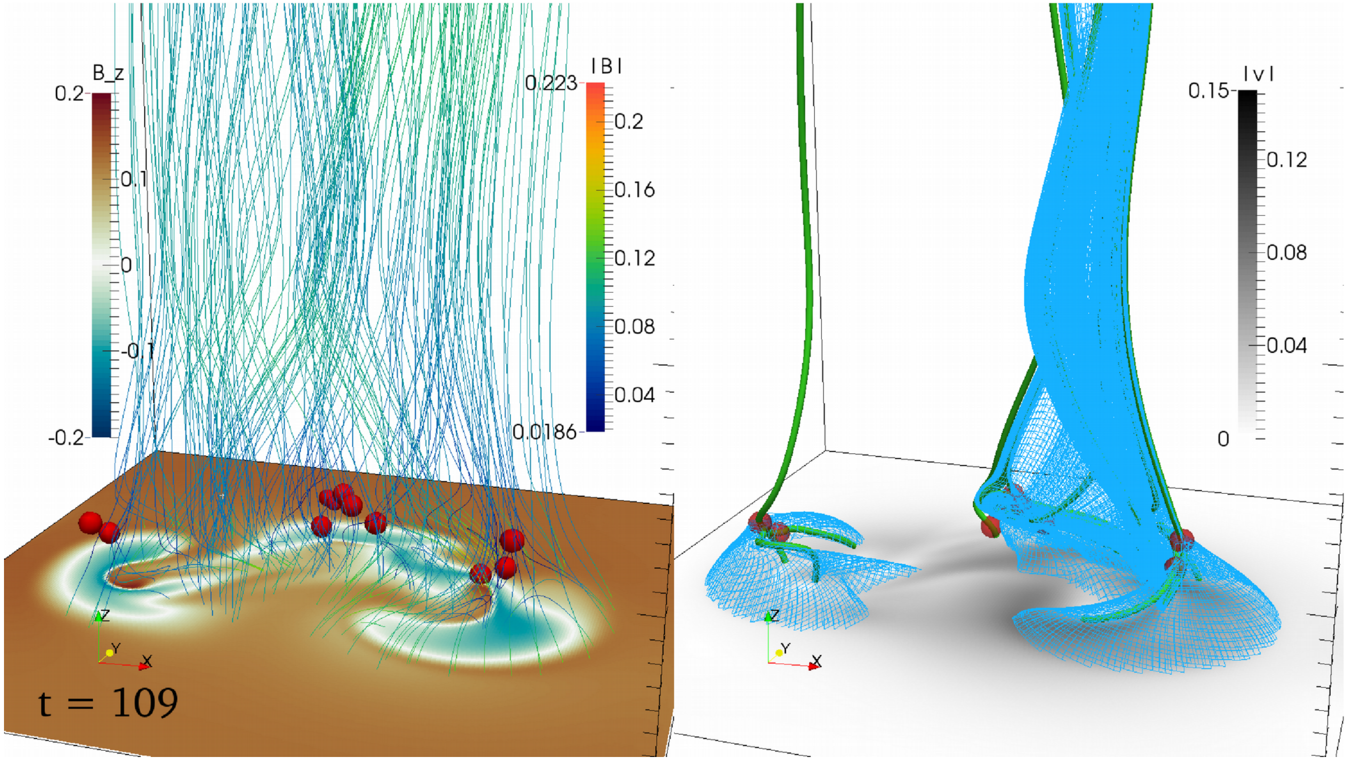
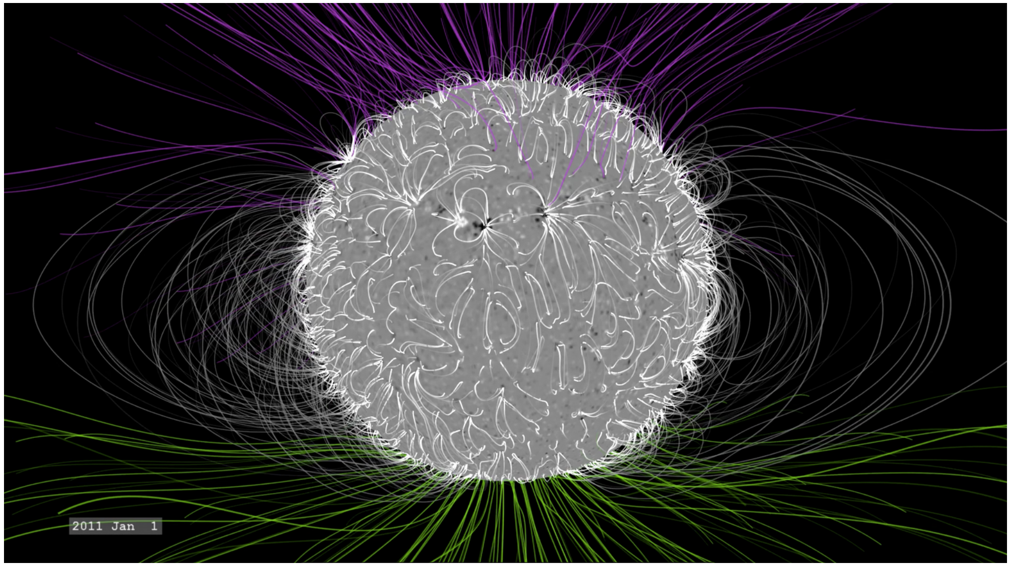
Magnetic Field Line Topology in the Solar Atmosphere

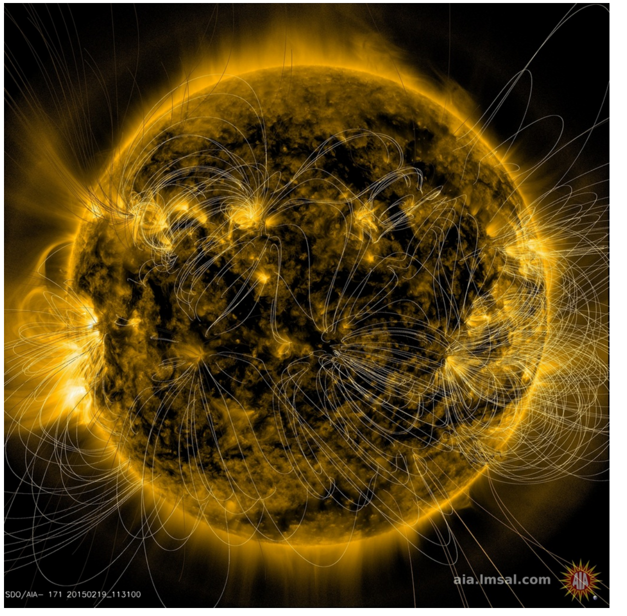
Simon Candelaresi, David Pontin, Gunnar Hornig



