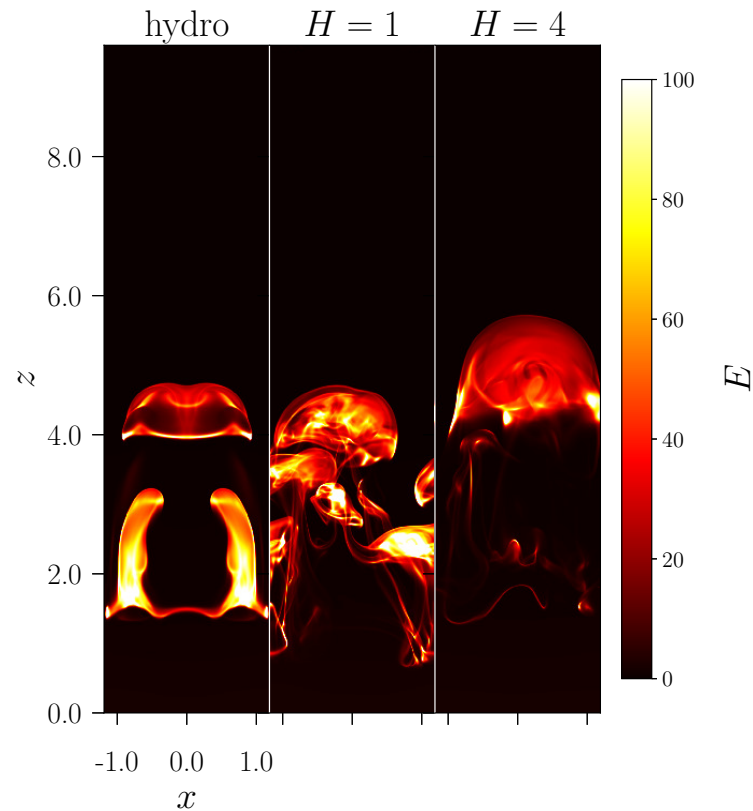# Stabilizing Effect of Magnetic Helicity on Magnetic Cavities in the Intergalactic Medium
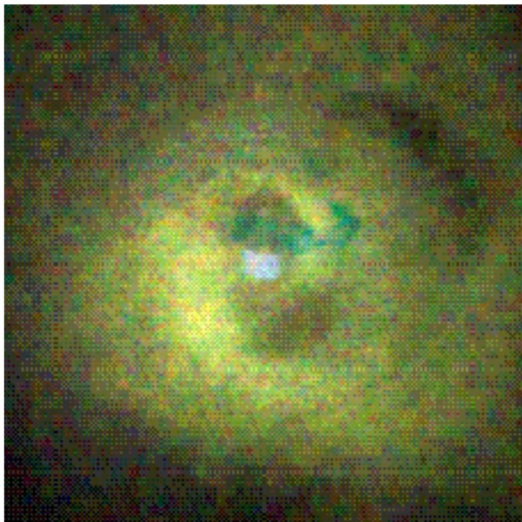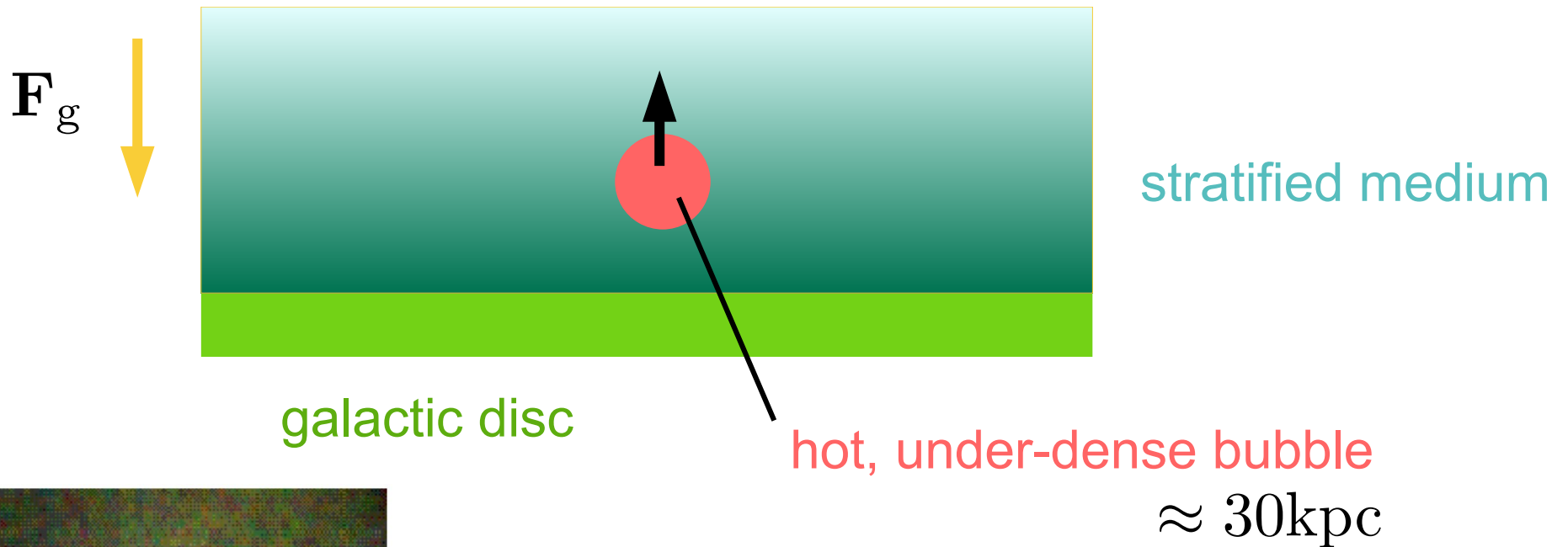
Simon Candelaresi, Fabio Del Sordo

