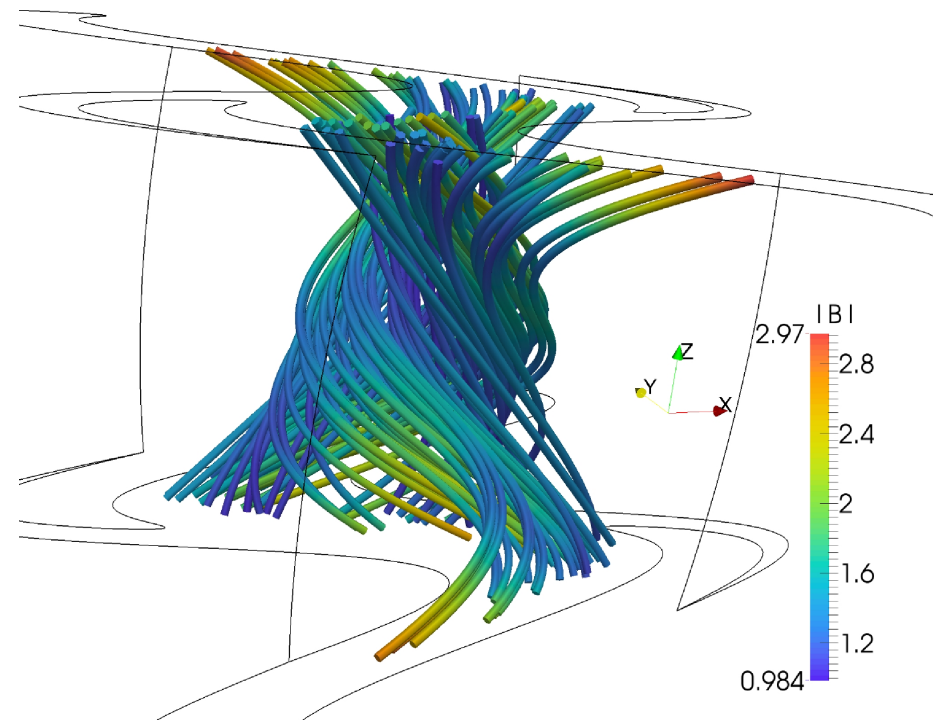


Current Formation During Magnetic Field Relaxation

Simon Candelaresi, David Pontin, Gunnar Hornig



Force-Free Magnetic Fields

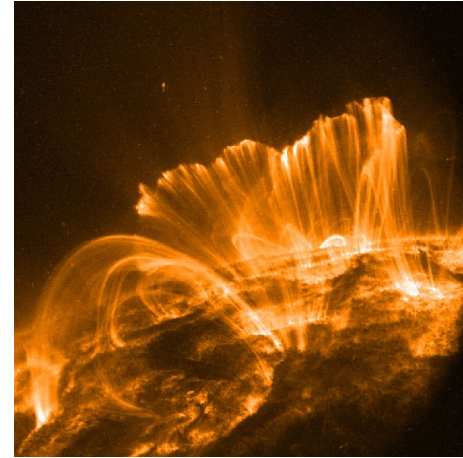
Solar corona: low plasma beta and magnetic resistivity

NASA

➔ Force-free magnetic fields

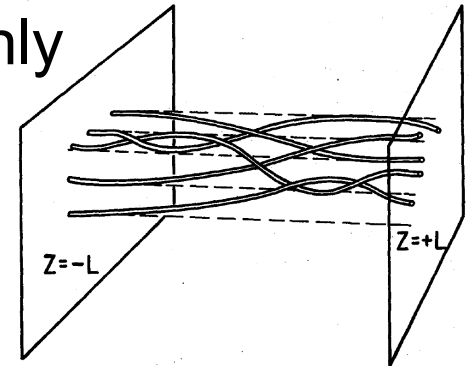
➔ Minimum energy state

$$(\nabla \times \mathbf{B}) \times \mathbf{B} = 0 \Leftrightarrow \nabla \times \mathbf{B} = \alpha \mathbf{B}$$



Parker: Equilibrium with the same topology exists only if the twist varies uniformly along the field lines. Strongly braided fields \rightarrow topological dissipation.

