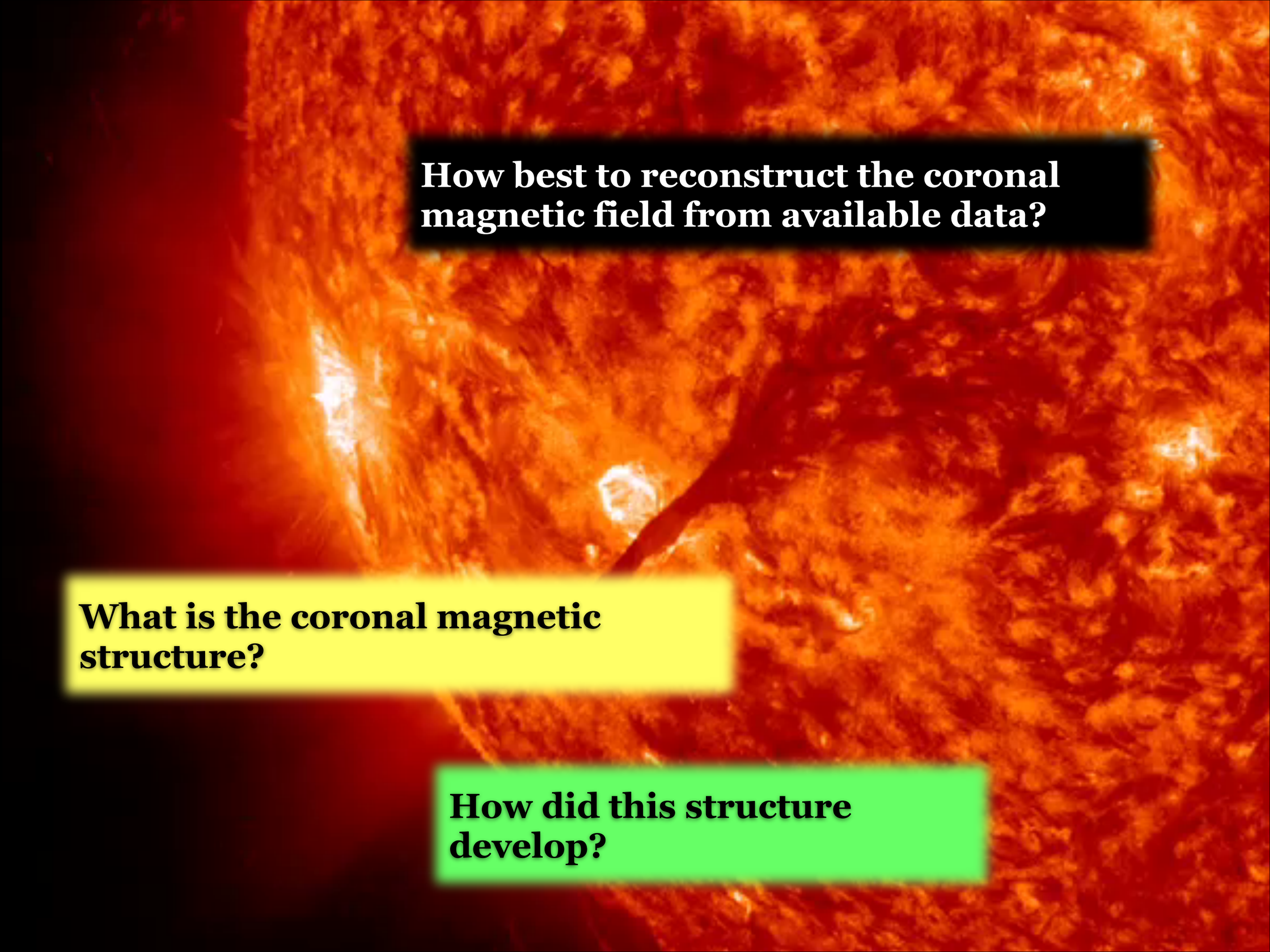
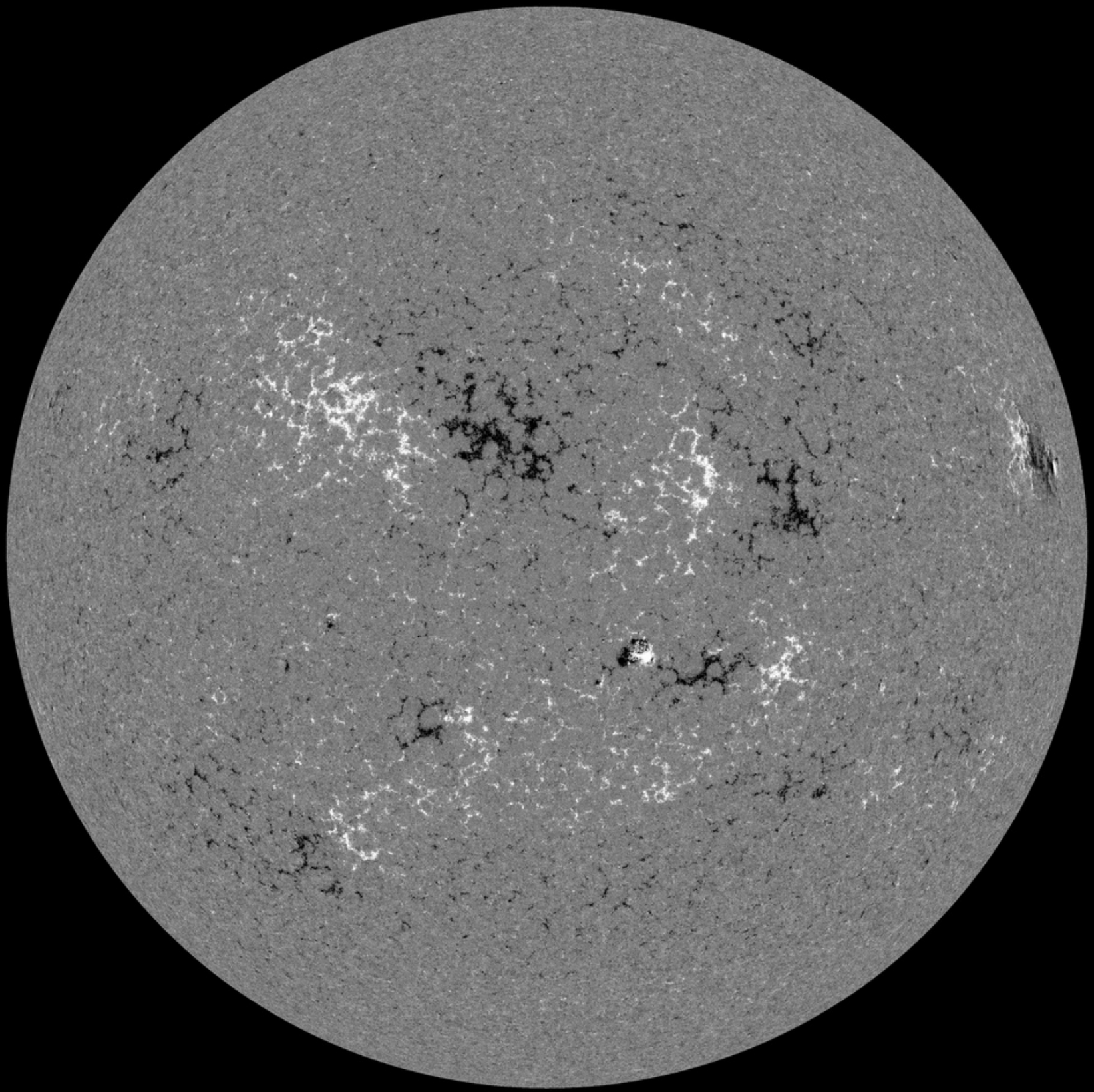
Filaments, Chirality and Magnetic Hysteresis