Intergalactic Bubbles
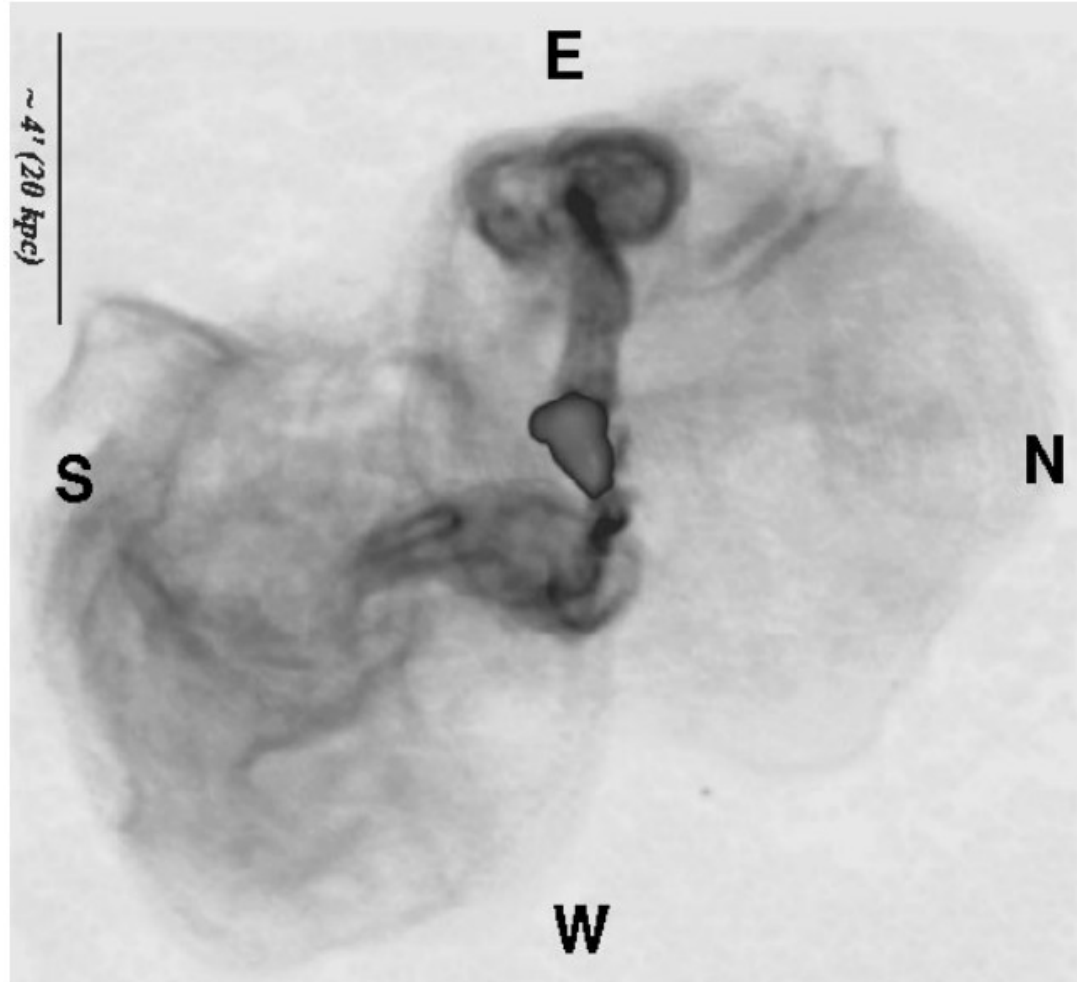
$\mathbf{F}_{g}$

stratified medium

galactic disc

hot, under-dense bubble

$\approx 30\mathrm{kpc}$

➡ Bubbles rise buoyantly through density difference.

➡ Bubbles' age is several tens of millions of years.

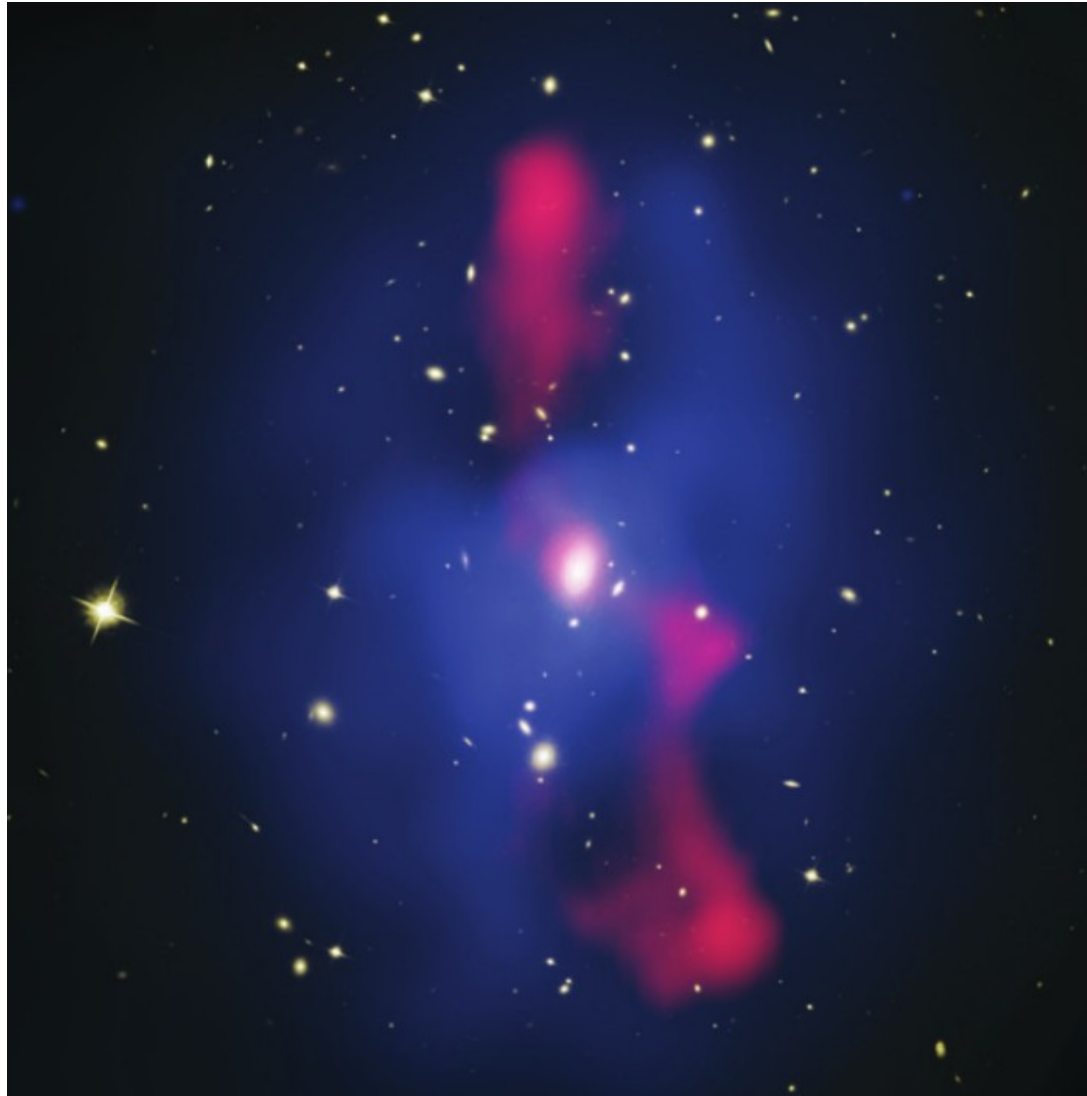Chandra: X-ray, Perseus cluster

(Fabian et al. 2000)

