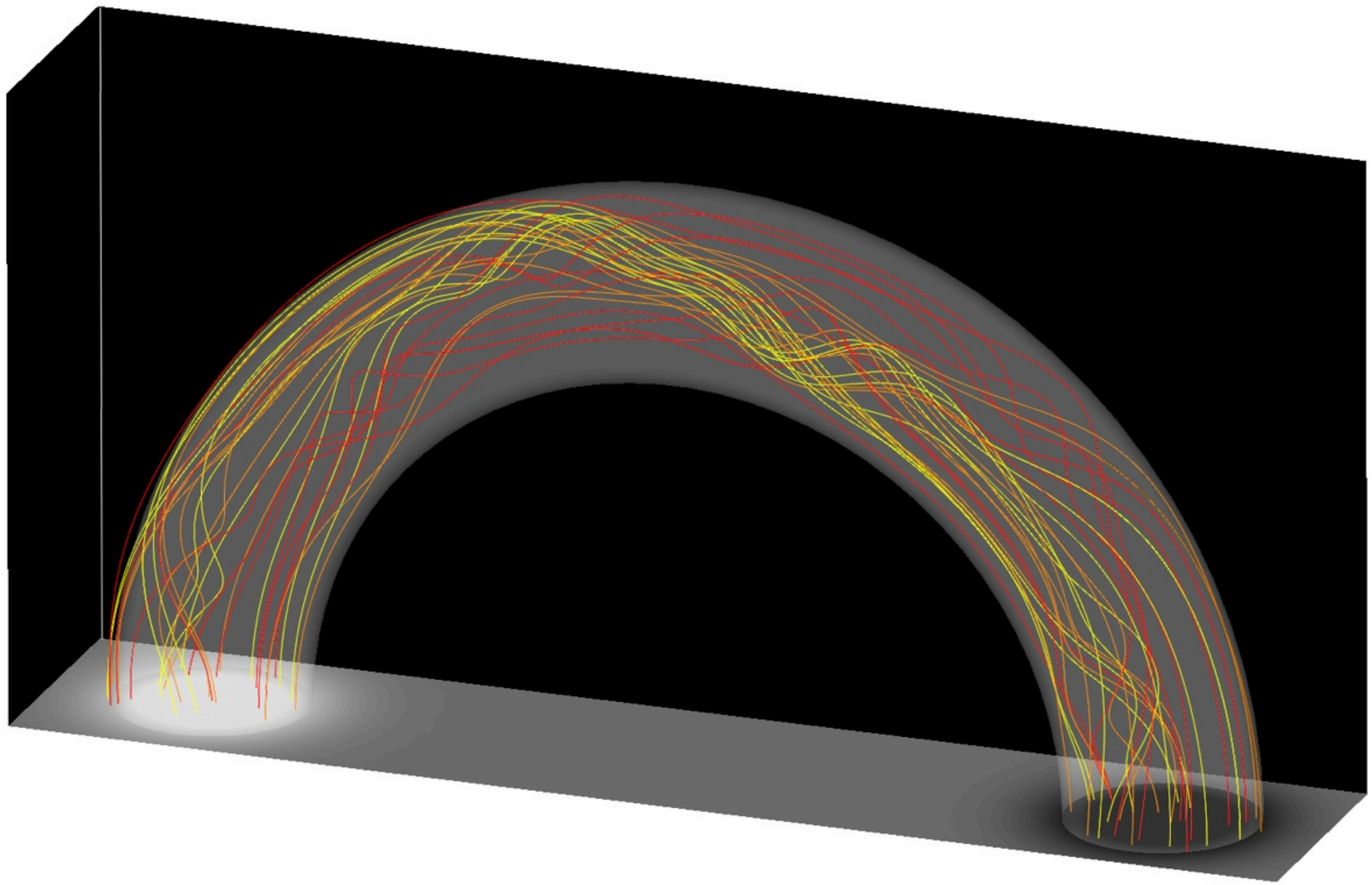
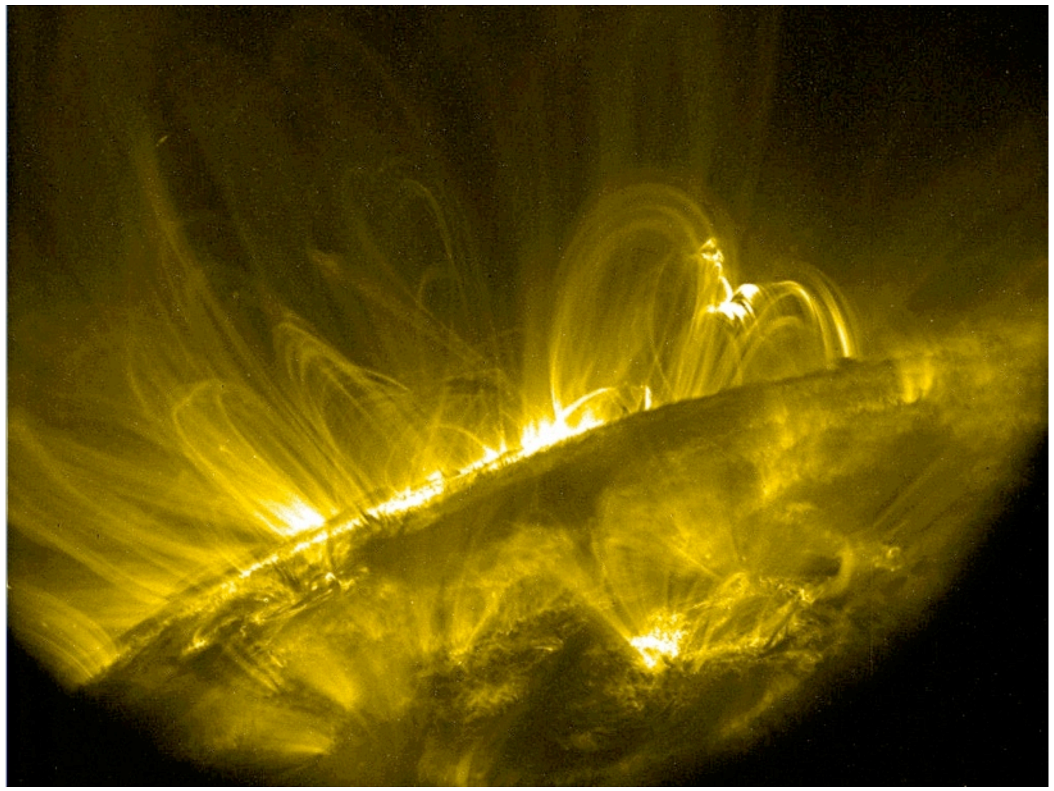
Dynamics of braided coronal loops

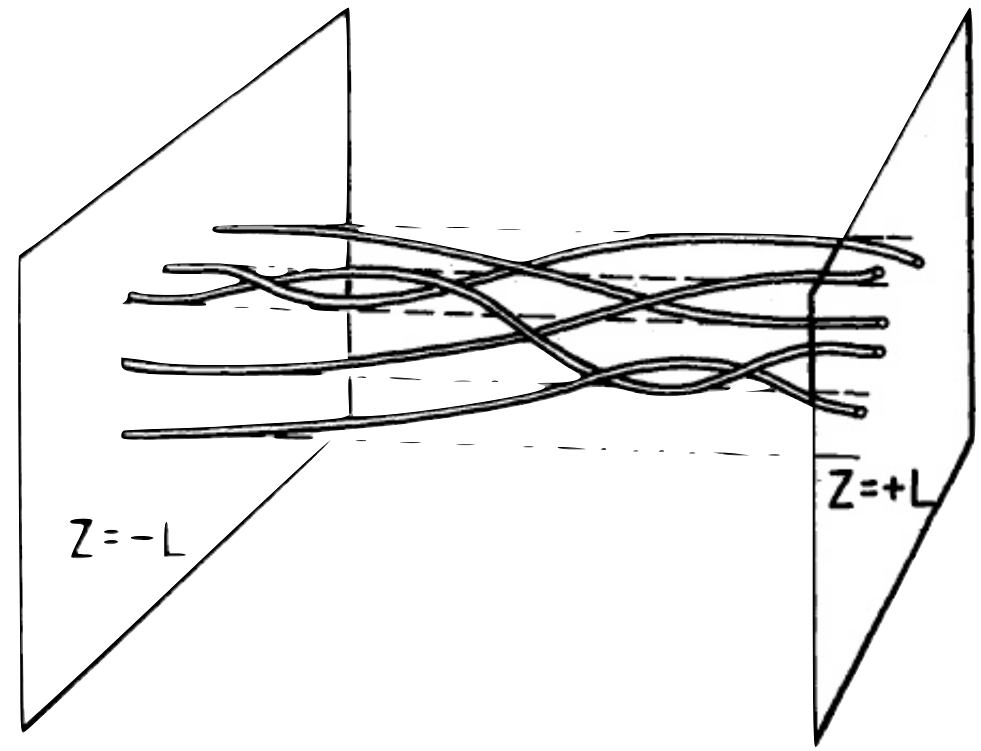


David Pontin (University of Dundee, UK)

collaborators:
Antonia Wilmot-Smith, Gunnar Hornig (University of Dundee, UK)
Anthony Yeates (University of Durham, UK)

'Topological Dissipation'

