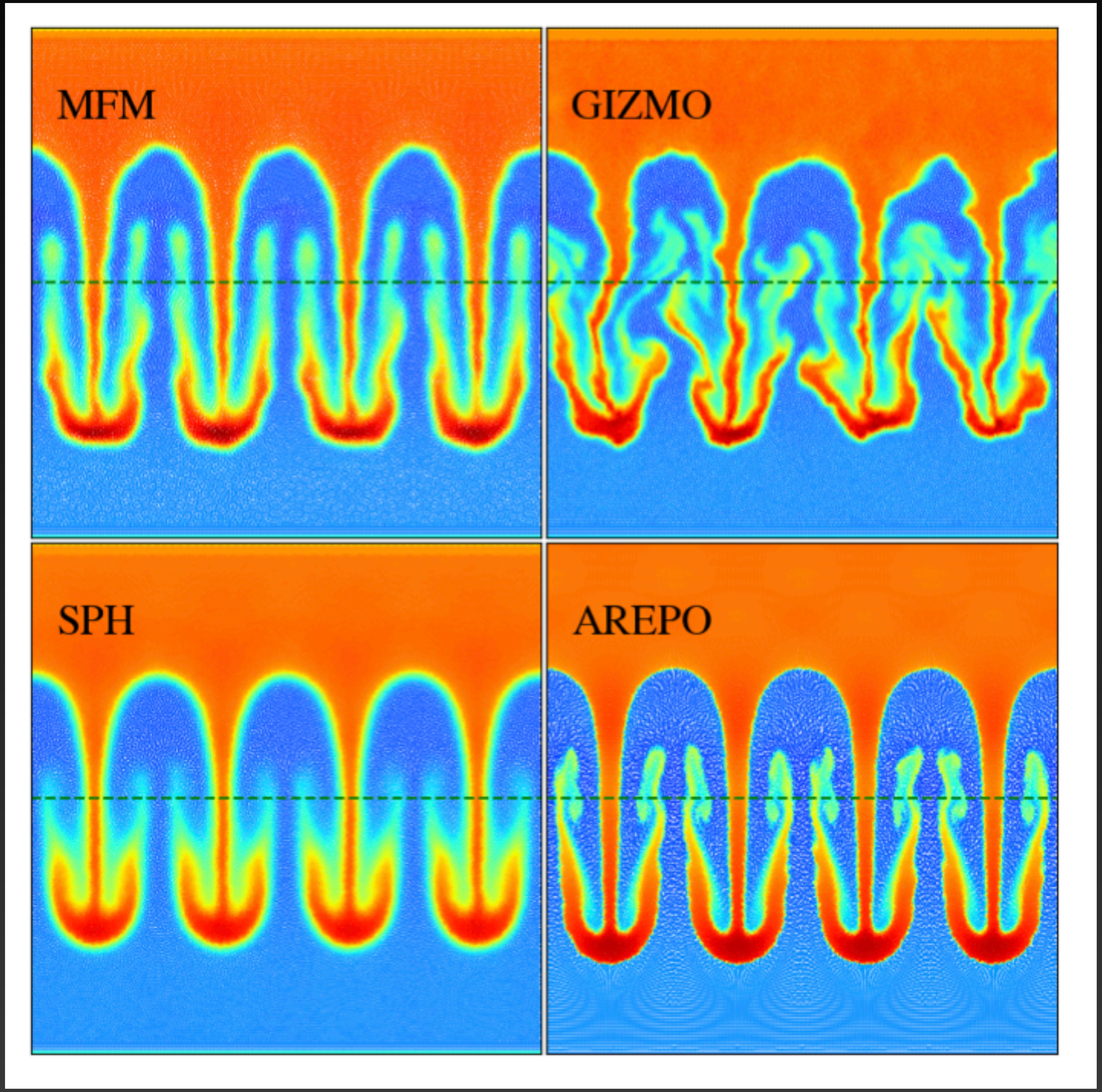


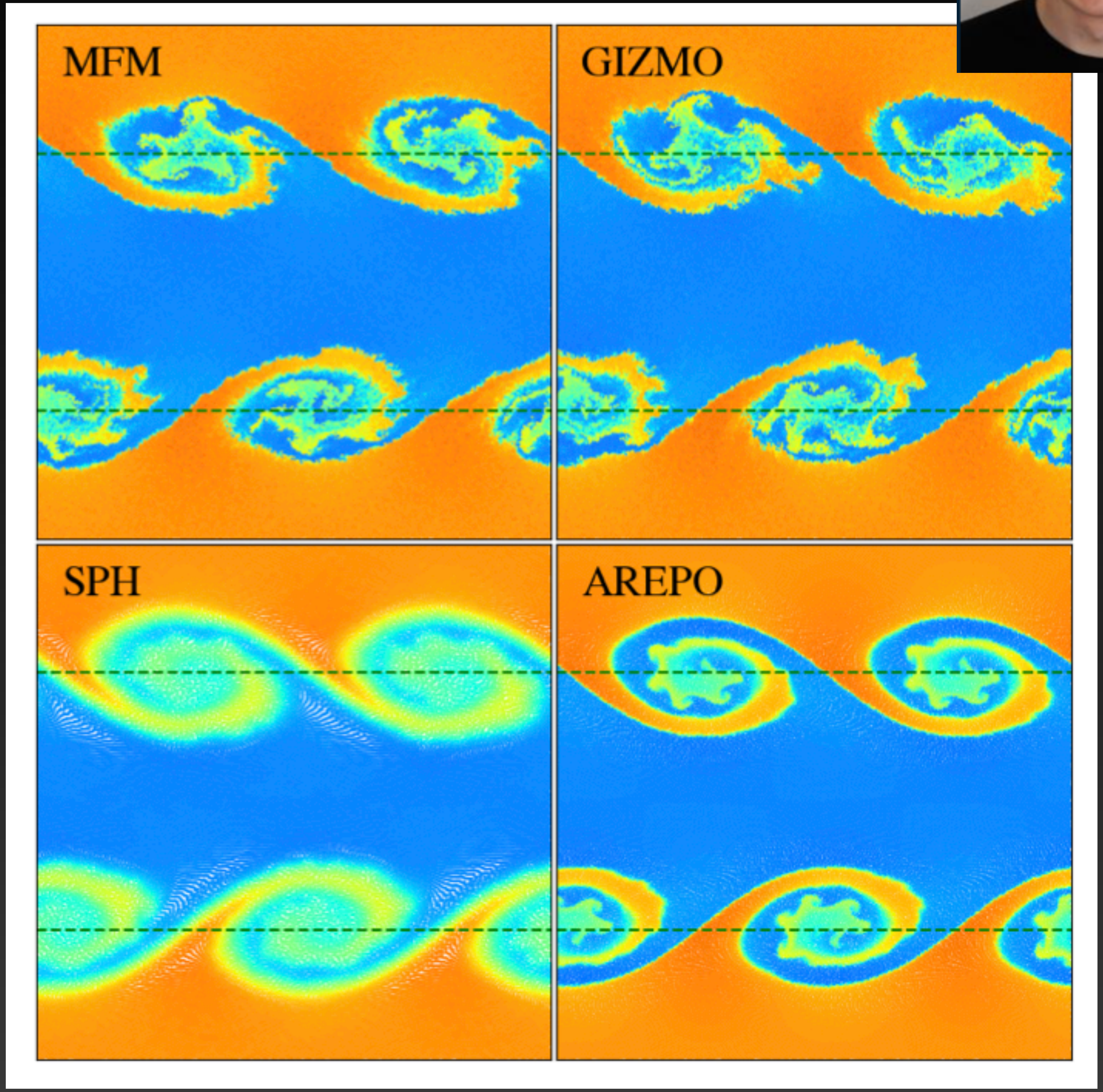
Coulton et al. 2022

The simulation code: OpenGadget3

- Updated version of the popular code P-Gadget3.
- Gravity is solved via the TreePM method in cosmological simulations.
- Variety of different solvers for hydrodynamics (density-entropy SPH, pressure-entropy SPH, pressure-energy SPH and MFM).
- If SPH is used the code adopts a higher order Wendland kernel, if MFM is used we adopt a cubic spline.
- Since MFM is Riemann based method we implemented several Riemann solvers (exact, Roe-solver, HLL, HLLE, HLLC, HLLD pending for MHD).
- The code supports magnetic fields and cosmic rays.
- The code supports anisotropic heat conduction and viscosity.

