Current Formation During Magnetic Field Relaxation

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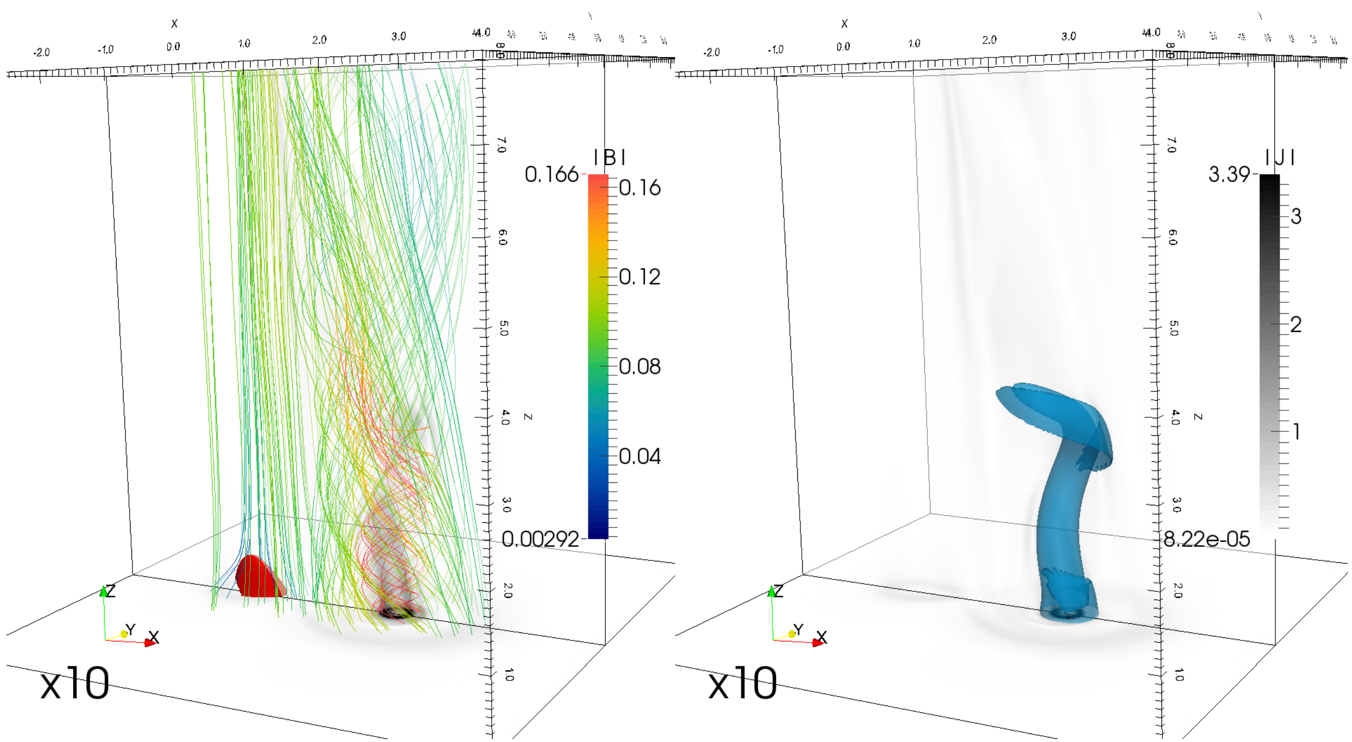
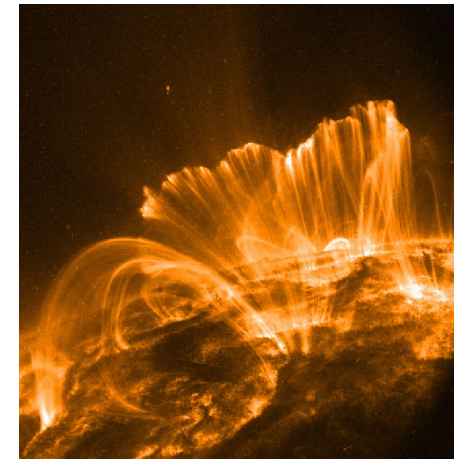


