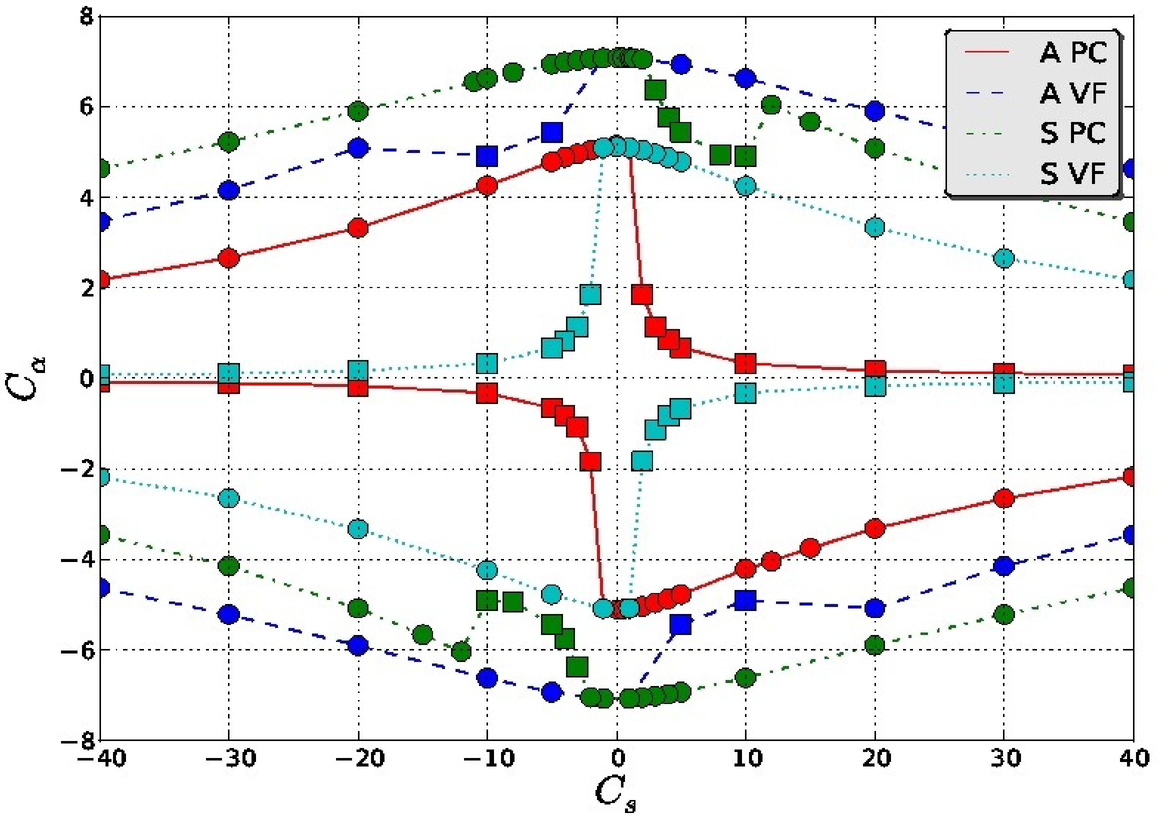
Magnetic Helicity Fluxes and their Effect on the Solar Dynamo

Simon Candelaresi



Magnetic helicity fluxes

Aim: Study the role of magnetic helicity in dynamical α quenching.

Method: 1d mean-field dynamo with helical forcing

Mean-field decomposition: $\mathbf{B} = \overline{\mathbf{B}} + \mathbf{b}$

Induction equation: $$\partial_t \overline{\mathbf{B}} = \eta \nabla^2 \overline{\mathbf{B}} + \boldsymbol{\nabla} \times (\overline{\mathbf{U}} \times \overline{\mathbf{B}} + \overline{\boldsymbol{\mathcal{E}}})$$

Electromotive force: $\overline{\boldsymbol{\mathcal{E}}} = \overline{\mathbf{u} \times \mathbf{b}}$

$$\overline{\boldsymbol{\mathcal{E}}} \underset{\alpha}{=} \alpha \overline{\mathbf{B}} - \eta_{\rm t} \boldsymbol{\nabla} \times \overline{\mathbf{B}}$$

