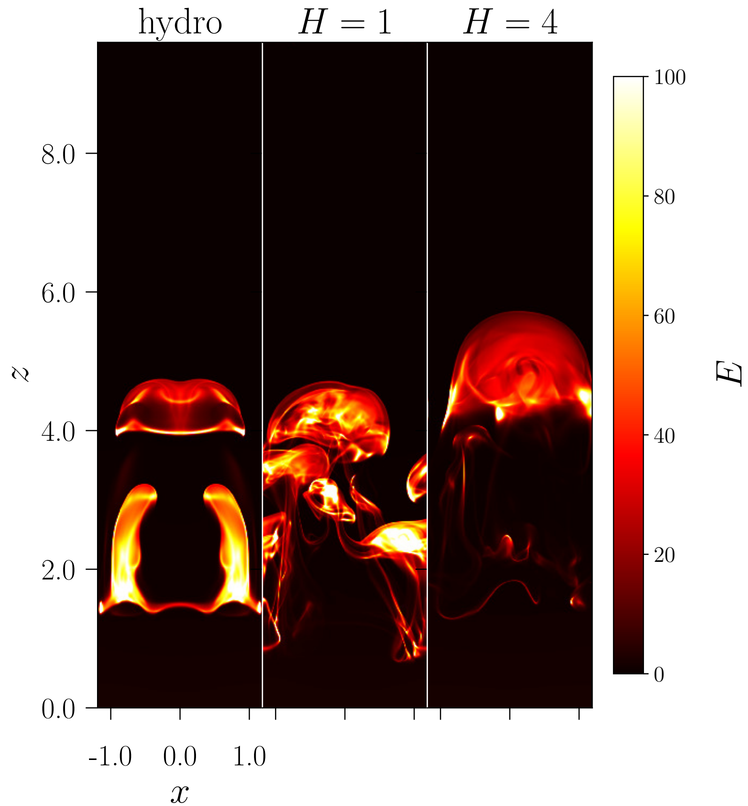
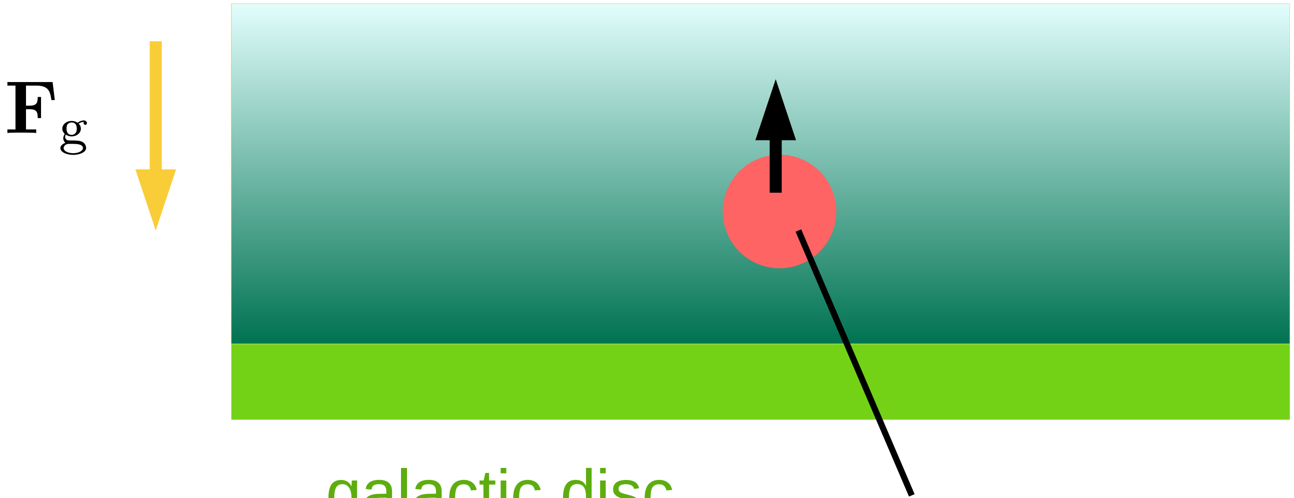
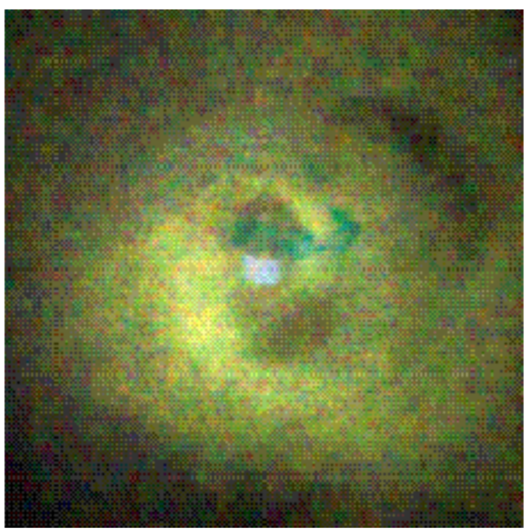
# Stabilizing Effect of Magnetic Helicity on Magnetic Cavities in the Intergalactic Medium