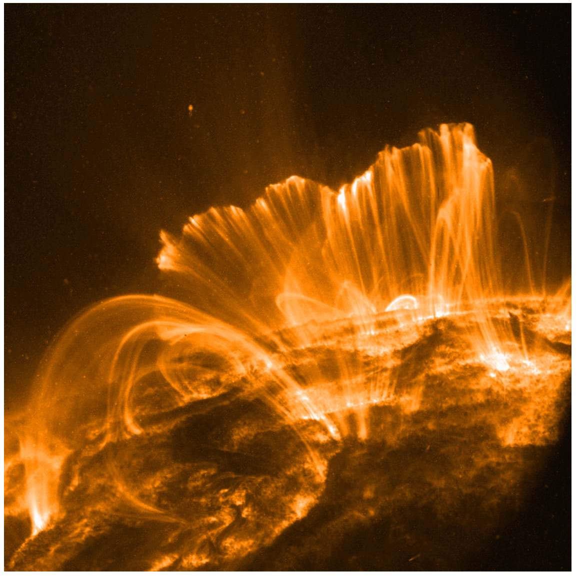
Solar Magnetic Field



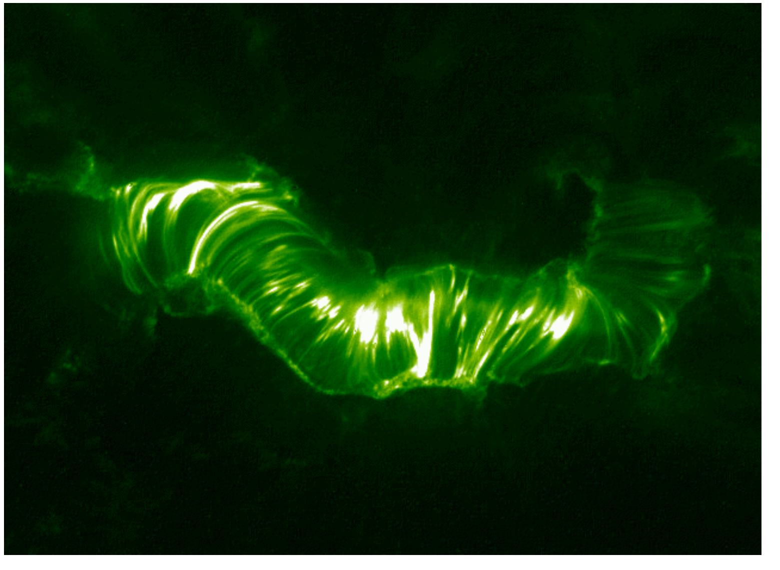
(NASA)



(NASA/SDO)



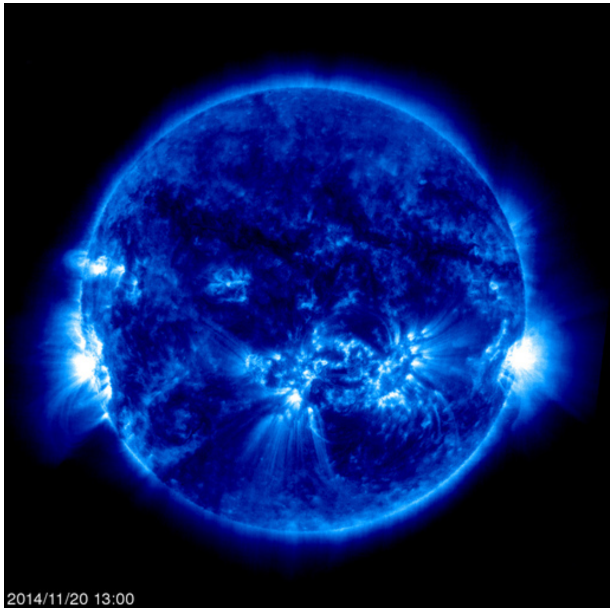
(Trace)



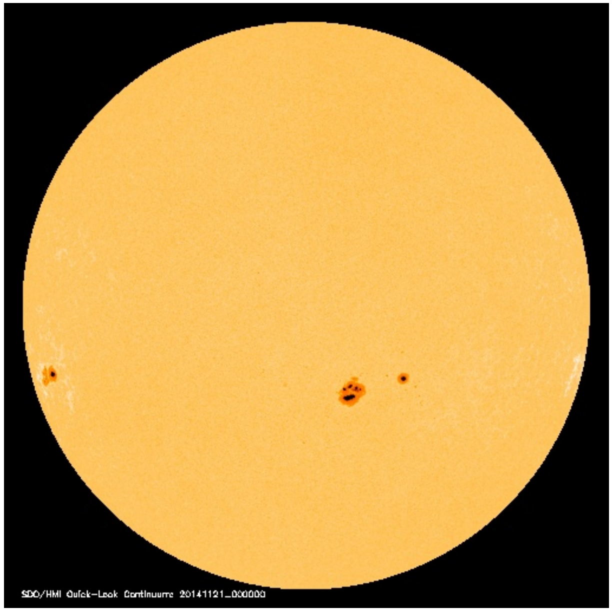
(Trace)

