Current Formation During Magnetic Field Relaxation

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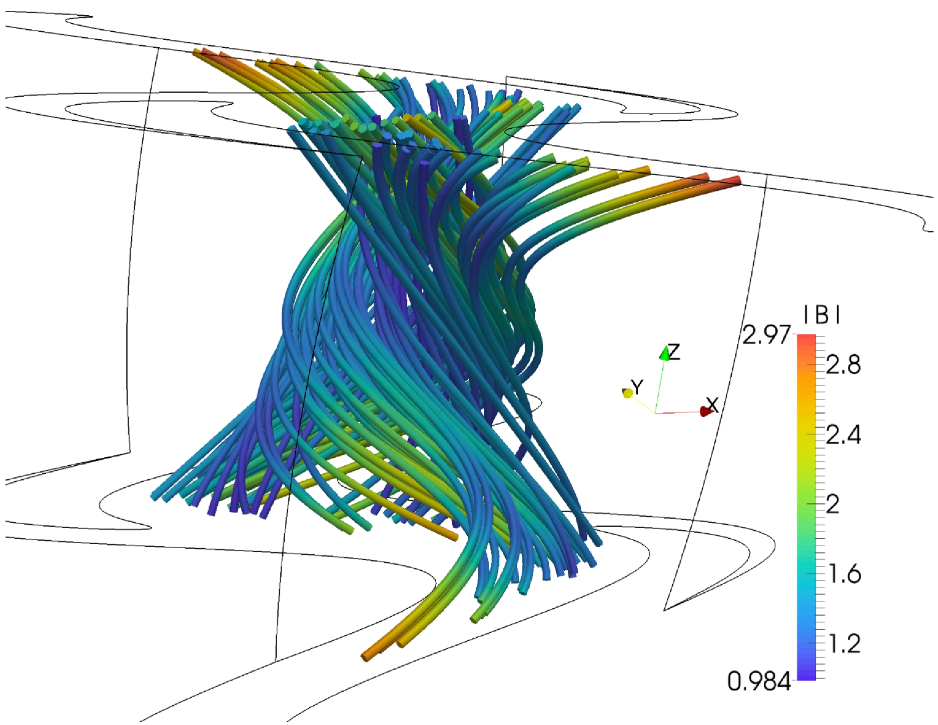
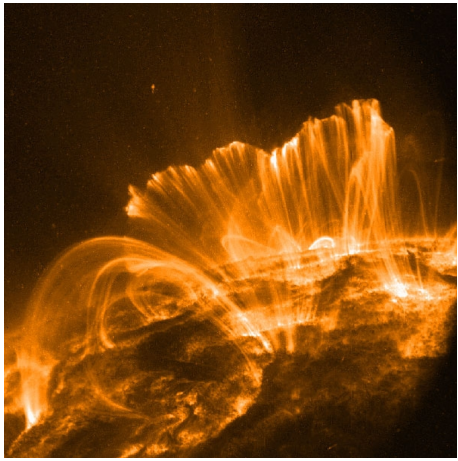


Force-Free Magnetic Fields

Solar corona: low plasma beta and magnetic resistivity

NASA



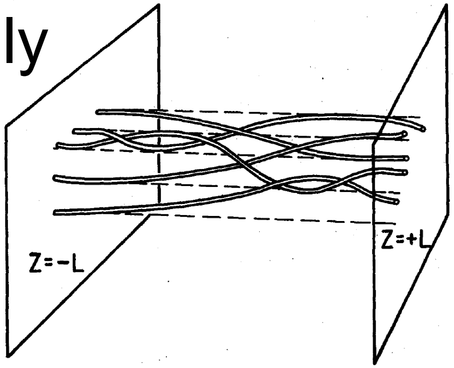
⇨ Force-free magnetic fields

⇨ 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 → 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 ⇨ use Lagrangian method

(Batchelor, 1950)

Preserves topology and divergence-freeness.