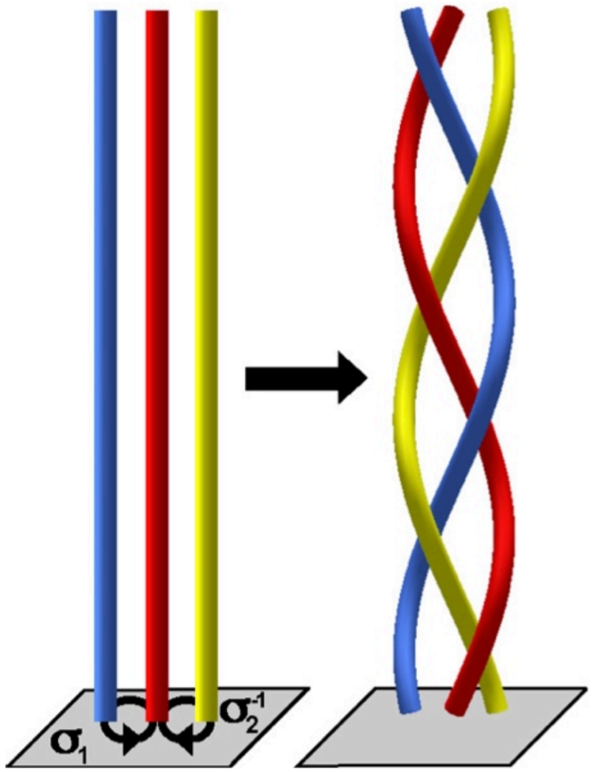


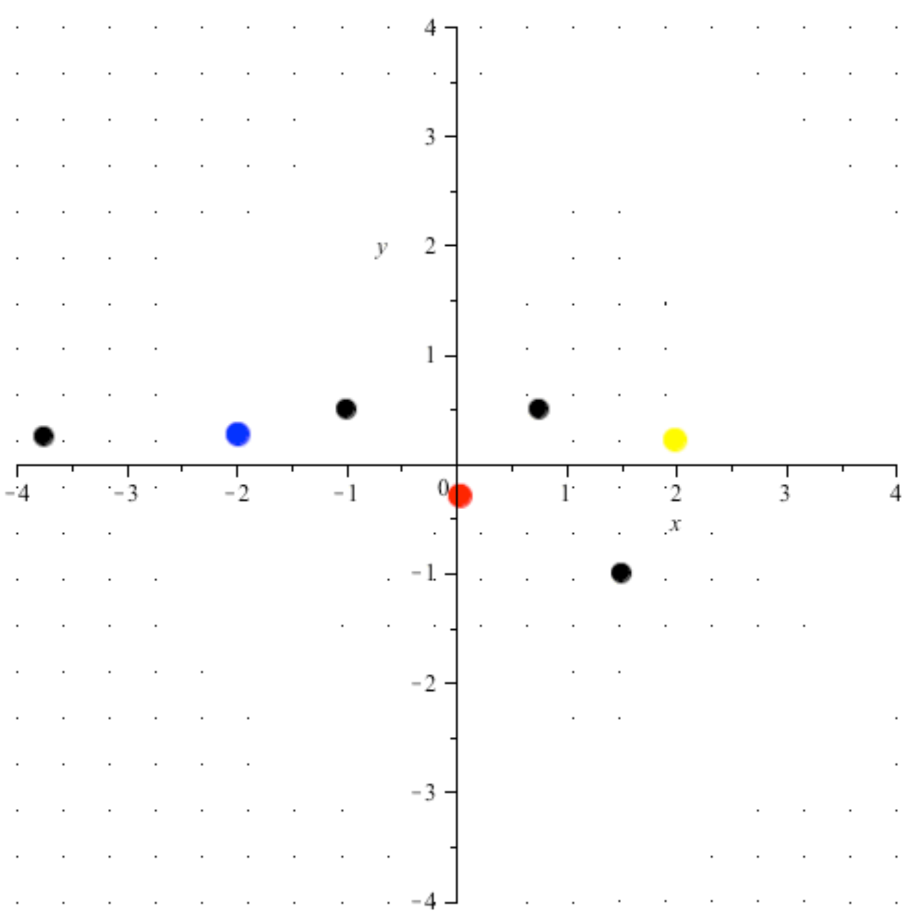


Parker, E.N., ApJ, **174**, 499 (1972).

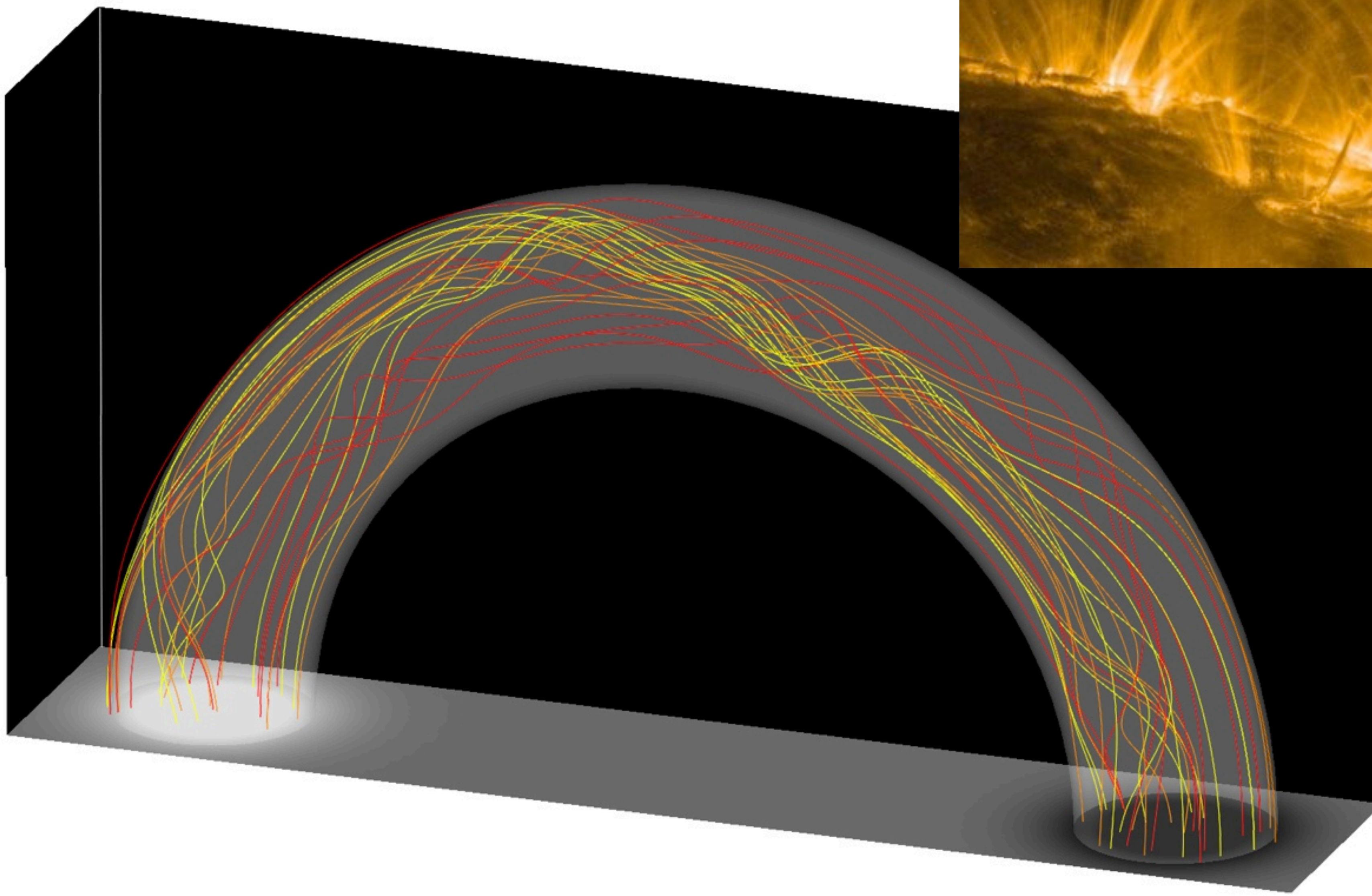
- Model solar loop as braided magnetic field between parallel plates.

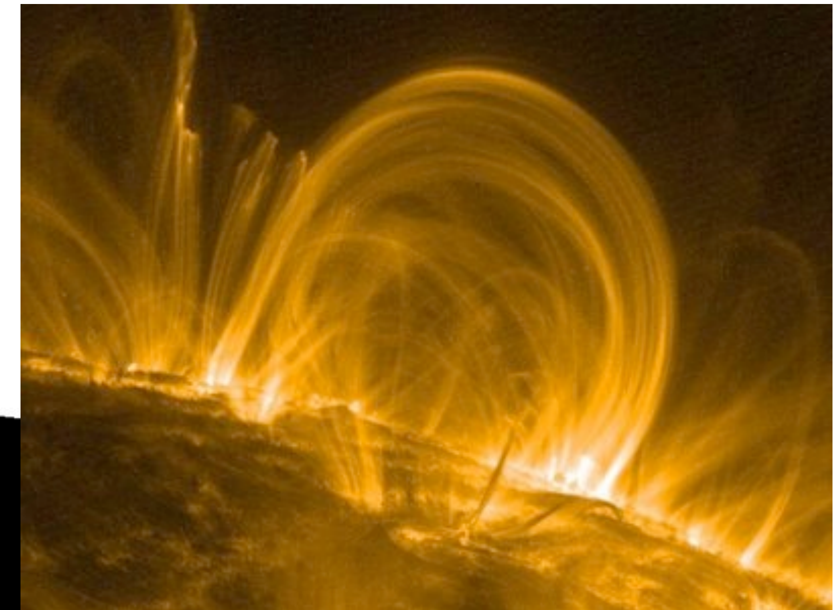
The model magnetic field

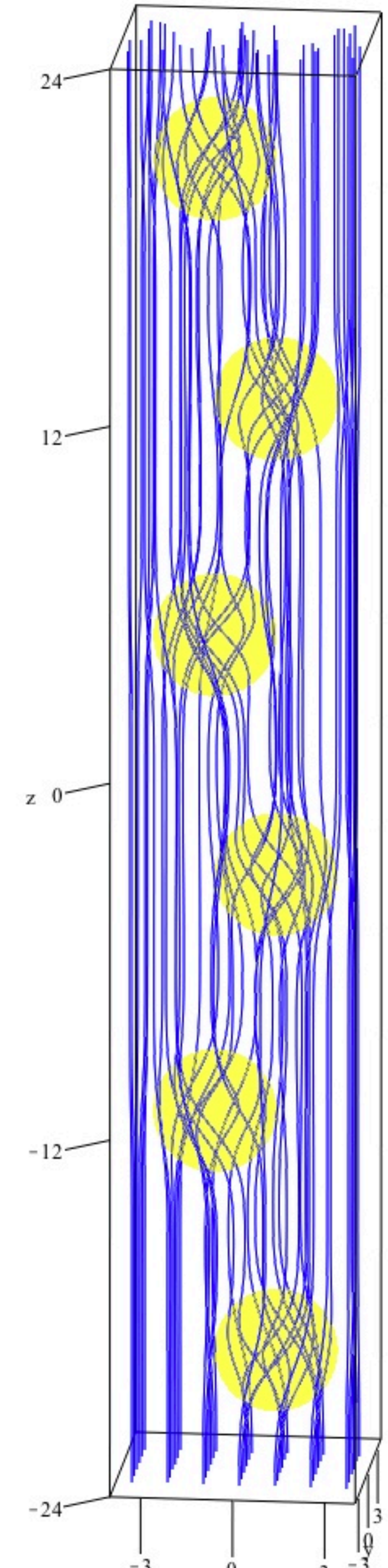




- Pigtail braid
- Net helicity (twist) is zero
- Could be generated by sequence of opposite-sense rotations at photosphere