The Hydro-solvers in the code





Groth, Steinwandel et al. (in prep)

Magnetic fields in the code

- Equations of ideal Magnetohydrodynamics (Cauchy equations)

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \cdot \mathbf{v}) = 0 \quad (1)$$

$$\rho \left(\frac{\partial}{\partial t} + \mathbf{v} \cdot \nabla \right) \mathbf{v} = -\nabla p + \mathbf{g} + \frac{(\mathbf{J} \times \mathbf{B})}{c} \quad (2)$$

$$\frac{\partial u}{\partial t} + (\mathbf{v} \cdot \nabla) u = \frac{p}{\rho} (\nabla \cdot \mathbf{v}) + \frac{\mathbf{B}^2}{8\pi\rho} (\nabla \cdot \mathbf{v}) \quad (3)$$

$$\frac{ds}{dt} = 0 \quad (4)$$

$$\left(\frac{\mathbf{J} \times \mathbf{B}}{c} \right) = \frac{(\mathbf{B} \cdot \nabla)\mathbf{B}}{4\pi} - \nabla \left(\frac{\mathbf{B}^2}{8\pi} \right)$$

1st term: magnetic tension
2nd term: magnetic pressure

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \Delta \mathbf{B} \quad (5)$$

Induction equation

$$\nabla \cdot \mathbf{B} = 0 \quad (6)$$

Solenoidal constraint

Currently we adopt SPMHD for magnetic fields:

- In principle it is trivial to derive the basic SPMHD equations.
- Just take the MHD Lagrangian and to exactly the sam as in HD.

$$\mathscr{L}_{\mathrm{MHD}} = \int \left[\frac{1}{2}\rho \mathbf{v}^2 - \rho u(\rho, s) - \frac{\mathbf{B}^2}{8\pi} \right] d^3 r \approx \sum m_i \left[\frac{1}{2}\mathbf{v}_i^2 - u_i(\rho, s) - \frac{1}{8\pi}\frac{\mathbf{B}_i^2}{\rho_i} \right]$$

- To obtain the basic SPMHD-EOM plus discretization of the induction equation.

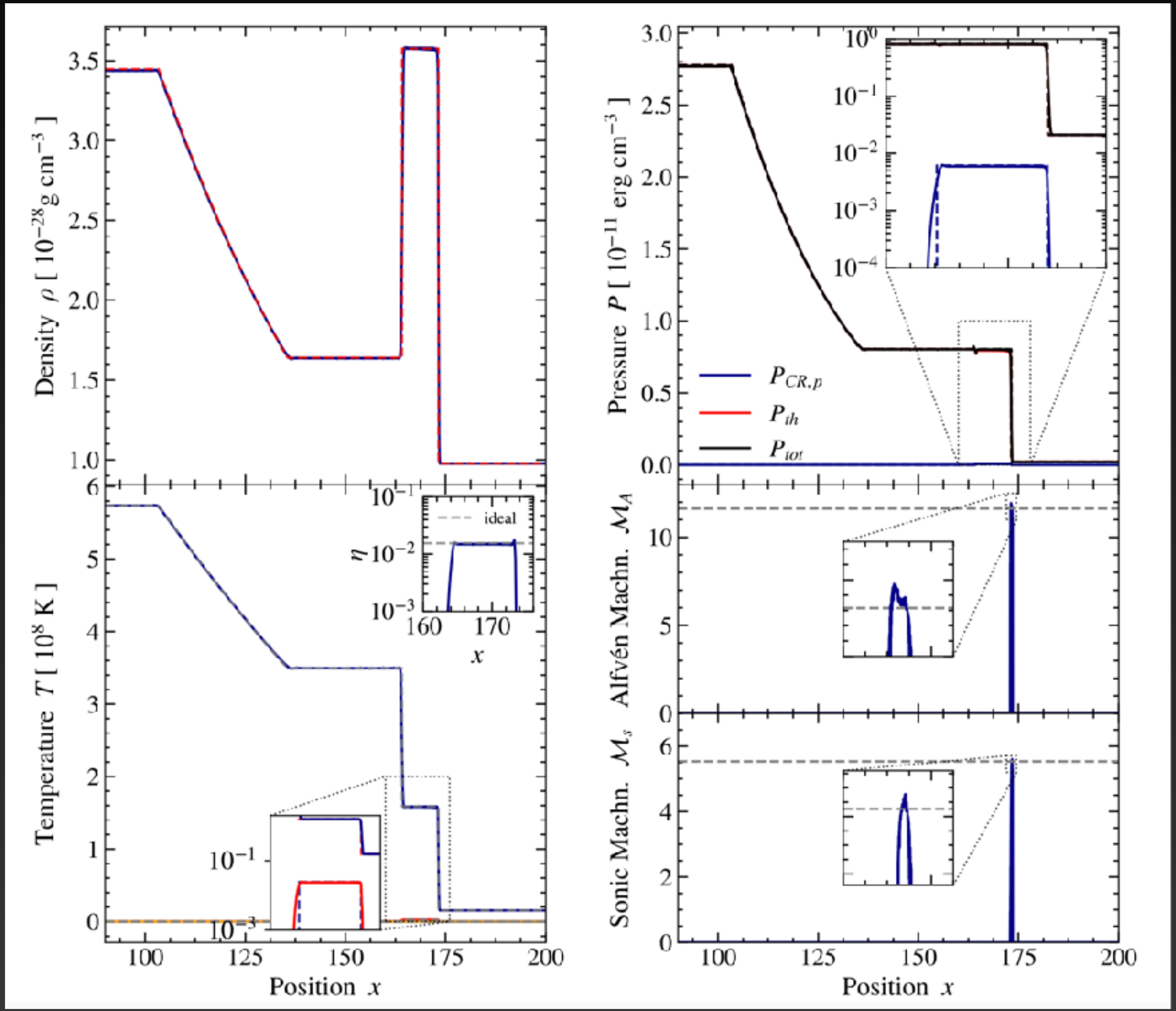
$$\frac{d\mathbf{v}_i}{dt} = -\sum m_j \left[\frac{P_i + \frac{\mathbf{B}_i^2}{8\pi}}{\rho_i^2 \Omega_i} \nabla_i W_{ij}(h_i) + \frac{P_j + \frac{\mathbf{B}_j^2}{8\pi}}{\rho_j^2 \Omega_j} \nabla_i W_{ij}(h_j) \right] + \frac{1}{4\pi} \sum m_j \left[\frac{\mathbf{B}_i(\mathbf{B}_i \cdot \nabla_i W_{ij}(h_i))}{\rho_i^2 \Omega_i} + \frac{\mathbf{B}_j(\mathbf{B}_j \cdot \nabla_i W_{ij}(h_j))}{\rho_j^2 \Omega_j} \right]$$