Simon Candelaresi, Fabio Del Sordo



# Intergalactic Bubbles



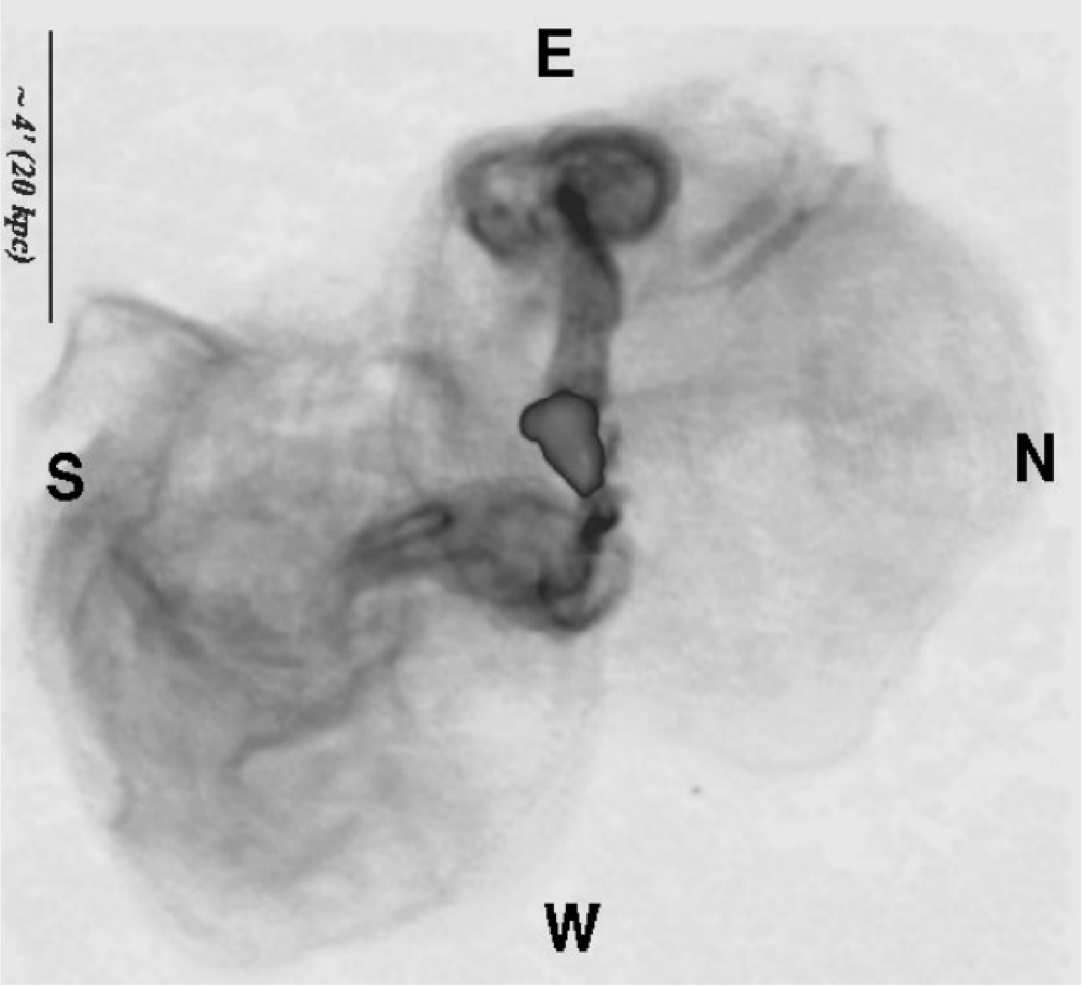



Chandra: X-ray, Perseus cluster

*(Fabian et al. 2000)*

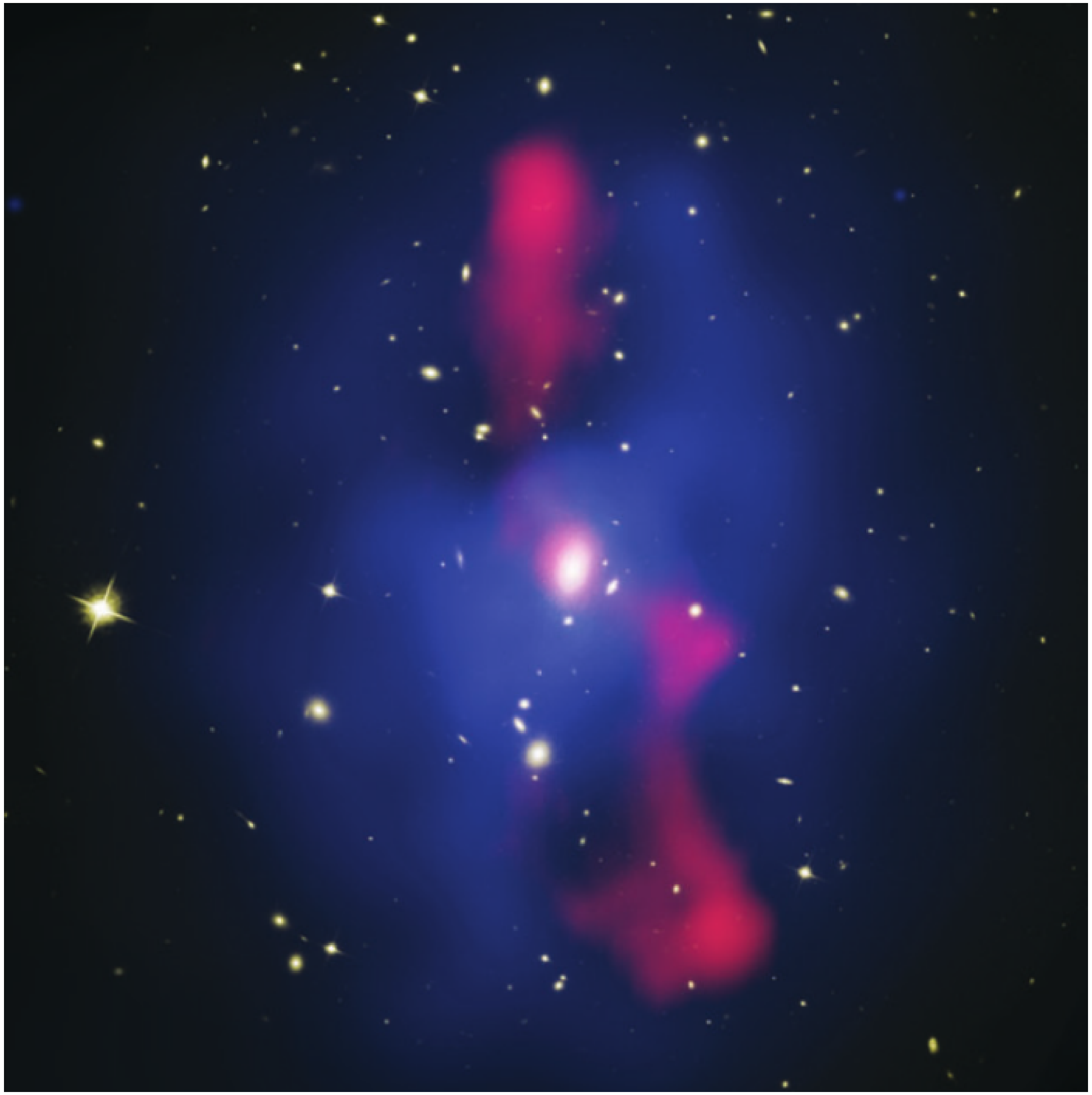
- Bubbles rise buoyantly through density difference.
- Bubbles' age is several tens of millions of years.