Solar Magnetic Field

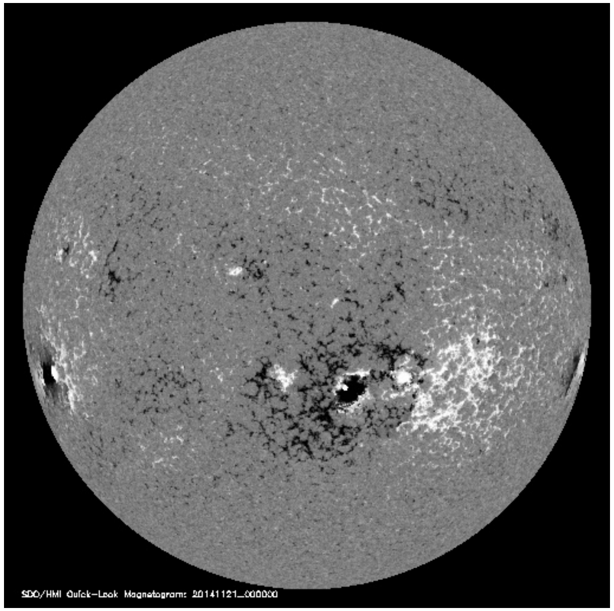
2014-11-20, 13:00



Corona, 171Å



White Light

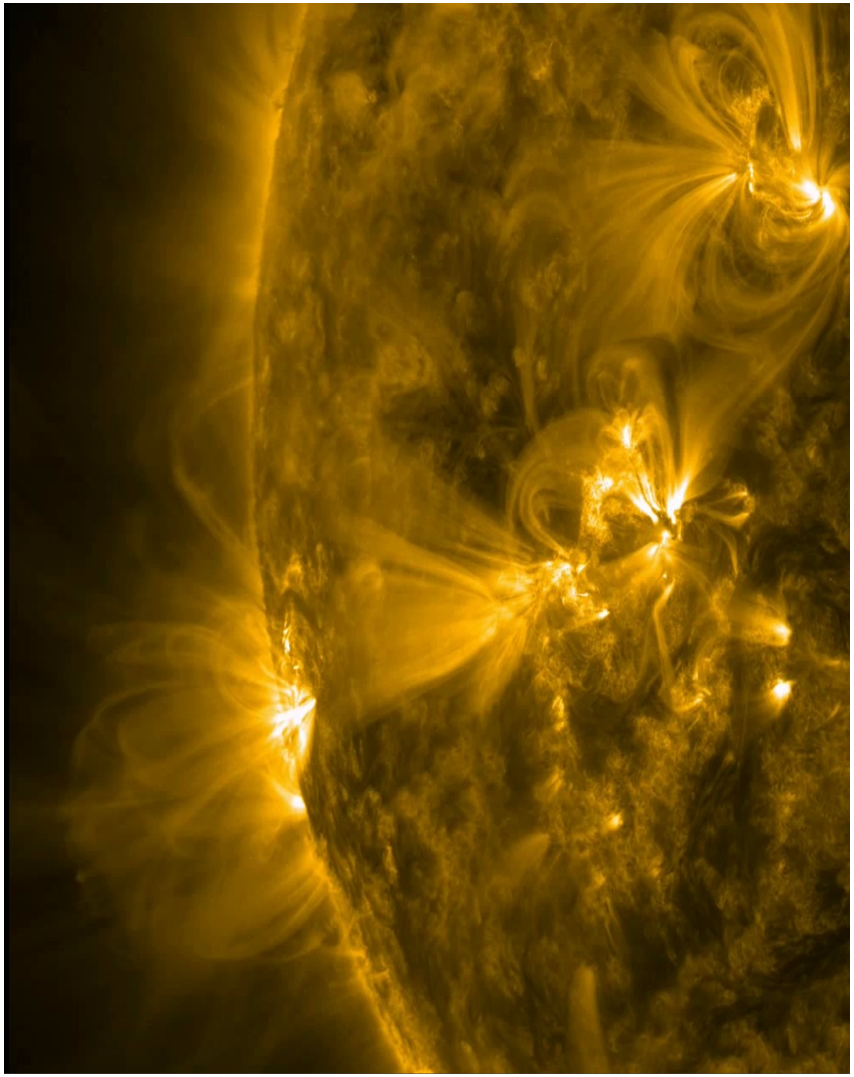


HMI Magnetogram

(SOHO)

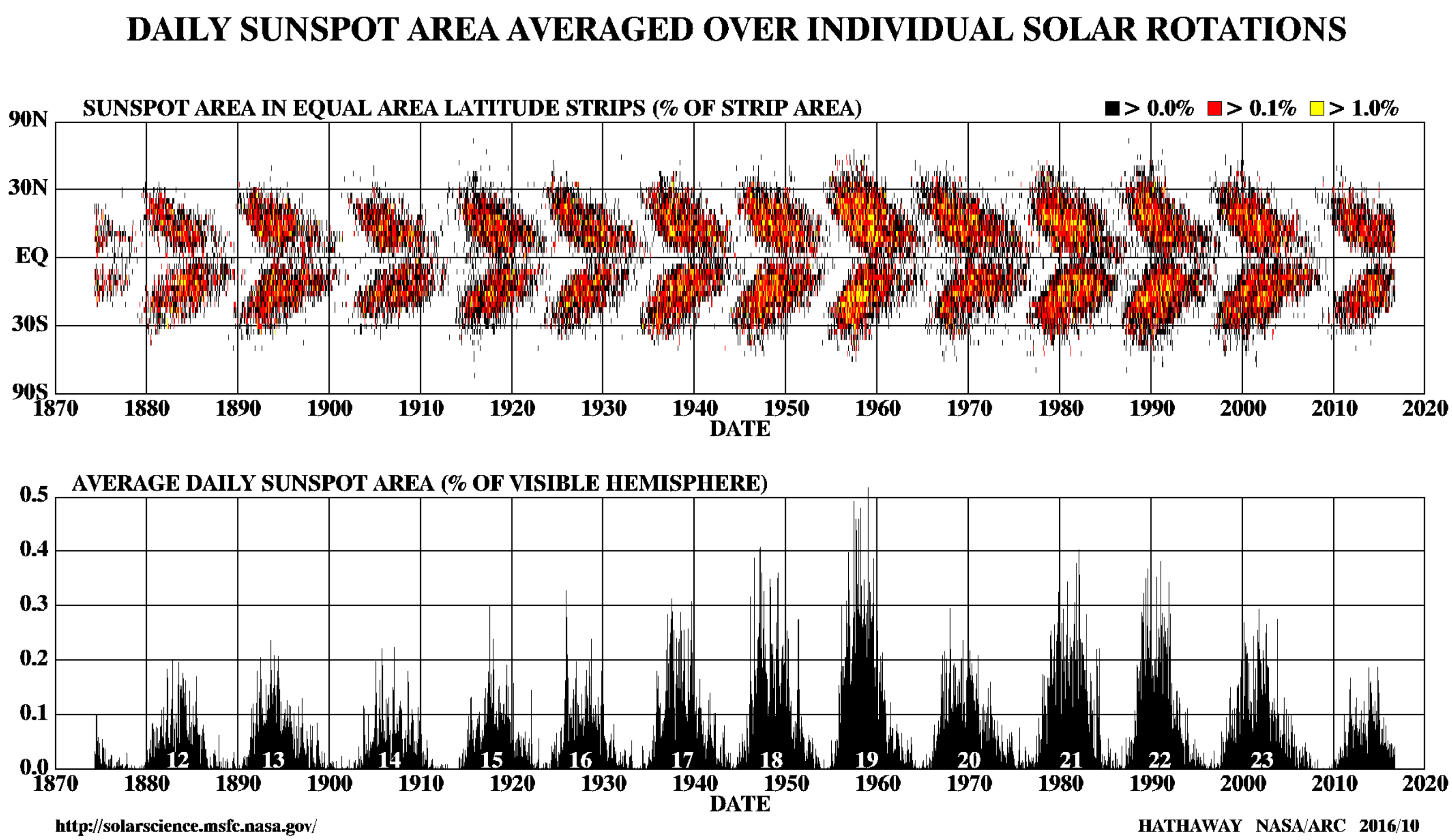
Magnetically active regions give rise to sunspots.
Magnetic loops are anchored at locations of intense magnetic field.

Solar Magnetic Field



(NASA)