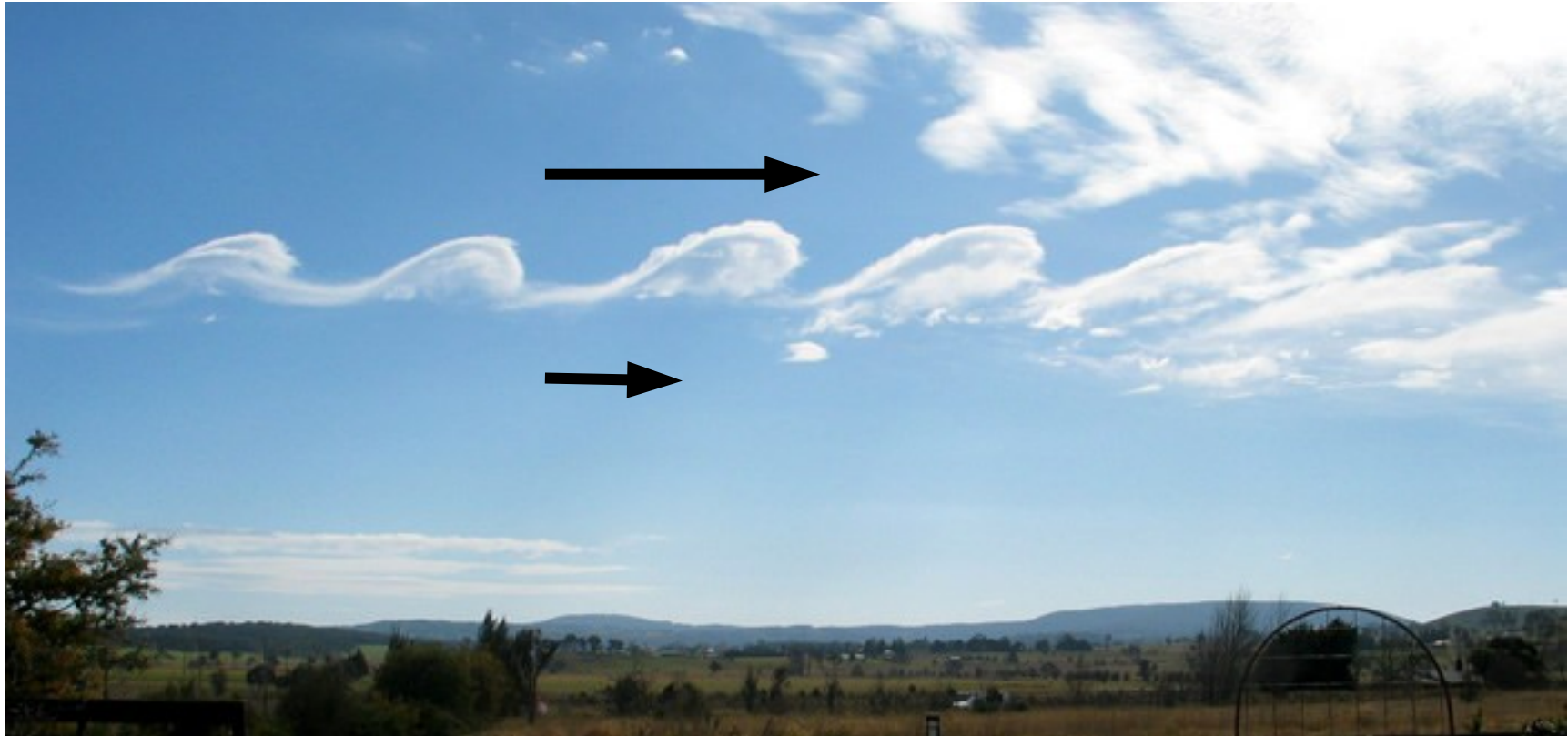# M87 in radio

(Churazov et al. 2001)

MS0735.6+7421 cluster

Hubble (visual) + Chandra (X-ray)