$$\frac{d}{dt}\left(\frac{B_i}{\rho_i} \right) = \sum m_j (\mathbf{v}_i - \mathbf{v}_j) \frac{B_i}{\rho_i^2 \Omega_i} \cdot \nabla_i W_{ij}(h_i)$$

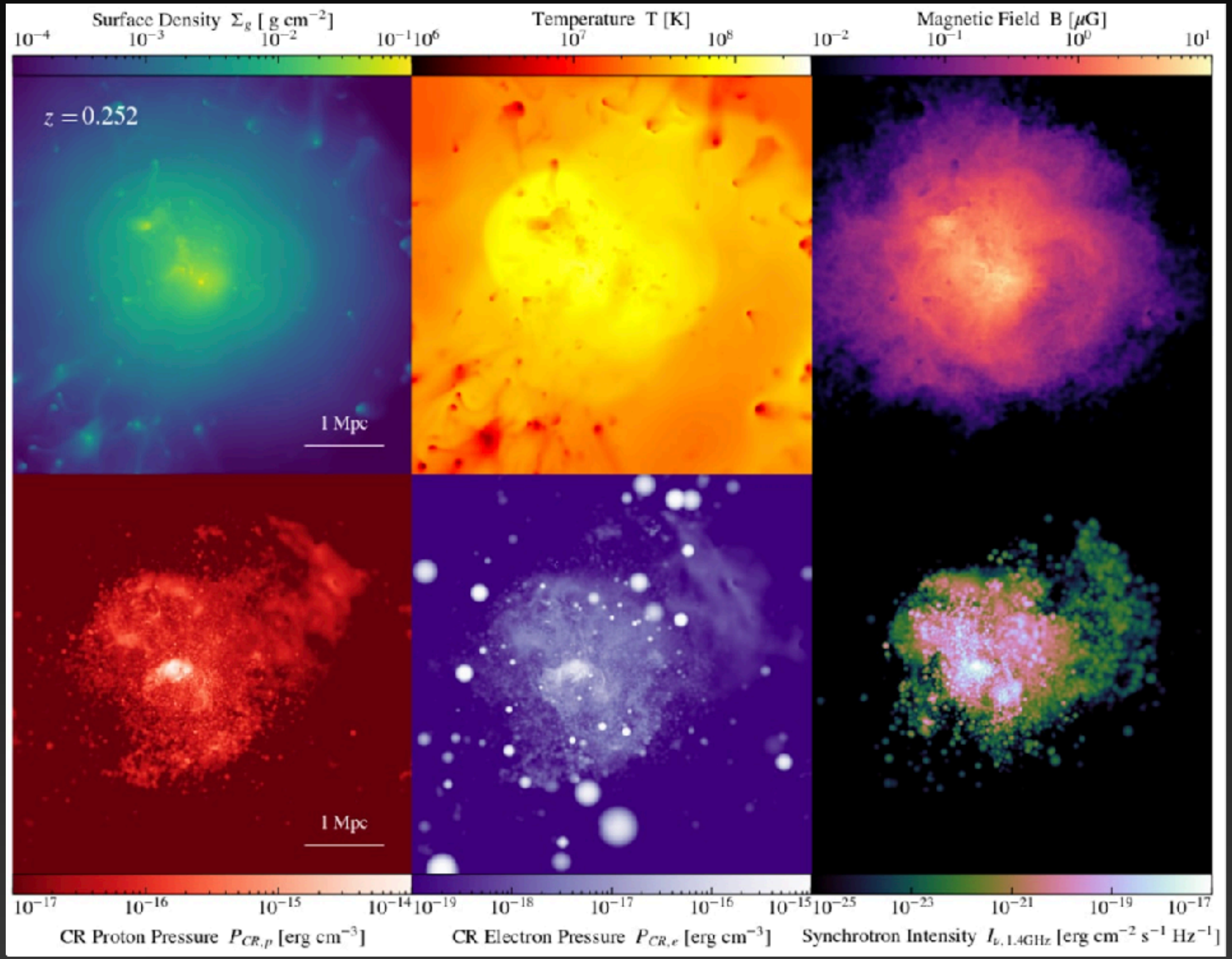
Magnetic fields in the code

Steinwandel et al. (2022)
Steinwandel (in prep)

Cosmic rays in the code



Boess, Steinwandel et al. (in press)