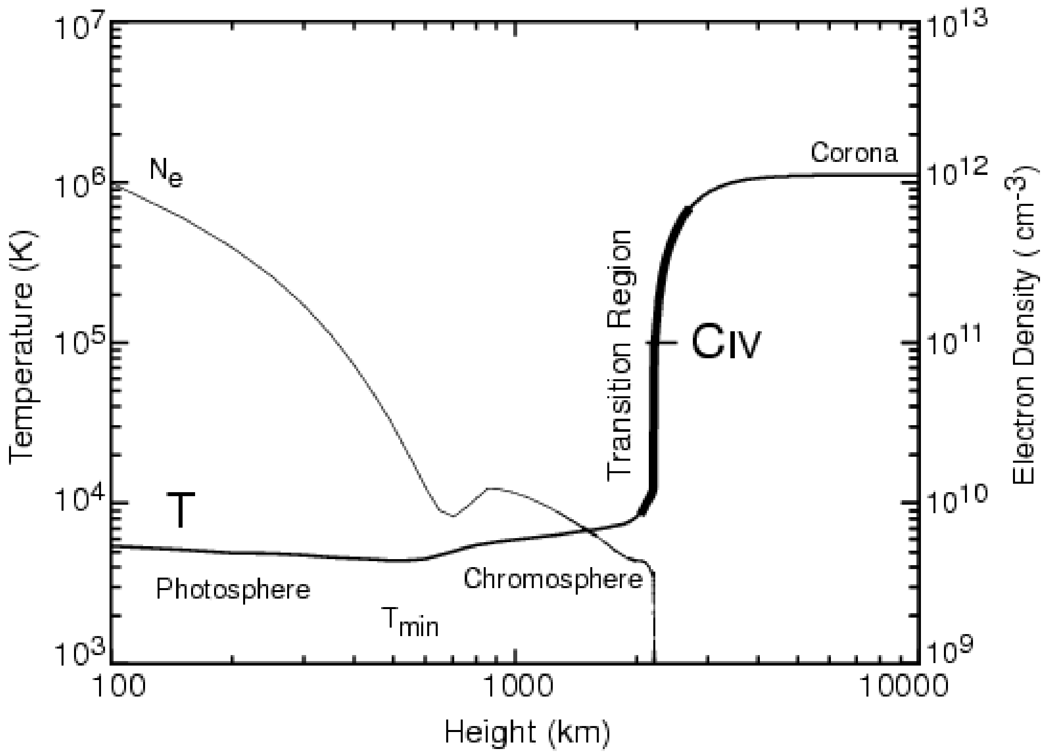
Solar Magnetic Field



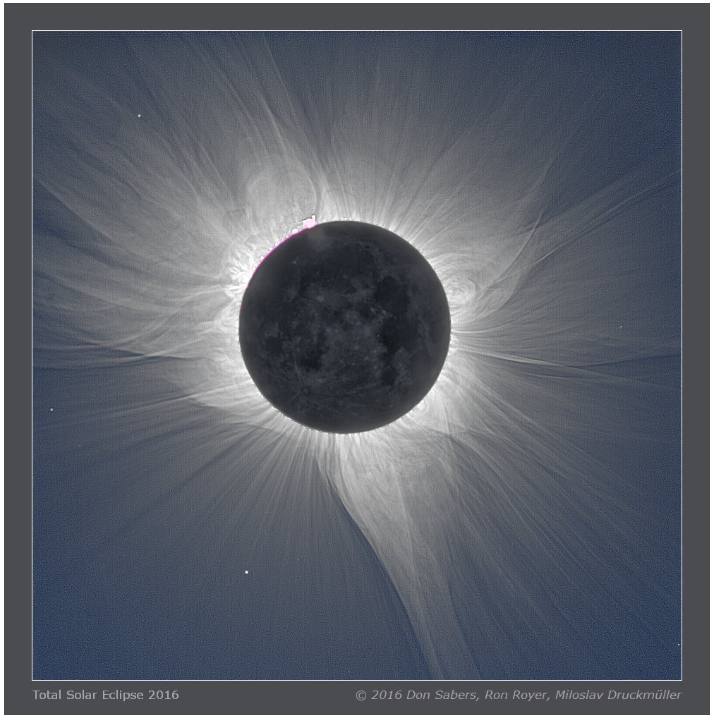
(NASA)

- Dynamo mechanism generating the solar magnetic field through turbulent motions.

Solar Corona



(Gary 2007)



(Sabers, Royer, Drückmuller 2016)

Heating models:

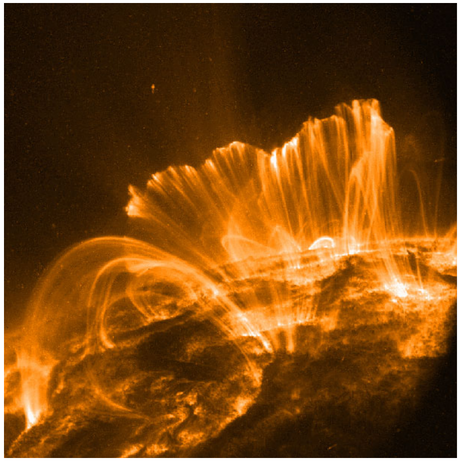
DC
- Magnetic Reconnection
- Flares
- Mass Flows

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

Magnetic Field Relaxation

Solar corona: low plasma beta and magnetic resistivity

(TRACE)

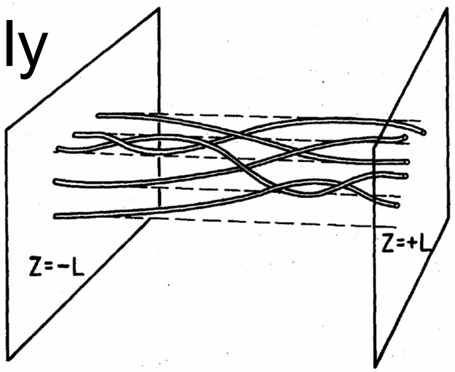


- Force-free magnetic fields
- Minimum energy state

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

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

(Parker 1972)

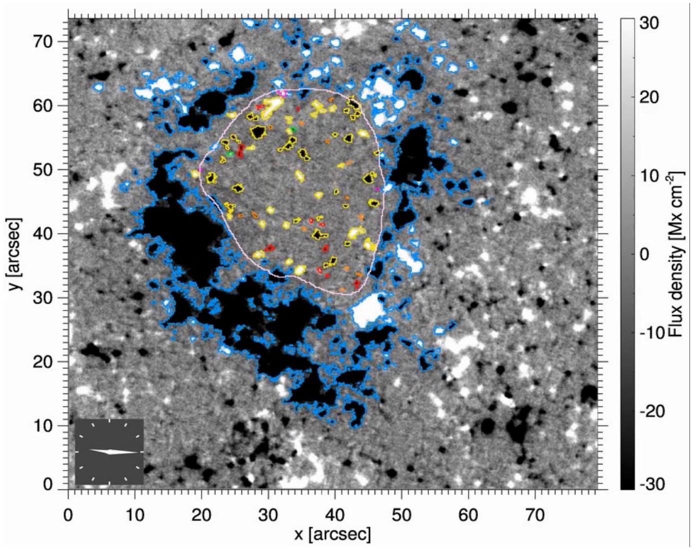


Braided fields from foot point motion complex enough. *(Parker 1983)*

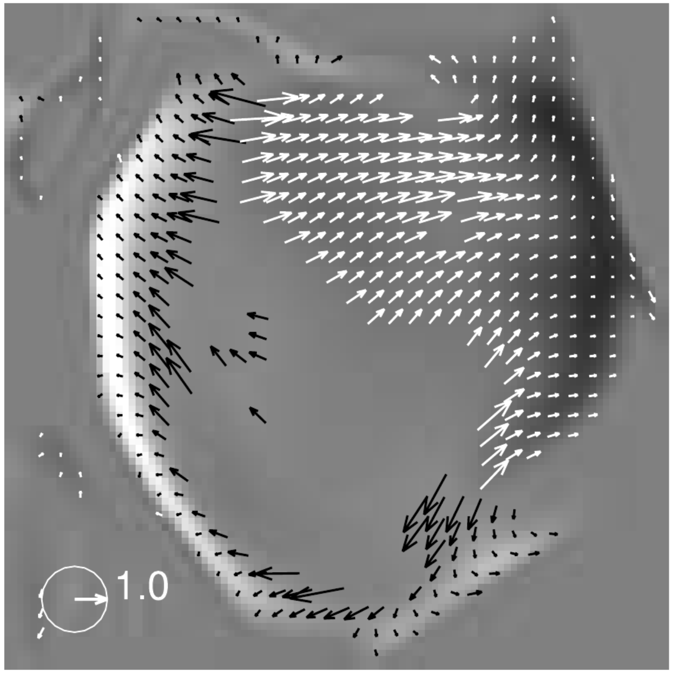
Solutions possible with filamentary current structures (sheets).