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

⇨ $\frac{\mathrm{d}E_\mathrm{M}}{\mathrm{d}t} < 0$ *(Craig and Sneyd 1986)*

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

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

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

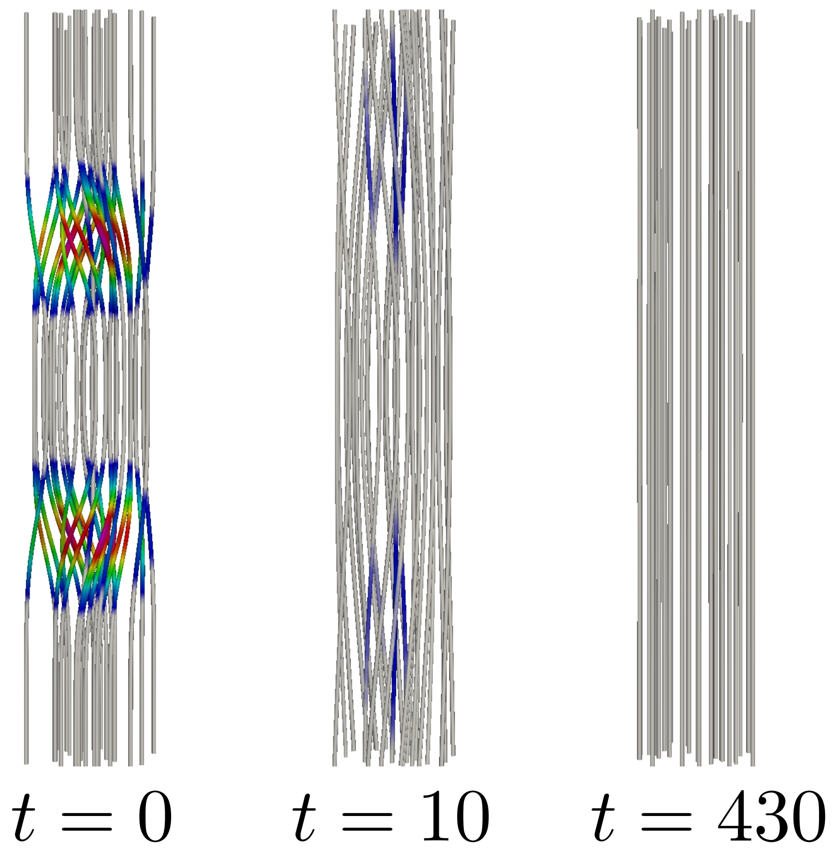
(Hyman, Shashkov 1997)