(Parker 1972)



Braided fields from foot point motion complex enough. *(Parker 1983)*

Solutions possible with filamentary current structures (sheets).

(Mikic 1989, Low 2010)

Methods

Ideal (non-resistive) evolution

Frozen in magnetic field


(Batchelor, 1950)



use Lagrangian method

Preserves topology and divergence-freeness.

Magneto-frictional term: $\mathbf{u} = \mathbf{J} \times \mathbf{B}$ $\mathbf{J} = \nabla \times \mathbf{B}$

 $\frac{dE_M}{dt} < 0$ *(Craig and Sneyd 1986)*

Fluid with pressure: $\mathbf{u} = \mathbf{J} \times \mathbf{B} - \beta \nabla \rho$

Fluid with inertia: $d\mathbf{u}/dt = (\mathbf{J} \times \mathbf{B} - \nu \mathbf{u} - \beta \nabla \rho) / \rho$

For $\mathbf{J} = \nabla \times \mathbf{B}$ use mimetic numerical operators.

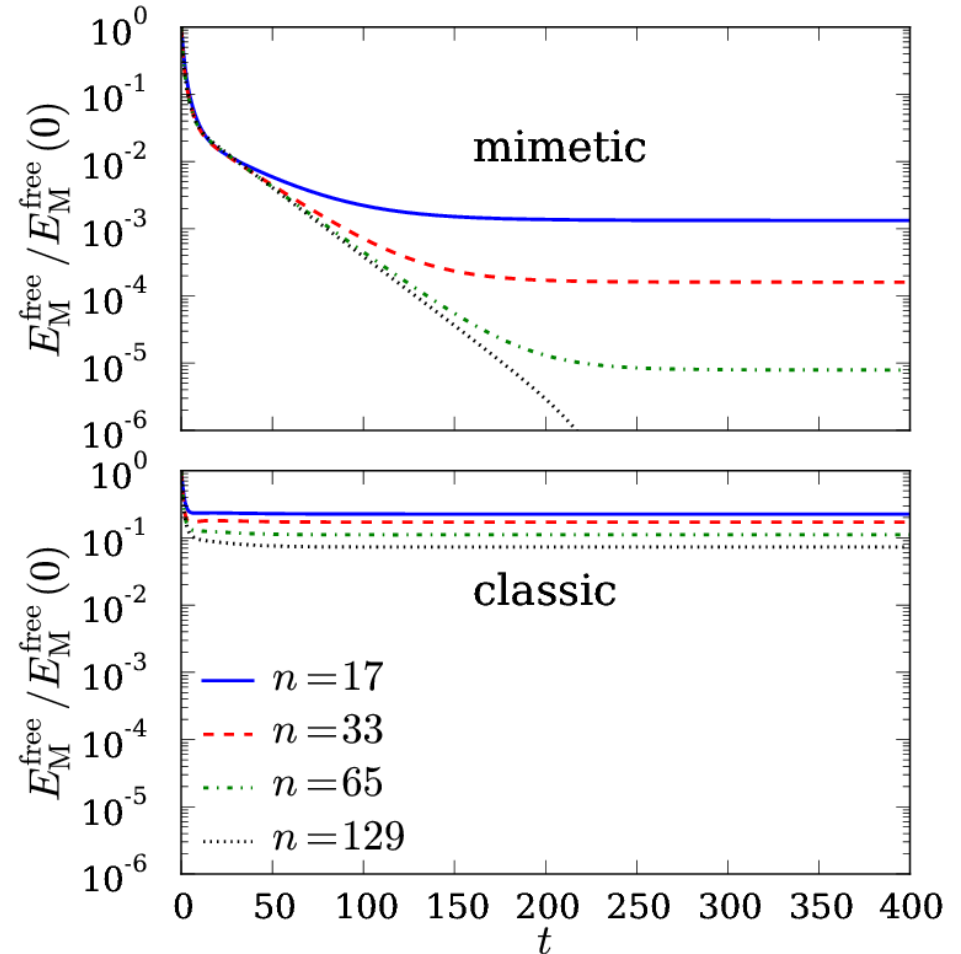
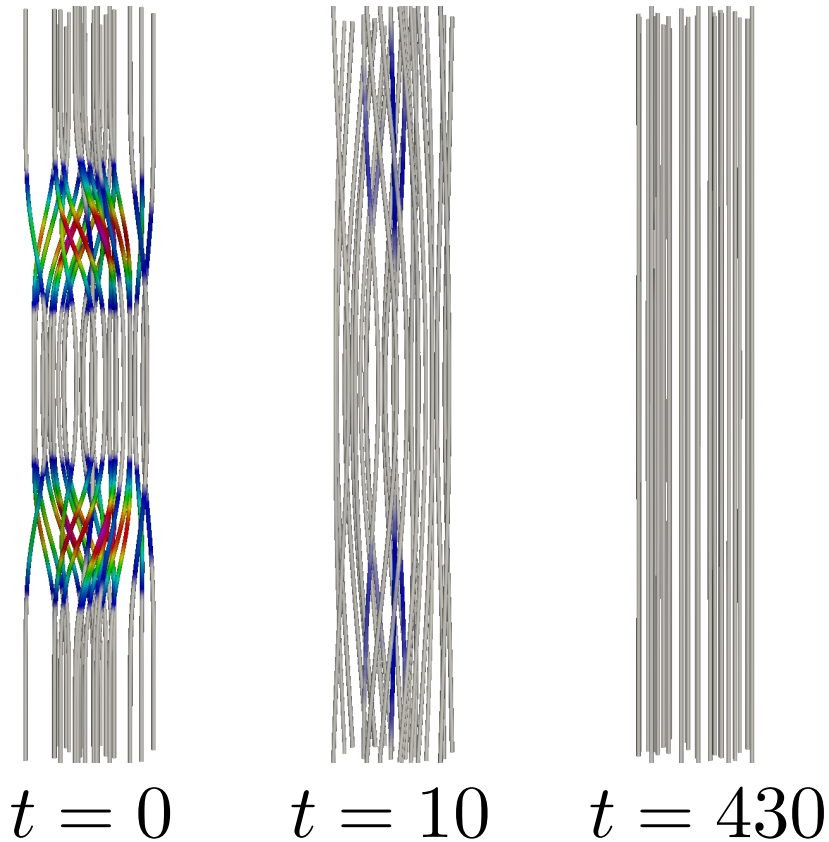
(Hyman, Shashkov 1997)