(Mikic 1989, Low 2010)

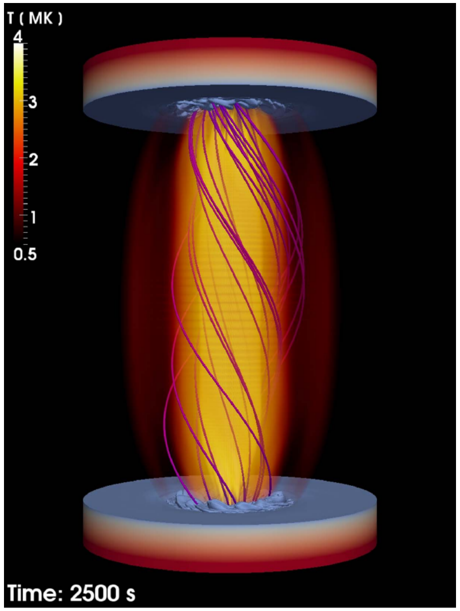
Photospheric Motions



(NASA)



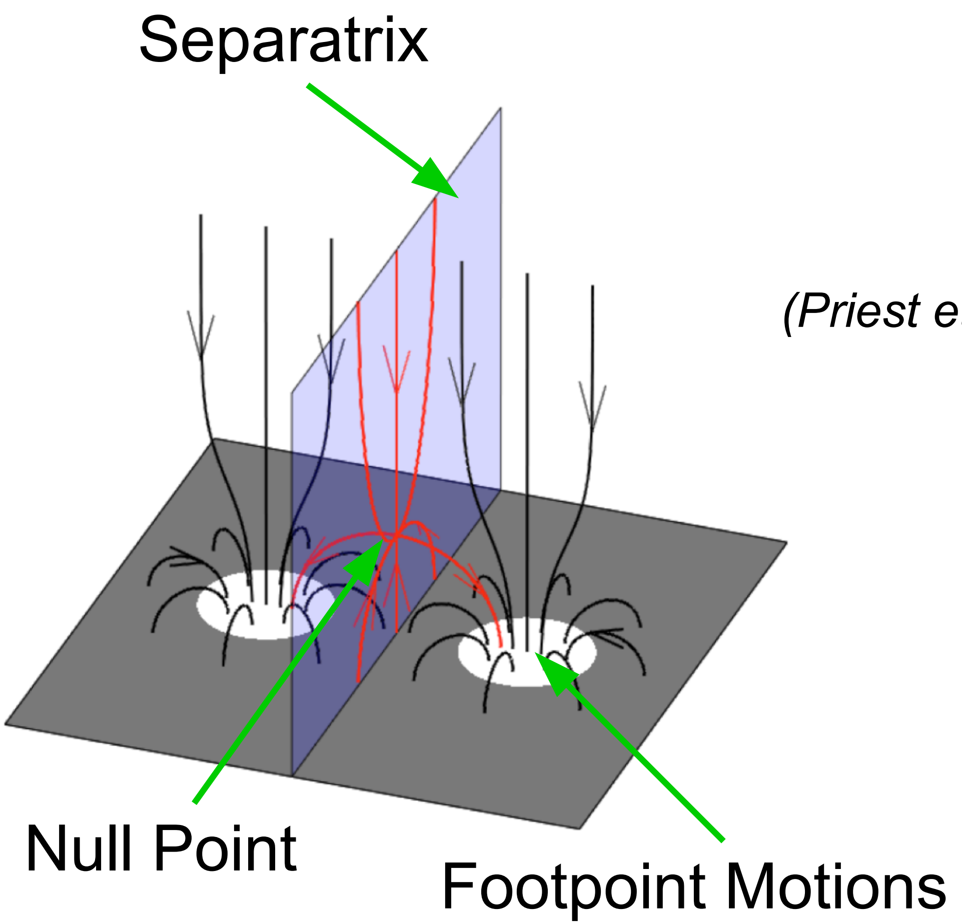
Local Correlation Tracking *(Chae 2007)*



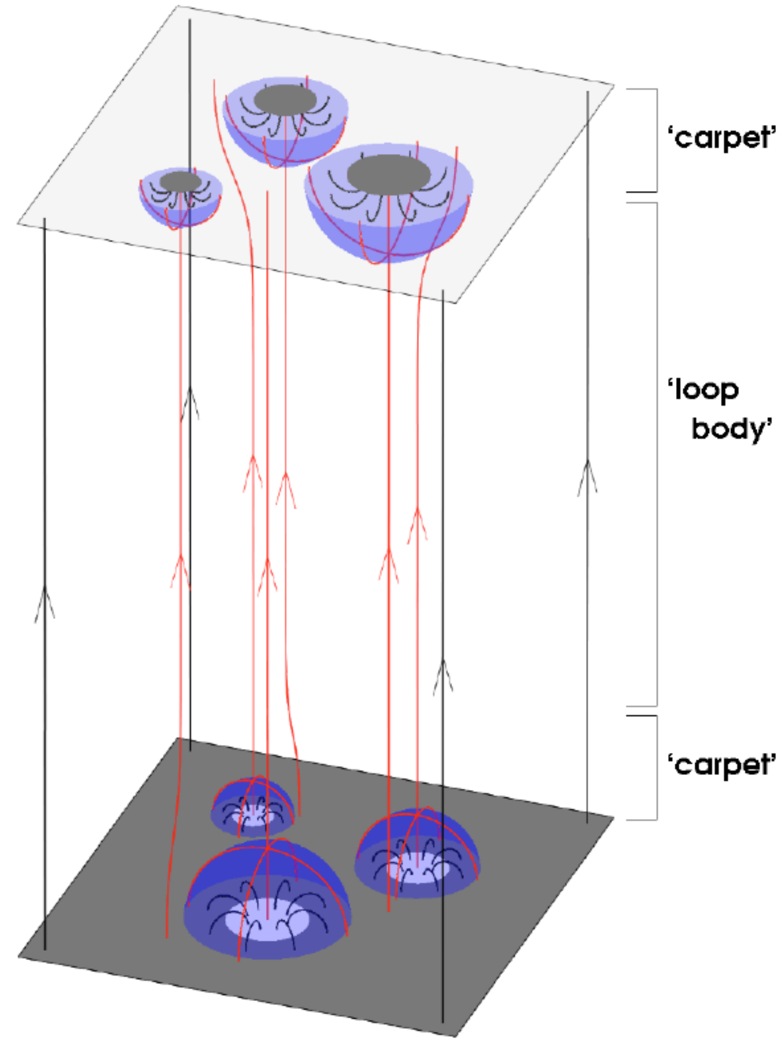
(Reale 2016)

- Braiding of magnetic loops.
- Injection of Energy

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.

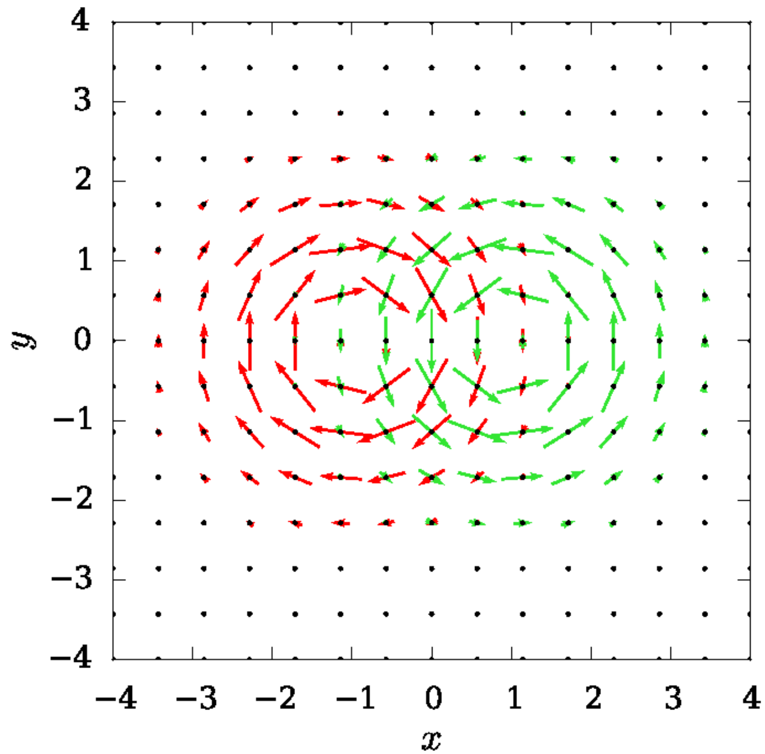
$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{U} \times \mathbf{B} + \eta \nabla^2 \mathbf{A}$$