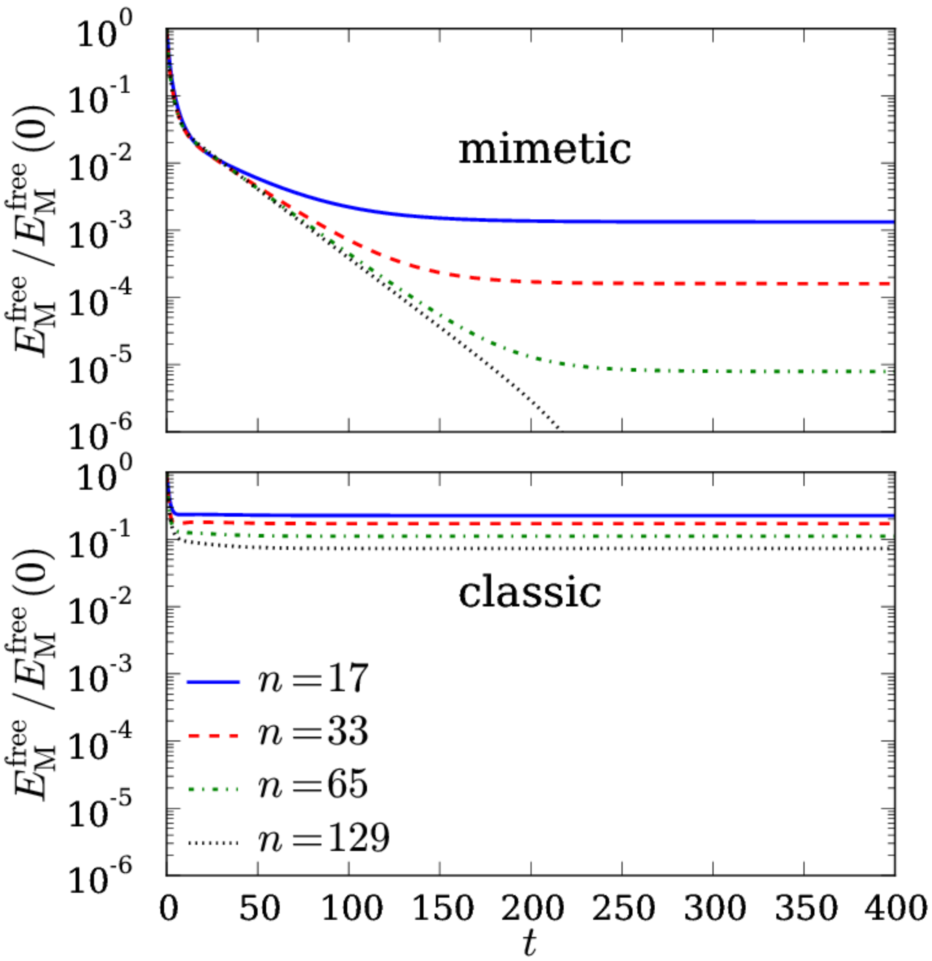
Own GPU code GLEMuR: (https://github.com/SimonCan/glemur)

(Candelaresi et al. 2014)

Simply Twisted Fields

Magnetic streamlines:

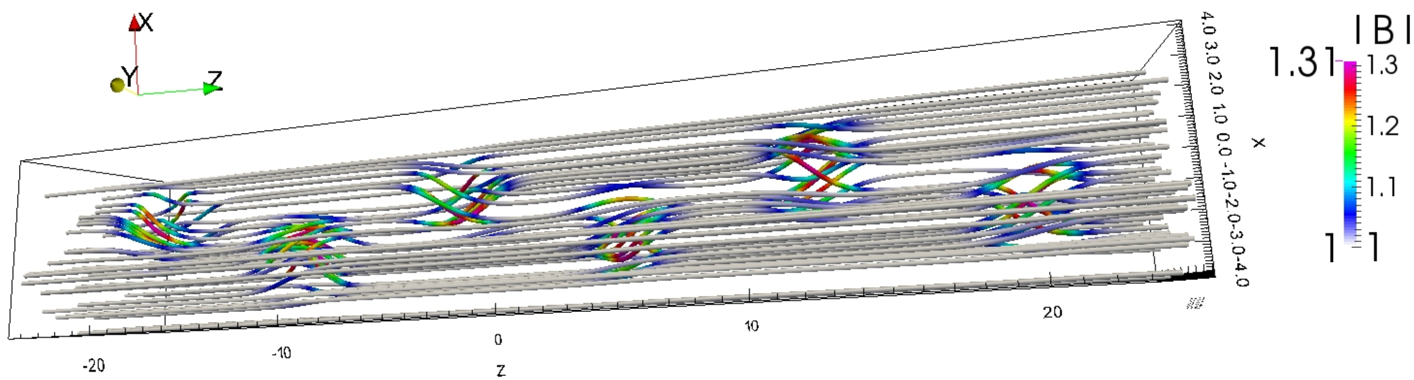


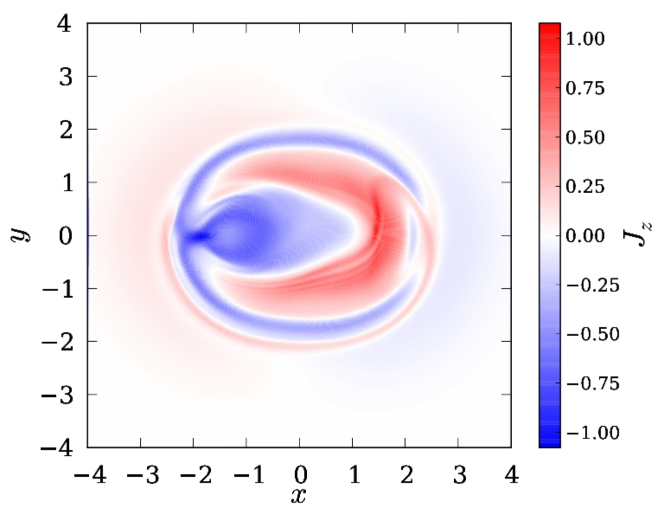


(Candelaresi et al. 2014)

Highly Braided Fields

Sufficiently highly braided
according to Parker.



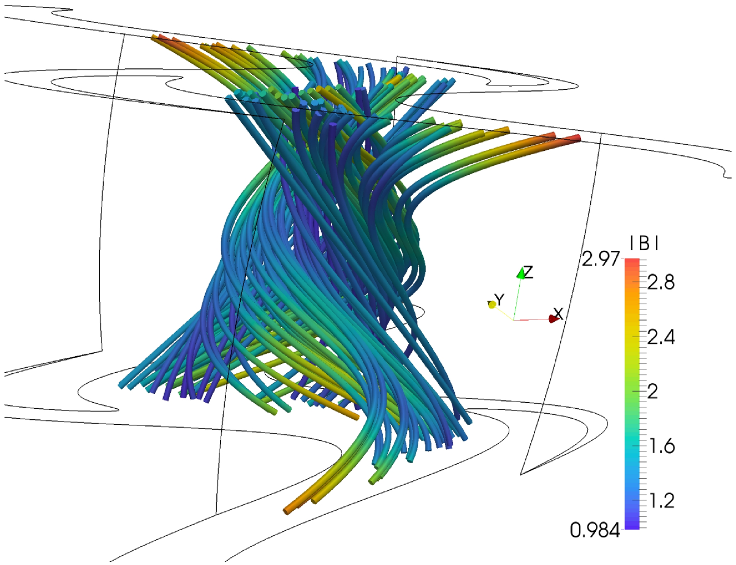


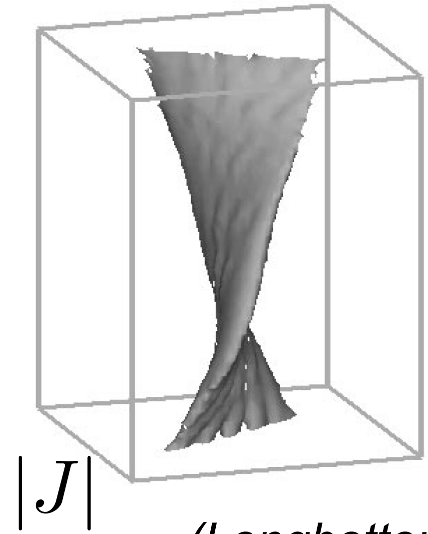
Force-free state is not reached.

