Magnetic Field Line Topology in the Solar Atmosphere

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Solar Magnetic Field

(NASA)

(NASA/SDO)

(Trace)

(Trace)
Magnetically active regions give rise to sunspots. Magnetic loops are anchored at locations of intense magnetic field.
Solar Magnetic Field

(NASA)
Dynamo mechanism generating the solar magnetic field through turbulent motions.
Solar Corona

Heating models:

DC
- Magnetic Reconnection
- Flares
- Mass Flows

AC
- Sound Waves
- Magneto-acoustic Waves
- Alfvén Waves
- Footpoint Motions

(Gary 2007)

(Sabers, Royer, Drückmuller 2016)
Magnetic Field Relaxation

Solar corona: low plasma beta and magnetic resistivity

- Force-free magnetic fields
- Minimum energy state

\[(\nabla \times \mathbf{B}) \times \mathbf{B} = 0 \iff \nabla \times \mathbf{B} = \alpha \mathbf{B}\]

**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).  

\[(Mikic \ 1989, \ Low \ 2010)\]
Photospheric Motions

Local Correlation Tracking (Chae 2007)

Braiding of magnetic loops.
Injection of Energy

(Reale 2016)
Magnetic Carpet

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

(Priest et al. 2002)
E3 Experiments

Full resistive MHD simulations with the PencilCode.

\[
\frac{\partial \mathbf{A}}{\partial t} = \mathbf{U} \times \mathbf{B} + \eta \nabla^2 \mathbf{A}
\]

\[
\frac{\mathbf{D} \mathbf{U}}{\mathbf{D} t} = -c_s^2 \nabla \ln \rho + \mathbf{J} \times \mathbf{B}/\rho + \mathbf{F}_{\text{visc}}
\]

\[
\frac{\mathbf{D} \ln \rho}{\mathbf{D} t} = -\nabla \cdot \mathbf{U}
\]

Initially homogeneous field, E3 type of boundary driving.
E3 Experiments

Blinking Vortex Footpoint Driving

Braid propagates into domain.
Controlled change of field line connectivity can be achieved through footpoint motions.
Null Points

Null pair creation/annihilation.

Footpoint motion can alter the field line topology.
Null Points

Null points diffusively annihilate.

Mixing enhances diffusivity.

Null points diffusively annihilate.
Energy Propagation

Homogeneous $B_0$

Magnetic Carpet $B_0$

Topology efficiently inhibits energy propagation.

After change of topology $\rightarrow$ efficient energy transport.
Polarity Mixing

Magnetic field polarities are efficiently mixed through footpoint motions.

White:  \( B < 0 \)
Grey:  \( B \approx 0 \)
Black:  \( B > 0 \)
Conclusions

- Braiding through photospheric footpoint motion.
- Null point disruption through boundary motions.
- Energy propagation inhibited due to carpet structure.
- Efficient energy transport into corona after topology change.
- Polarity mixing on the photosphere.

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