Force-Free Magnetic Fields

Solar corona: low plasma beta and magnetic resistivity

NASA



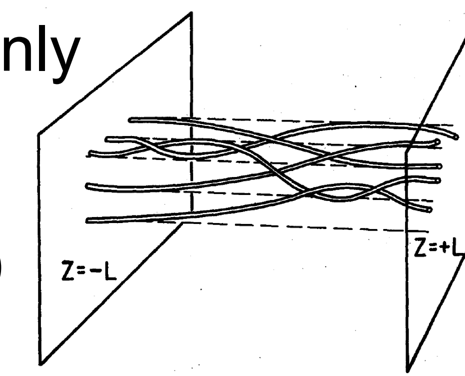
⇨ Force-free magnetic fields

⇨ 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: $\mathbf{u} = \mathbf{J} \times \mathbf{B}$ $\qquad \mathbf{J} = \nabla \times \mathbf{B}$

$$\Rightarrow \frac{\mathrm{d}E_\mathrm{M}}{\mathrm{d}t} < 0$$

(Craig and Sneyd 1986)

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

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

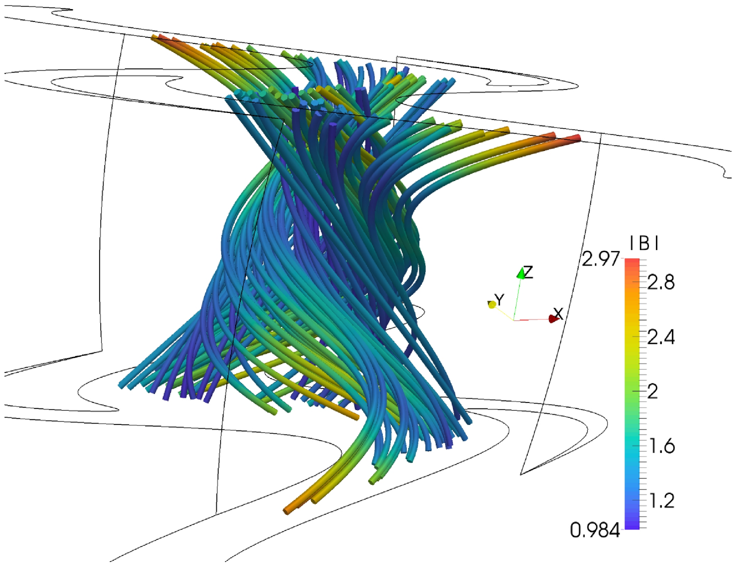
For $\mathbf{J} = \nabla \times \mathbf{B}$ use mimetic numerical operators.

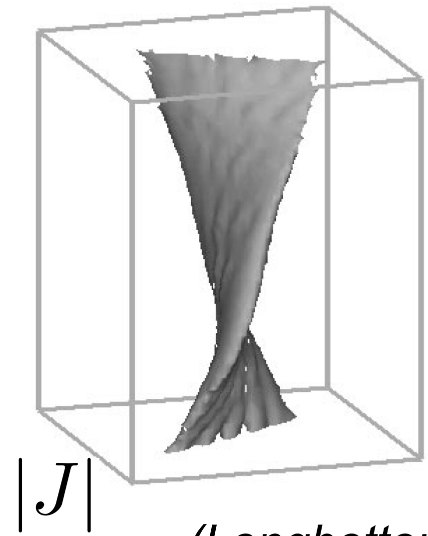
(Hyman, Shashkov 1997)

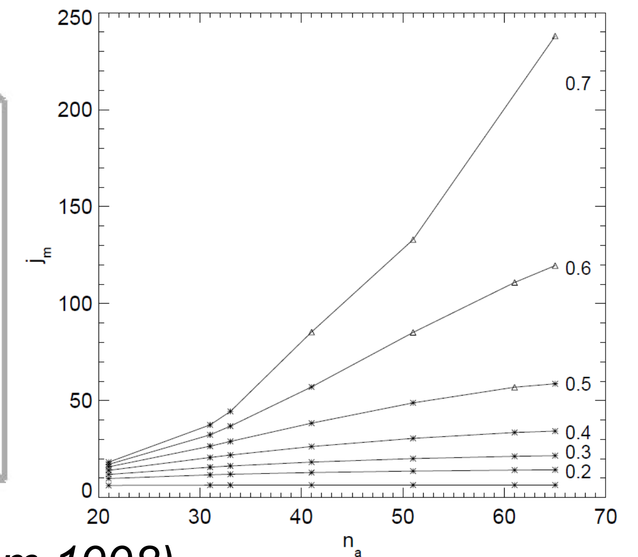
Own GPU code GLEMuR: (https://github.com/SimonCan/glemur)

(Candelaresi et al. 2014)