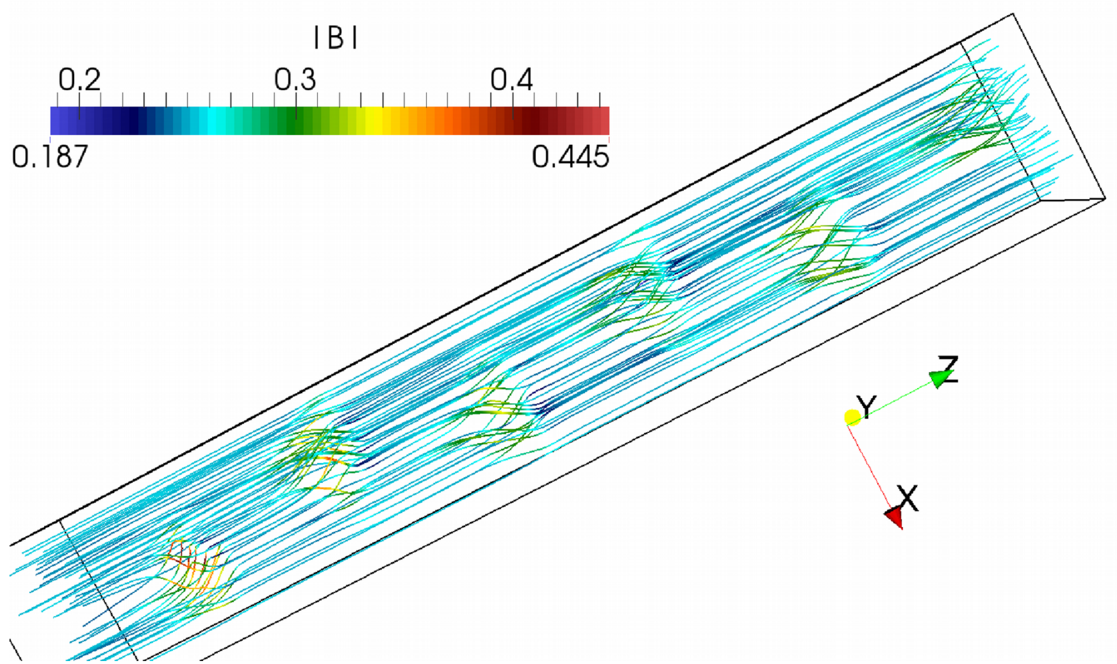
$$\frac{\mathrm{D}\mathbf{U}}{\mathrm{D}t} = -c_{\mathrm{S}}^2 \nabla \ln \rho + \mathbf{J} \times \mathbf{B}/\rho + \mathbf{F}_{\mathrm{visc}}$$

$$\frac{\mathrm{D} \ln \rho}{\mathrm{D}t} = -\nabla \cdot \mathbf{U}$$

Initially homogeneous field, E3 type of boundary driving.

E3 Experiments

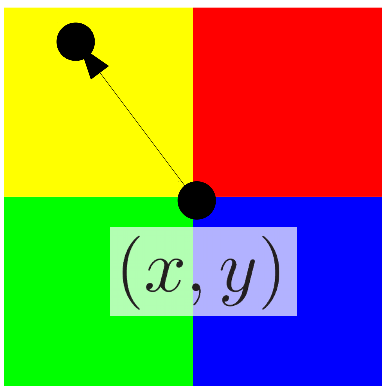


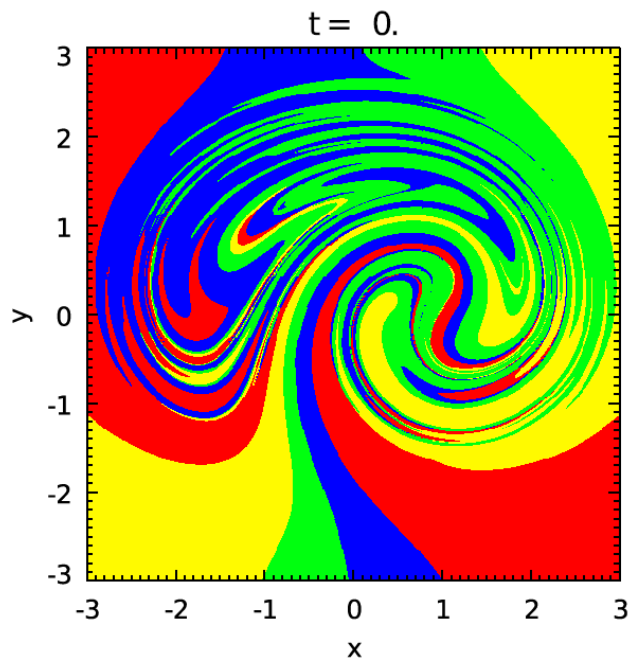


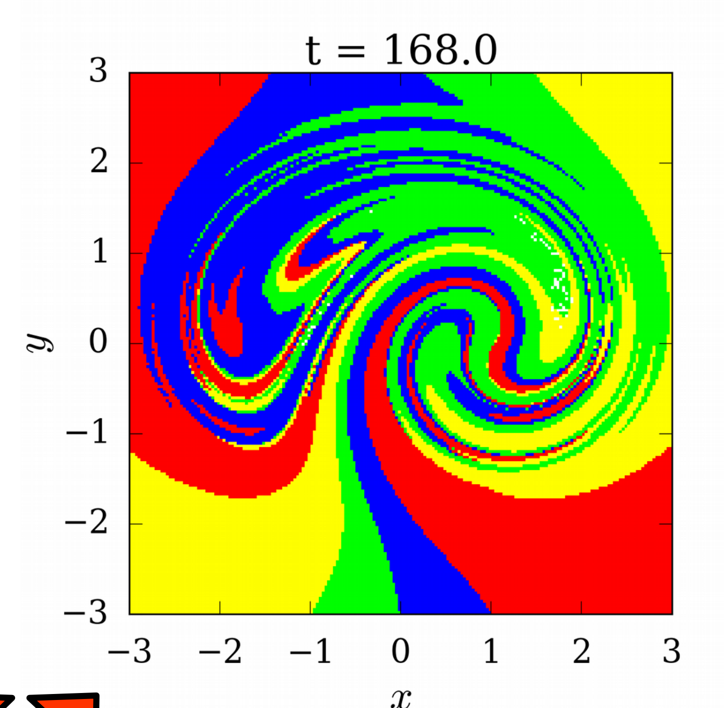
- Blinking Vortex Footpoint Driving
- Braid propagates into domain.