Achieved in practice by adding regions of twist to uniform B

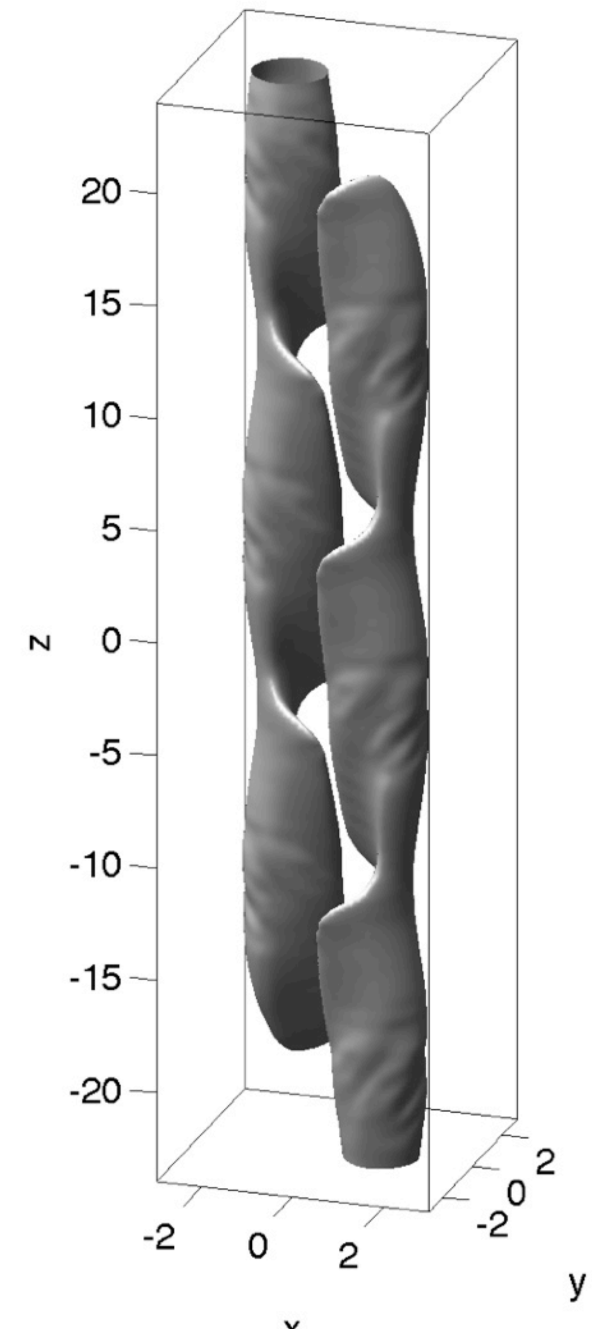
Aspect ratio (1:10), low twist consistent with observed loops

Conservative approach: free energy only ~3% above potential

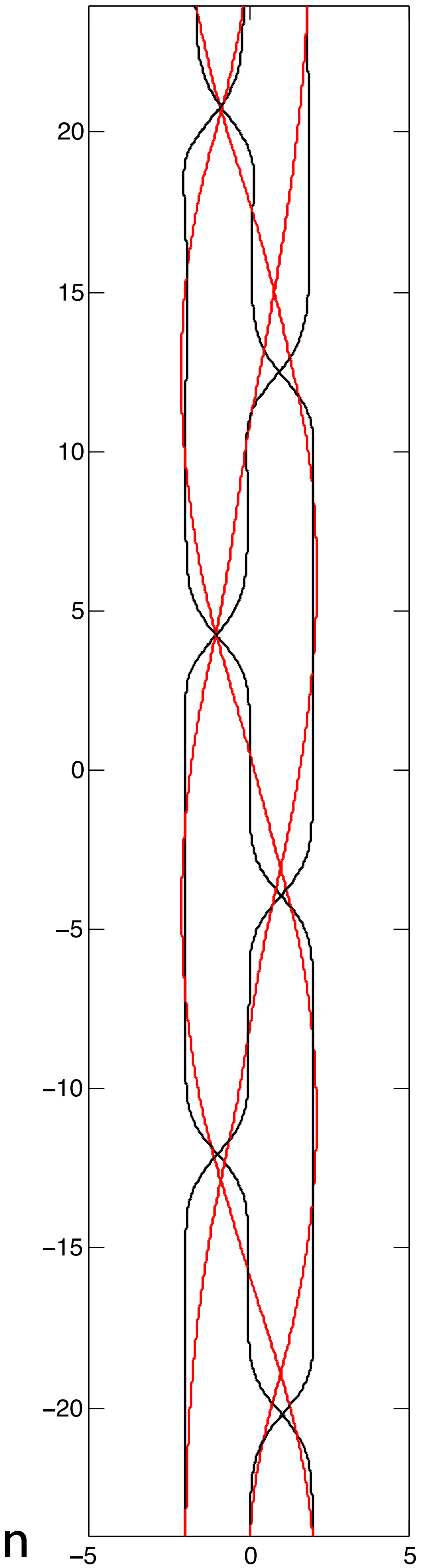
Simulation setup

- Take field and first perform an <u>ideal</u> relaxation

- Then transfer to resistive MHD code: $\underline{J}\times\underline{B}\approx 0$, and initialise with a uniform background plasma