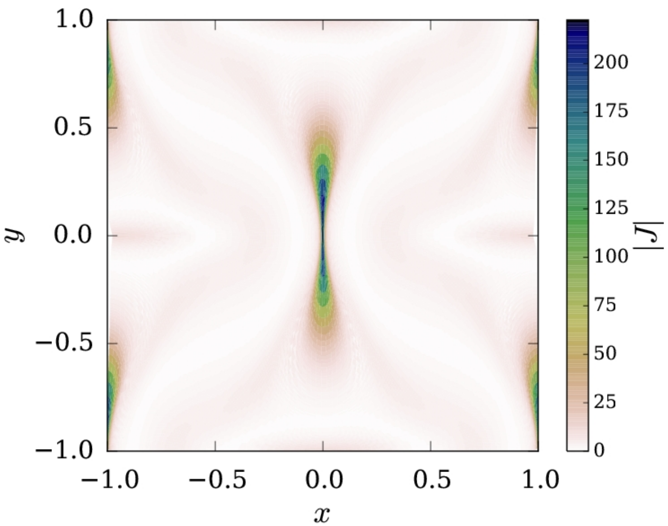
Distorted Magnetic Fields

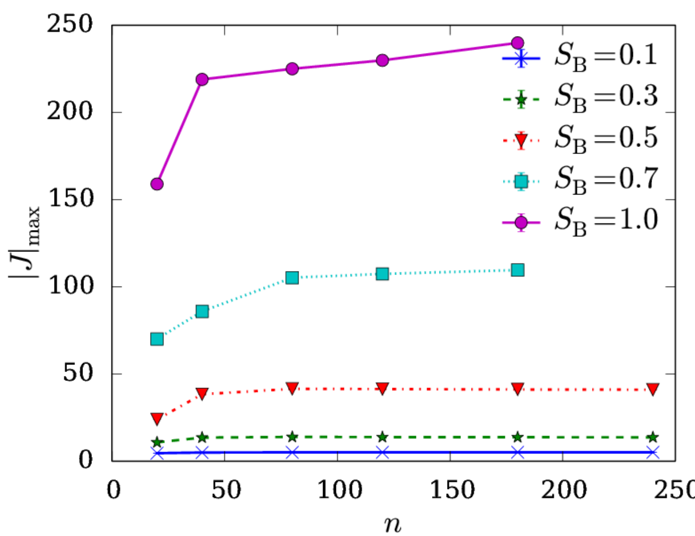






(Longbottom 1998)





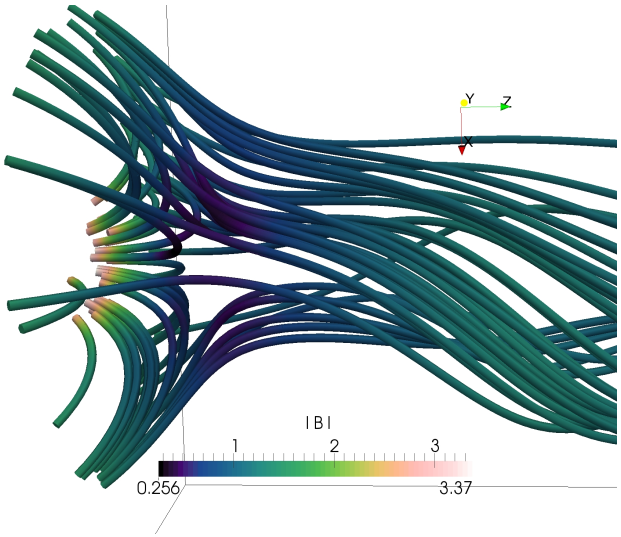
- resolved current concentrations
- shear leads to strong currents

(Candelaresi et al. 2015)