# M87 in radio




(Churazov et al. 2001)

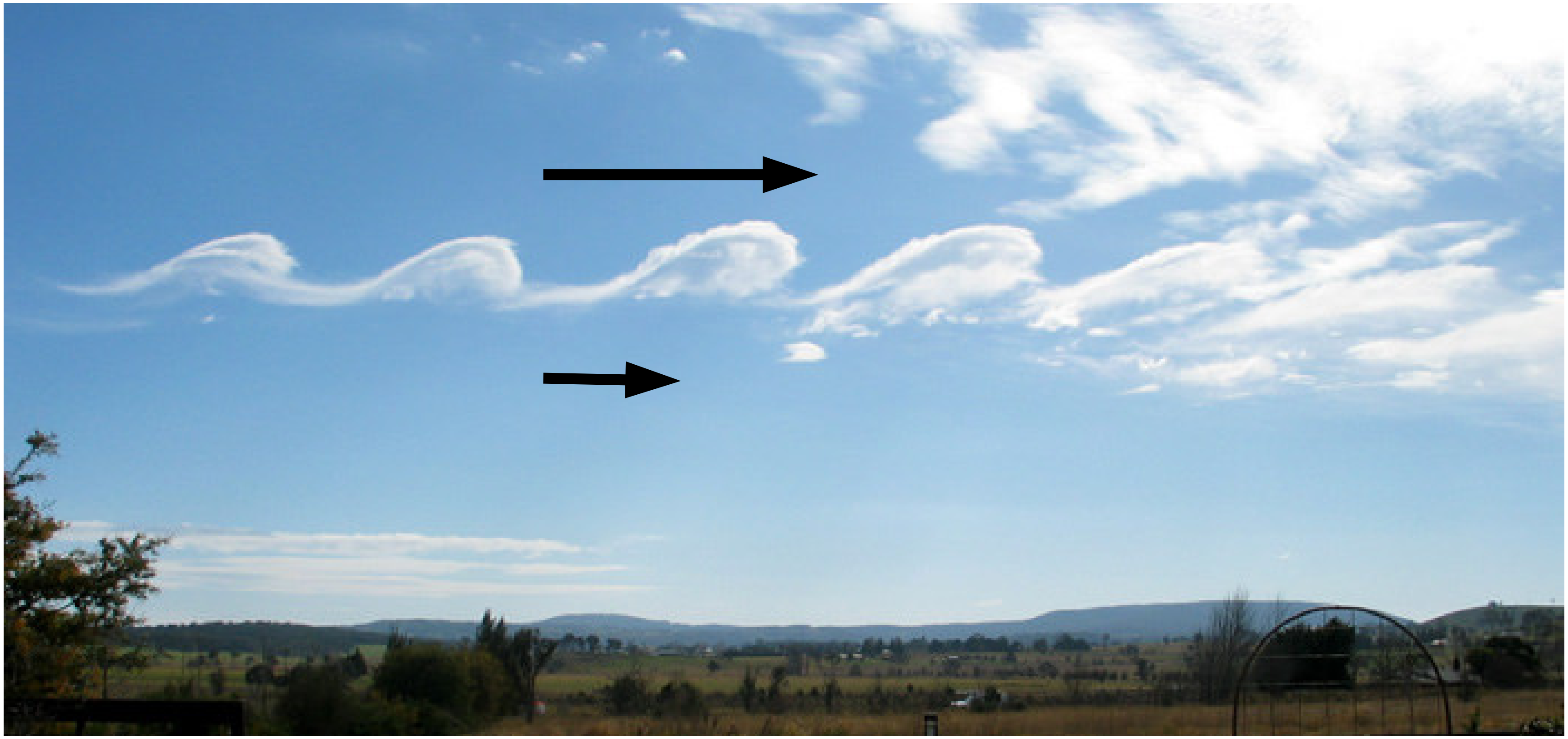
# MS0735.6+7421 cluster



Hubble (visual) + Chandra (X-ray)

(McNamara and Nulsen 2007)

