Stabilizing Effect of Magnetic Helicity on Magnetic Cavities in the Intergalactic Medium

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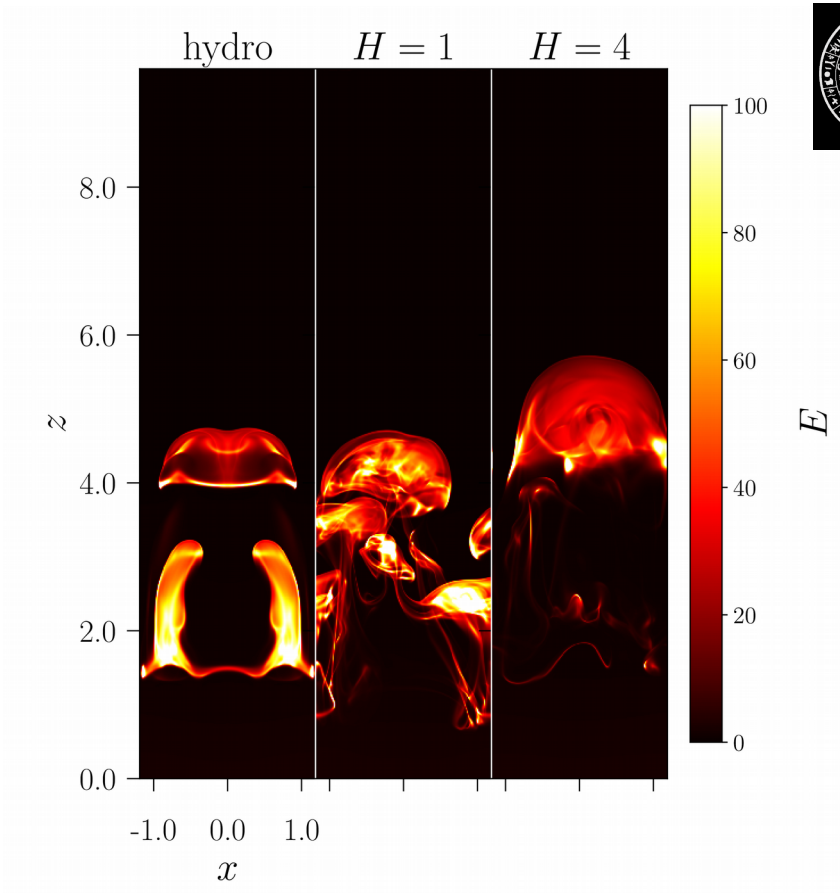
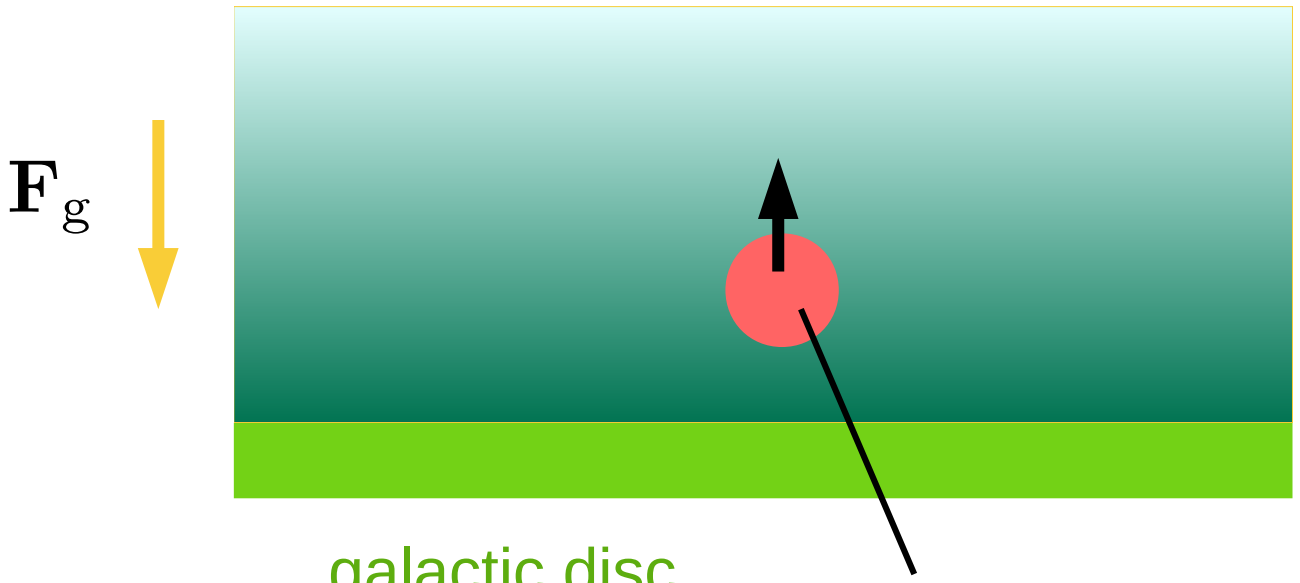
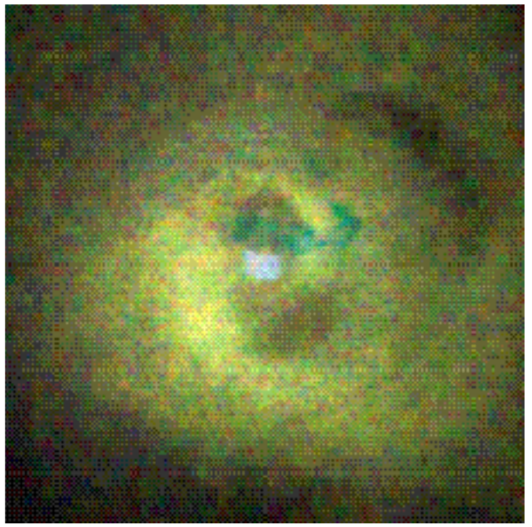