(McNamara and Nulsen 2007)
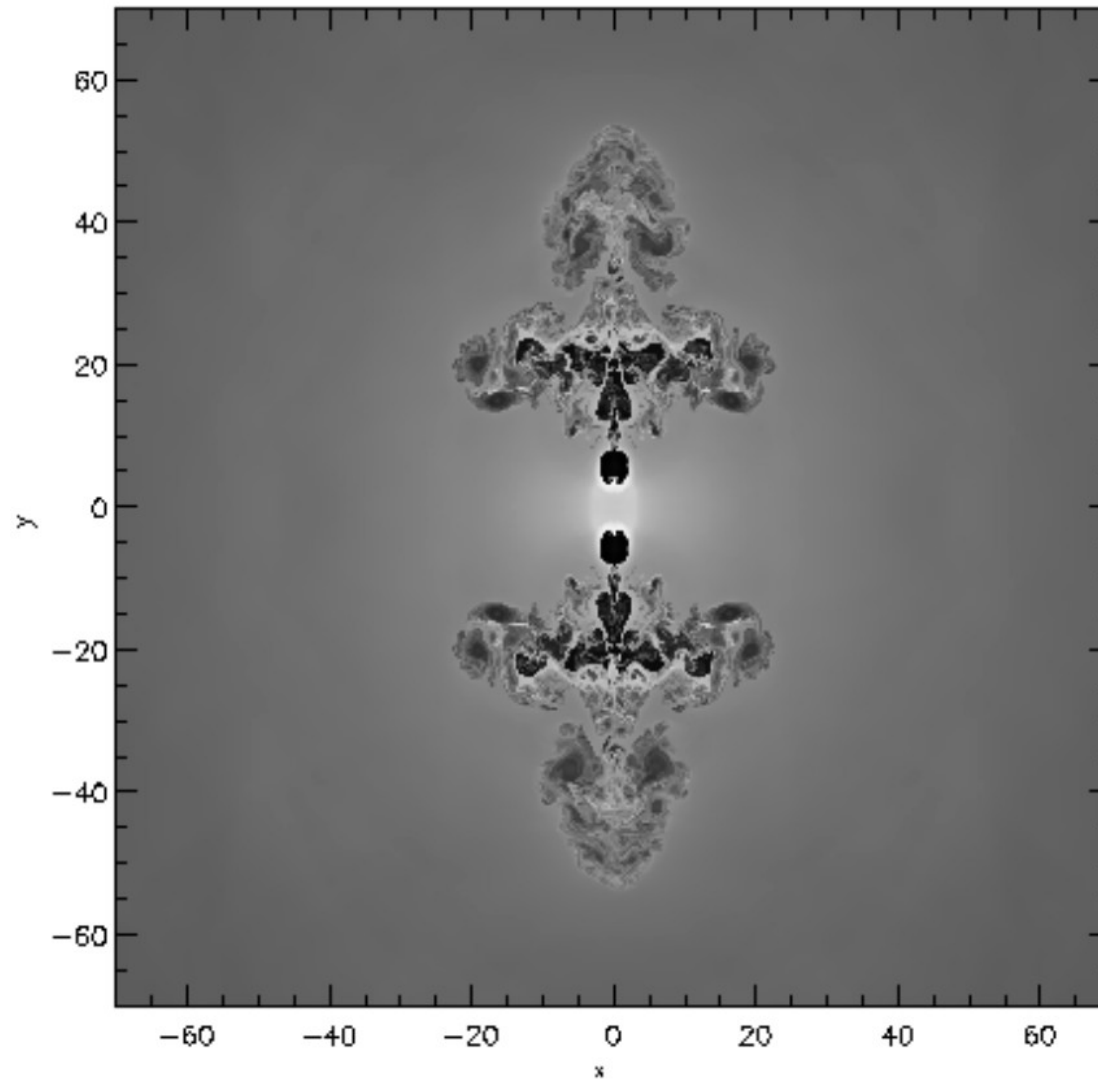
Kelvin-Helmholtz Instability

(GRAHAMUK/Wikimedia Commons)
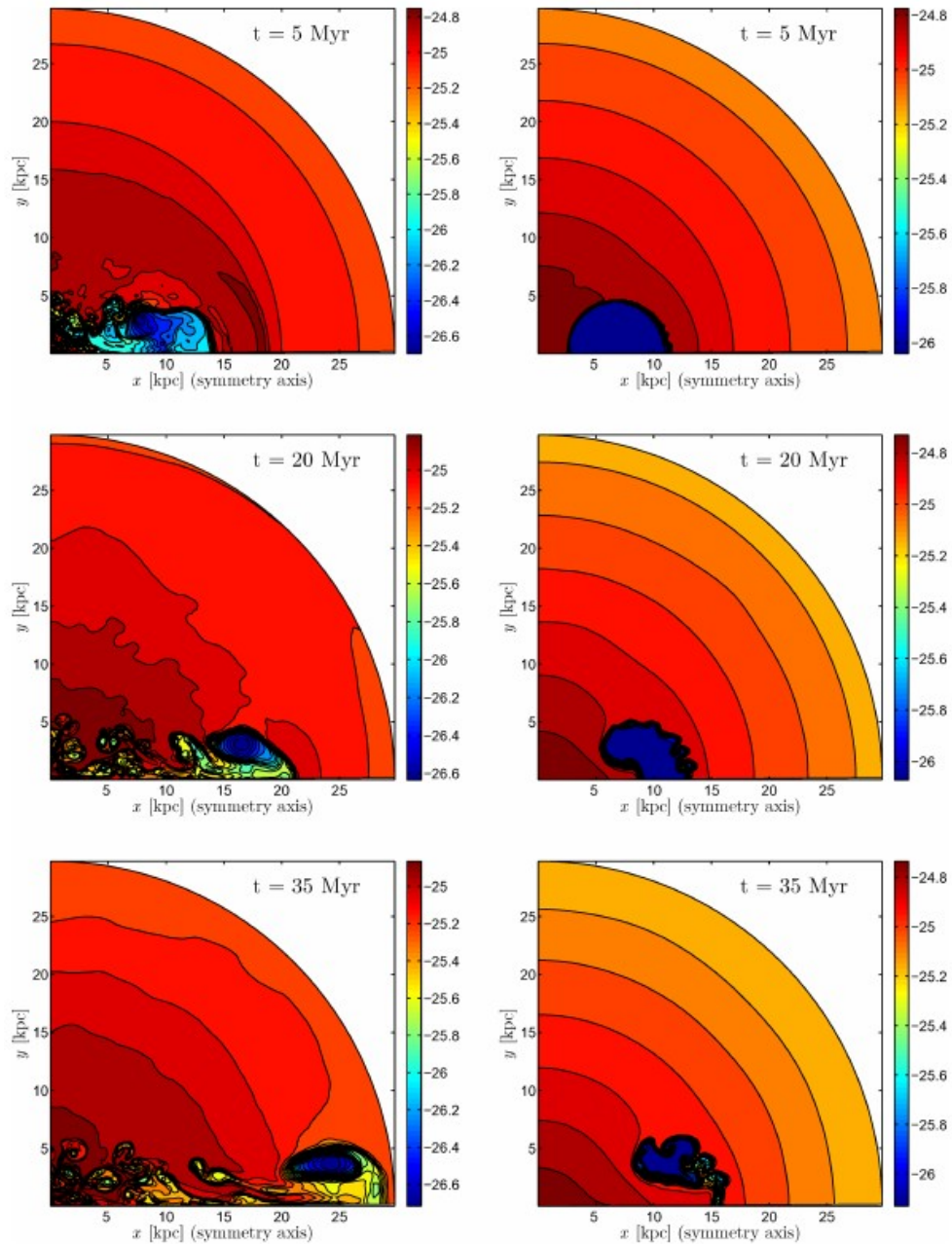
➡ Bubbles should get disrupted.

➡ What is the reason for their stability?