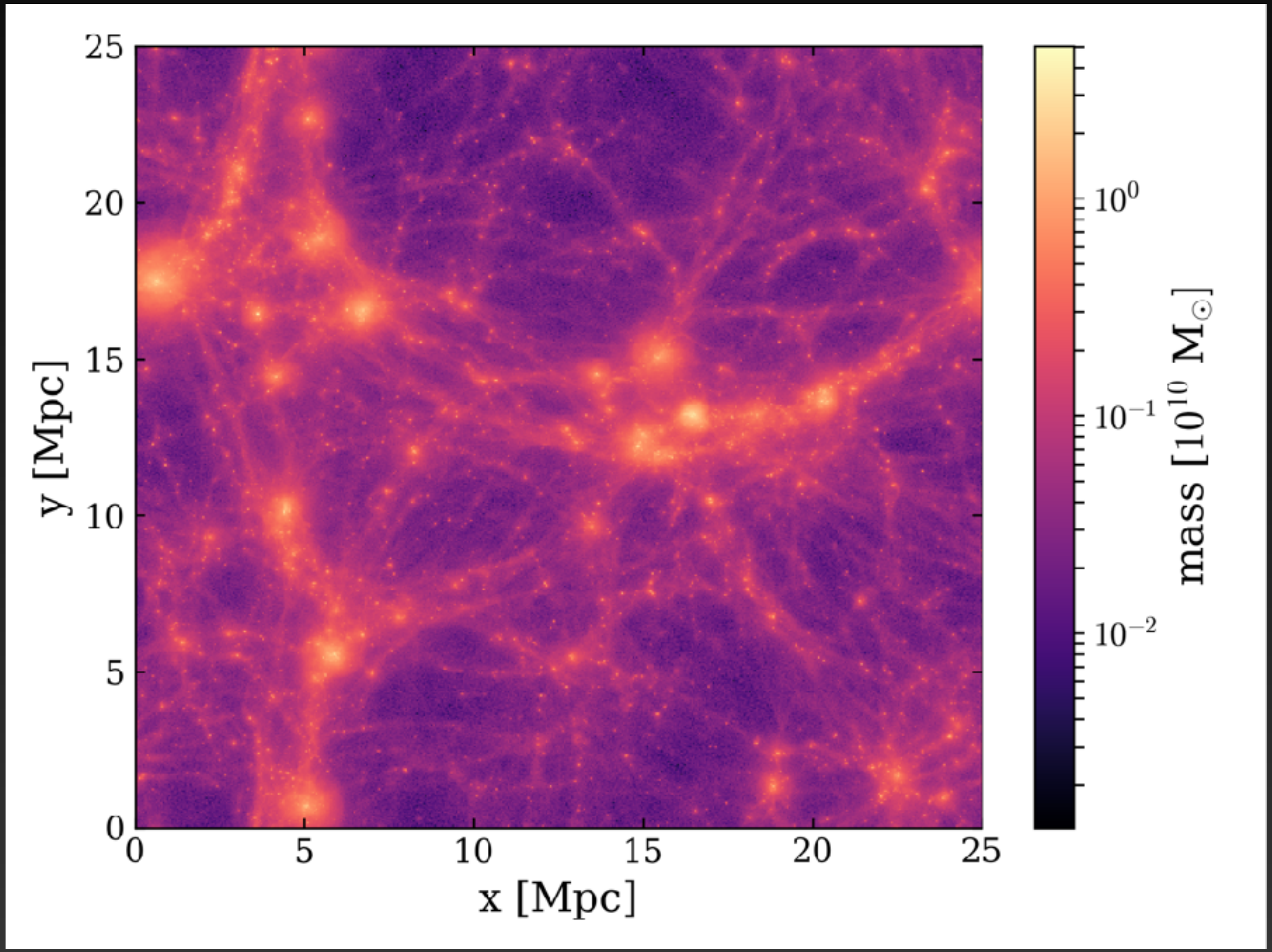