Intergalactic Bubbles

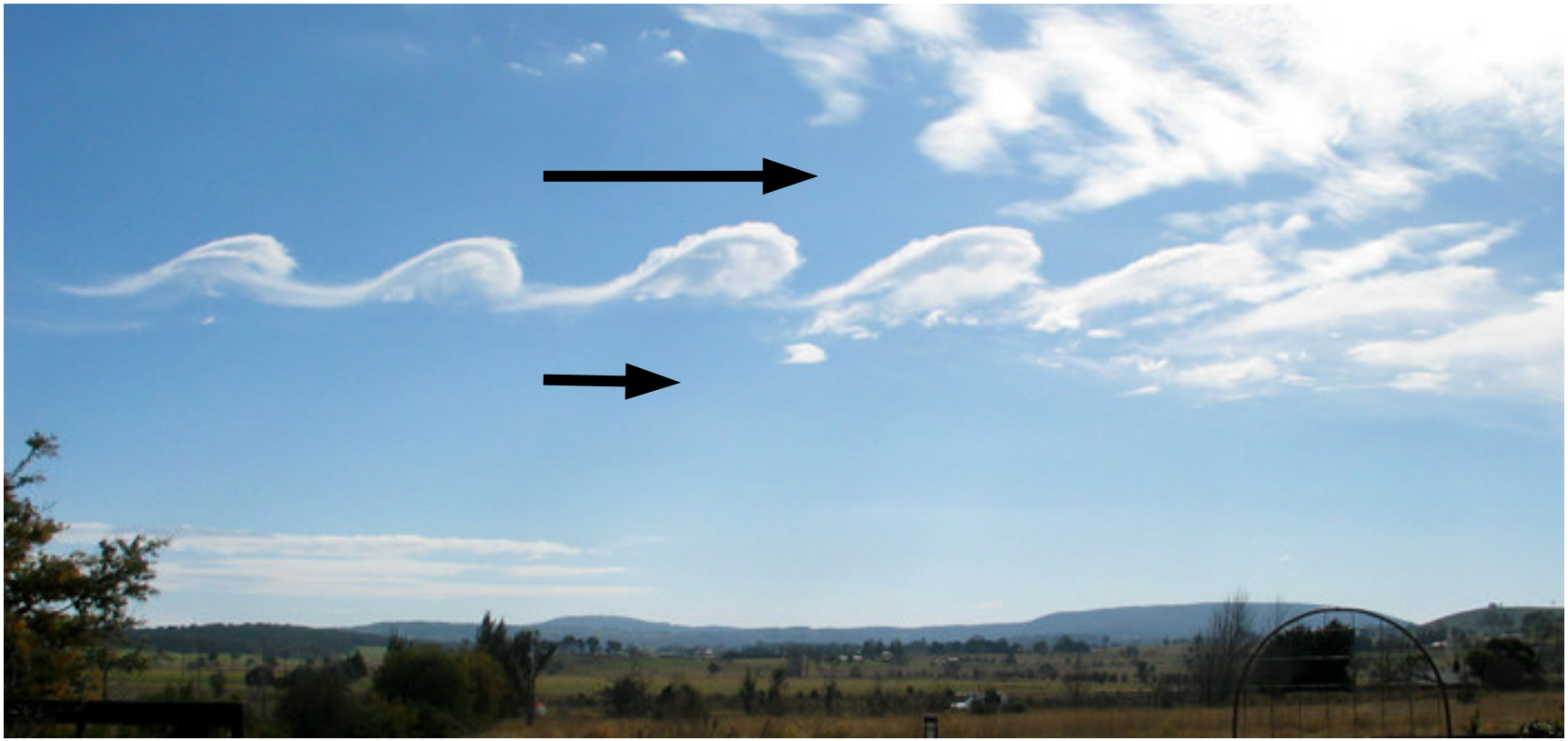




(Fabian et al. 2000)

- Bubbles rise buoyantly through density difference.
- Bubbles' age is several tens of millions of years.

Kelvin-Helmholtz Instability



(GRAHAMUK/Wikimedia Commons)

- Bubbles should get disrupted.
- What is the reason for their stability?

Magnetic Helicity

Conservation of magnetic helicity:

$$\lim_{\eta \to 0} \frac{\partial}{\partial t} \int \boldsymbol{A} \cdot \boldsymbol{B} \, \mathrm{d}V = 0$$

$\eta =$ magnetic resistivity

Realizability condition:

$$E_{\mathrm{m}}(k) \geq k|H(k)|/2\mu_0$$

Magnetic energy is bound from below by magnetic helicity.

Can magnetic helicity stabilize intergalactic cavities?