Simulations (hydro)

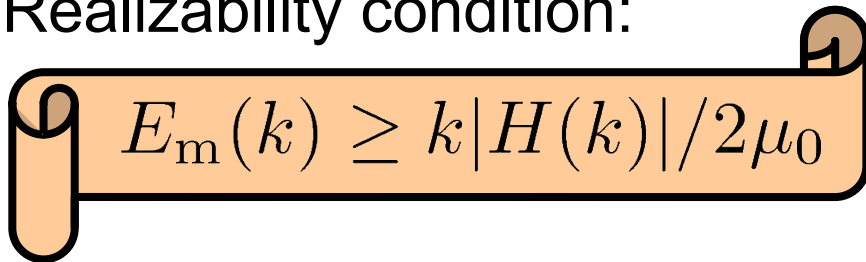(Brüggen 2003)

Simulations (jet inflation)
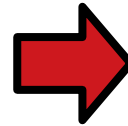

(Sternberg, Soker 2008)

Magnetic Helicity

Conservation of magnetic helicity:

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

Realizability condition:

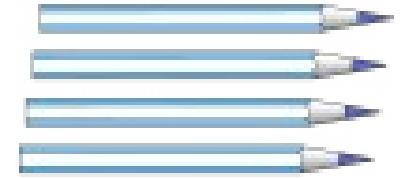$$E_{\mathrm{m}}(k) \geq k|H(k)|/2\mu_0$$

Magnetic energy is bound from below by magnetic helicity.

Can magnetic helicity stabilize intergalactic cavities?

Numerical Experiments

Full resistive magnetohydrodynamics simulations with the PencilCode.

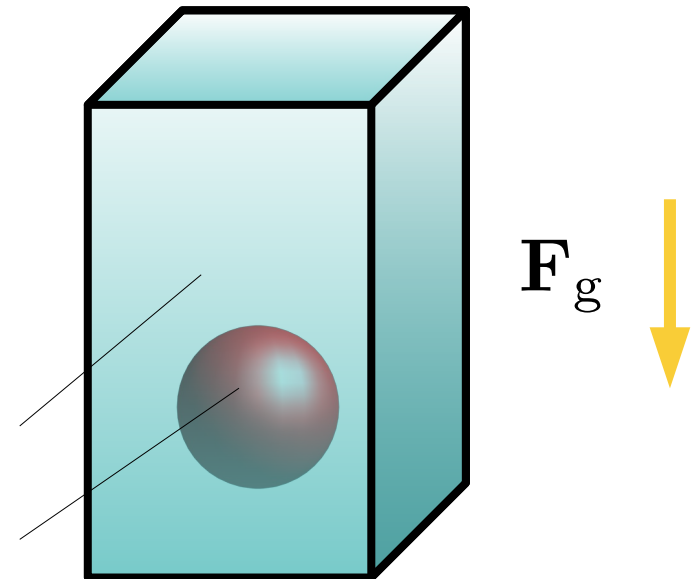$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{U} \times \mathbf{B} + \eta \nabla^2 \mathbf{A}$$

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

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

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

$\mathbf{F}_{\mathrm{g}}$

stratified medium

hot, under-dense bubble

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Numerical Experiments
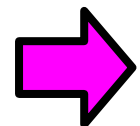
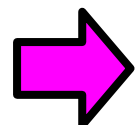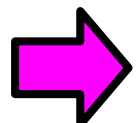| box size	L_{xy}, L_z	$24, 96\mathrm{kpc}$
bubble radius	r_b	$8\mathrm{kpc}$
bubble density	ρ_b	$2.5 \times 10^{-26}\mathrm{gcm}^{-3}$
bubble temperature	T_b	$4 \times 10^{6}\mathrm{K}$
medium density	ρ_0	$10^{-25}\mathrm{gcm}^{-3}$
medium temperature	T_0	$10^{6}\mathrm{K}$
gravitational acceleration	g	$3 \times 10^{-7}\mathrm{cms}^{-2}$
magnetic field strength	B_0	$2.5 \times 10^{-6}\mathrm{G}$
viscosity	ν	$3 \times 10^{27}\mathrm{cm}^2 s^{-1}$
magnetic diffusivity	η	$9 \times 10^{26}\mathrm{cm}^2 s^{-1}$
total time	t_end	$200 - 250\mathrm{Myr}$

Initial Condition: Beltrami Field

$$\mathbf{A} = f(r)A_0 \begin{pmatrix} \cos(yk) + \sin(zk) \\ \cos(zk) + \sin(xk) \\ \cos(xk) + \sin(yk) \end{pmatrix}$$
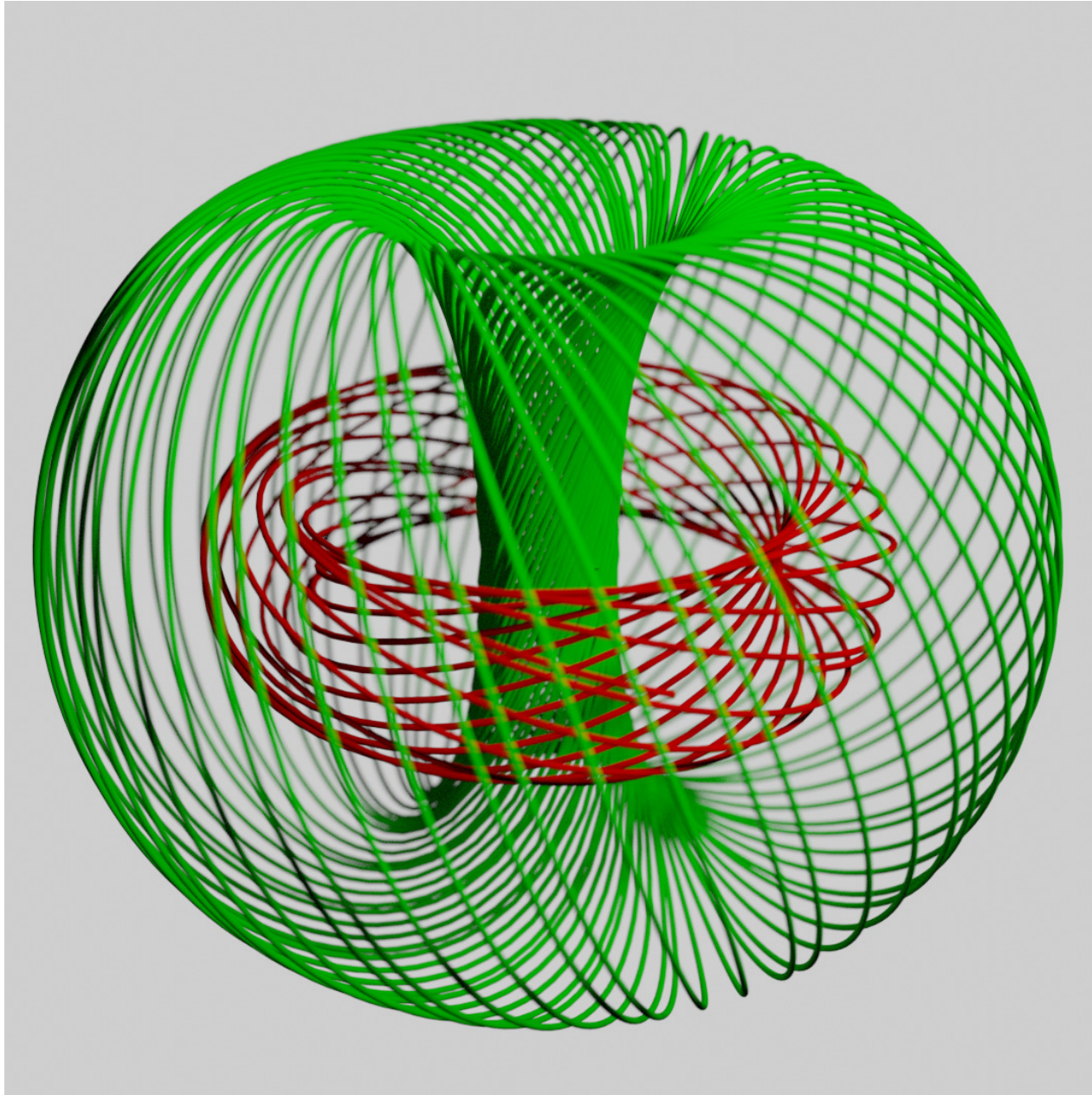
smoothing function: $f(r) = 1 - (r/r_{\mathrm{b}})^{n_{\mathrm{smooth}}}$