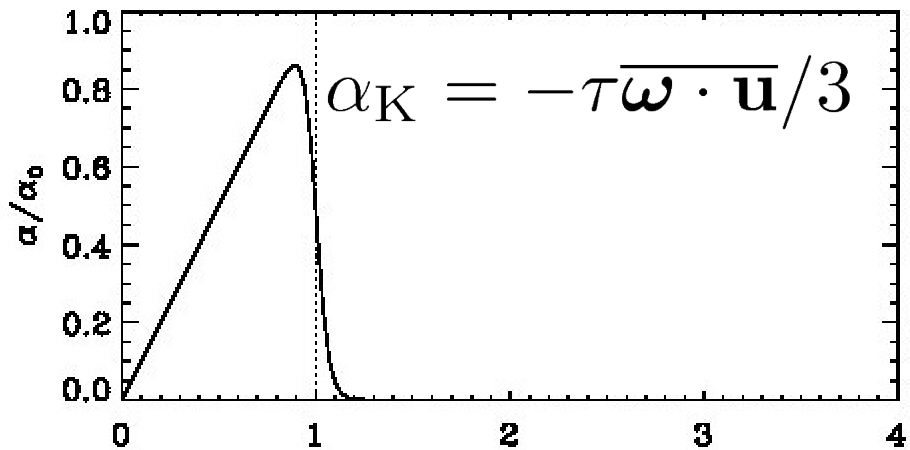
α effect: $\alpha = \alpha_{\rm K} + \alpha_{\rm M}$

$$\alpha_{\rm K} = -\tau \overline{\boldsymbol{\omega} \cdot \mathbf{u}}/3$$

$$\alpha_{\rm M} = \tau \overline{\mathbf{j} \cdot \mathbf{b}}/(3\overline{\rho}) = \tau \overline{\mathbf{a} \cdot \mathbf{b}}/(3\overline{\rho} k^2) = \overline{h}_{\rm m}$$

Magnetic helicity fluxes

$$\frac{\partial \alpha_{\rm M}}{\partial t} = -2\eta_{\rm t} k_{\rm f}^2 \left(\frac{\overline{\boldsymbol{\mathcal{E}}} \cdot \overline{\mathbf{B}}}{B_{\rm eq}^2} + \frac{\alpha_{\rm M}}{R_{\rm m}} \right) - \frac{\partial}{\partial z} \overline{\mathcal{F}}_{\alpha}$$