E3 Experiments

Field Line Mapping





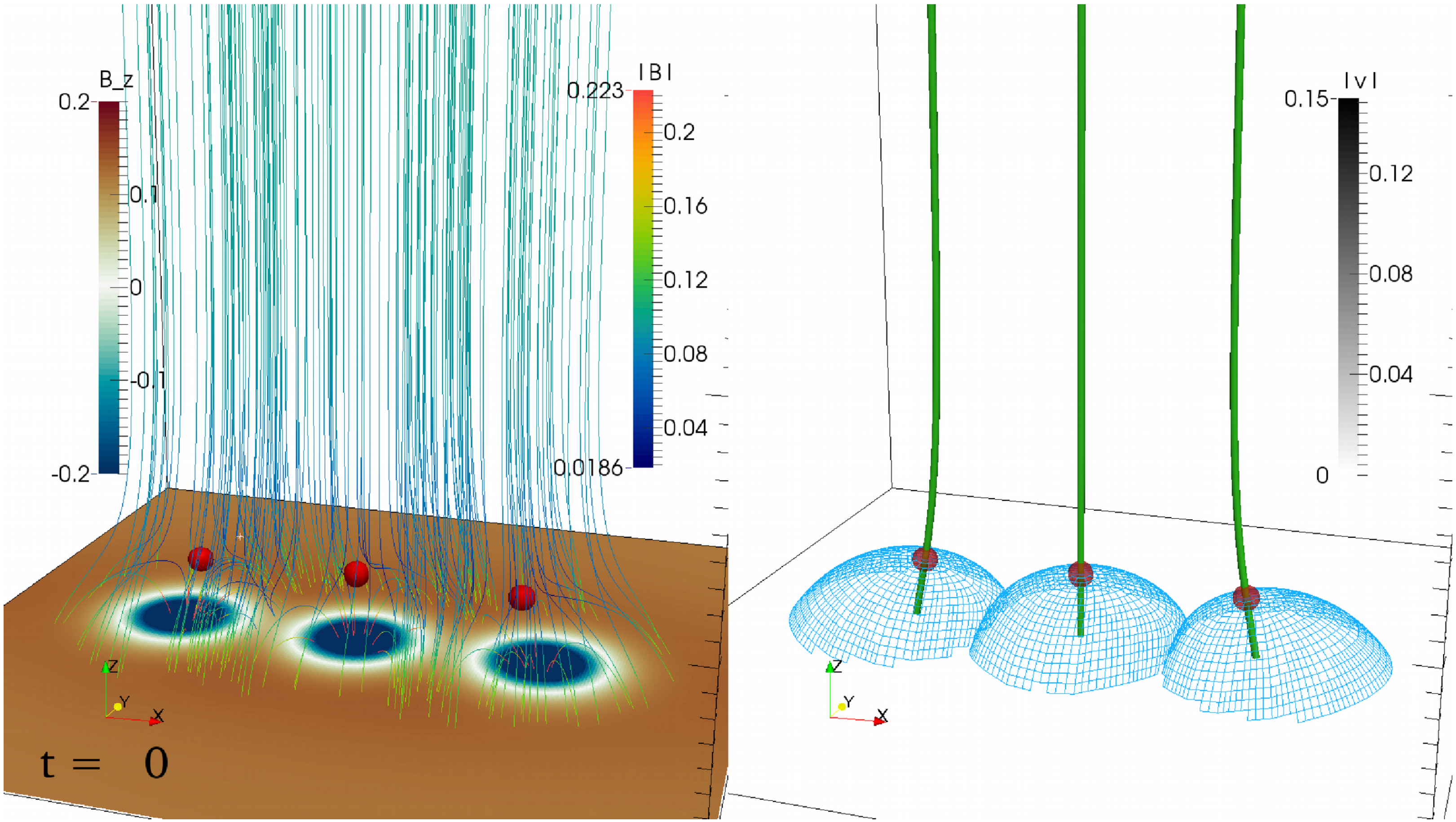


(Yeates et al. 2010)

vs.

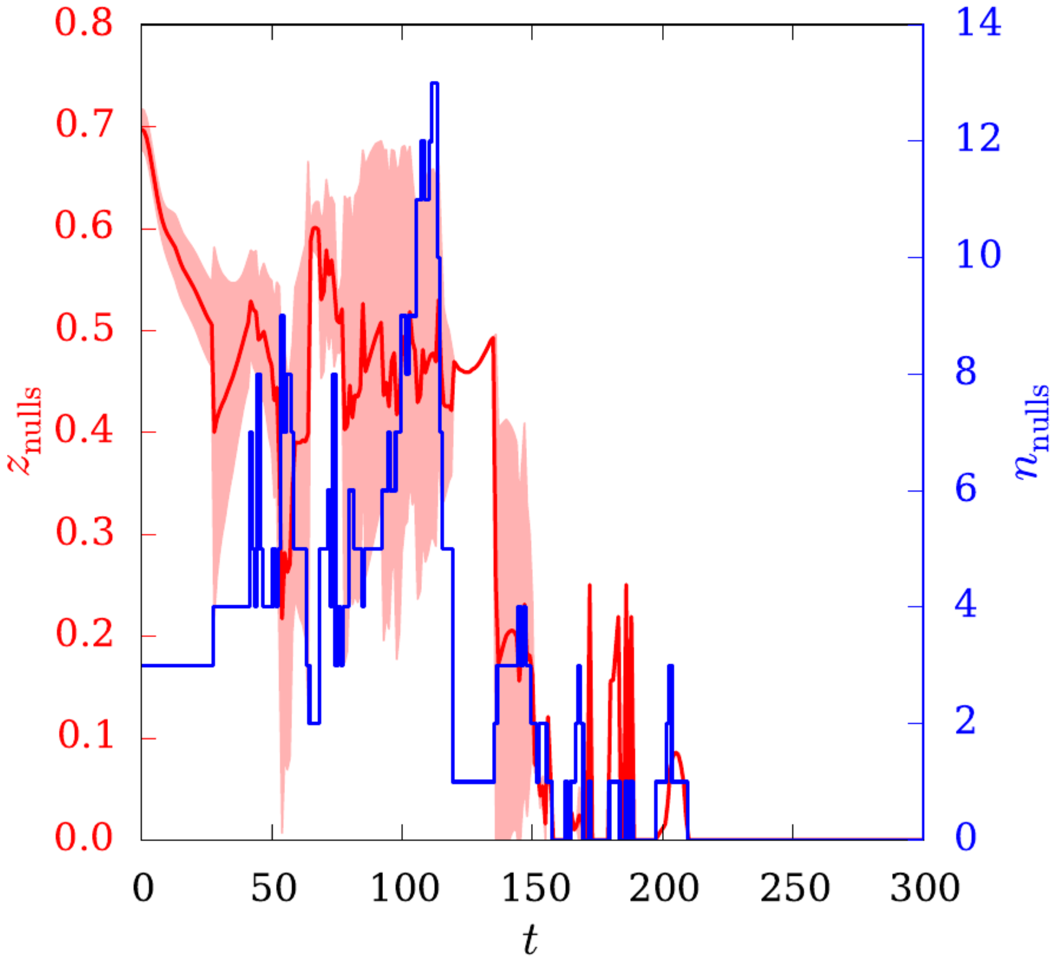
- Controlled change of field line connectivity can be achieved through footpoint motions.

Null Points



- Null pair creation/annihilation.
- Footpoint motion can alter the field line topology.