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

$\Rightarrow$ $E_{\mathrm{m}} \propto A_0^2 k^2$
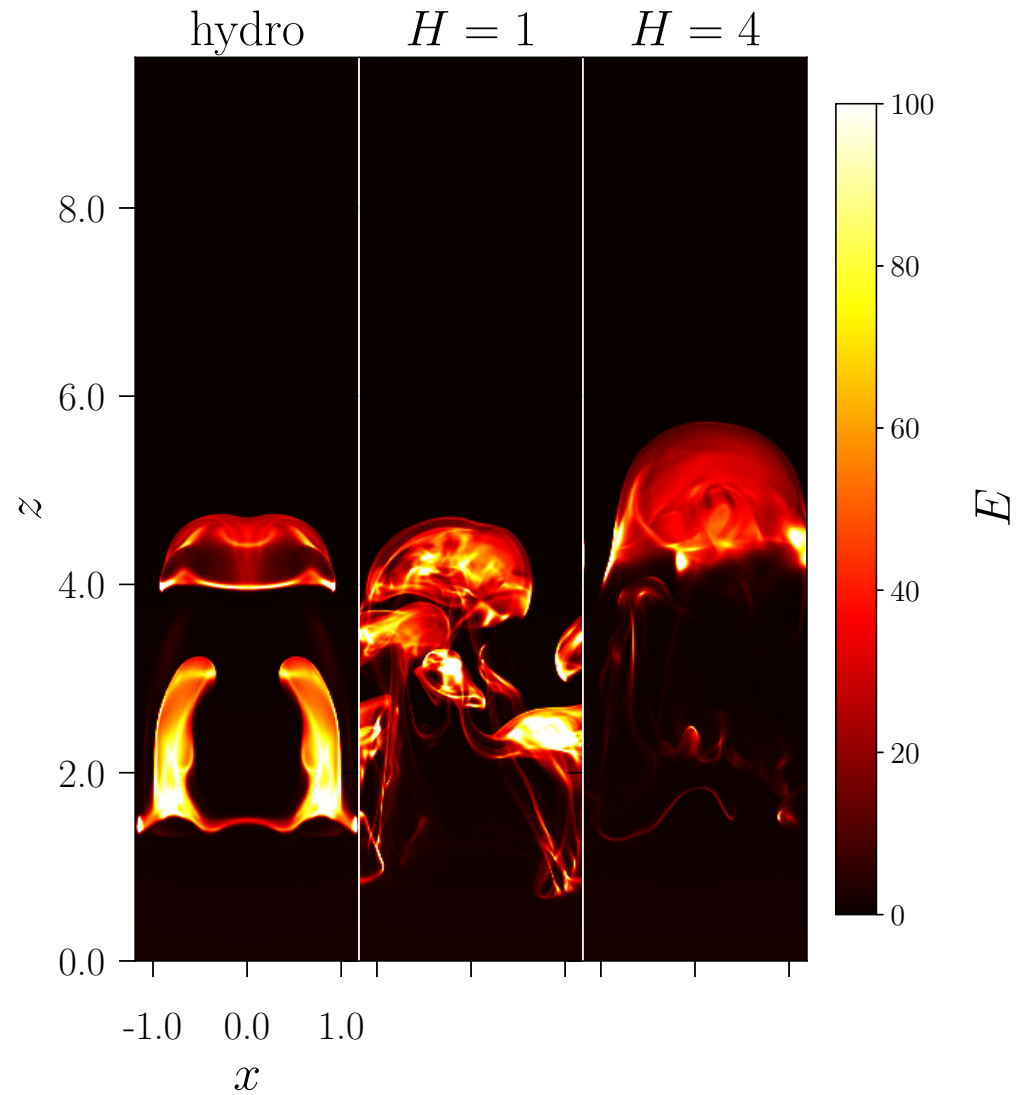
$\Rightarrow$ $H_{\mathrm{m}} \propto A_0^2 k$