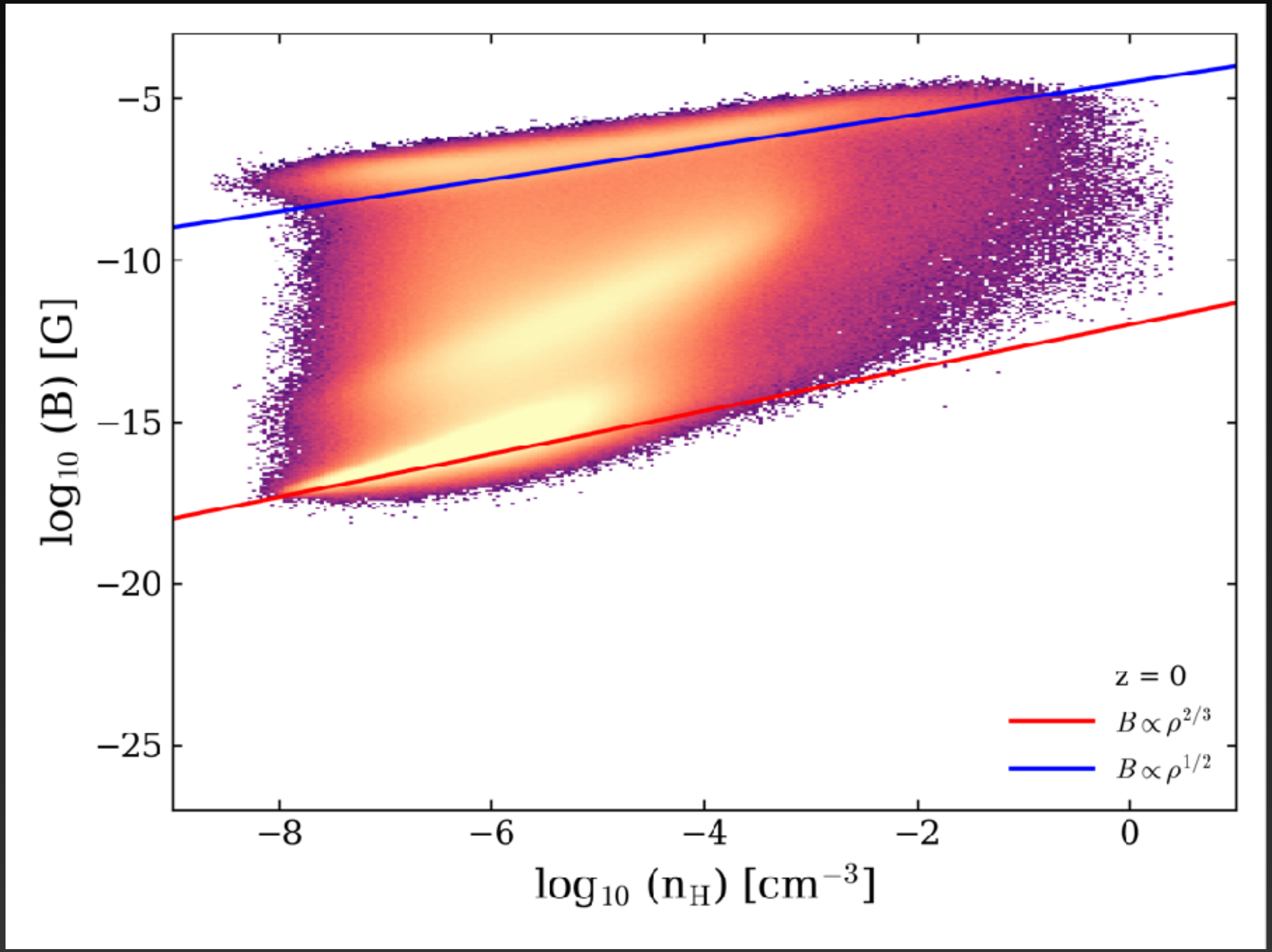
Boess, Steinwandel et al. (in prep)