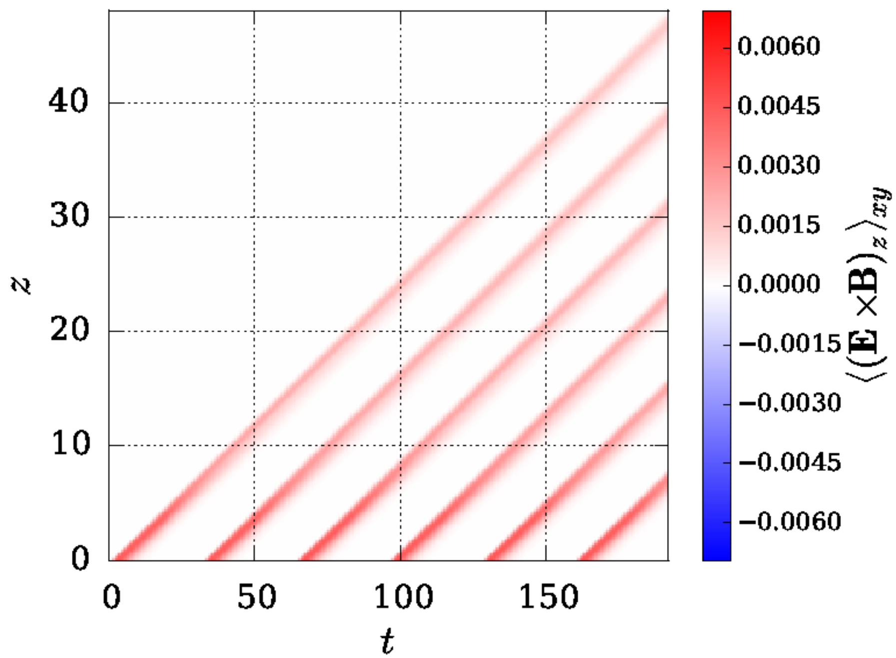
Null Points



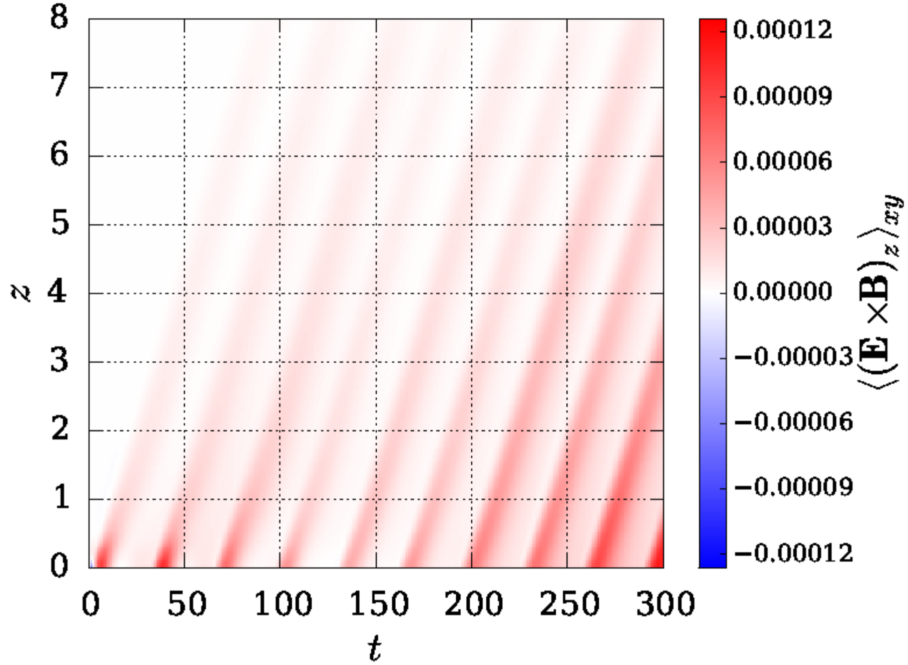
- Mixing enhances diffusivity.
- Null points diffusively annihilate.

Energy Propagation

Homogeneous $\mathbf{B}_0$

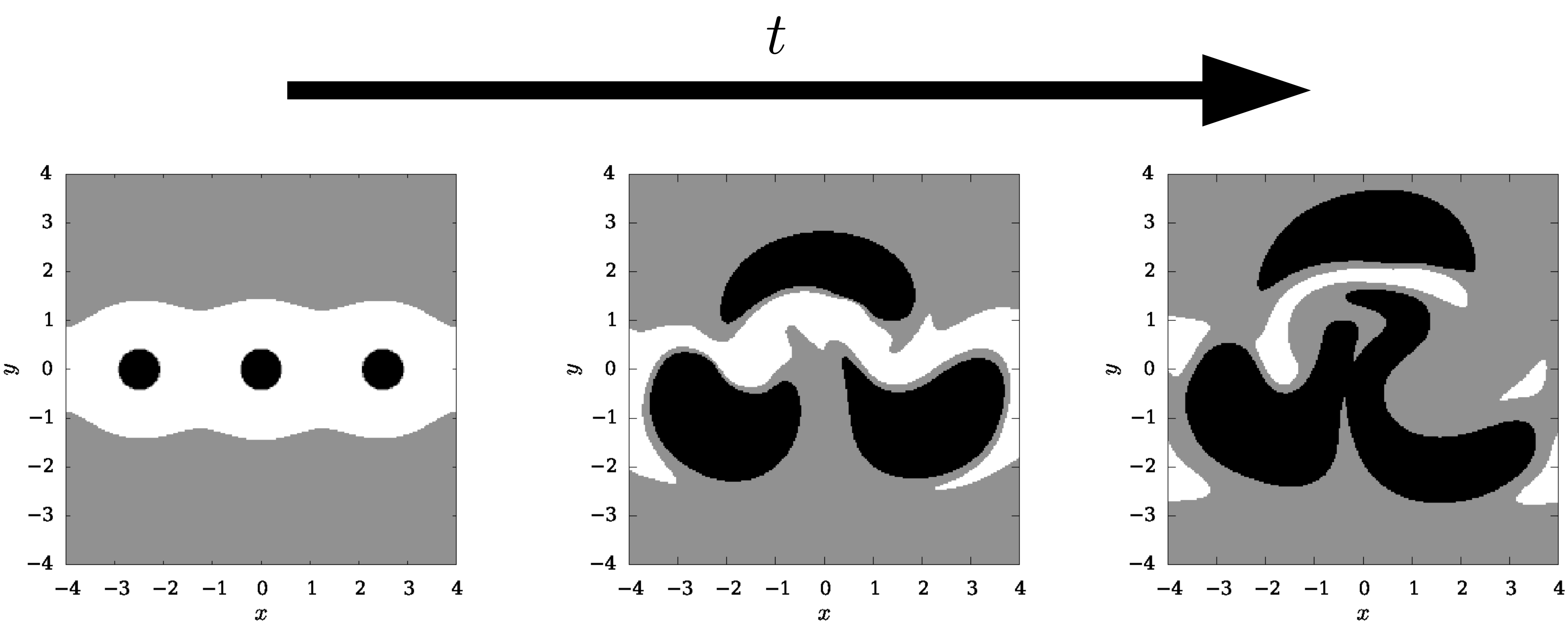


Magnetic Carpet $\mathbf{B}_0$



- Topology efficiently inhibits energy propagation.
- After change of topology → efficient energy transport.

Polarity Mixing



White: $B < 0$

Grey: $B \approx 0$

Black: $B > 0$

- Magnetic field polarities are efficiently mixed through footpoint motions.

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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