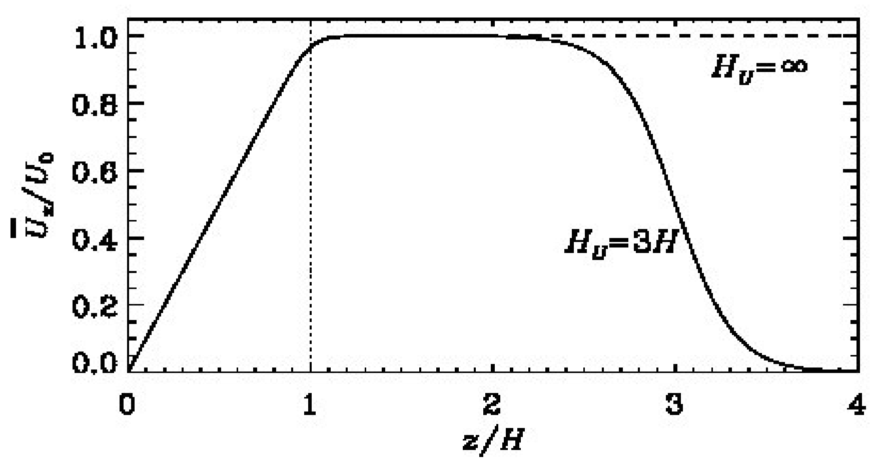


advective: $\alpha_{\rm M} \overline{\mathbf{U}}$

α diffusion $\kappa_{\alpha} \frac{\partial \alpha_{\rm M}}{\partial z}$

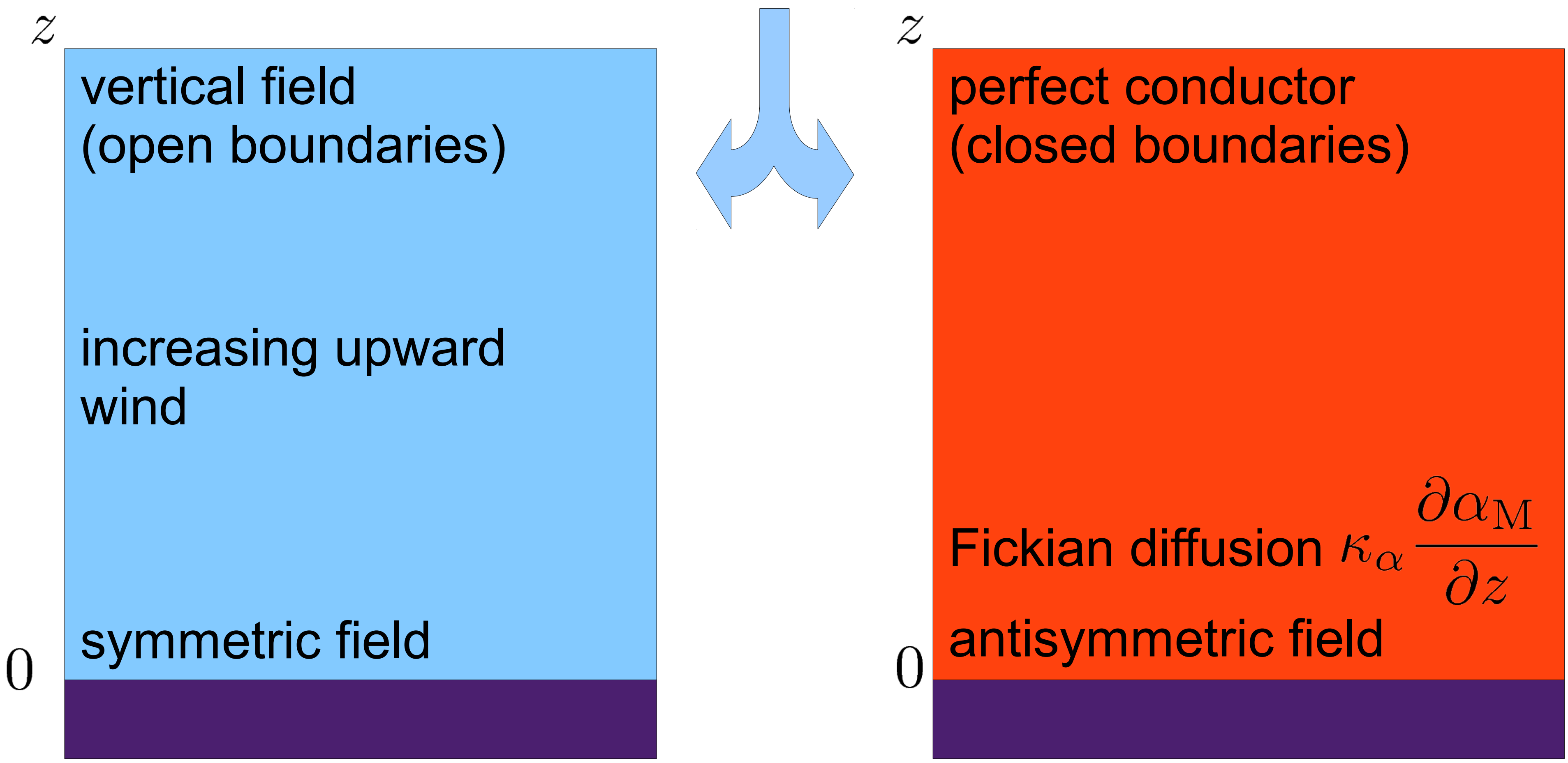
$$\frac{\partial \overline{h}_{\rm m}}{\partial t} = 2\overline{\boldsymbol{\mathcal{E}}} \cdot \overline{\mathbf{B}} - 2\eta\mu_0 \overline{\mathbf{J}} \cdot \overline{\mathbf{B}} - \nabla \cdot \overline{\mathbf{F}}_{\rm m}$$

$$\frac{\partial \overline{h}_{\rm f}}{\partial t} = -2\overline{\boldsymbol{\mathcal{E}}} \cdot \overline{\mathbf{B}} - 2\eta\mu_0 \overline{\mathbf{j}} \cdot \overline{\mathbf{b}} - \nabla \cdot \overline{\mathbf{F}}_{\rm f}$$



Magnetic helicity fluxes

Solve equations for one hemisphere.
Impose (anti)symmetric field at the equator.



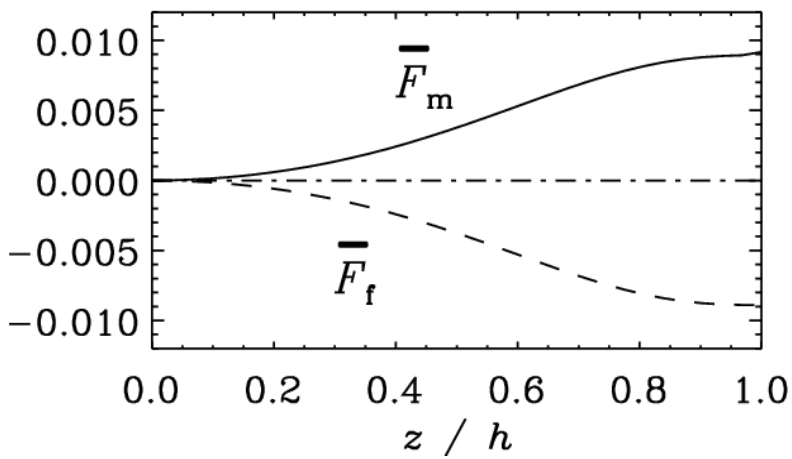
$$\mathrm{Re}_{\rm M} = \frac{U_{\rm rms} L}{\eta}$$