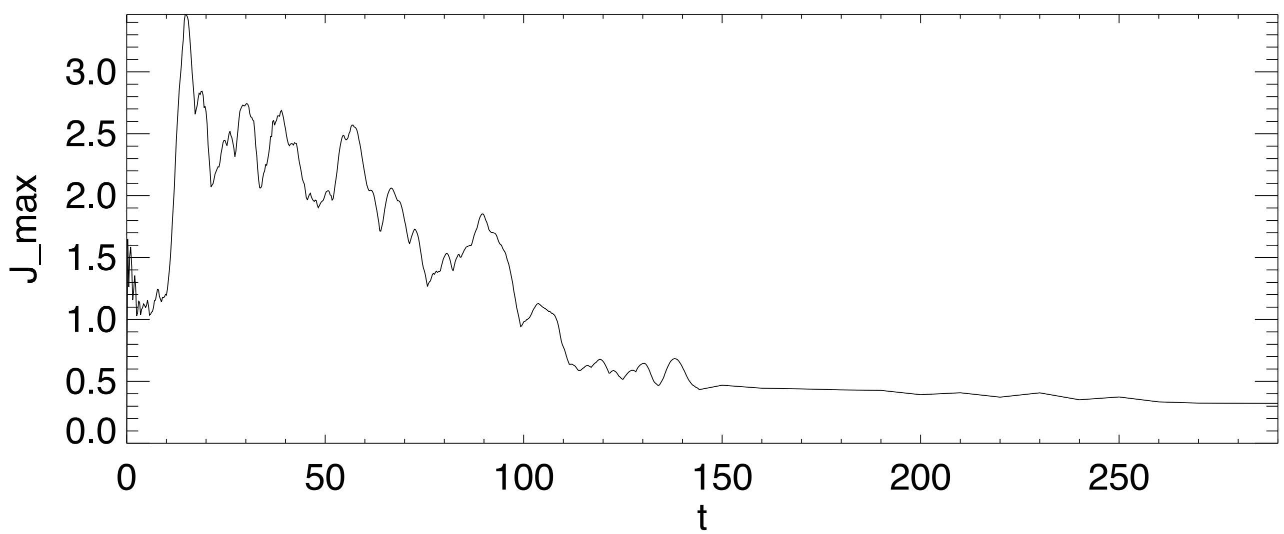
|J| at start of resistive relaxation



Field lines before ideal relaxation

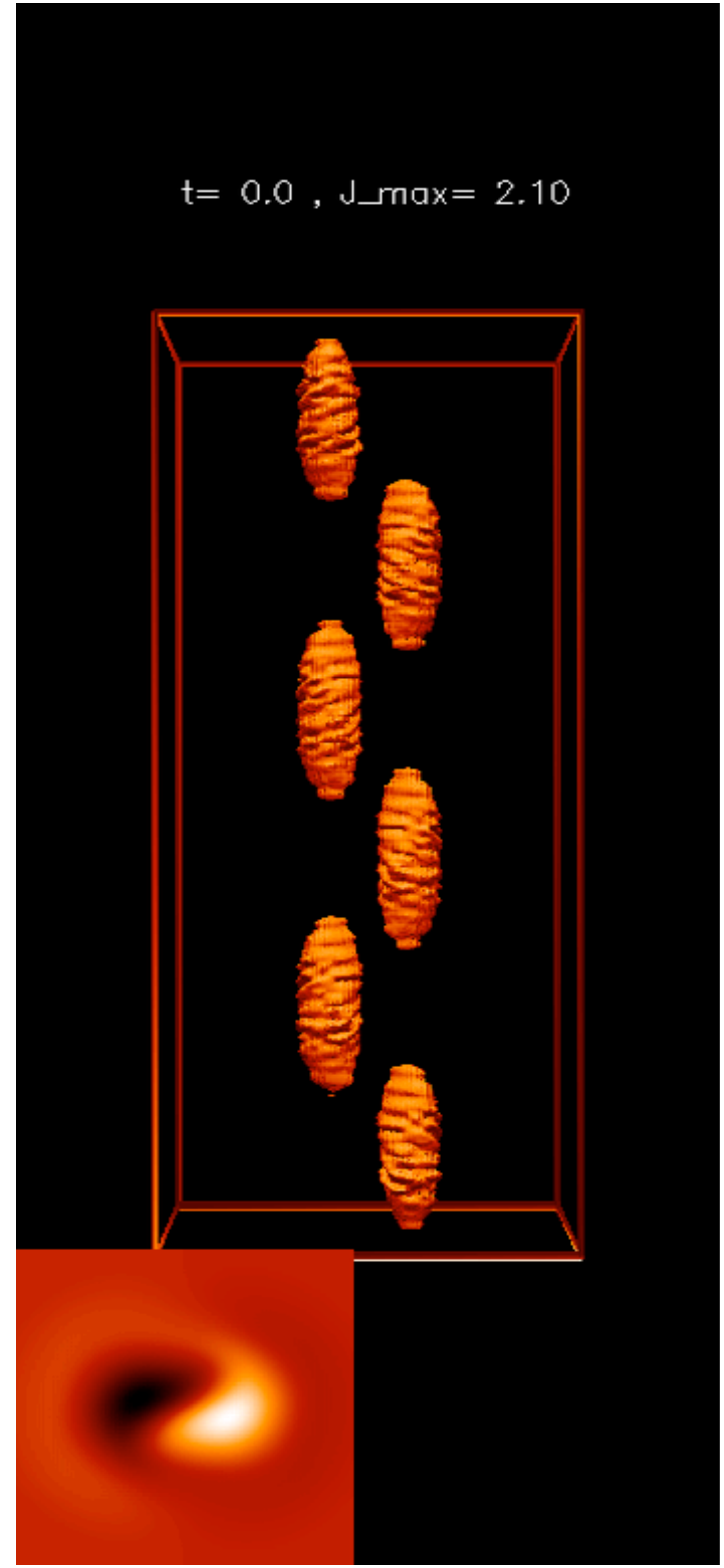
Field lines after ideal relaxation

Instability → relaxation

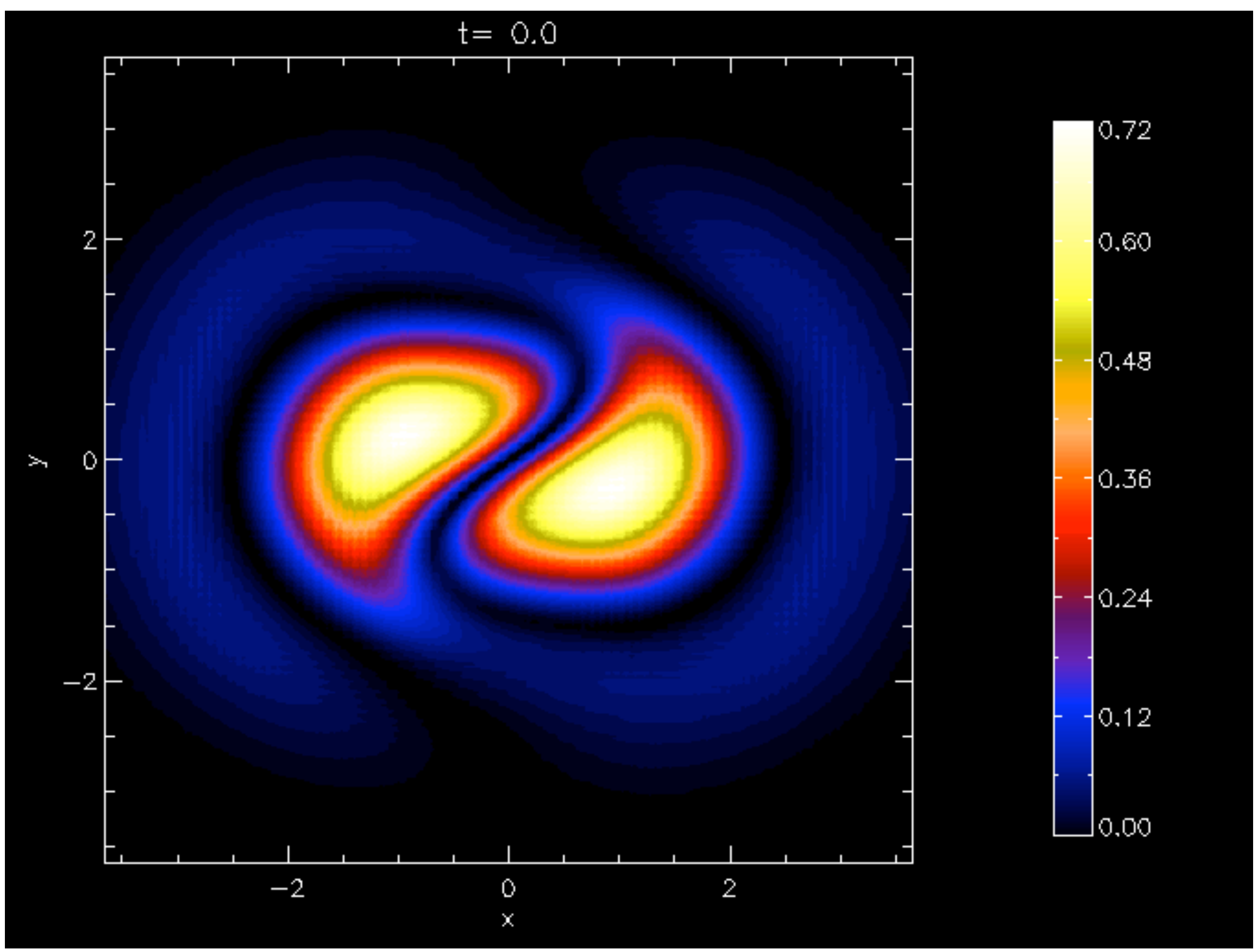


40% isosurface of |J|

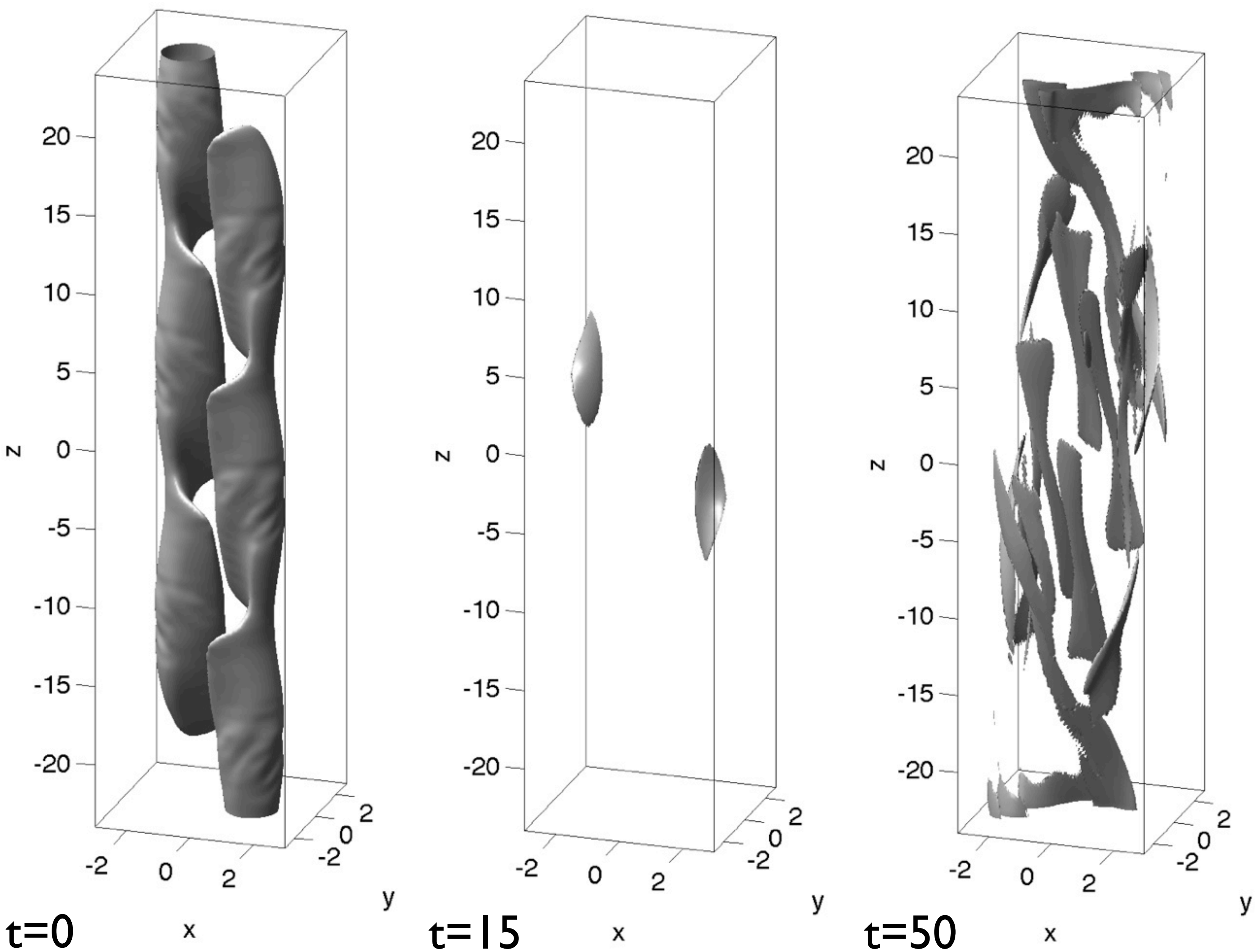
and J_z at z=0:

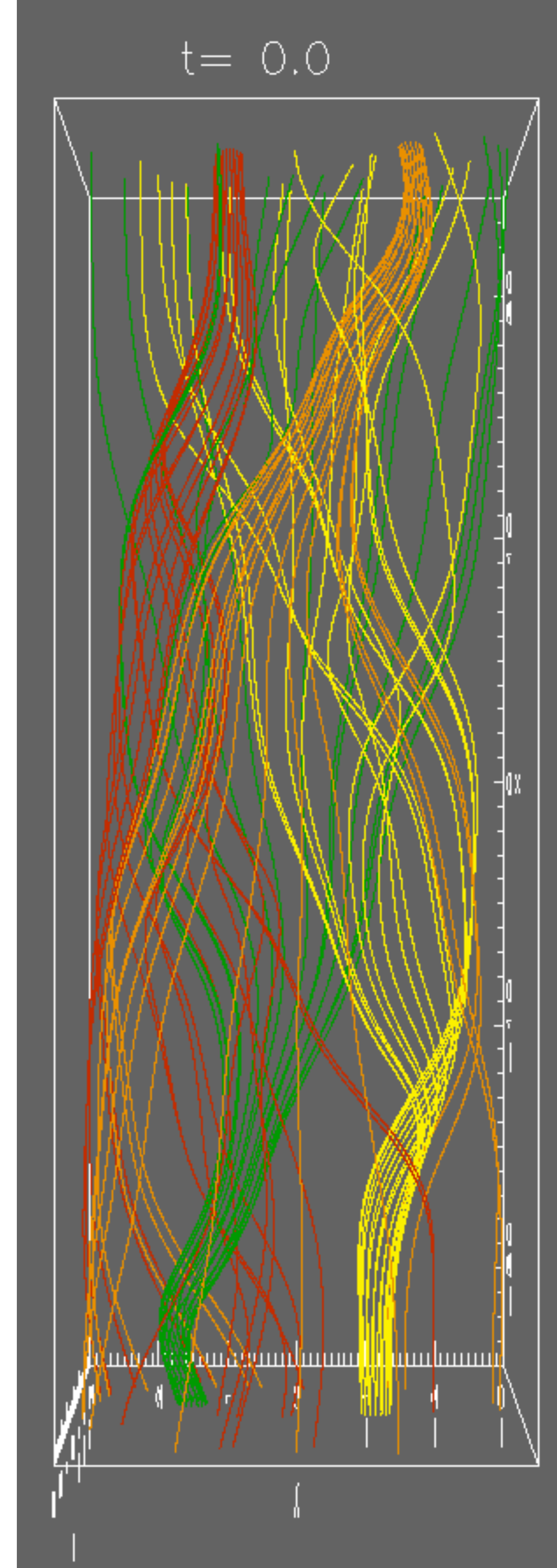


|J| at z=0



Instability → relaxation



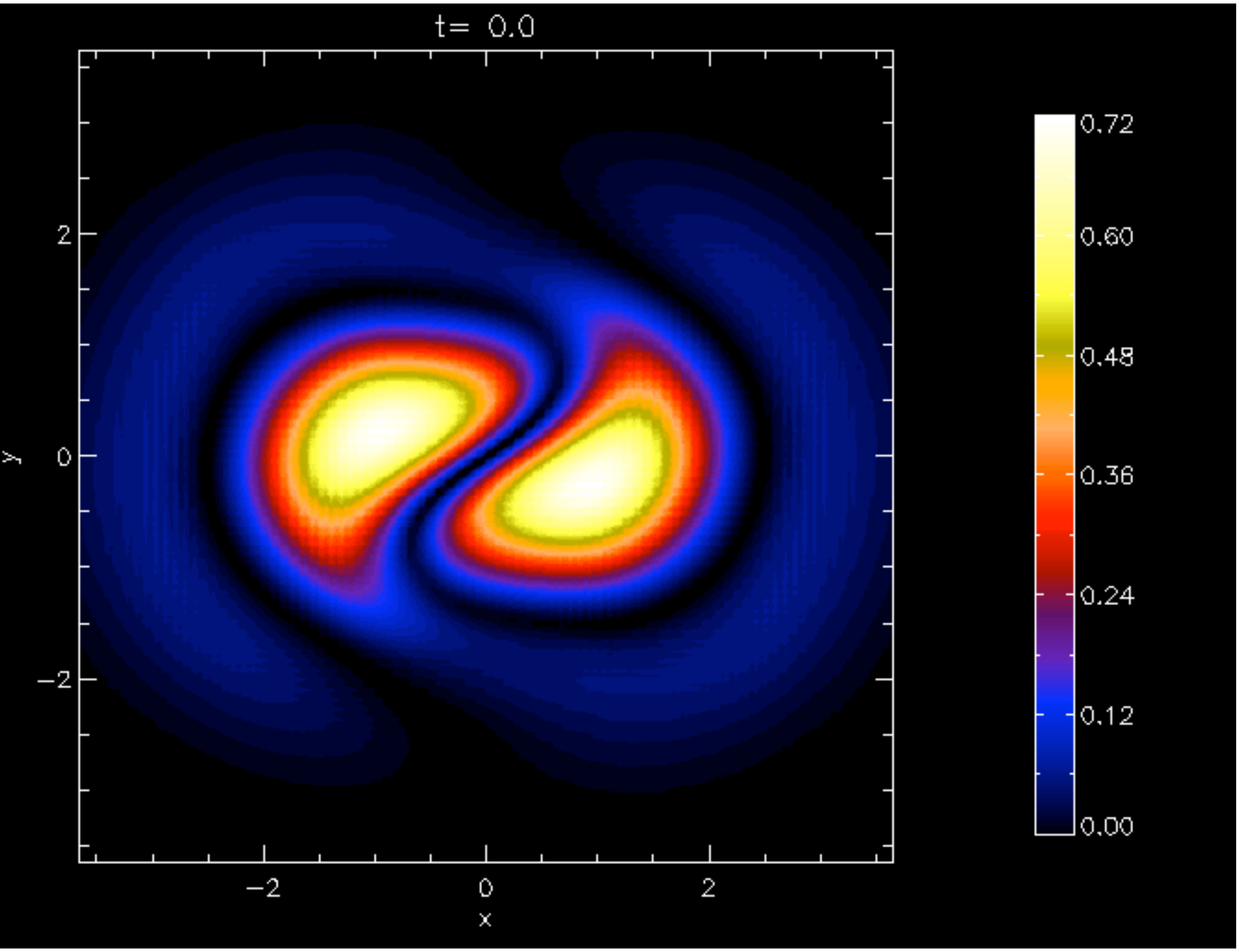


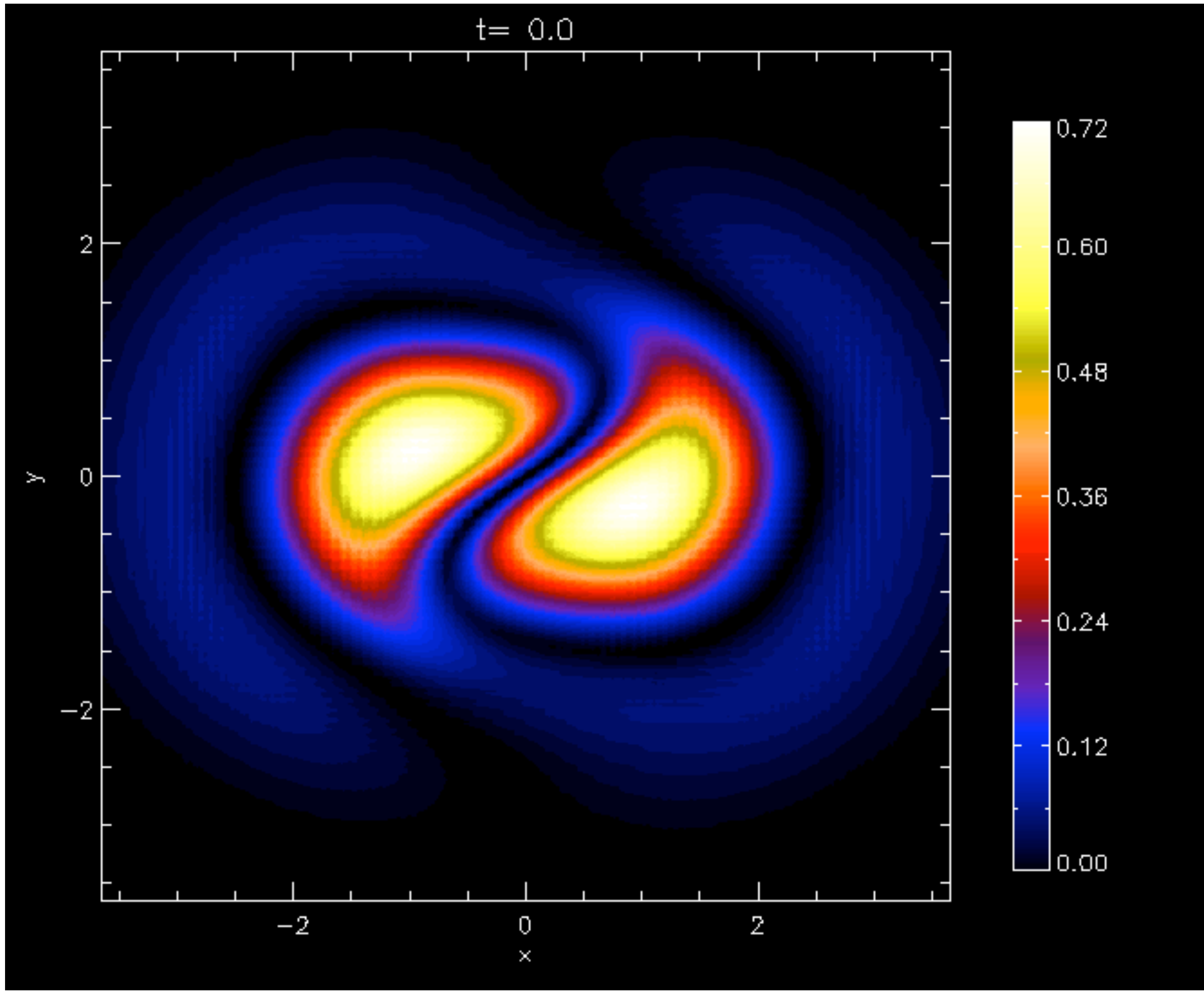
Magnetic field ‘unbraids’