This can be coupled to the galaxy formation model

- Cooling and Star formation (Wiersma et al. 2009, Springel & Hernquist 2003).
- Metals, stellar populations and chemical enrichment SNIa, CCSN, AGB stars (Tornatore et al. 2007).
- Black Hole accretion and feedback (Springel et al. 2005, Fabjan et al. 2010, Hirschmann et al. 2014, Steinborn et al. 2015/2016).

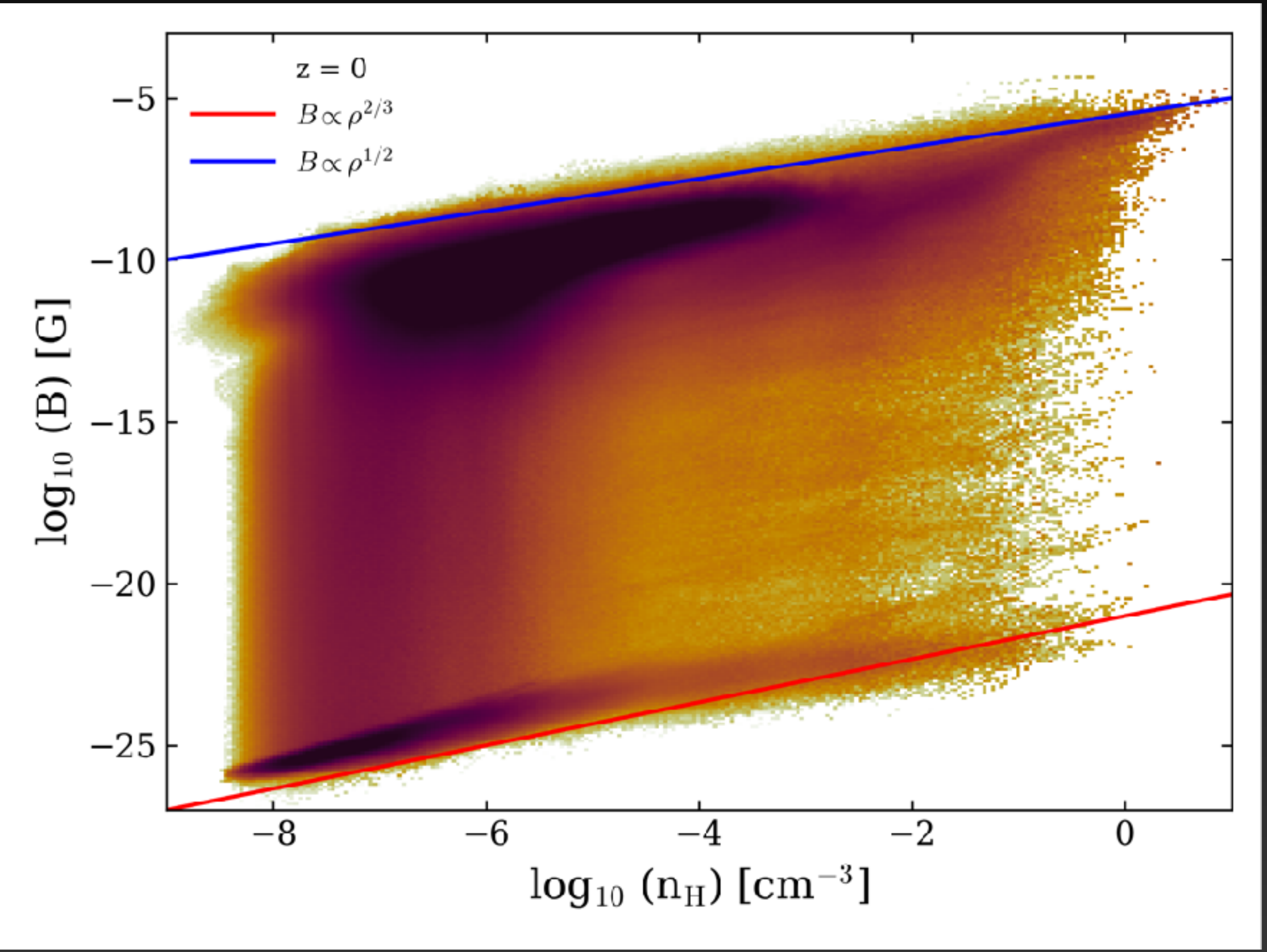
Running a CAMELS box with magnetic fields