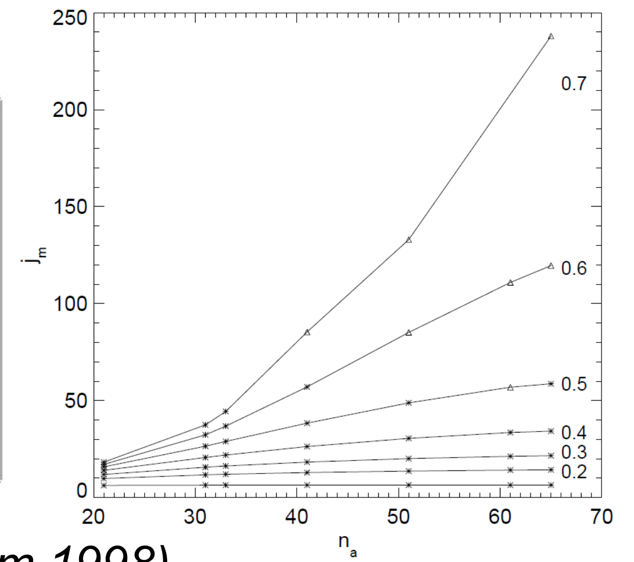
Current layers well resolved.

(Candelaresi et al. 2015)

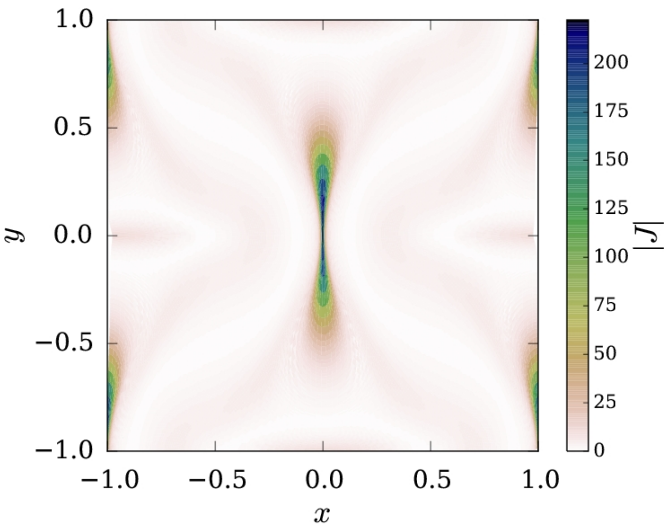
Distorted Magnetic Fields

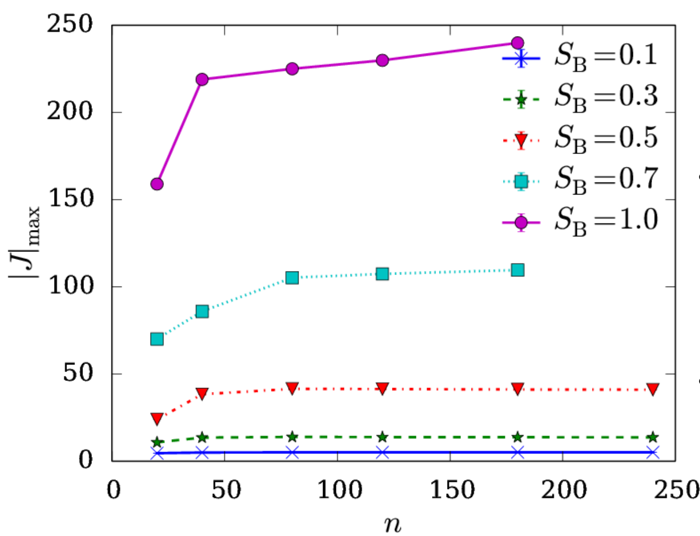






(Longbottom 1998)