Numerical Experiments

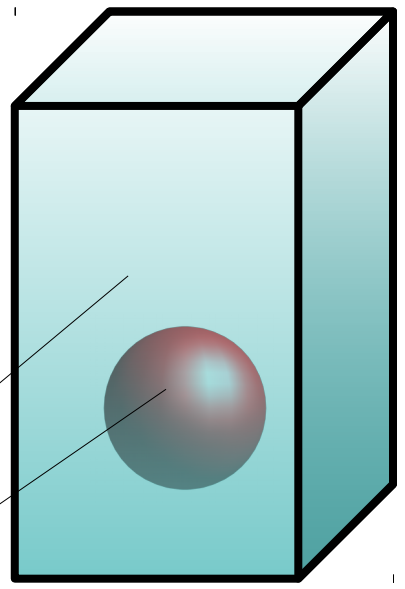
Full resistive magnetohydrodynamics simulations with the PencilCode.

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{U} \times \mathbf{B} + \eta \nabla^2 \mathbf{A}$$

$$\frac{\mathrm{D}\mathbf{U}}{\mathrm{D}t} = -c_{\mathrm{S}}^2 \nabla \left(\frac{\ln T}{\gamma} \ln \rho \right) + \mathbf{J} \times \mathbf{B}/\rho - \mathbf{g} + \mathbf{F}_{\mathrm{visc}}$$

$$\frac{\partial \ln T}{\partial t} = -\mathbf{U} \cdot \nabla \ln T - (\gamma - 1) \nabla \cdot \mathbf{U} + \frac{1}{\rho c_V T} \left(\nabla \cdot (K \nabla T) + \eta \mathbf{J}^2 + 2\rho\nu \mathsf{S} \otimes \mathsf{S} + \zeta \rho (\nabla \cdot \mathbf{U})^2 \right)$$