Reynolds number comparison

|J| at z=0

$\eta=10^{-3}$ $\eta=2\times10^{-4}$

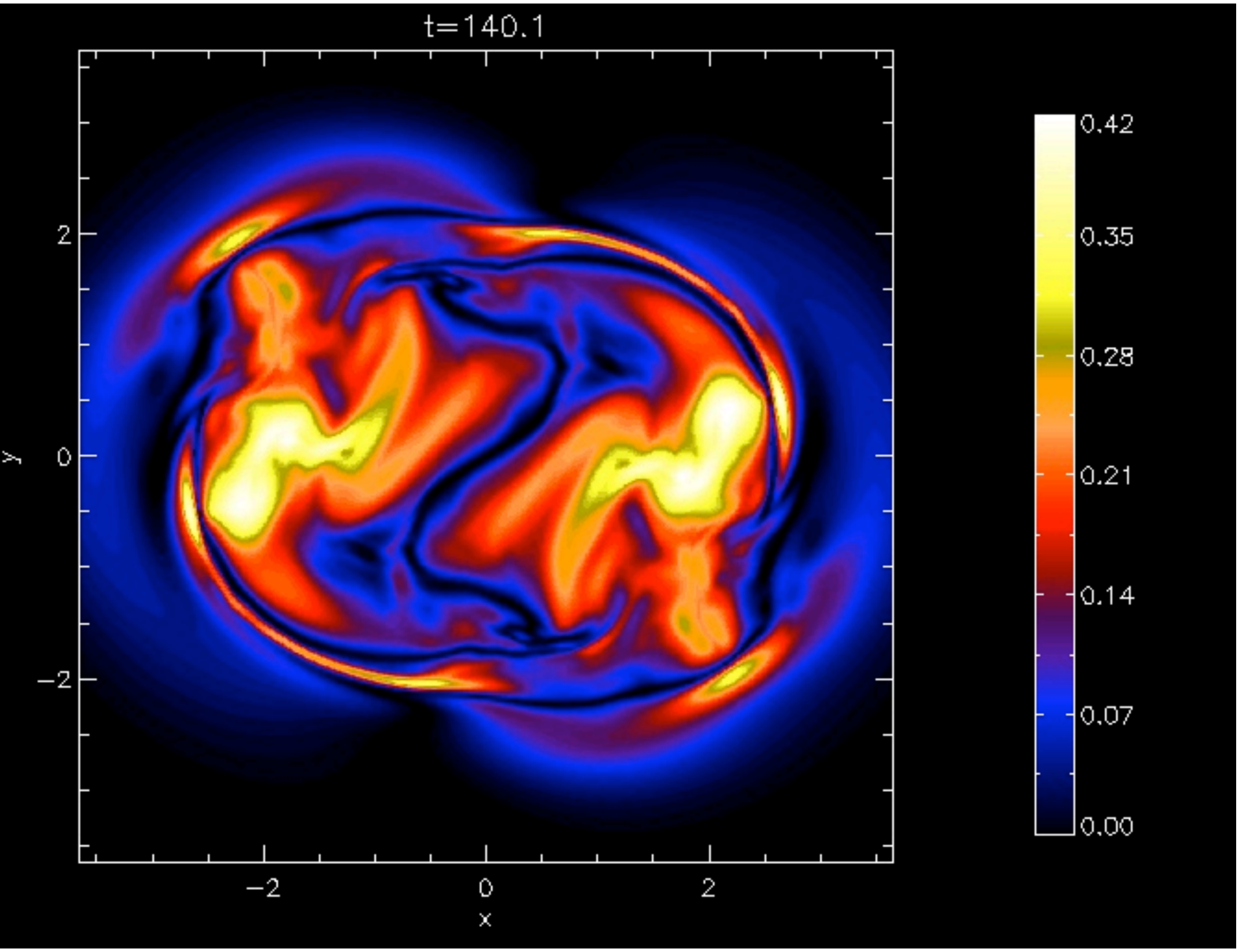




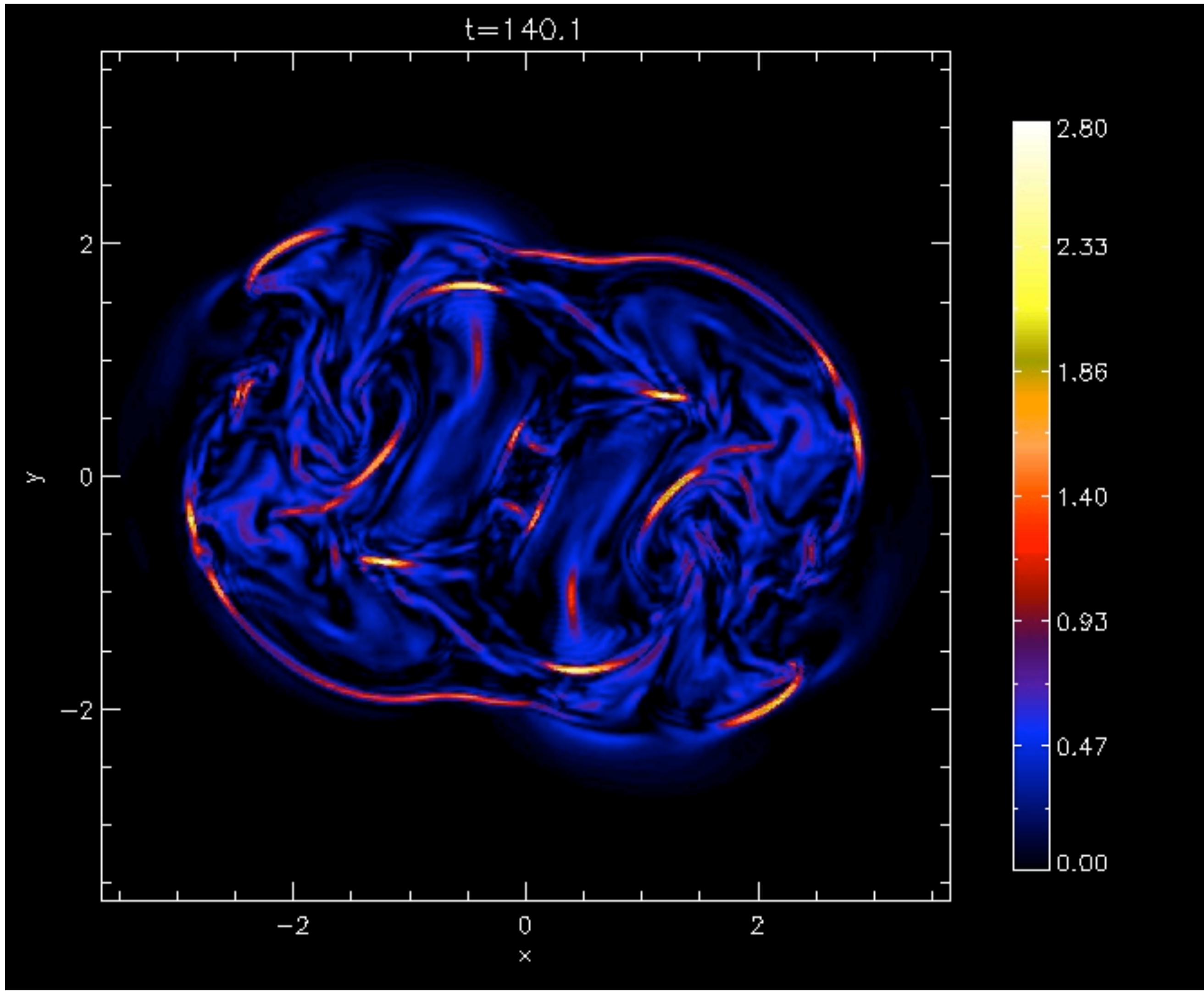
Reynolds number comparison

|J| at z=0

$\eta=10^{-3}$



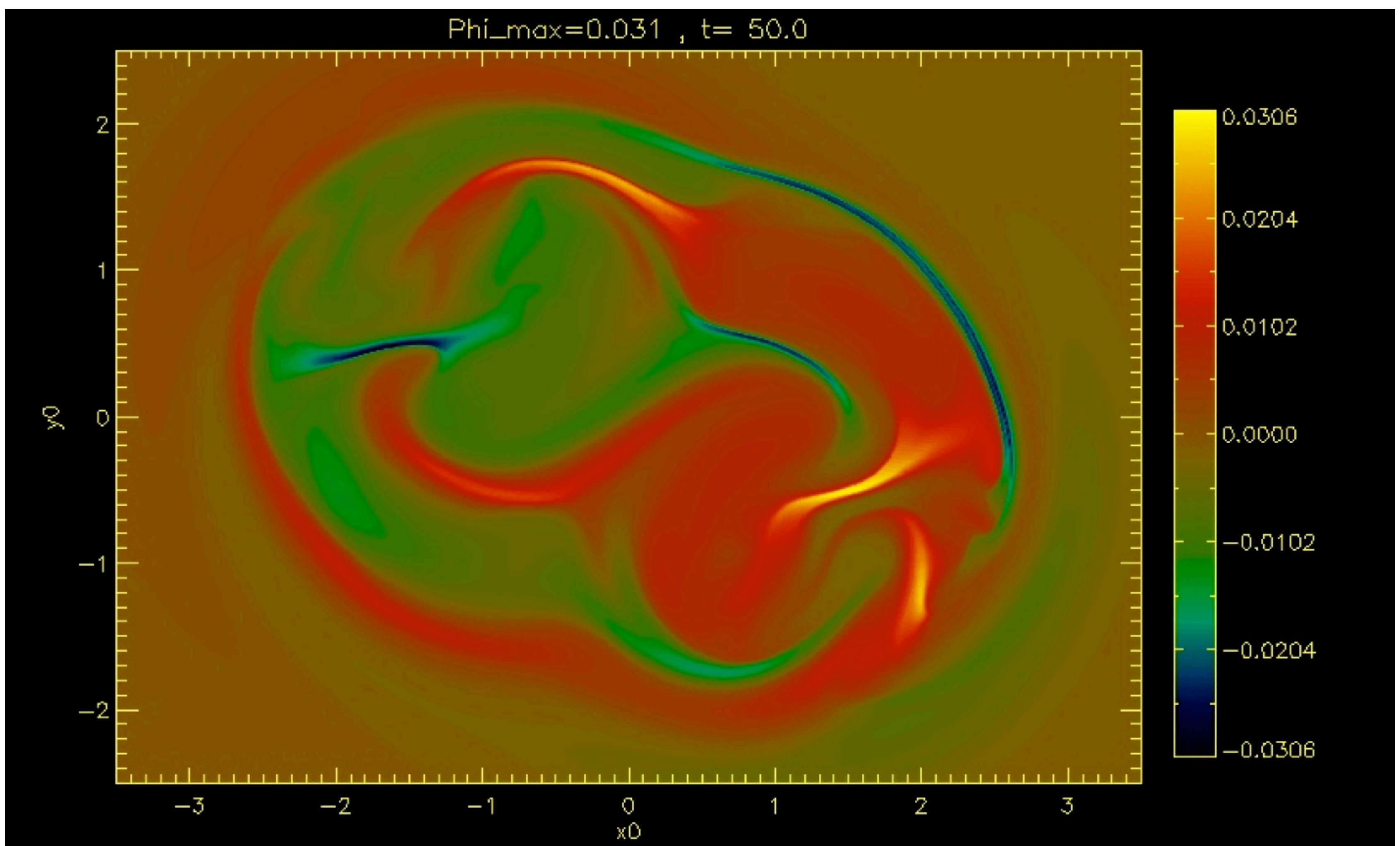
$\eta=2\text{x}10^{-4}$



Reconnection rate

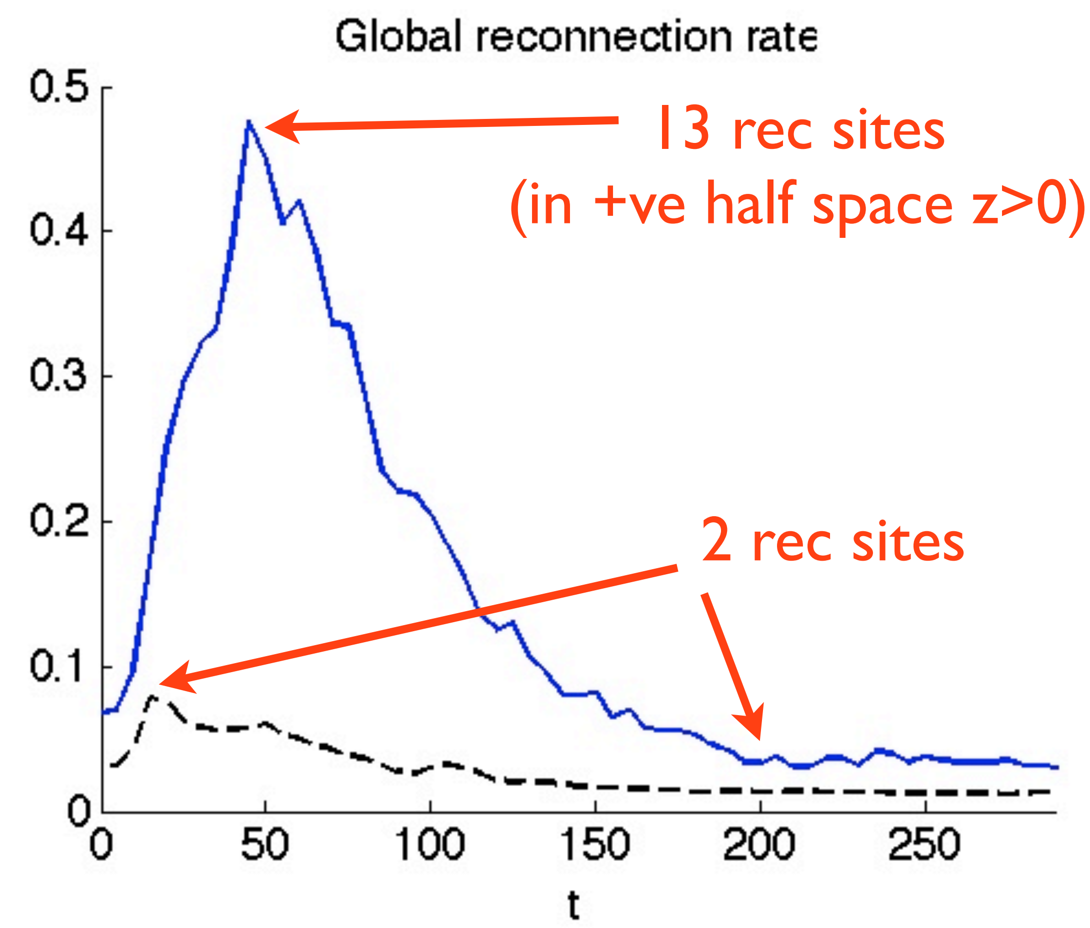
Procedure, at each time:

- Integrate along an grid of field lines: $\Phi = \int E_{\|} ds\,.$
- In 2D Φ profile, seek peaks.
- Sum moduli of Φ_{max} and Φ_{min} to obtain global rec rate



Spatial coords indicate fieldline intersection with z=0 plane

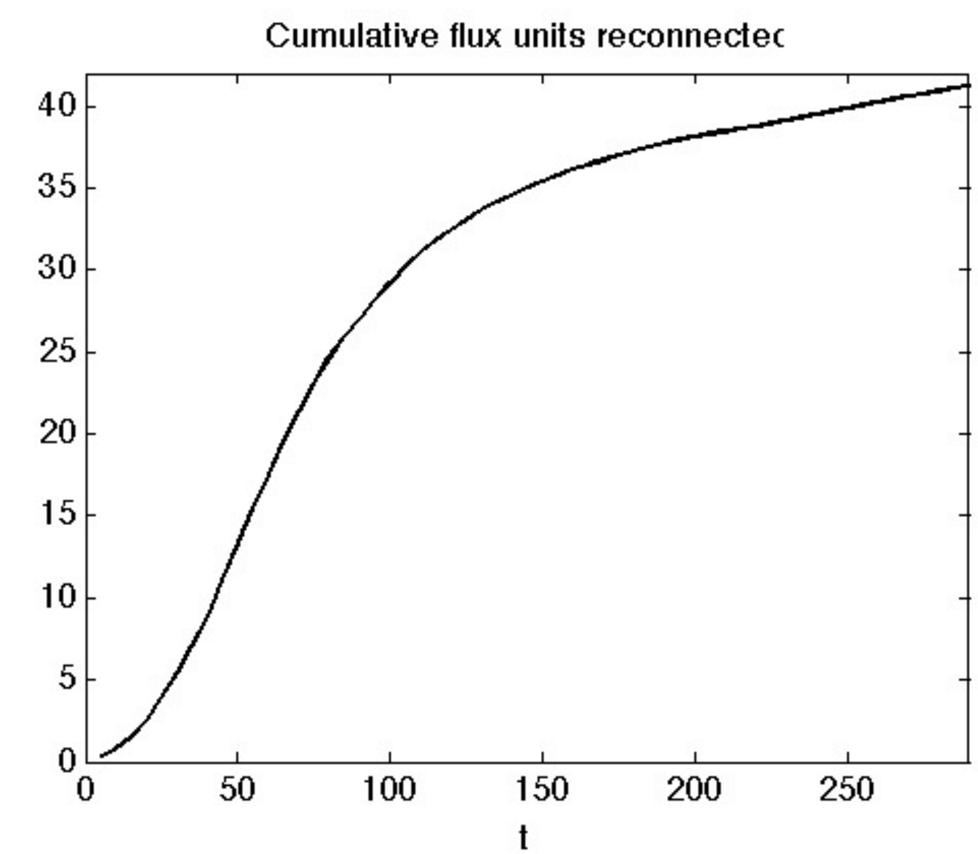
Reconnection rate