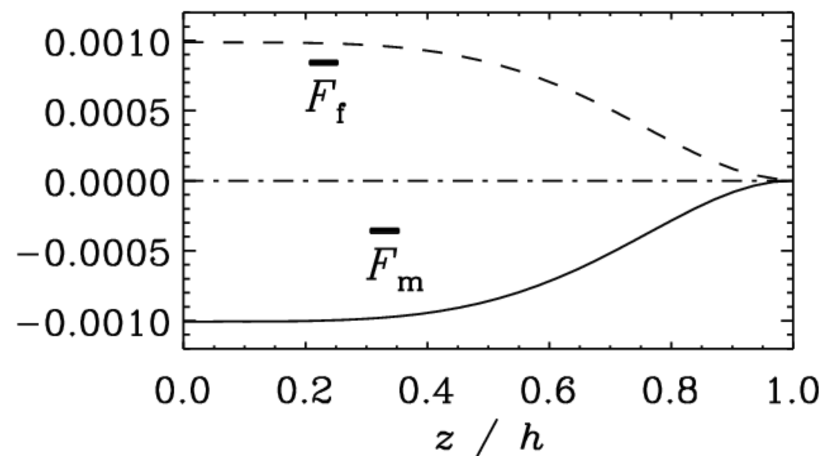
Magnetic helicity fluxes

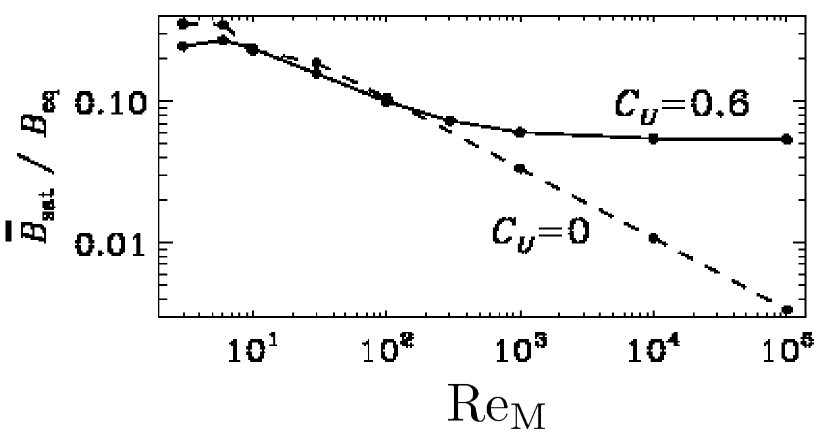
open boundary
symmetric
wind

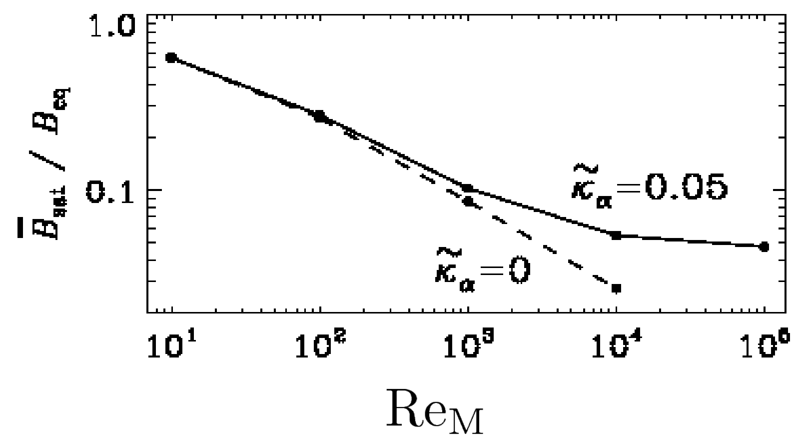
vs.