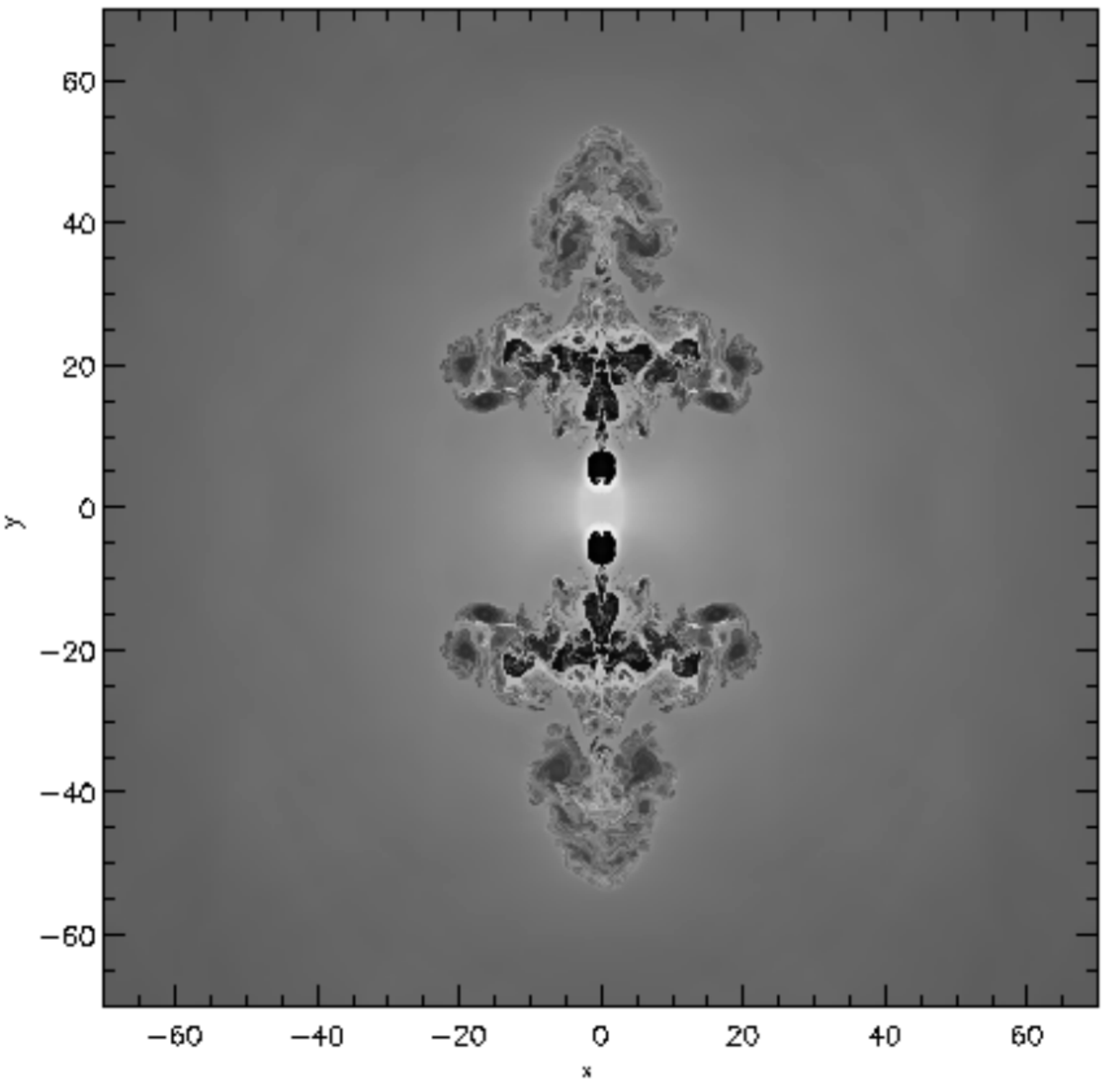
# Kelvin-Helmholtz Instability



*(GRAHAMUK/Wikimedia Commons)*

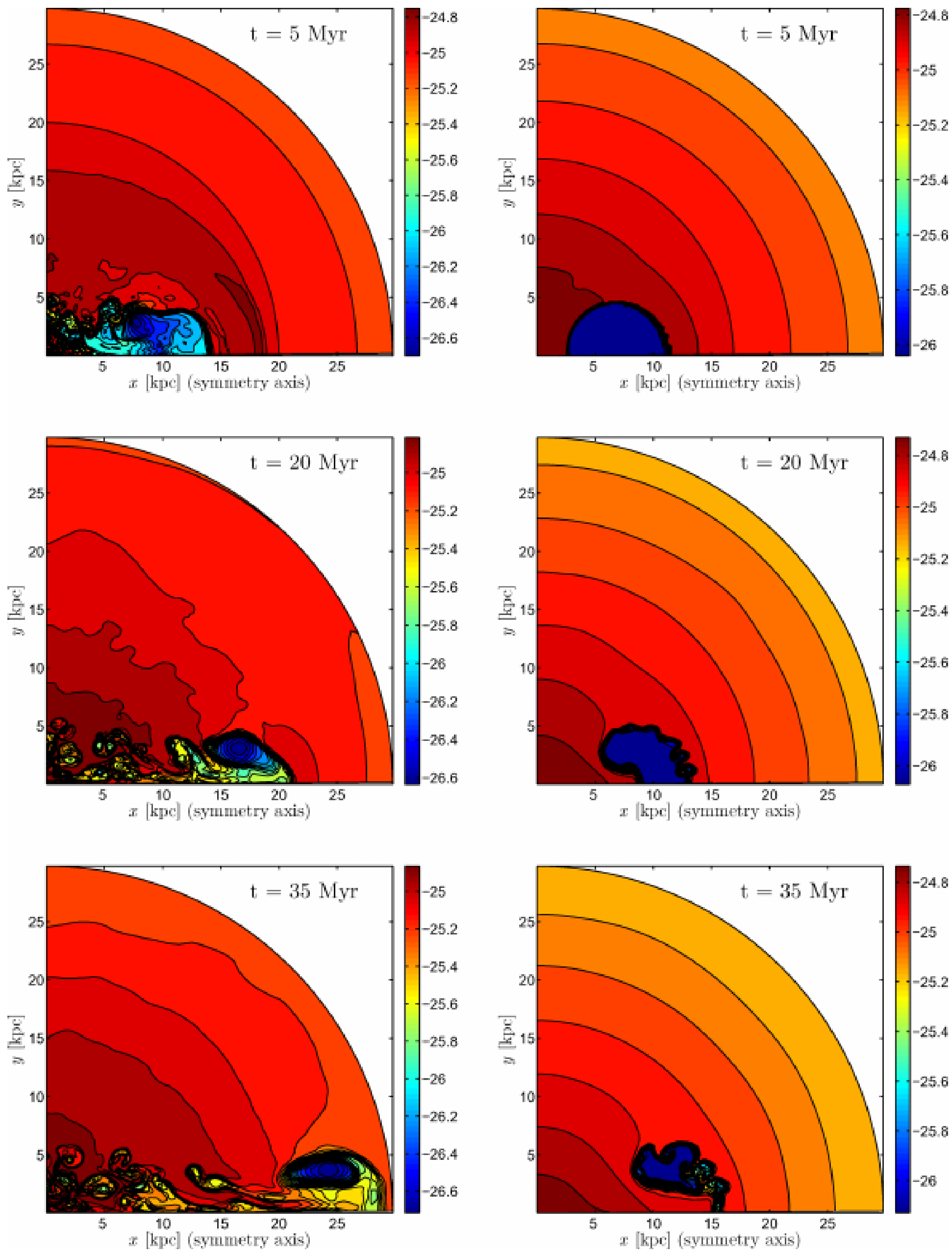
- Bubbles should get disrupted.
- What is the reason for their stability?