$$\frac{\mathrm{D} \ln \rho}{\mathrm{D}t} = -\nabla \cdot \mathbf{U}$$



Initial Condition: Beltrami Field

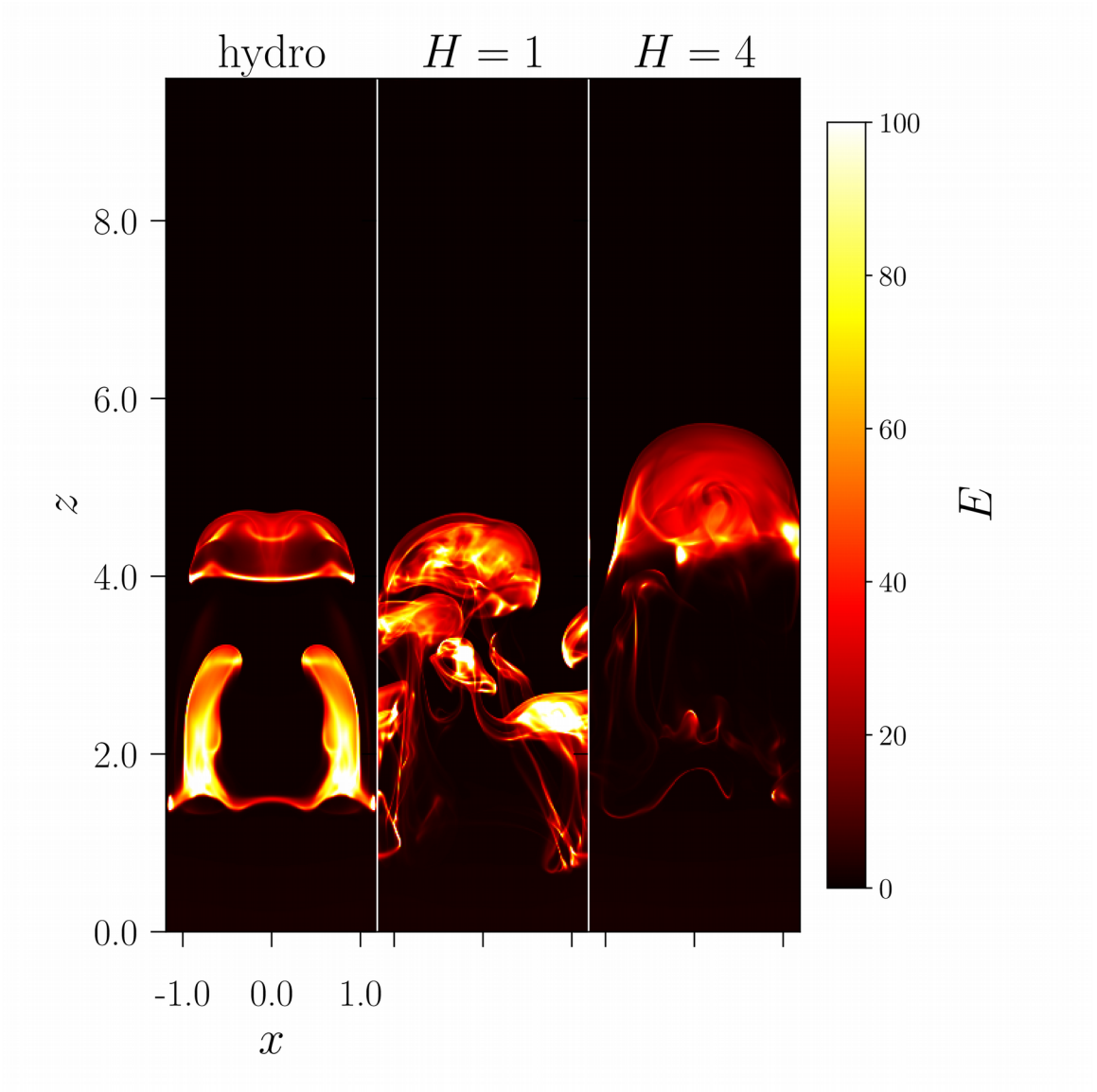
$$\mathbf{A} = f(r) A_0 \begin{pmatrix} \cos(yk) + \sin(zk) \\ \cos(zk) + \sin(xk) \\ \cos(xk) + \sin(yk) \end{pmatrix}$$