closed boundary
antisymmetric
κ_α







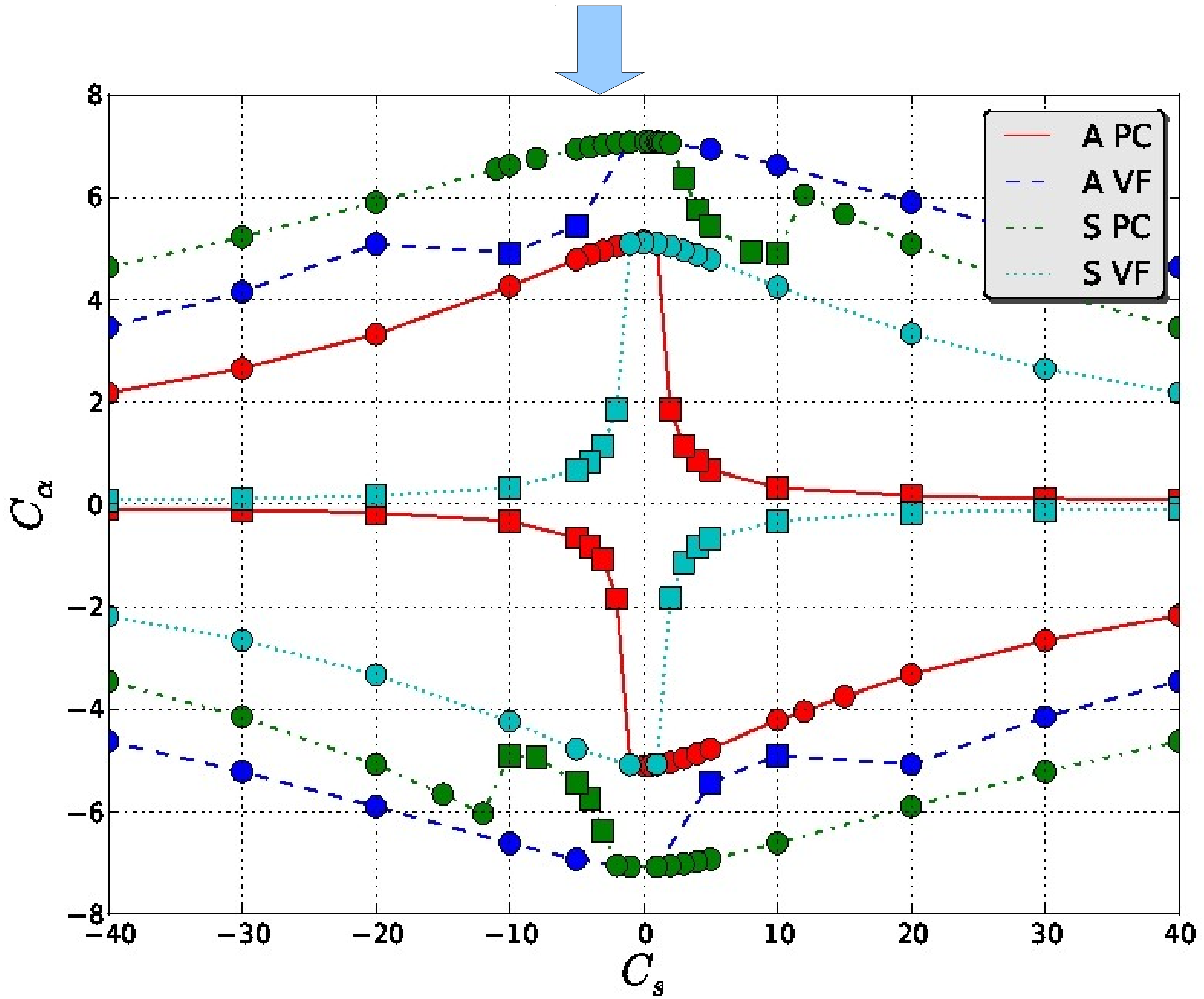


Adding shear

Shearing velocity field:

$$\overline{\mathbf{U}} = \begin{pmatrix} 0 \\ Sz \\ 0 \end{pmatrix}$$

Critical values for the forcing and the shearing amplitude

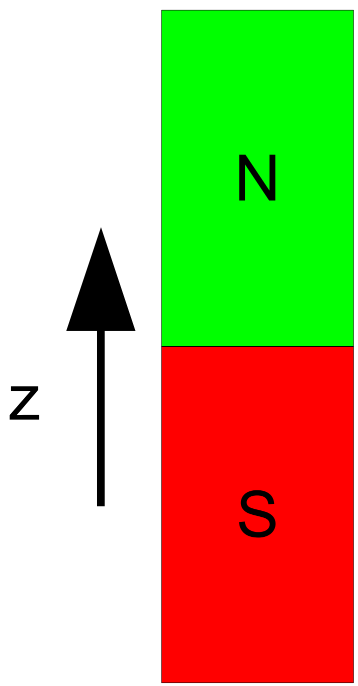


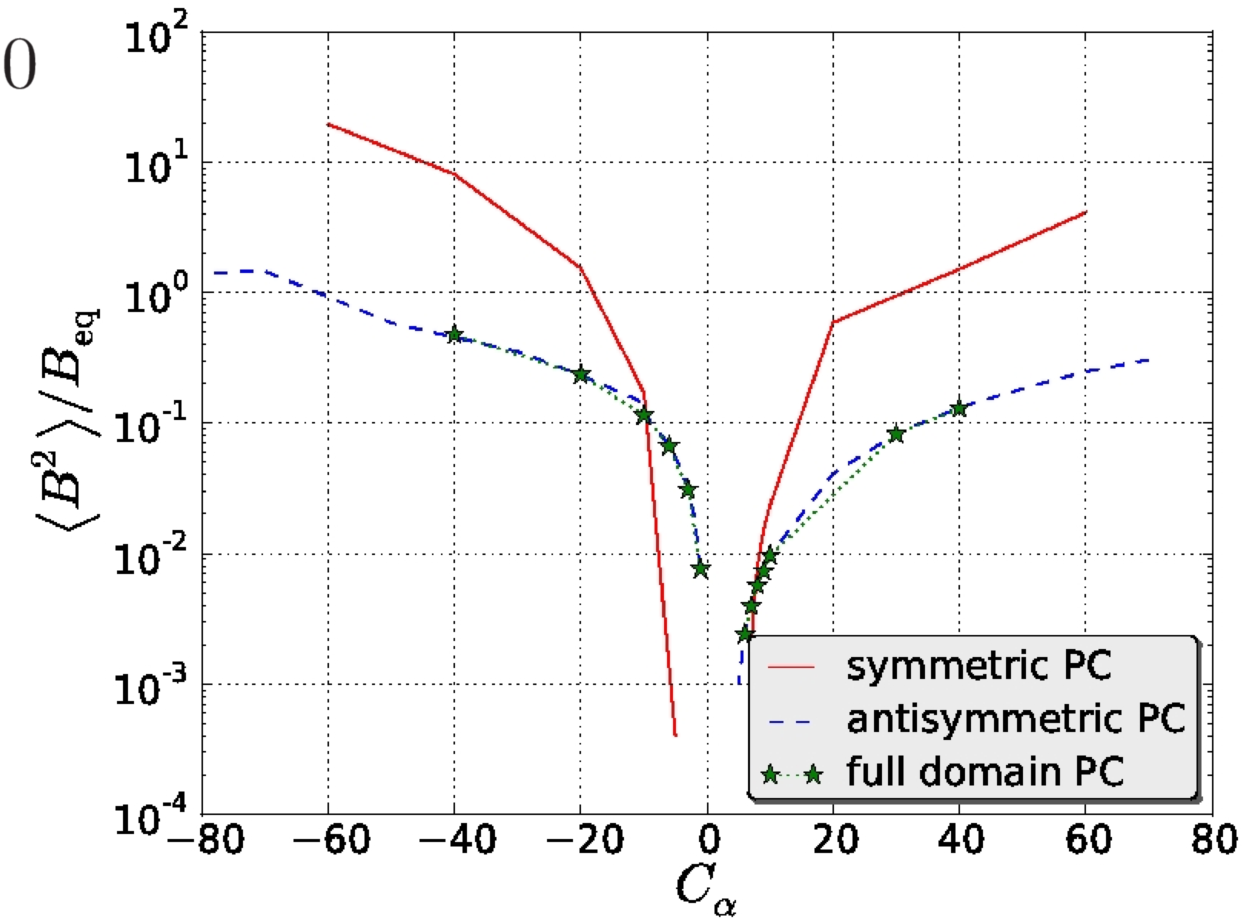
Full domain

Imposed parity in the hemispheric model is artificial.

→ Include both hemispheres.