# Simulations (hydro)




(Brüggen 2003)

# Simulations (jet inflation)




(Sternberg, Soker 2008)

# 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

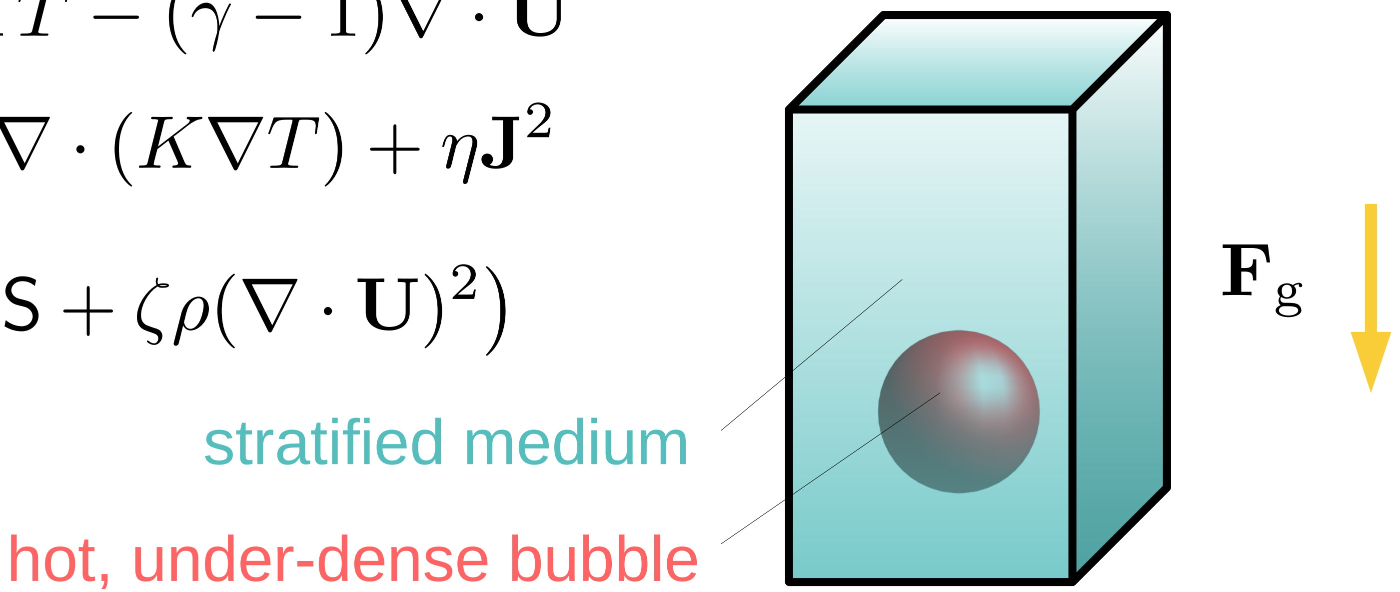
Full resistive magnetohydrodynamics simulations with the PencilCode.

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

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

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

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



# Numerical Experiments

| | | |
|---|---|---|
| box size | $L_{xy}, L_z$ | $24, 96\mathrm{kpc}$ |
| bubble radius | $r_\mathrm{b}$ | $8\mathrm{kpc}$ |
| bubble density | $\rho_\mathrm{b}$ | $2.5 \times 10^{-26}\mathrm{gcm}^{-3}$ |
| bubble temperature | $T_\mathrm{b}$ | $4 \times 10^{6}\mathrm{K}$ |
| medium density | $\rho_0$ | $10^{-25}\mathrm{gcm}^{-3}$ |
| medium temperature | $T_0$ | $10^{6}\mathrm{K}$ |
| gravitational acceleration | $g$ | $3 \times 10^{-7}\mathrm{cms}^{-2}$ |
| magnetic field strength | $B_0$ | $2.5 \times 10^{-6}\mathrm{G}$ |
| viscosity | $\nu$ | $3 \times 10^{27}\mathrm{cm}^2 s^{-1}$ |
| magnetic diffusivity | $\eta$ | $9 \times 10^{26}\mathrm{cm}^2 s^{-1}$ |
| total time | $t_\mathrm{end}$ | $200 - 250\mathrm{Myr}$ |