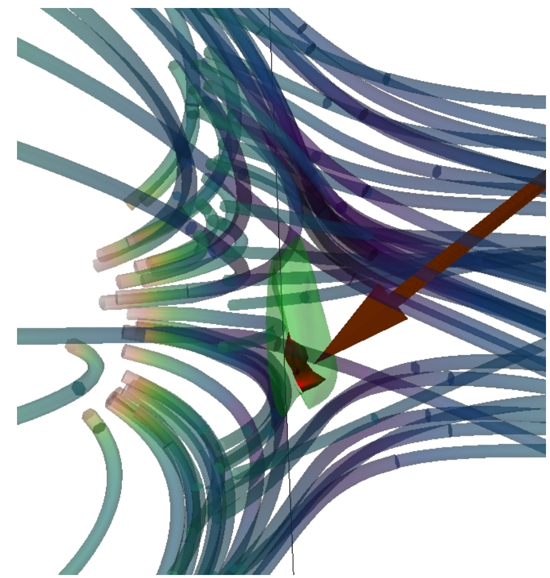
Magnetic Nulls

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

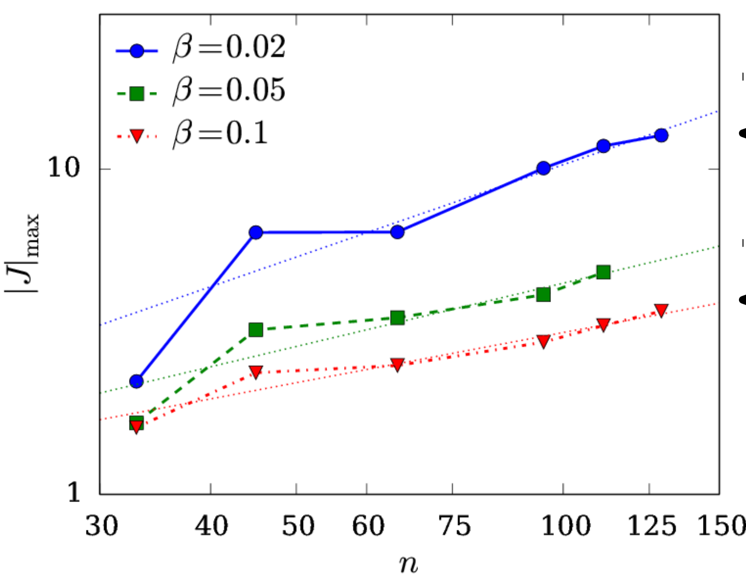
(Syrovatskiĭ 1971; Pontin & Craig 2005; Fuentes-Fernández & Parnell 2012, 2013; Craig & Pontin 2014)