$$C_{\mathrm{S}} = -10$$



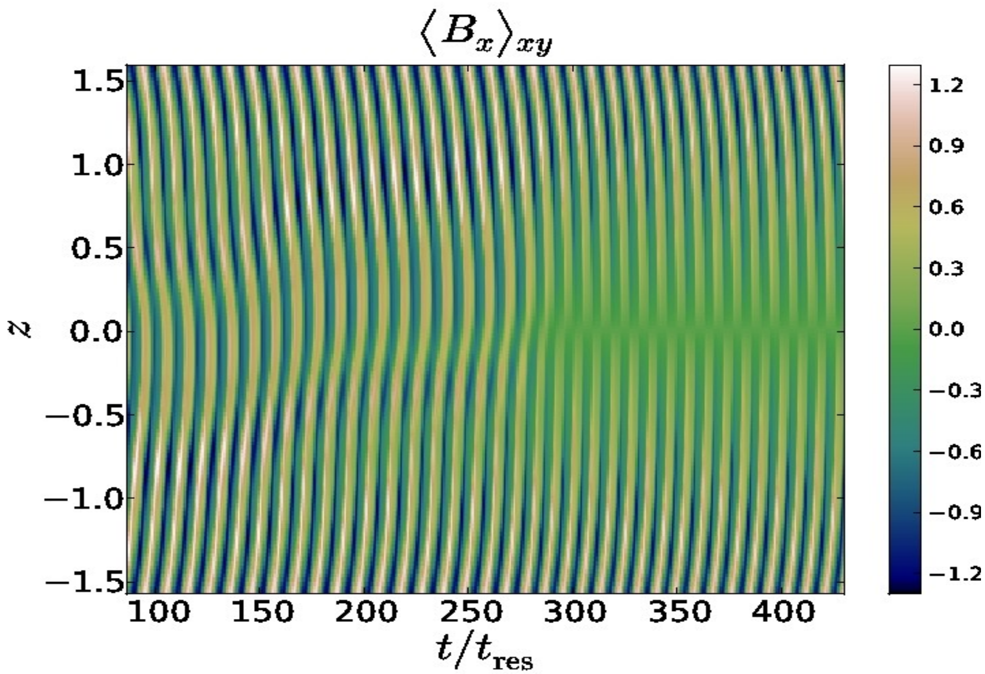


Preferred antisymmetric mode?

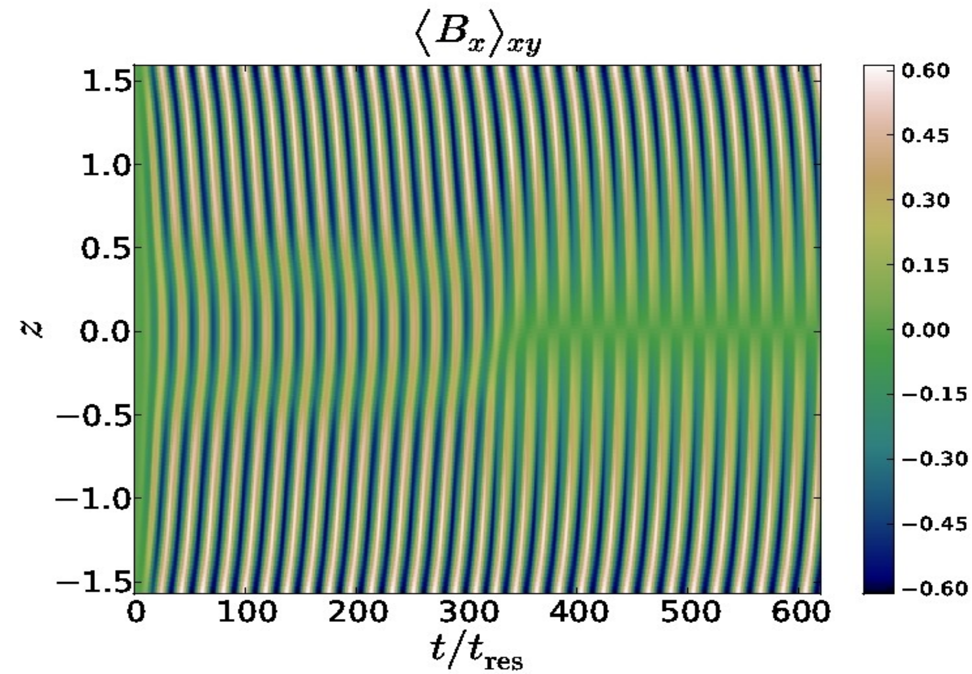
Parity change

Look at the parity of the magnetic field $\overline{\mathbf{B}}_y$

Random initial field



Symmetric initial field



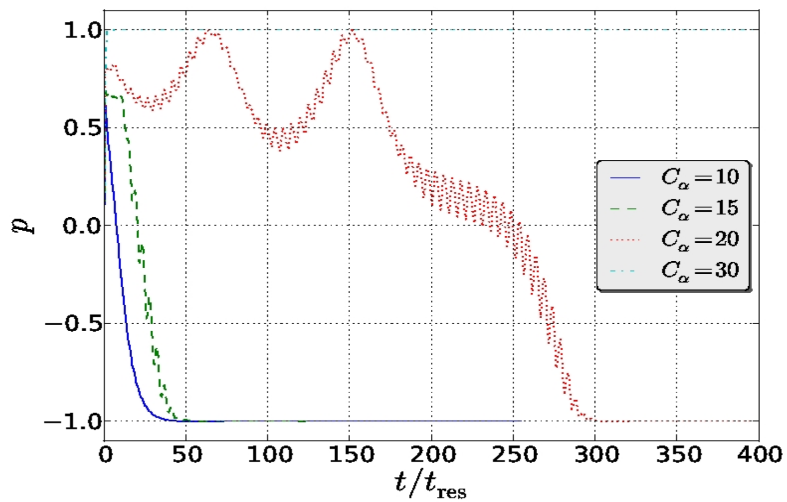
➡ The antisymmetric solution seems to be the preferred one.