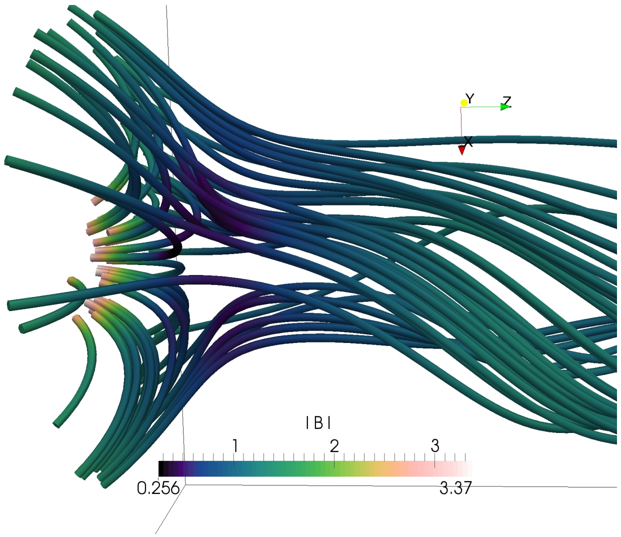
- resolved current concentrations
- shear leads to strong currents

(Candelaresi et al. 2015)

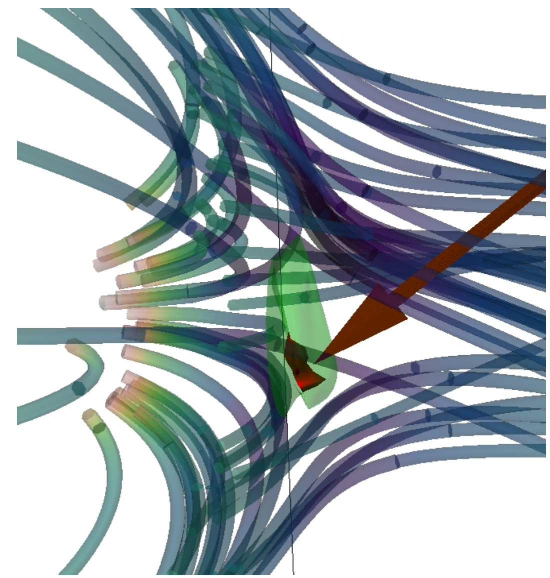
Magnetic Nulls

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

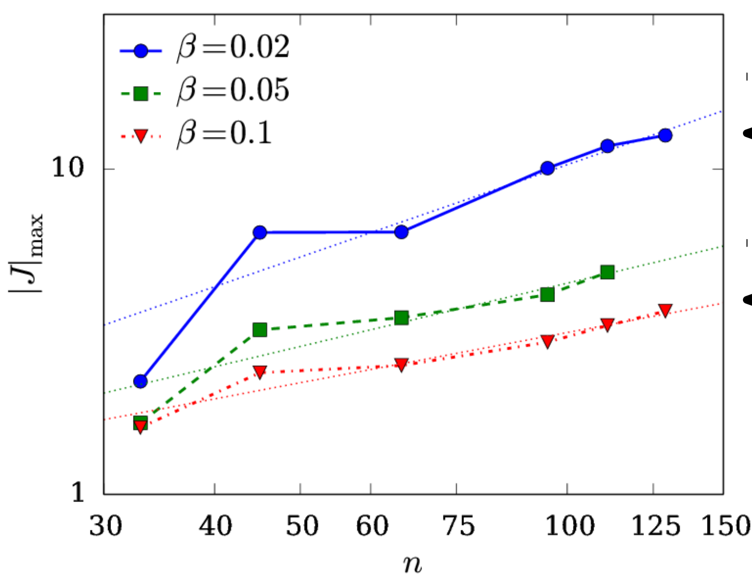
(Syrovatskiĭ 1971; Pontin & Craig 2005; Fuentes-Fernández & Parnell 2012, 2013; Craig & Pontin 2014)



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



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



- 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.

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PhD Projects @ Dundee

Project areas:

- Modelling of solar or astrophysical magnetic fields.
- Dynamics of the Sun's atmosphere.
- Topology of magnetic fields.
- Modelling of three-dimensional magnetic reconnection.
- Development of numerical codes for MHD problems.
- Development of measures of complexity for magnetic and electromagnetic fields.
- Application of knot theory to magnetic fields.
- Representation and visualization of electromagnetic fields.

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http://www.maths.dundee.ac.uk/mhd/phd.shtml