# Initial Condition: Beltrami Field

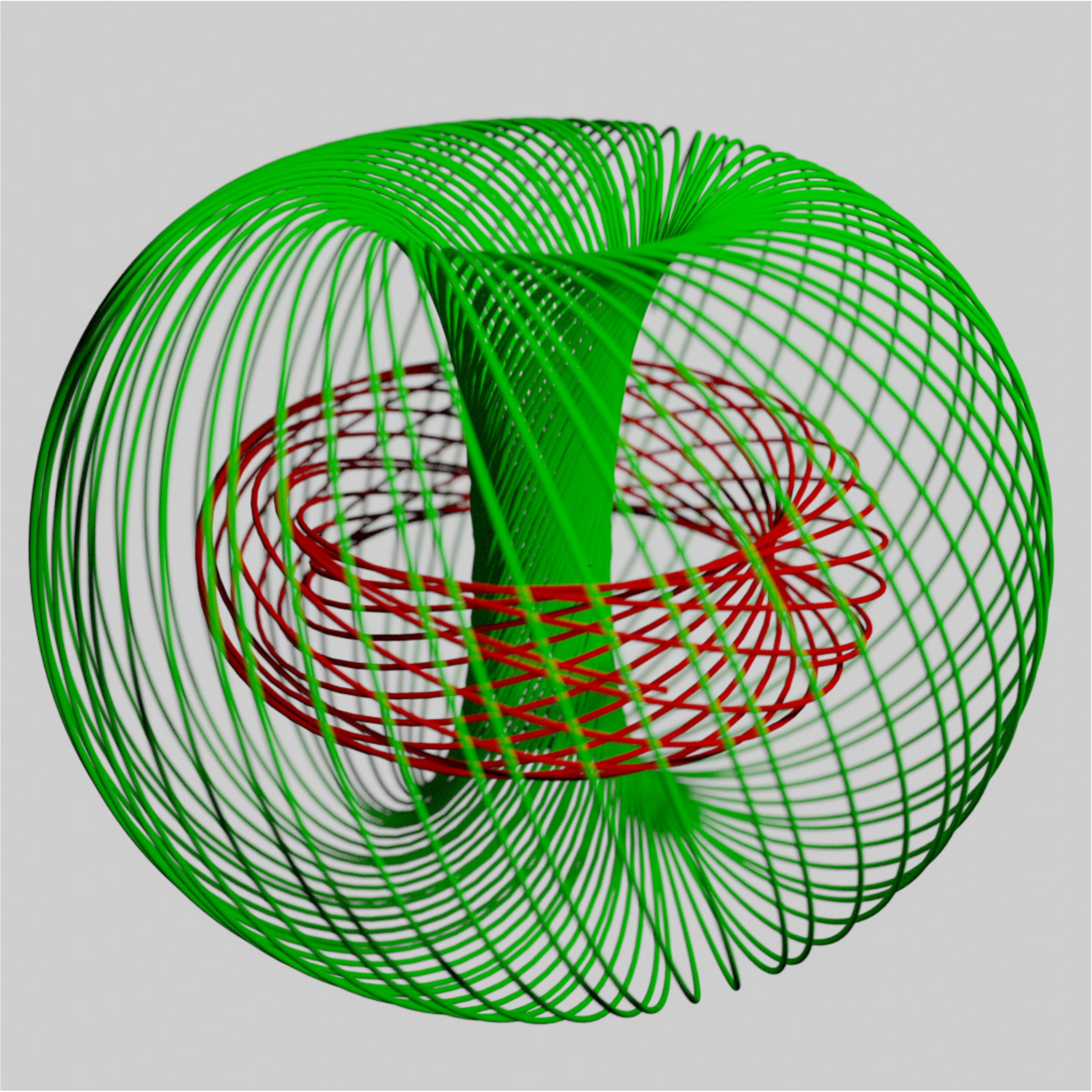
$$\mathbf{A} = f(r) A_0 \begin{pmatrix} \cos(yk) + \sin(zk) \\ \cos(zk) + \sin(xk) \\ \cos(xk) + \sin(yk) \end{pmatrix}$$

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

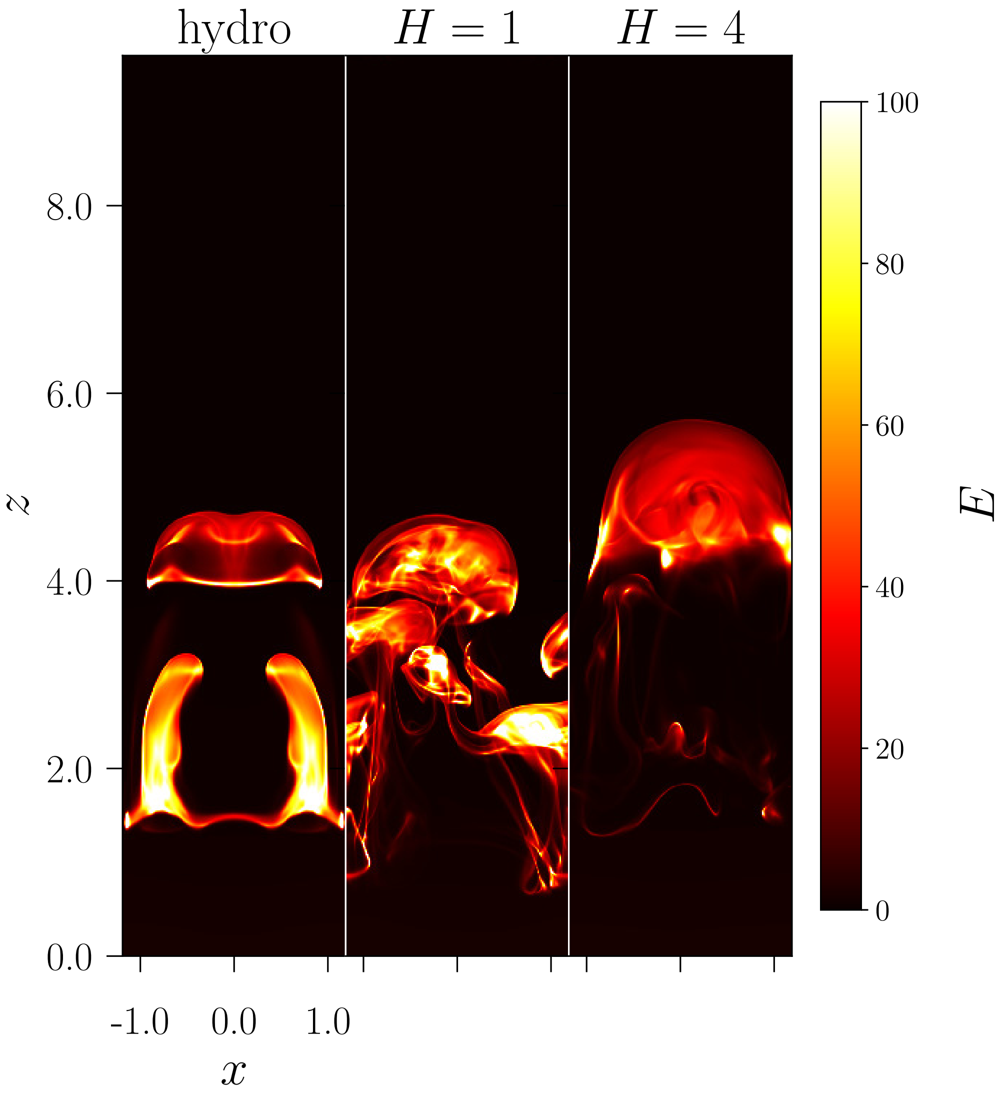
inside bubble: $\nabla \times \mathbf{A} \approx k\mathbf{A}$