Own GPU code GLEMUR: (<https://github.com/SimonCan/glemur>)

(Candelaresi et al. 2014)

Simply Twisted Fields

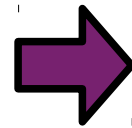
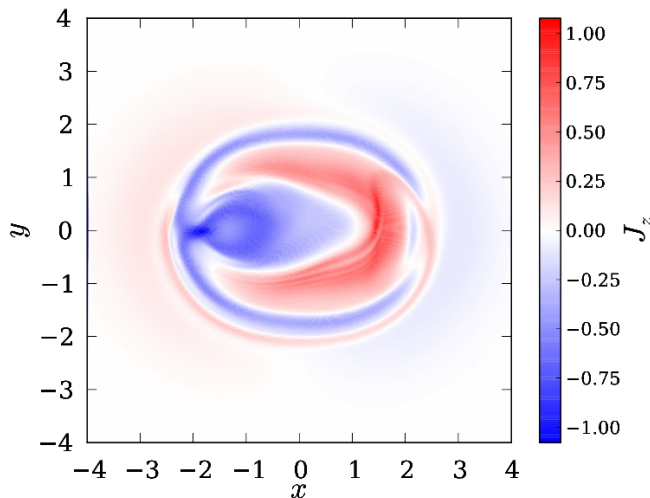
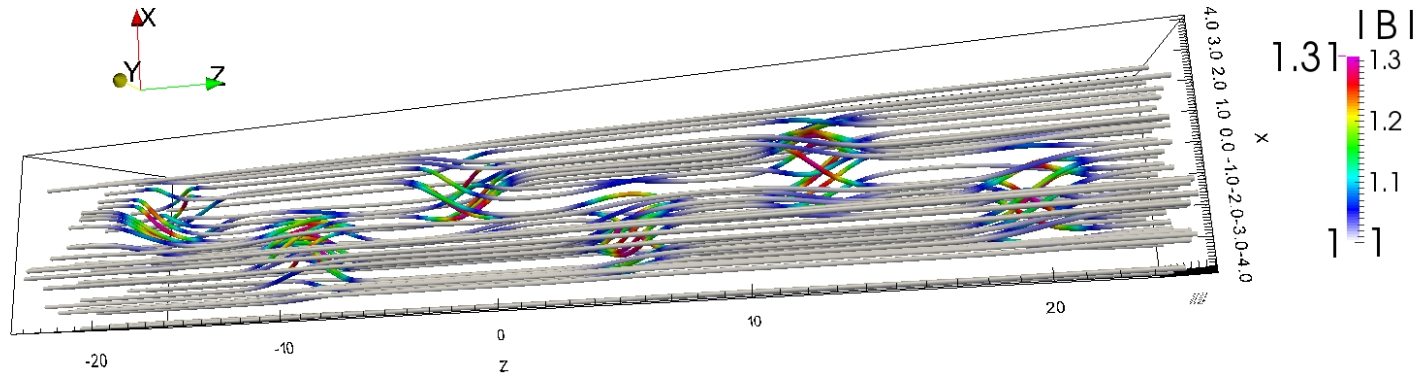
Magnetic streamlines:



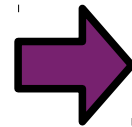
(Candelaresi et al. 2014)

Highly Braided Fields

Sufficiently highly braided according to Parker.



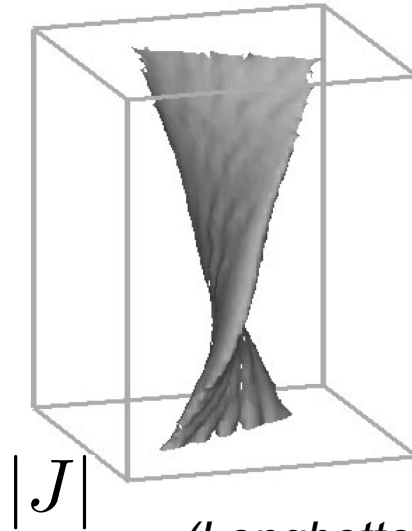
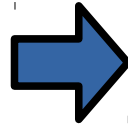
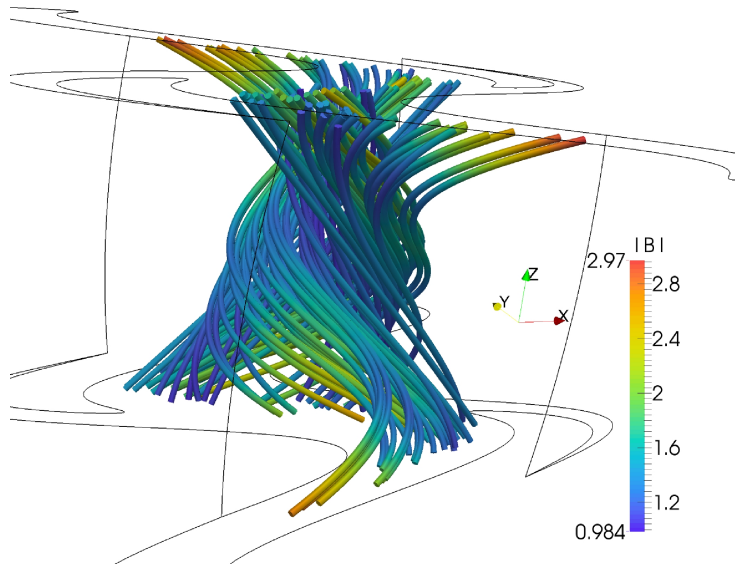
Force-free state is not reached.