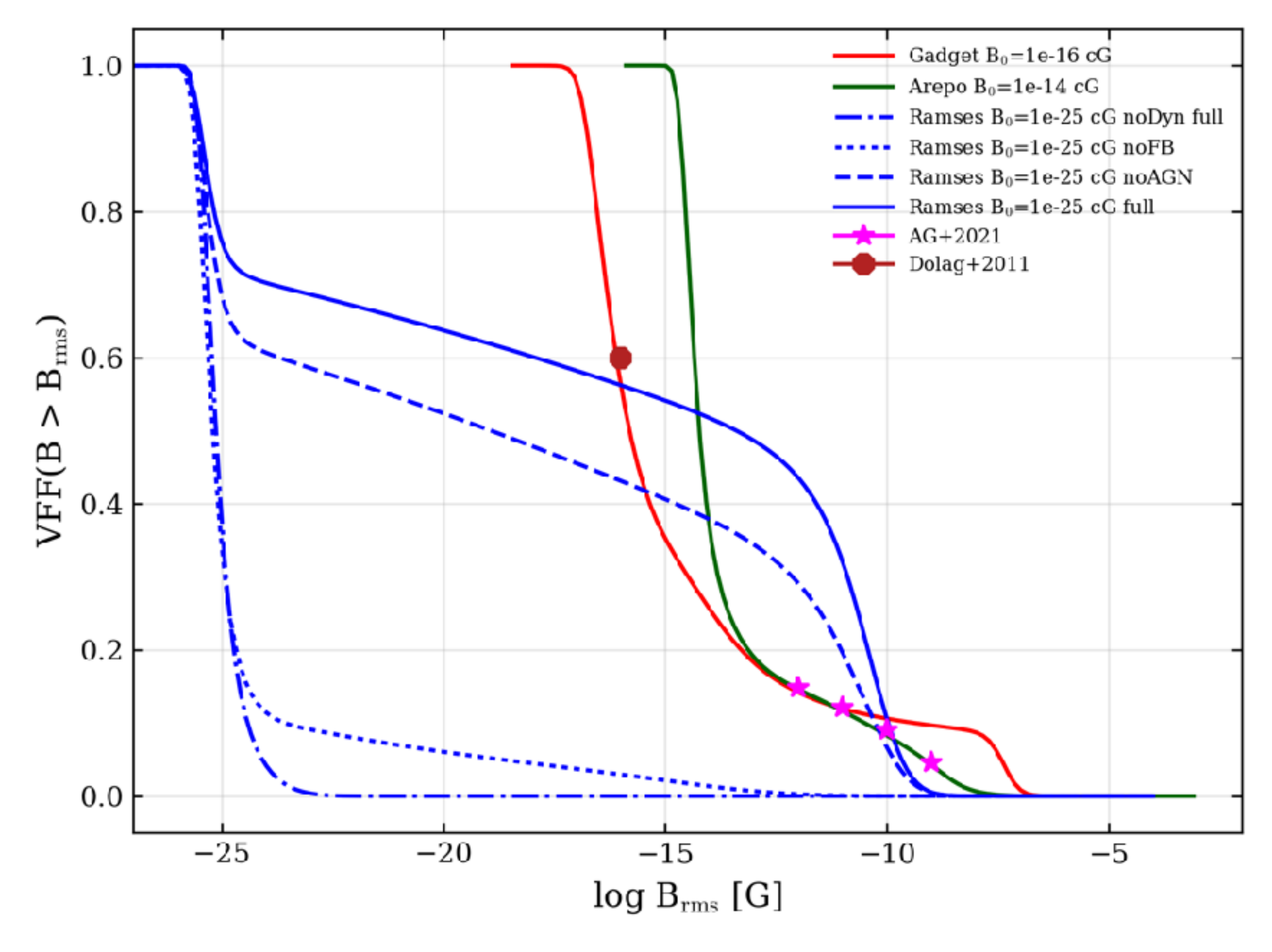




Steinwandel & Teyssier (or vice versa in prep)

Running the same box with RAMSES





Steinwandel & Teyssier (or vice versa in prep)

The state of Magneticum-CAMELS

- There is a small latin hyper cube set present that consists out of 50 simulations.
- The CV set is running now, but is almost finished.
- Subfind data for these runs will be available soon.
- Planning to run more simulations.