smoothing function: $f(r) = 1 - (r/r_{\rm b})^{n_{\rm smooth}}$

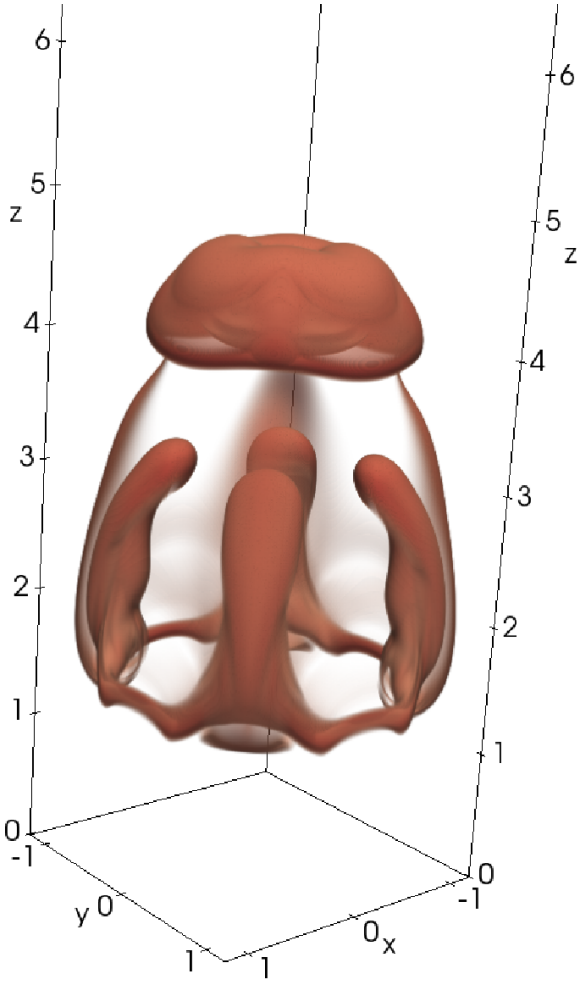
inside bubble: $\nabla \times \mathbf{A} \approx k\mathbf{A}$

- $E_{\rm m} \propto A_0^2 k^2$
- $H_{\rm m} \propto A_0^2 k$
- Fix magnetic energy, vary magnetic helicity.