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

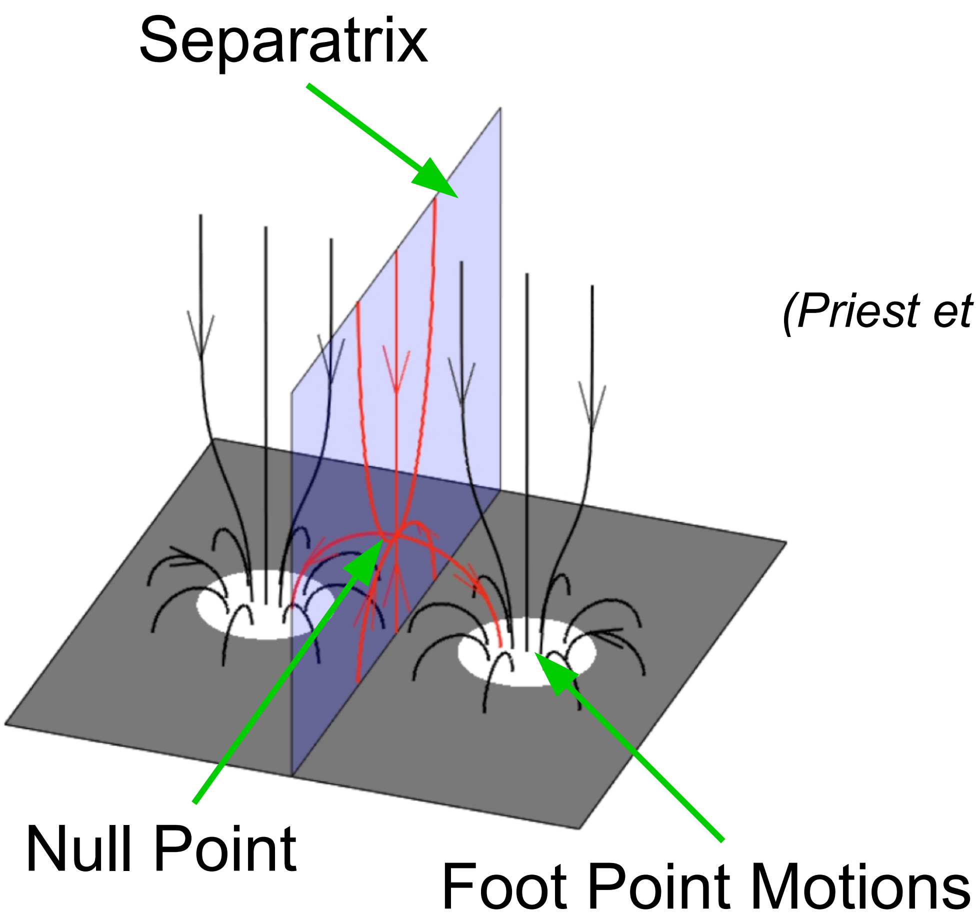


$$\mathbf{u} = \mathbf{J} \times \mathbf{B} - \beta \nabla \rho$$

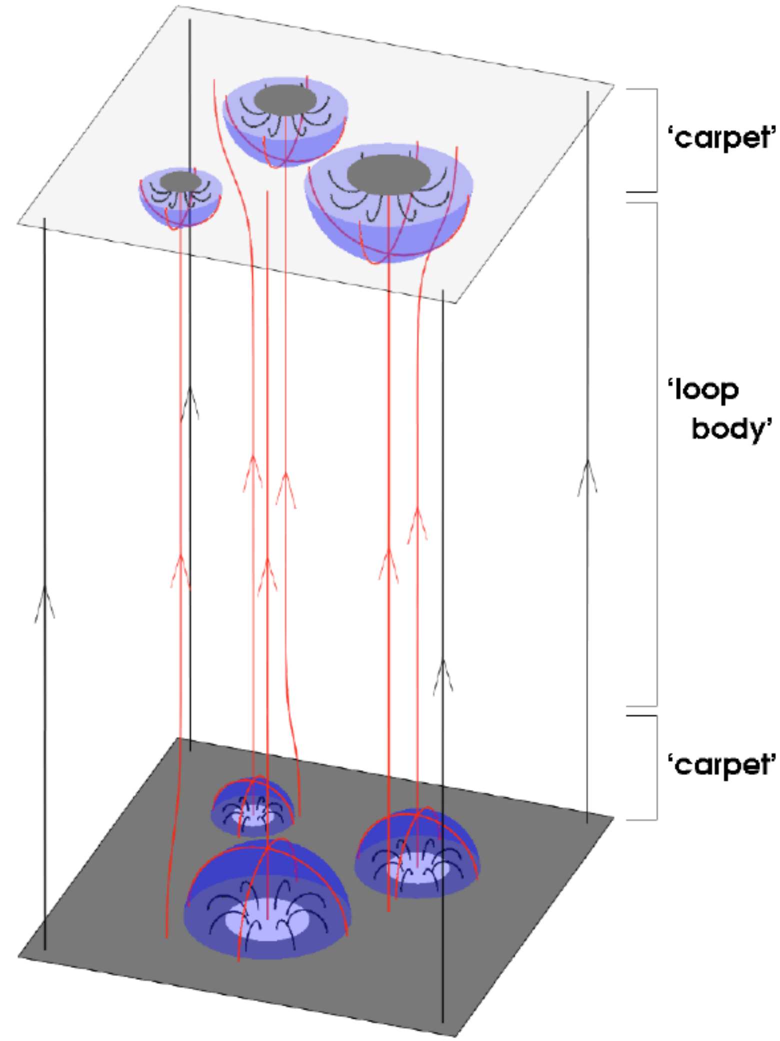


- singular current sheets at magnetic nulls
- Pressure cannot balance singularity.

Magnetic Carpet



(Priest et al. 2002)