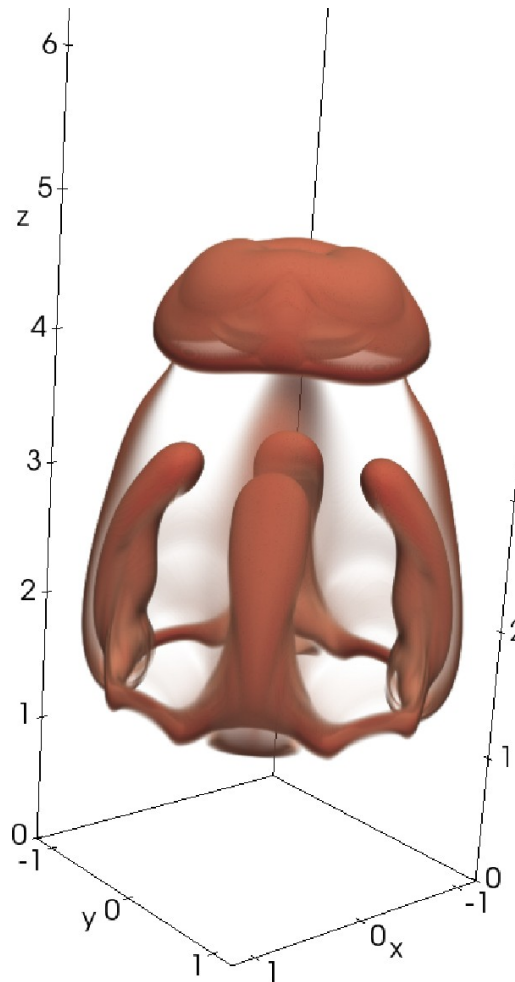$\Rightarrow$ Fix magnetic energy, vary magnetic helicity.
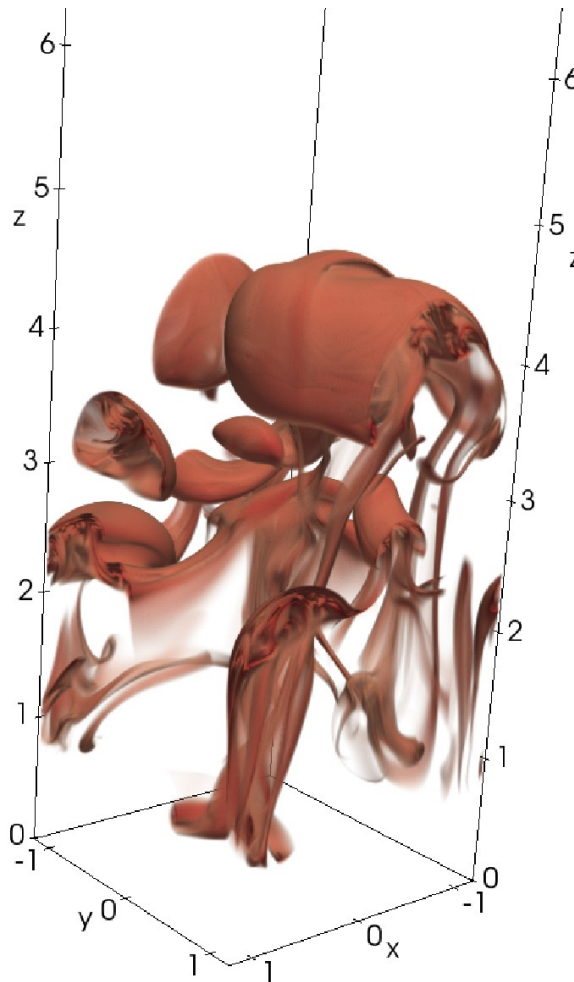
Initial Condition: Spheromak