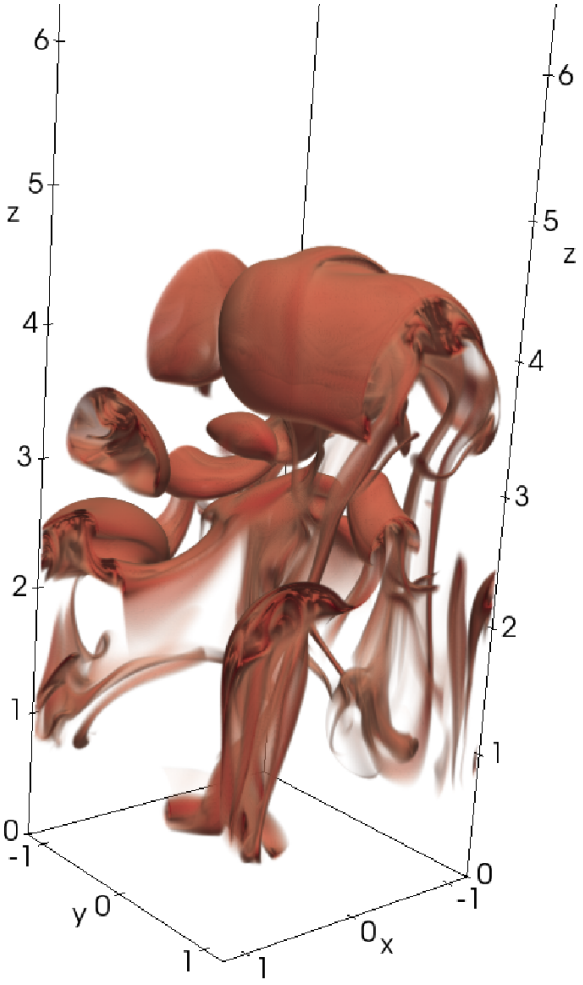
Thermal Emission



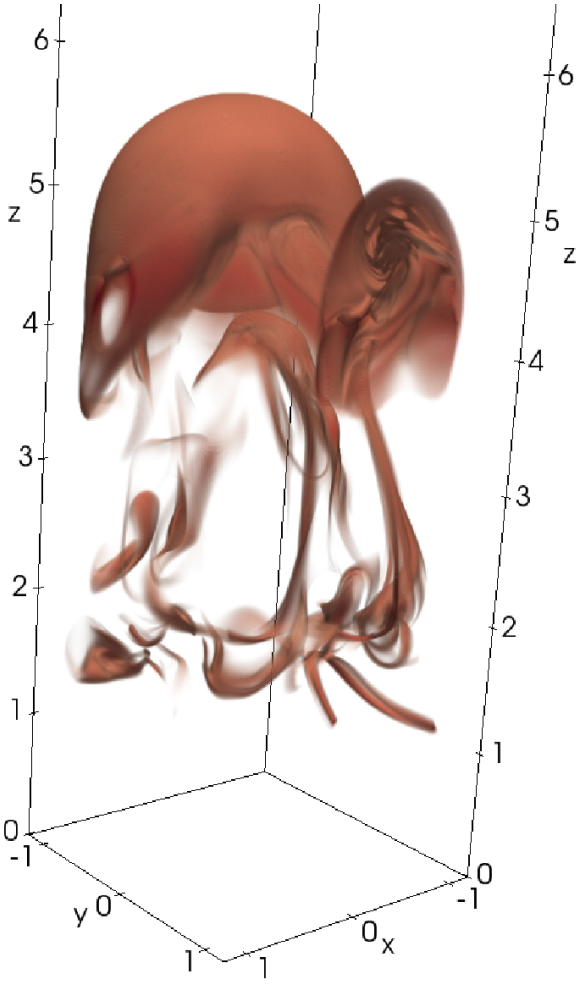
Temperature Iso-Surfaces



hydro

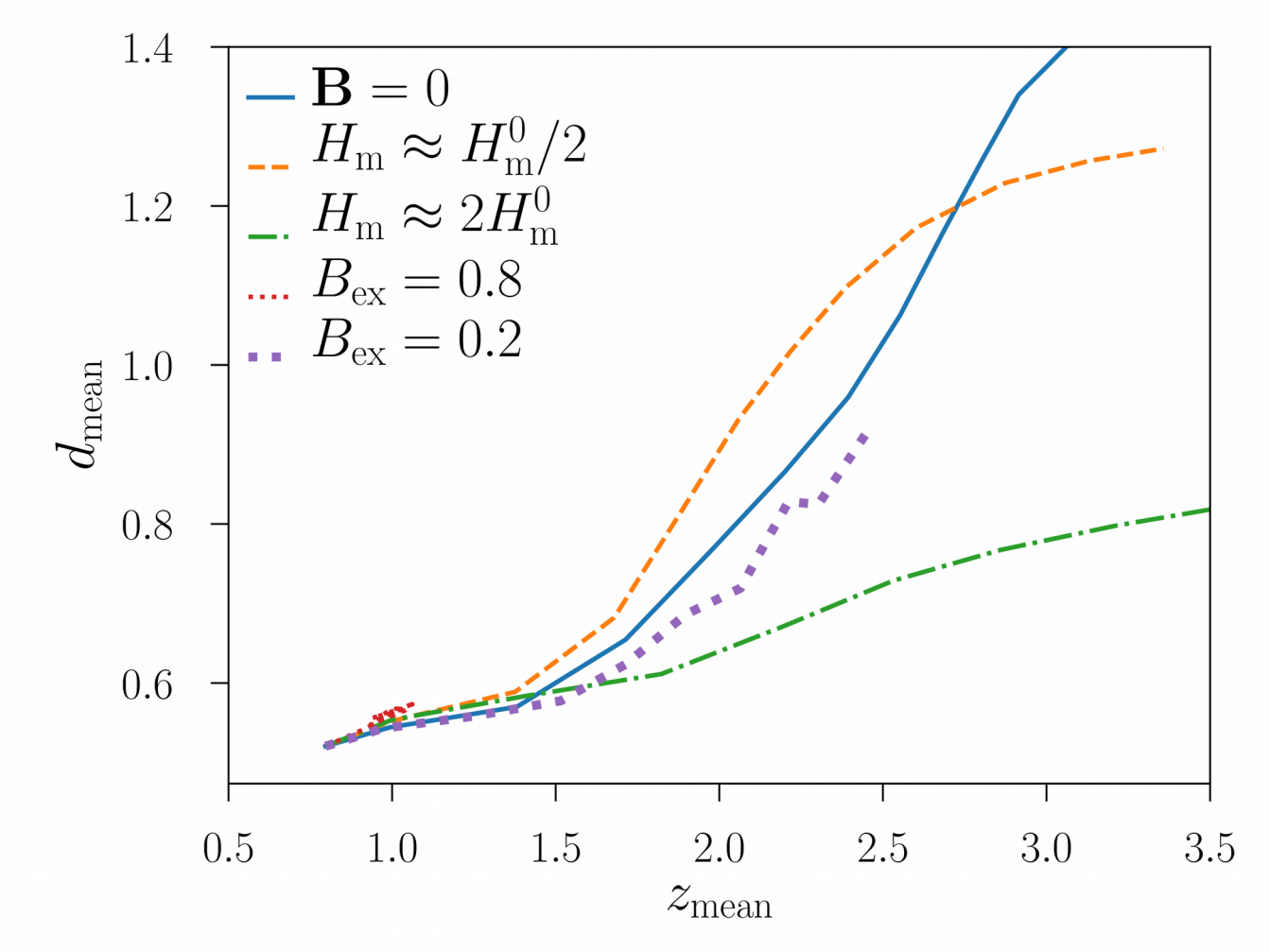


low helicity



high helicity

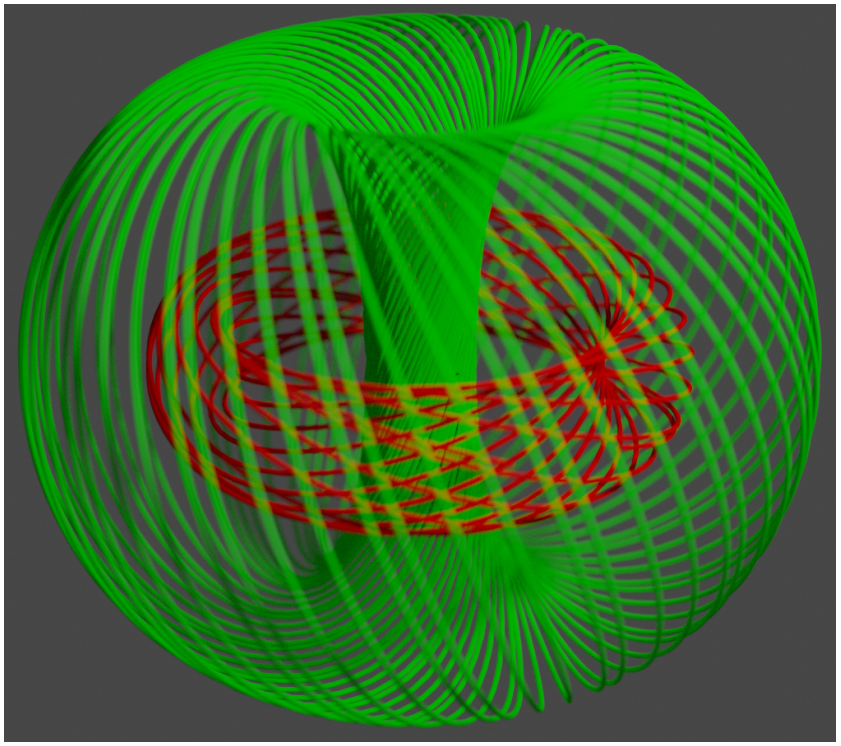
Bubble Coherence



Helical magnetic fields can stabilize the bubbles.

Conclusions

- Magnetic helicity as constraint on plasma dynamics.
- Magnetic helicity leads to stability at small magnetic energy.
- Possible mechanism to stabilize intergalactic bubbles.
- Outlook: Test with geometrically different field (spheromak).



(arXiv:1912.12723)

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