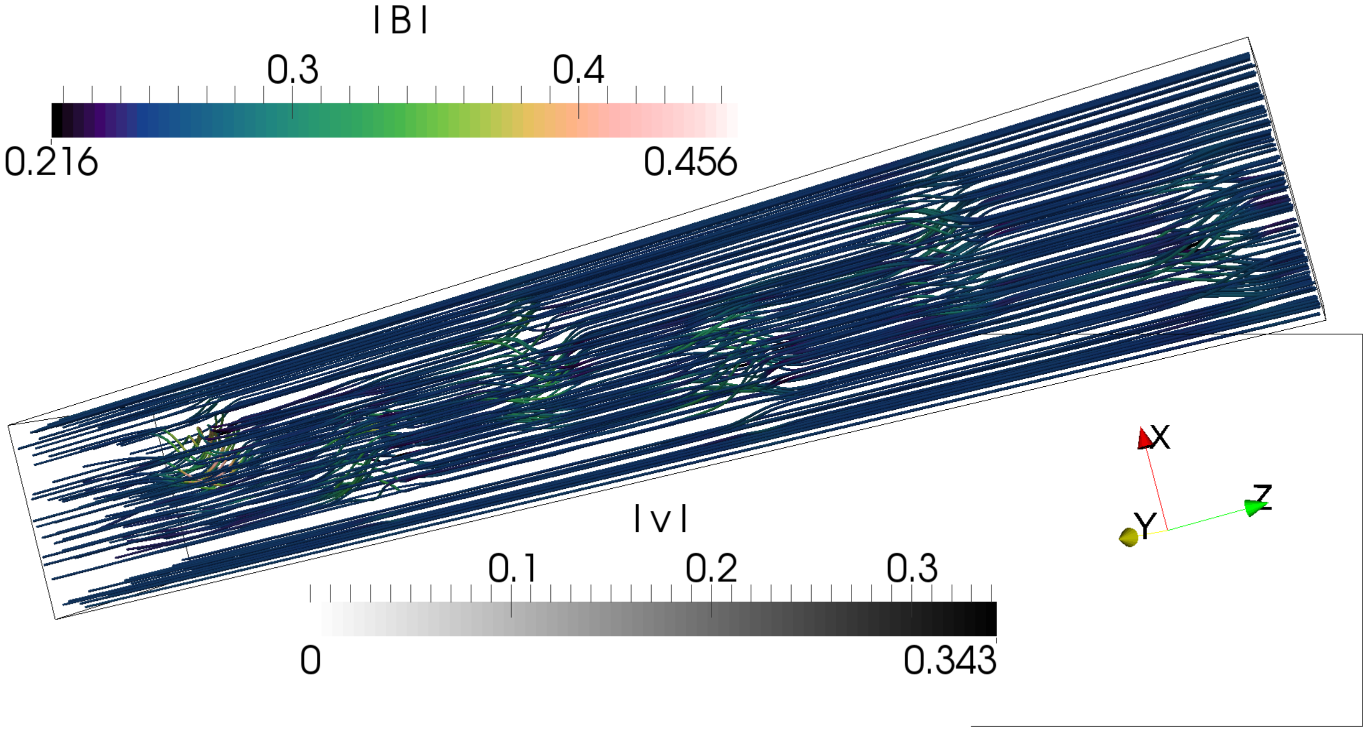


Questions: How do disturbances travel into the domain?
Reconnection at null point?
Propagation in presence of nulls?

E3 Experiments

full resistive MHD simulations with the PencilCode

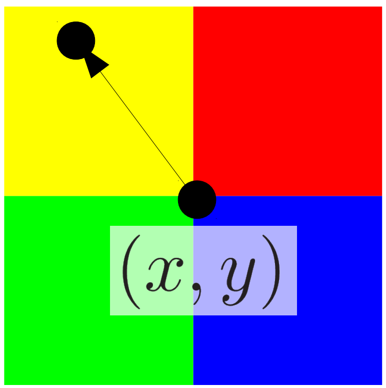
initially homogeneous field, E3 type of boundary driving

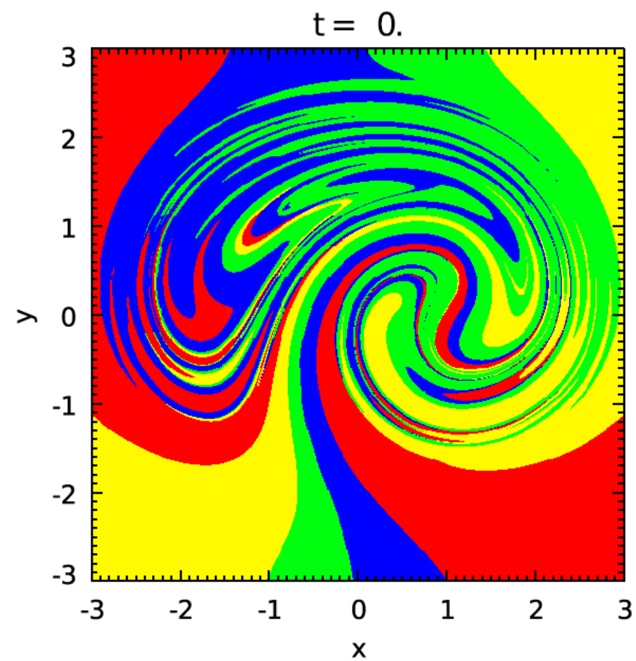


☀ Braid propagates into domain.