Thermal Emission

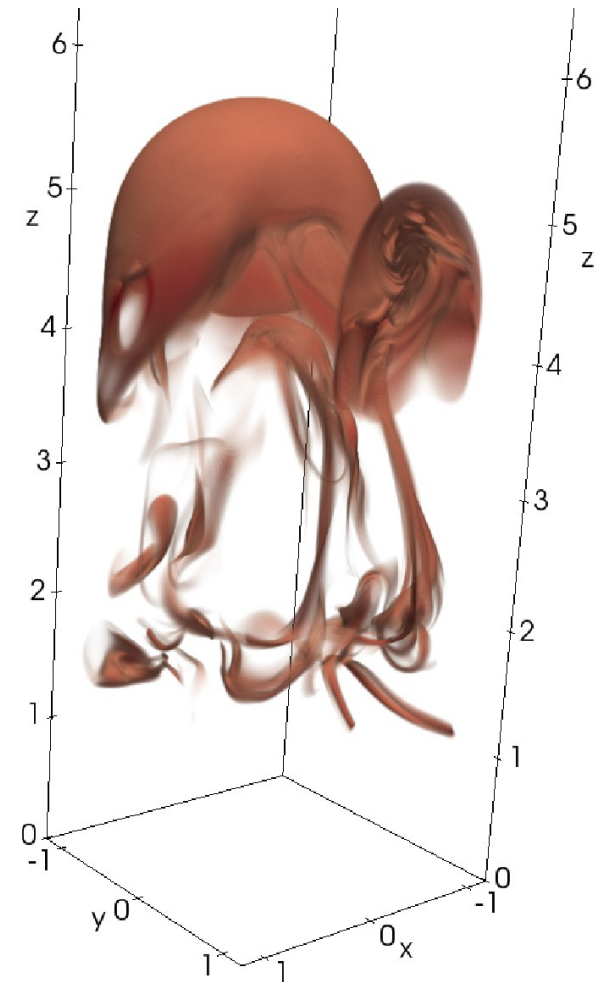# Temperature Iso-Surfaces
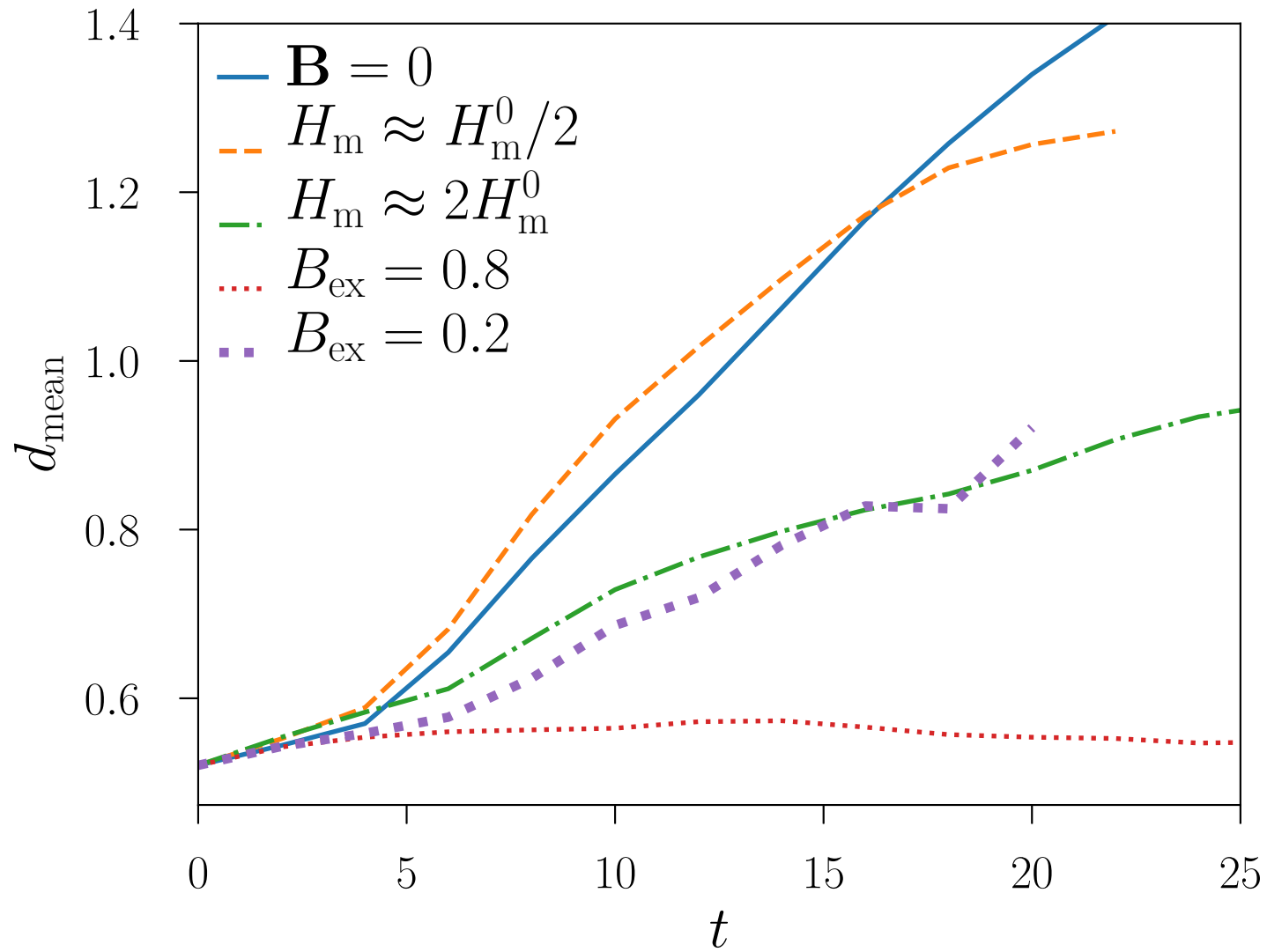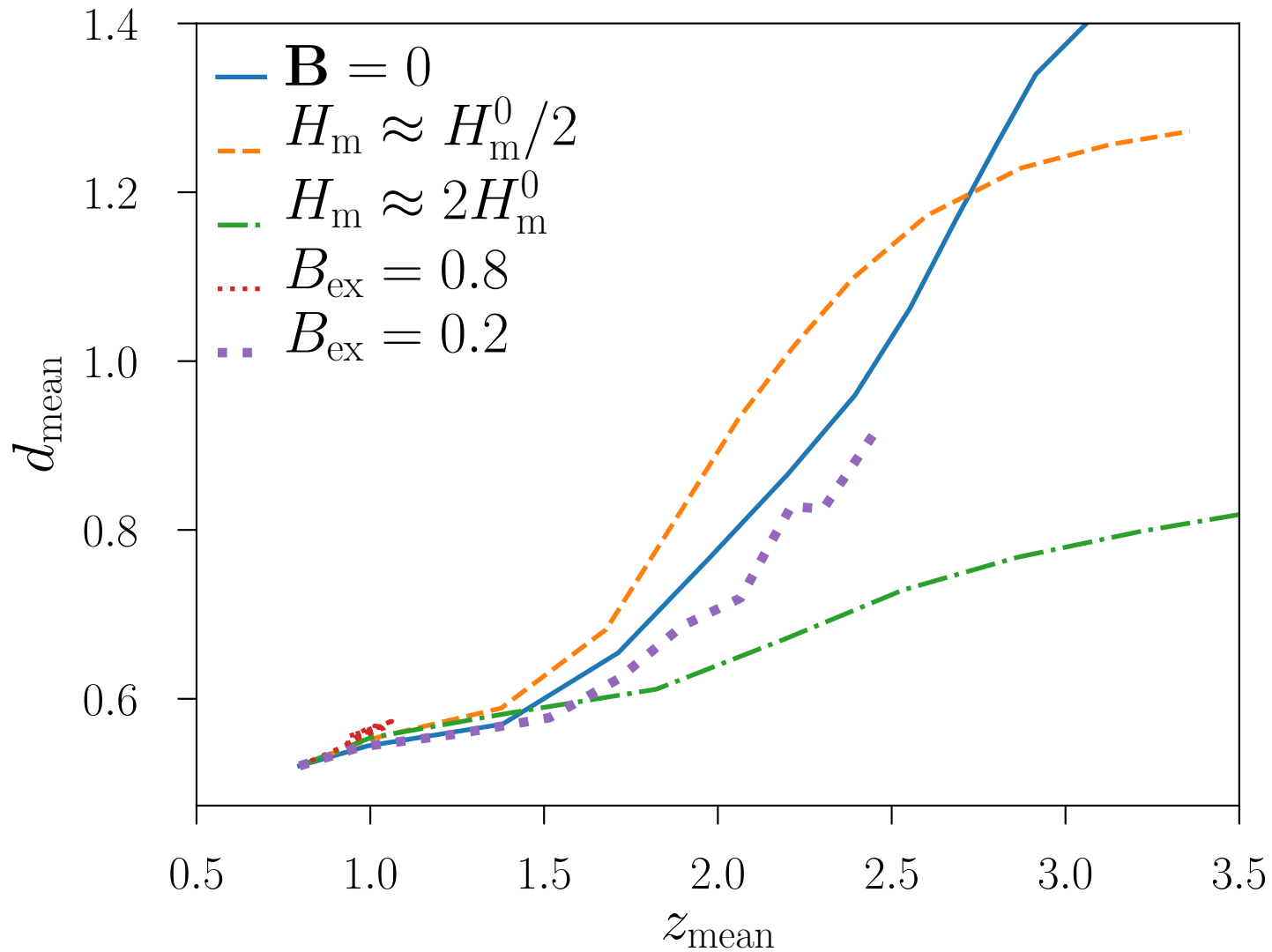

hydro   low helicity   high helicity

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.

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