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

Simon Candelaresi, Fabio Del Sordo
Intergalactic Bubbles

- **hot, under-dense bubble**
- **stratified medium**
- Bubbles' age is several tens of millions of years.
- Bubbles rise buoyantly through density difference.
- ≈ 30kpc

(Fabian et al. 2000)
Kelvin-Helmholtz Instability

Bubbles should get disrupted.

What is the reason for their stability?
Magnetic Helicity

Conservation of magnetic helicity:

\[
\lim_{{\eta \to 0}} \frac{\partial}{\partial t} \int A \cdot B \ dV = 0 \quad \eta = \text{magnetic resistivity}
\]

Realizability condition:

\[
E_m(k) \geq k |H(k)|/2\mu_0
\]

Magnetic energy is bound from below by magnetic helicity.

Can magnetic helicity stabilize intergalactic cavities?
Numerical Experiments

Full resistive magnetohydrodynamics simulations with the PencilCode.

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

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

\[
\frac{\partial \ln T}{\partial t} = -\mathbf{U} \cdot \nabla \ln T - (\gamma - 1) \nabla \cdot \mathbf{U} + \frac{1}{\rho c_v T} \left( \nabla \cdot (K \nabla T) + \eta \mathbf{J}^2 \right.
\]

\[
\left. + 2 \rho \nu S \otimes S + \zeta \rho (\nabla \cdot \mathbf{U})^2 \right)
\]

\[
\frac{\mathrm{D} \ln \rho}{\mathrm{D} t} = -\nabla \cdot \mathbf{U}
\]
Initial Condition: Beltrami Field

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

smoothing function: \( f(r) = 1 - (r/r_b)^{n_{smooth}} \)

inside bubble: \( \nabla \times A \approx kA \)

\[ E_m \propto A_0^2 k^2 \]

\[ H_m \propto A_0^2 k \]

Fix magnetic energy, vary magnetic helicity.
Thermal Emission
Temperature Iso-Surfaces

hydro

low helicity

high helicity
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)

simon.candelaresi@gmail.com