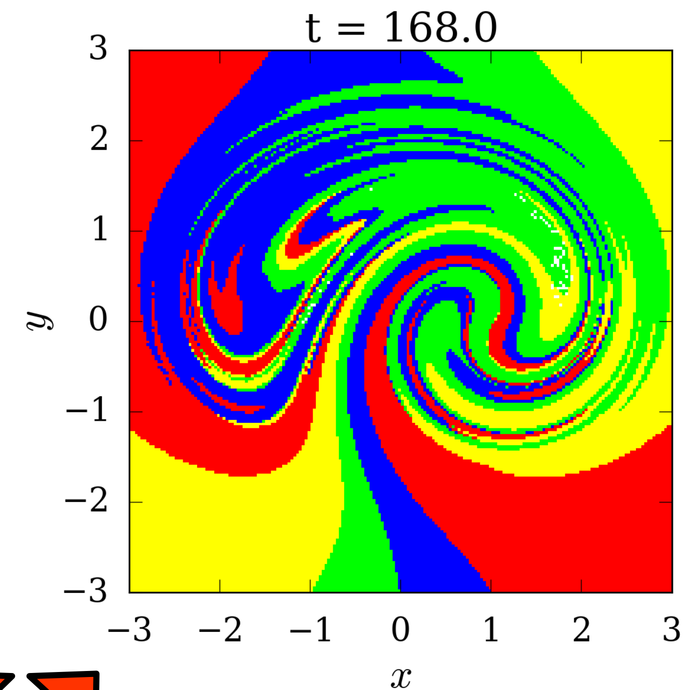
E3 Experiments

field line mapping





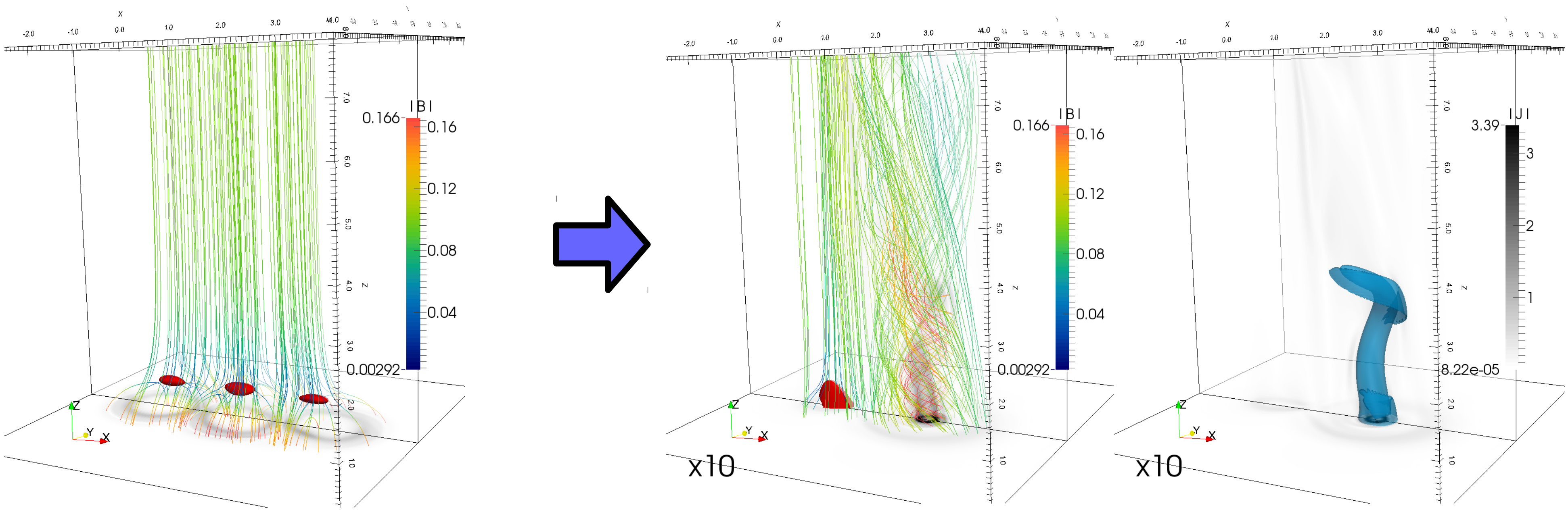
(Yeates et al. 2010)



vs.

field line connectivity with foot point motions

Null Points



- Nulls inhibit the propagation of perturbations.
- Foot point motion can annihilate nulls.
- waves/oscillations?

Conclusions

- Topology preserving relaxation of magnetic fields.
- Current concentrations not singular.
- Current increases strongly with field complexity.
- Singular currents at magnetic nulls.
- Braiding through photospheric foot point motion.
- Null point disruption through boundary motions.