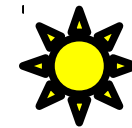
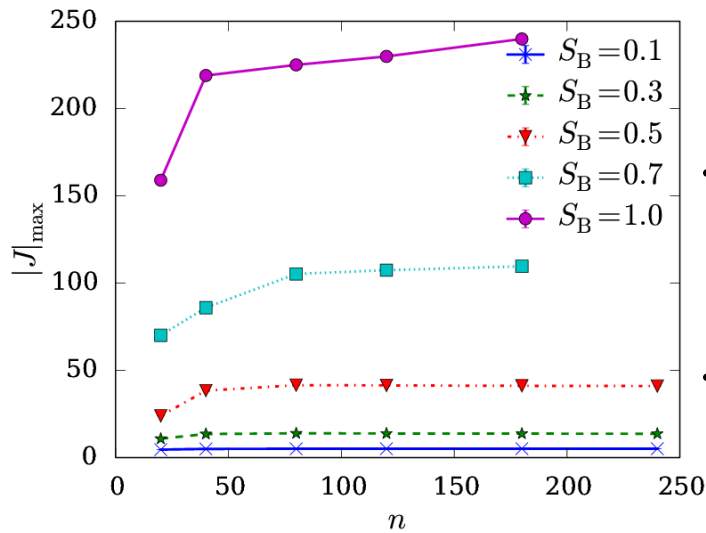
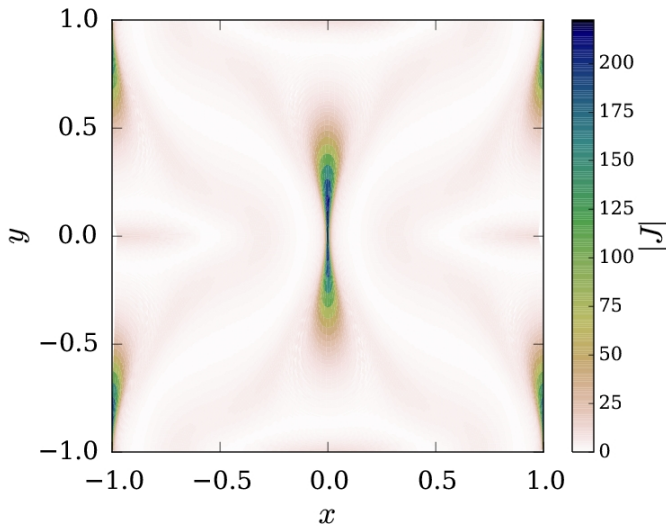
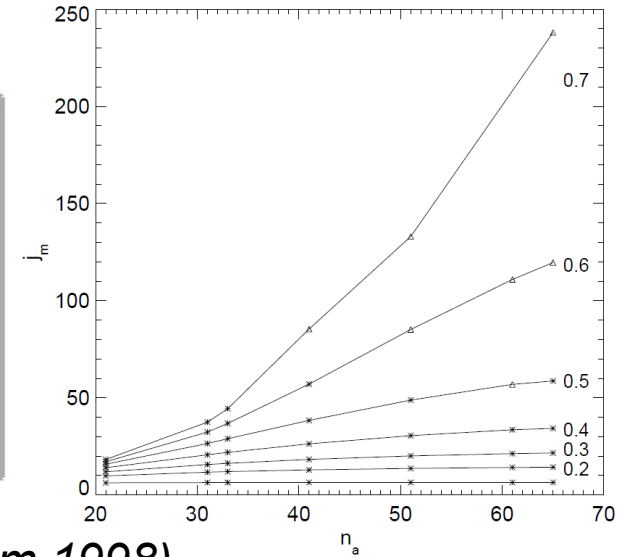
Current layers well resolved.

(Candelaresi et al. 2015)

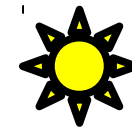
Distorted Magnetic Fields



$|J|$
(Longbottom 1998)