- Rec rate increase a result of splitting into multiple rec regions
- (note: length of field lines = 48)

- Overall reconnected flux:
  - Total poloidal (xy) flux at t=0 : $\approx$ 30

    at t=300: $\approx$ 15.3
  - Total reconnected flux $\approx$ 41.2
  - Flux is multiply reconnected - cf. Parnell et al. 2008

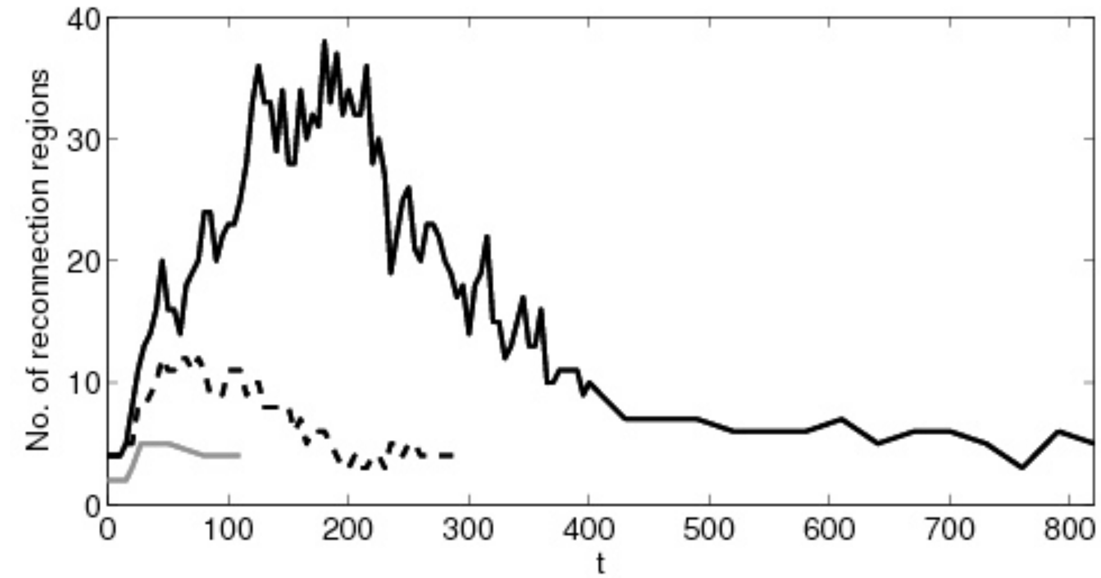


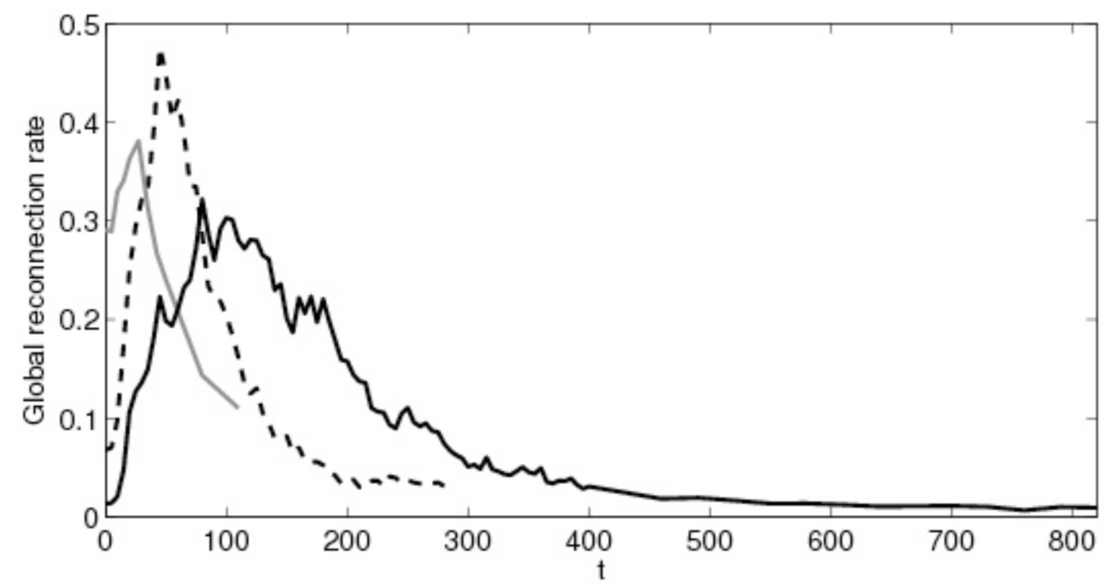
Rec rate comparison

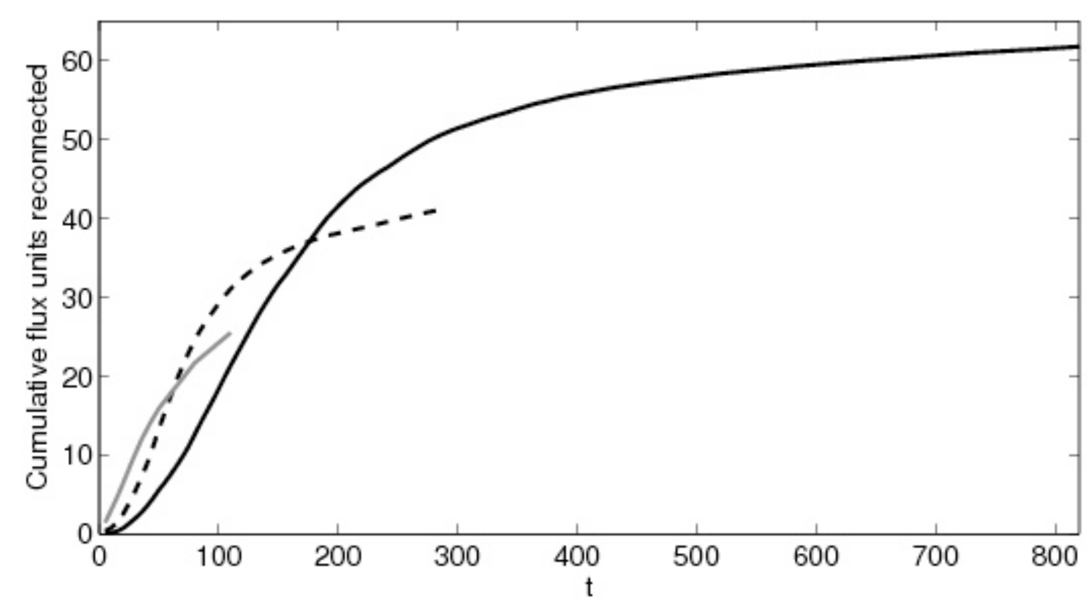
- As η is decreased:
  - ✳ No. of individual rec regions increases
  - ✳ Global rec rate varies (at most) weakly
  - ✳ Cumulative rec'd flux increases
- Starting with 30 units poloidal flux:

η	units rec'd	units remaining
10^{-2}	24.5	13.1
10^{-3}	41.2	15.3
2×10^{-4}	61.8	16.1

(grey $\eta=10^{-2}$; dashed $\eta=10^{-3}$; black $\eta=2\times10^{-4}$)

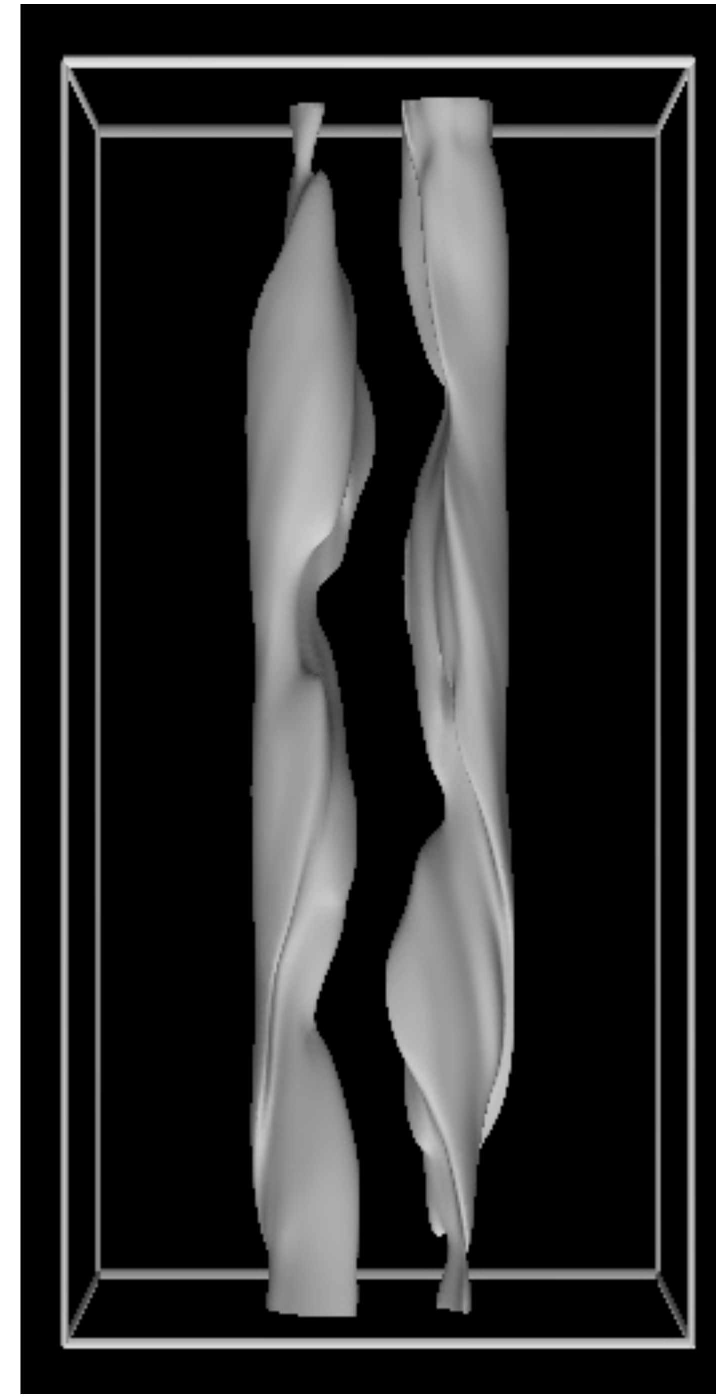




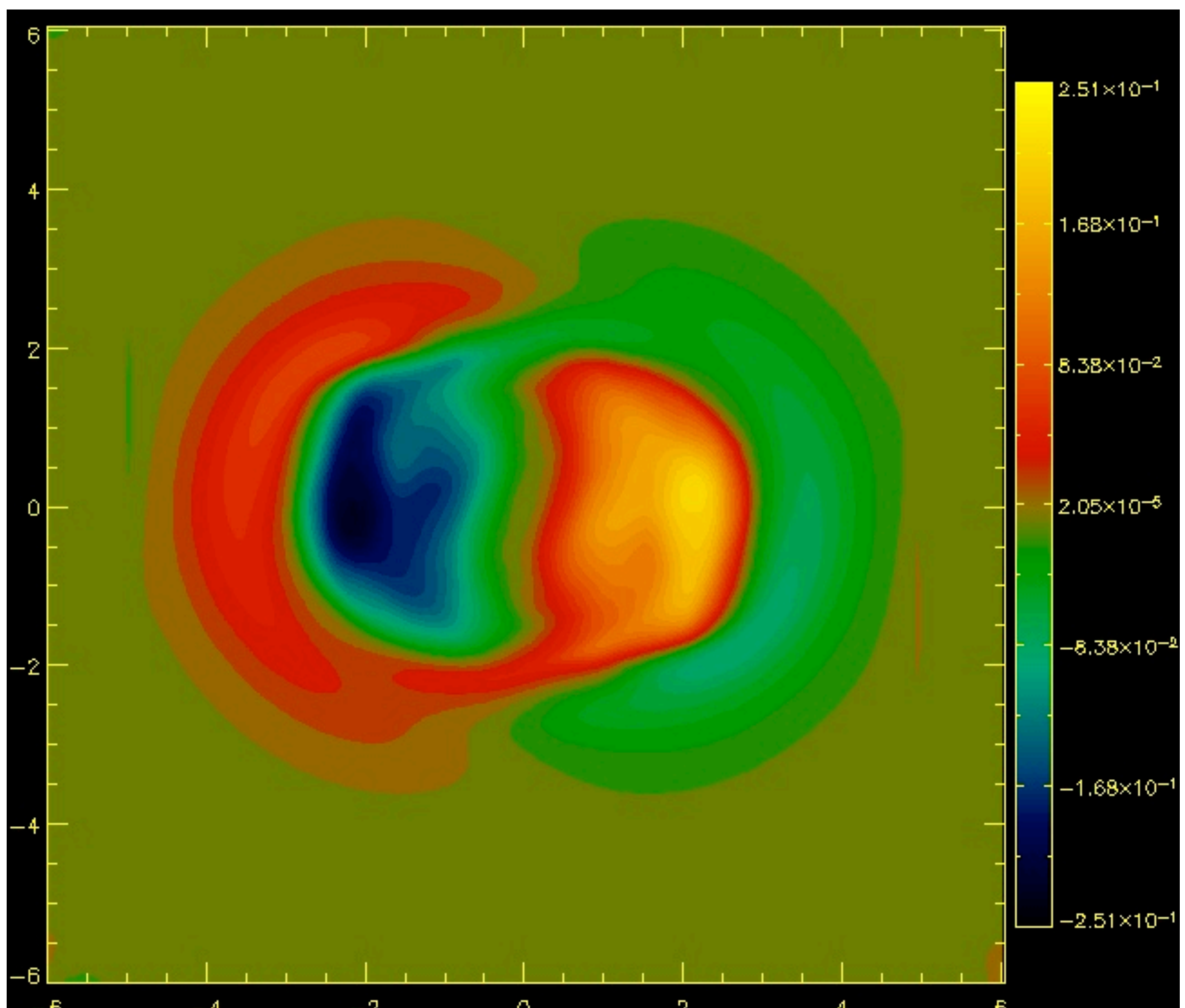


Final state non-potential

- Initial state has net helicity zero
- Taylor relaxation would predict homogeneous B as final state
- Twist not all cancelled
- In fact final state approximates *non-linear* fff, containing flux tubes with positive and negative twist



50% isosurface of $\left|\frac{J_{\|}}{B}\right|$



Map of $\frac{J_{\|}}{B}$ at z=0

Summary

- Braided field undergoes instability, leading to 'turbulent cascade' with many reconnection events, field 'unbraids'
- Recursive reconnection of flux: poloidal flux reconnected multiple times
- For lower η:
  - ✳ 'Cascade' enhanced in complexity and duration for lower η.
  - ✳ Average number of reconnections increases
- Although net helicity is zero, final state does not manage to annihilate all twist (no Taylor relaxation)
- J sheets fill volume effectively (→ expect uniform heating of loop?)
- Low threshold (free energy only a few %) makes it a mechanism for 'background' heating

Pontin, D.I., Wilmot-Smith, A.L., Hornig, G., Galsgaard, K., Dynamics of Braided Coronal Loops - II. Cascade to Multiple Small Scale Events, A&A, 525, A57 (2011)

Wilmot-Smith, A.L., Pontin, D.I., Hornig, G., Dynamics of Braided Coronal Loops - I. Loss of Equilibrium, A&A, 516, A5 (2010)

Thanks for listening

References:

- Pontin, D.I., Wilmot-Smith, A.L., Hornig, G., Galsgaard, K., Dynamics of Braided Coronal Loops - II. Cascade to Multiple Small Scale Events, A&A, 525, A57 (2011)
- Wilmot-Smith, A.L., Pontin, D.I., Hornig, G., Dynamics of Braided Coronal Loops - I. Loss of Equilibrium, A&A, 516, A5 (2010)

and

- Wilmot-Smith, A.L., Pontin, D.I., Yeates, A.R. and Hornig, G. Heating of braided coronal loops, A&A, 536, A67 (2011)
- Yeates, A.R., Hornig, G. and Wilmot-Smith, A.L. Topological Constraints on Magnetic Relaxation, Phys. Rev. Lett., 105, 085002 (2010)
- Wilmot-Smith, A.L., Hornig, G. and Pontin, D.I. Magnetic braiding and parallel electric fields, ApJ, 696, 1339 (2009)