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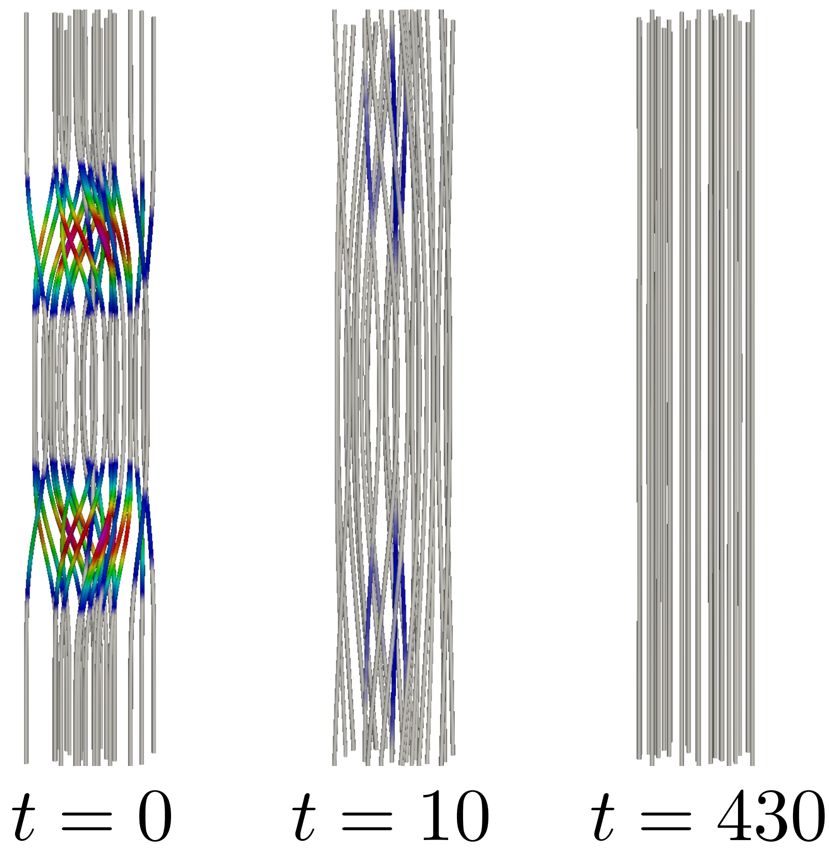
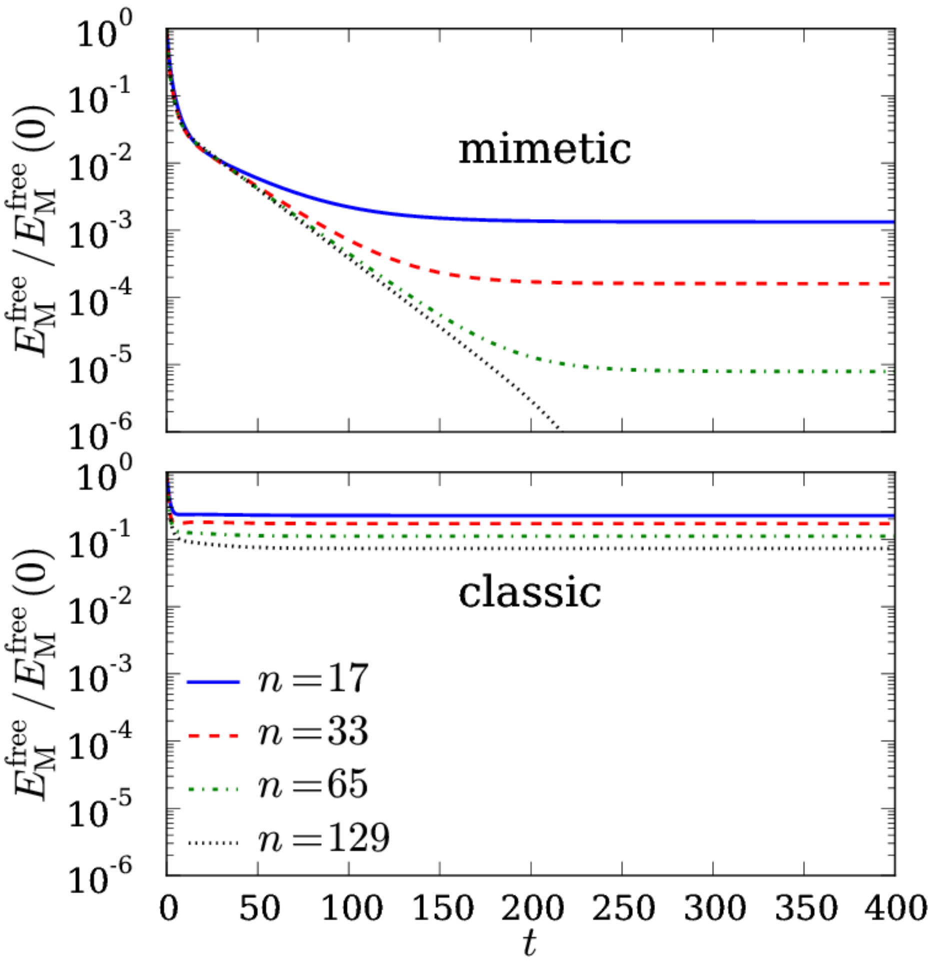
Simply Twisted Fields

Magnetic streamlines:





(Candelaresi et al. 2014)

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.

Funding: PhD Scholarship is currently available for UK nationals (or equivalent UK status as detailed by STFC)

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