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

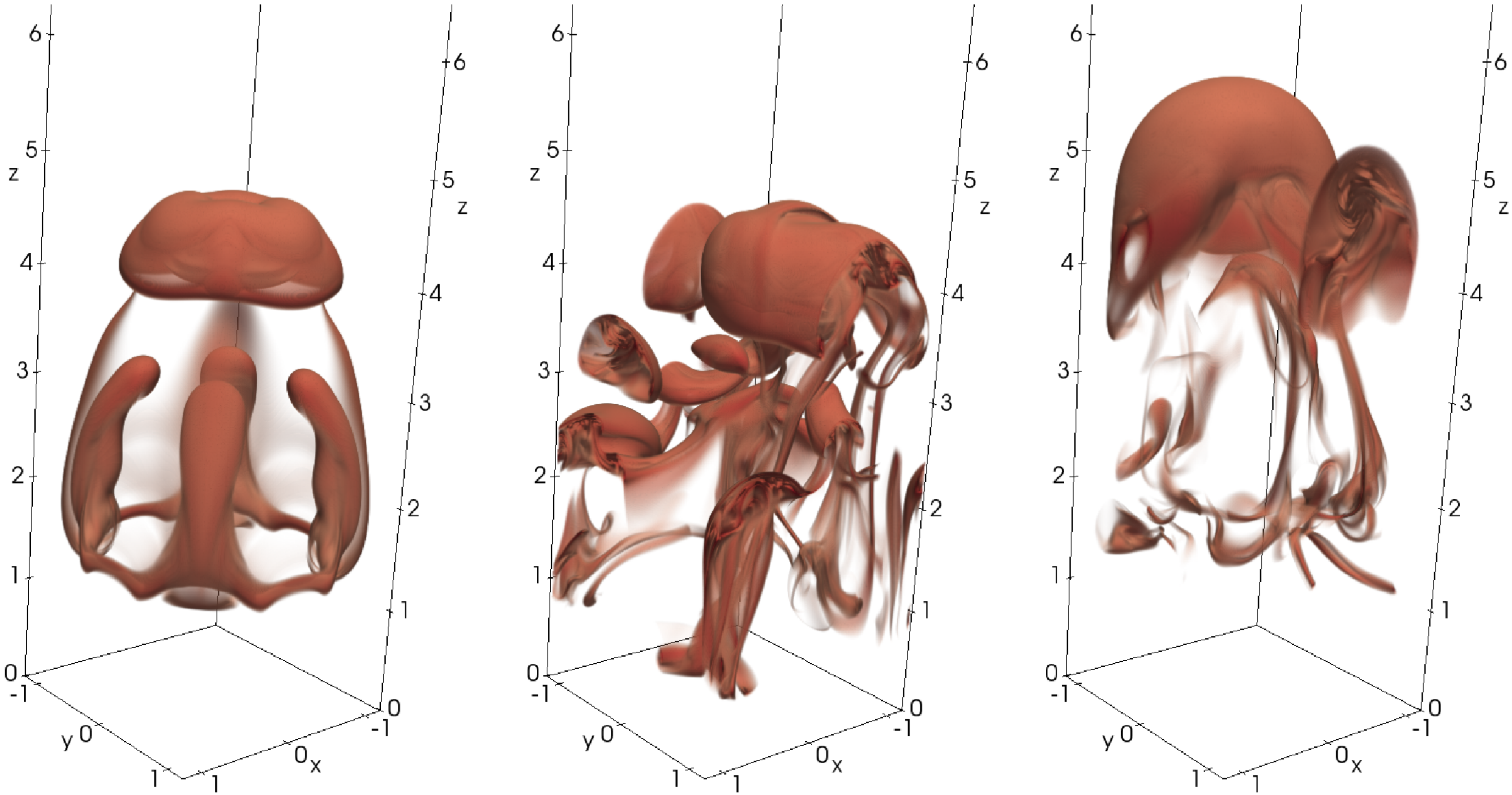
# Initial Condition: Spheromak



# Thermal Emission

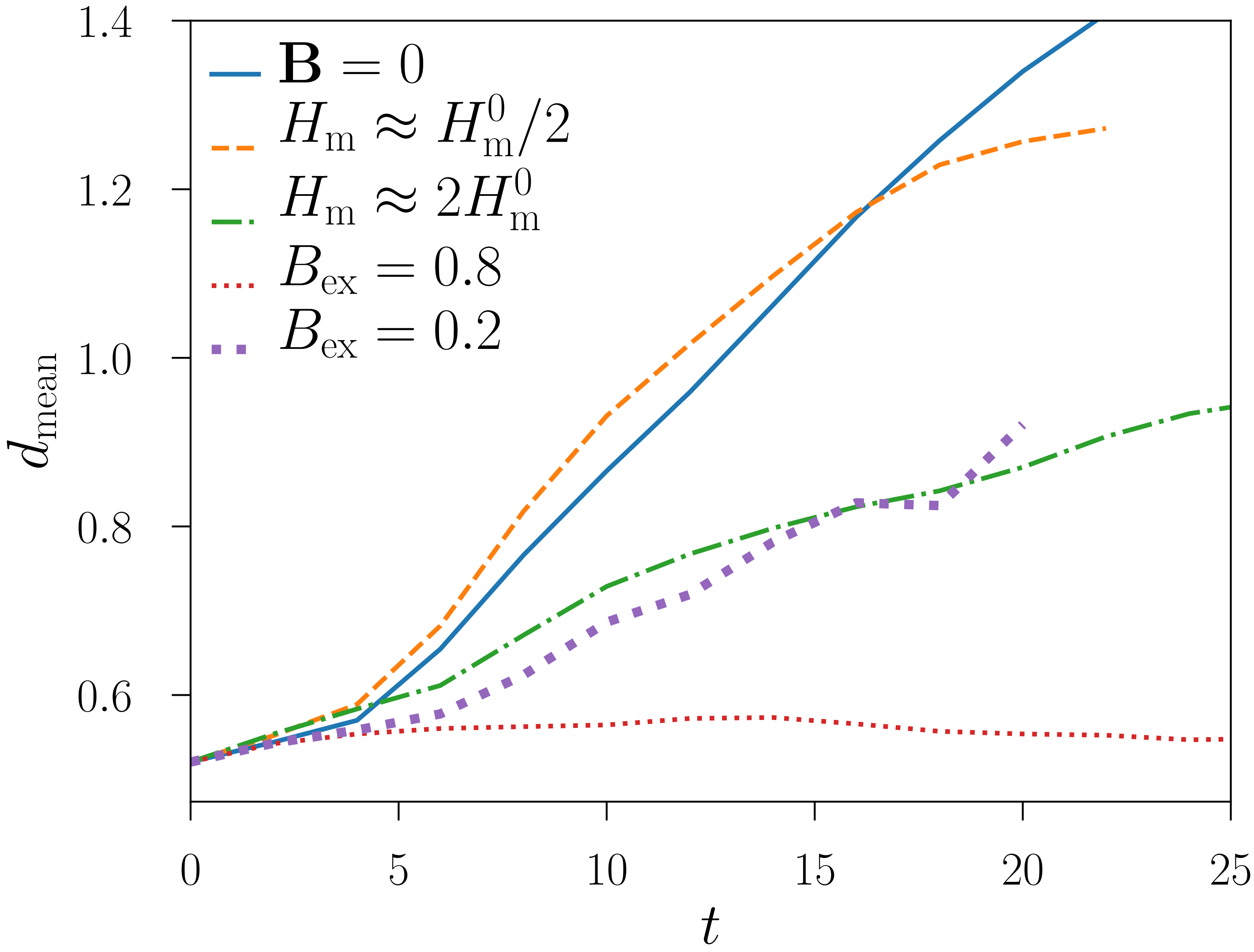


# Temperature Iso-Surfaces

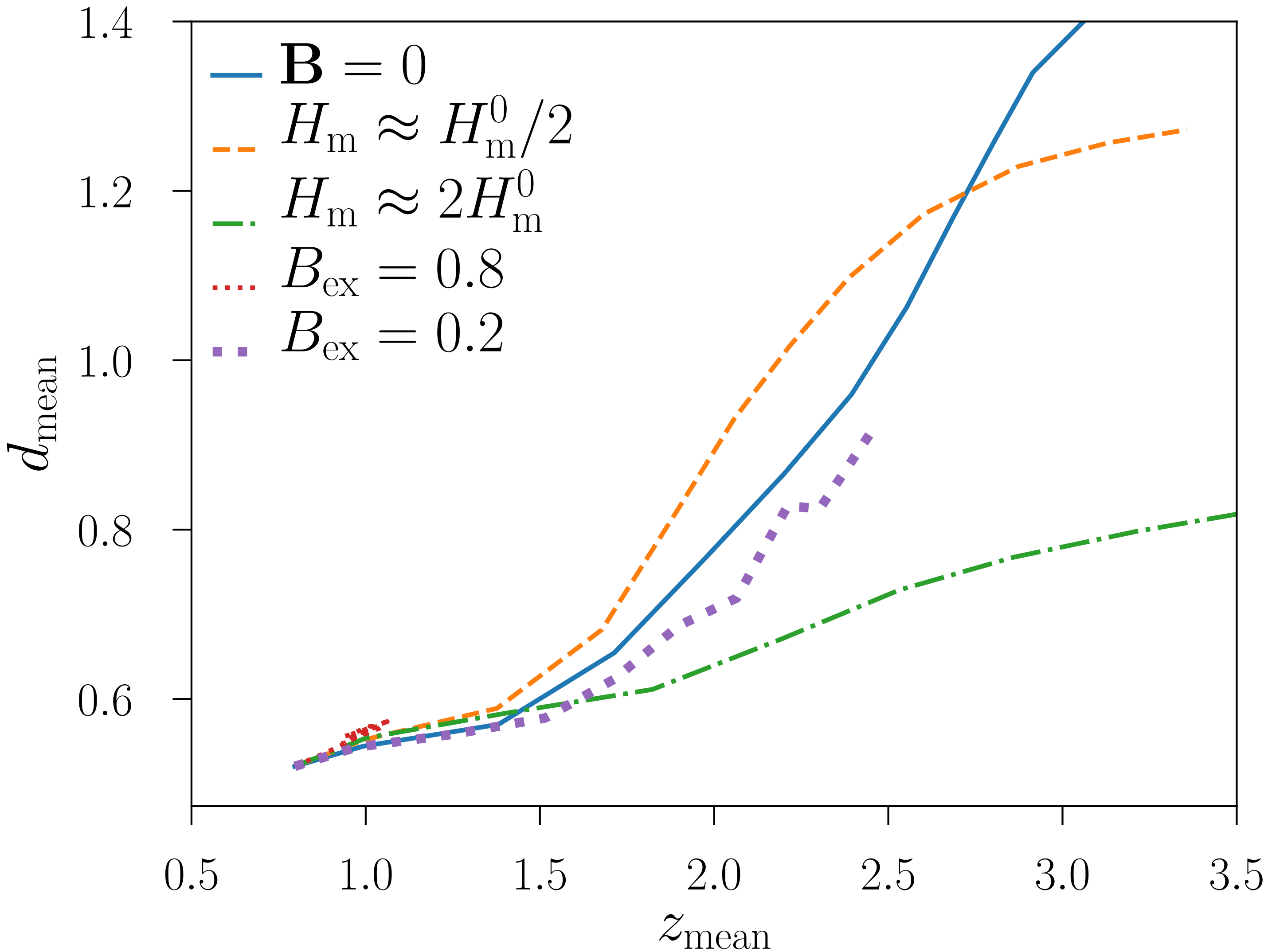



hydro | low helicity | high helicity

# Bubble Coherence



# 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.
- Mechanism to stabilize intergalactic bubbles.

(Candelaresi and Del Sordo 2020 ApJ **896** 86)

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