resolved current concentrations



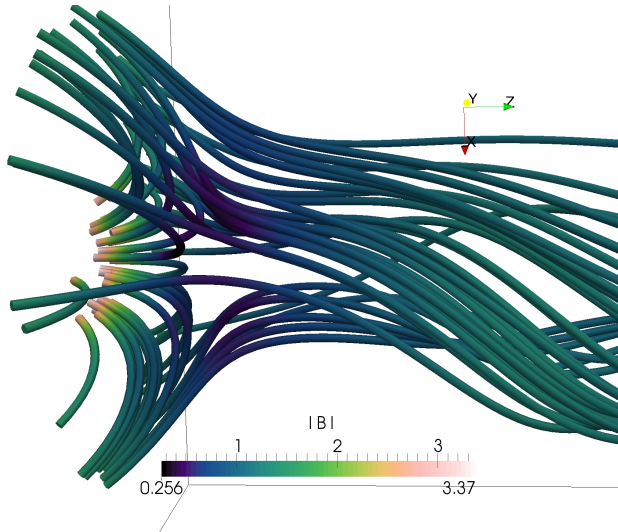
shear leads to strong currents

(Candelaresi et al. 2015)

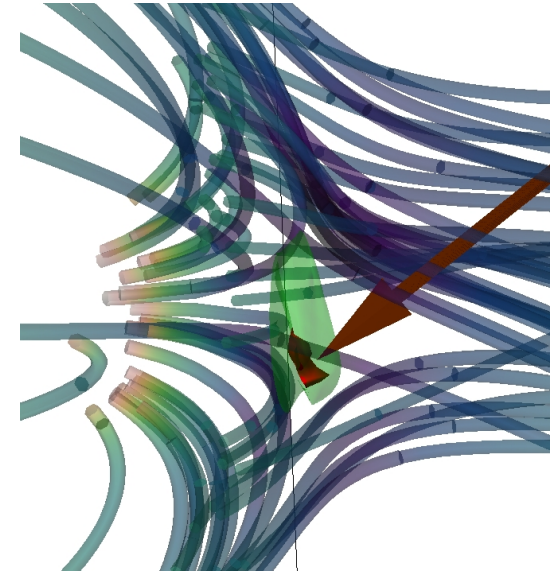
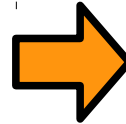
Magnetic Nulls

Singular current sheets observed at magnetic nulls ($B = 0$)

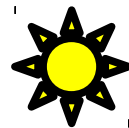
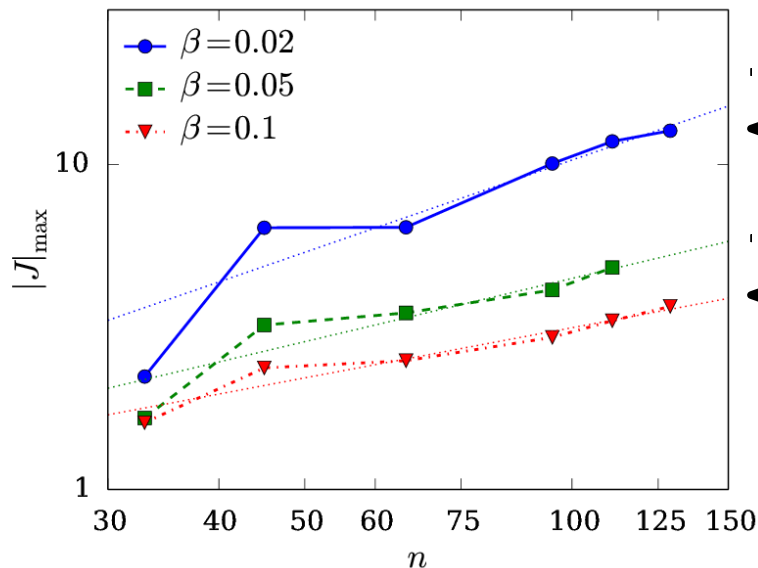
(Svrovatskiĭ 1971; Pontin & Craig 2005; Fuentes-Fernández & Parnell 2012, 2013; Craig & Pontin 2014)



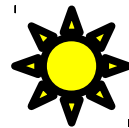
$$\mathbf{u} = \mathbf{J} \times \mathbf{B}$$



$$\mathbf{u} = \mathbf{J} \times \mathbf{B} - \beta \nabla \rho$$



singular current sheets at magnetic nulls



Pressure cannot balance singularity.

Conclusions

- Topology preserving relaxation of magnetic fields.
- Current concentrations not singular.
- Current increases strongly with field complexity.
- Singular currents at magnetic nulls.