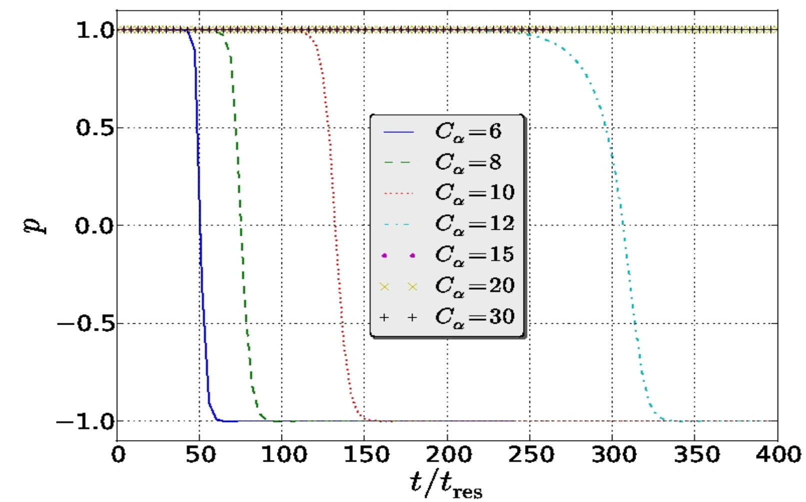
Parity change

Random initial field

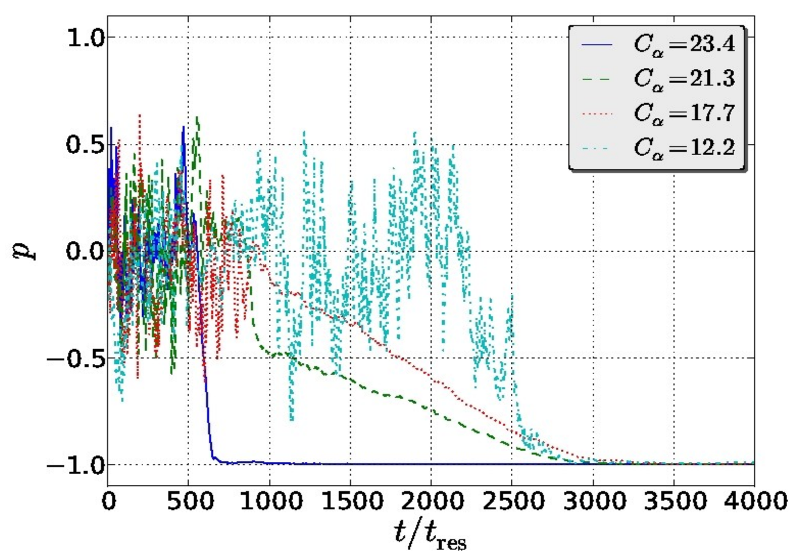
Symmetric initial field

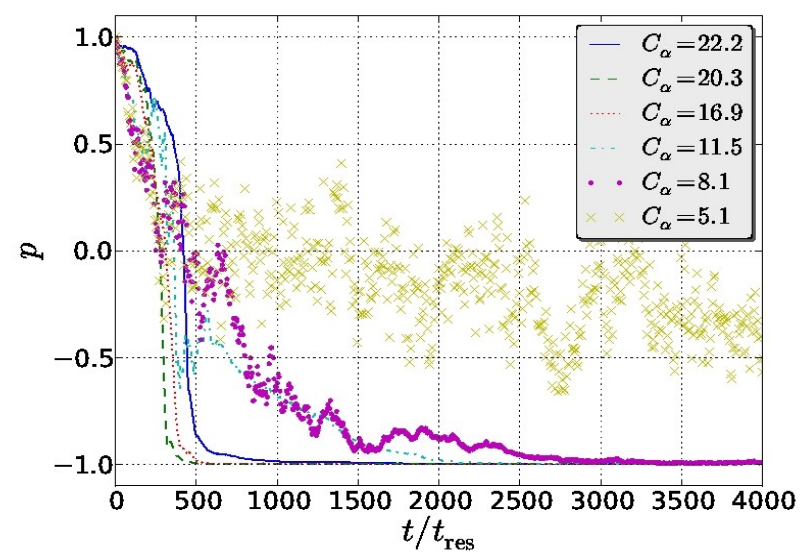
MF





DNS





Conclusions

- Advective magnetic helicity α_f fluxes can alleviate catastrophic quenching.
- Diffusive magnetic helicity fluxes can alleviate catastrophic quenching.

- Symmetric mode is unstable.
- The antisymmetric mode seems to be the preferred one.
- Check the growth rate of the modes.

References

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