Anthony Yeates (Mathematical Sciences)
with Duncan Mackay (St Andrews)

Astronomy Lunch Talk, 14-June-2013


How best to reconstruct the coronal magnetic field from available data?
What is the coronal magnetic structure?
How did this structure develop?



SDO/HMI Quick-Look Magnetogram: 20130612_071500

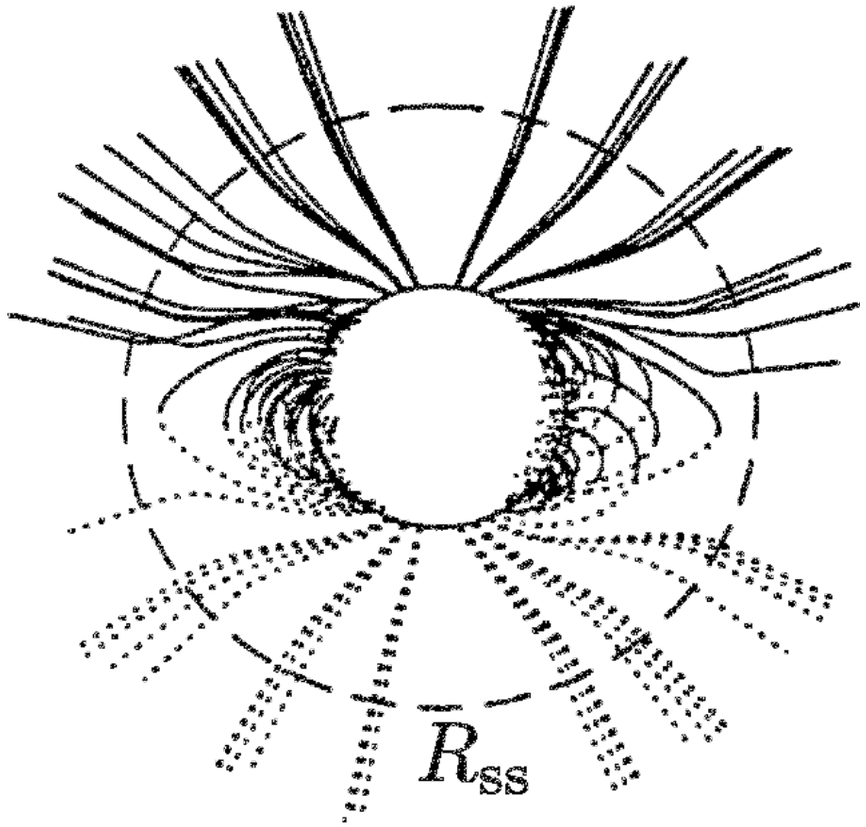
MHD Momentum equation:

$$\rho\left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v}\cdot\nabla\mathbf{v}\right) = \mathbf{j}\times\mathbf{B} - \nabla p + \rho\mathbf{g} + \nabla\cdot(\nu\rho\nabla\mathbf{v})$$

Neglecting small terms gives a **force-free** equilibrium $\mathbf{j}\times\mathbf{B} = 0$

Potential field

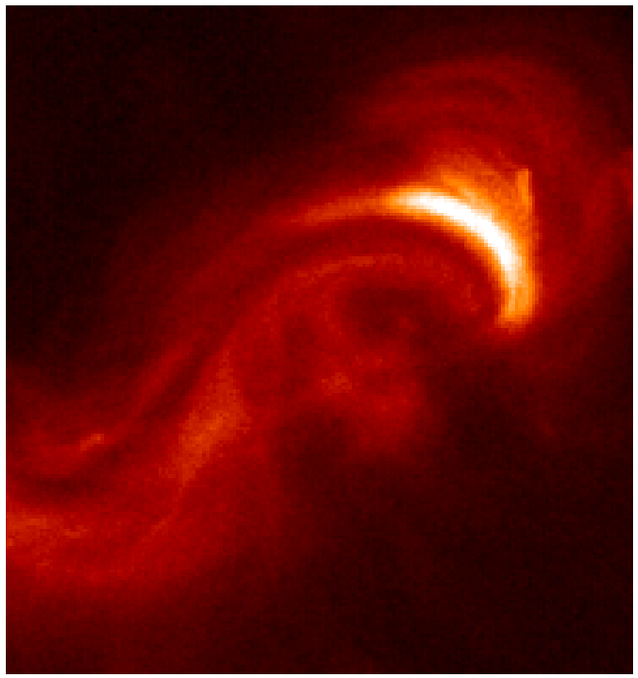
$$\mathbf{j} = 0$$



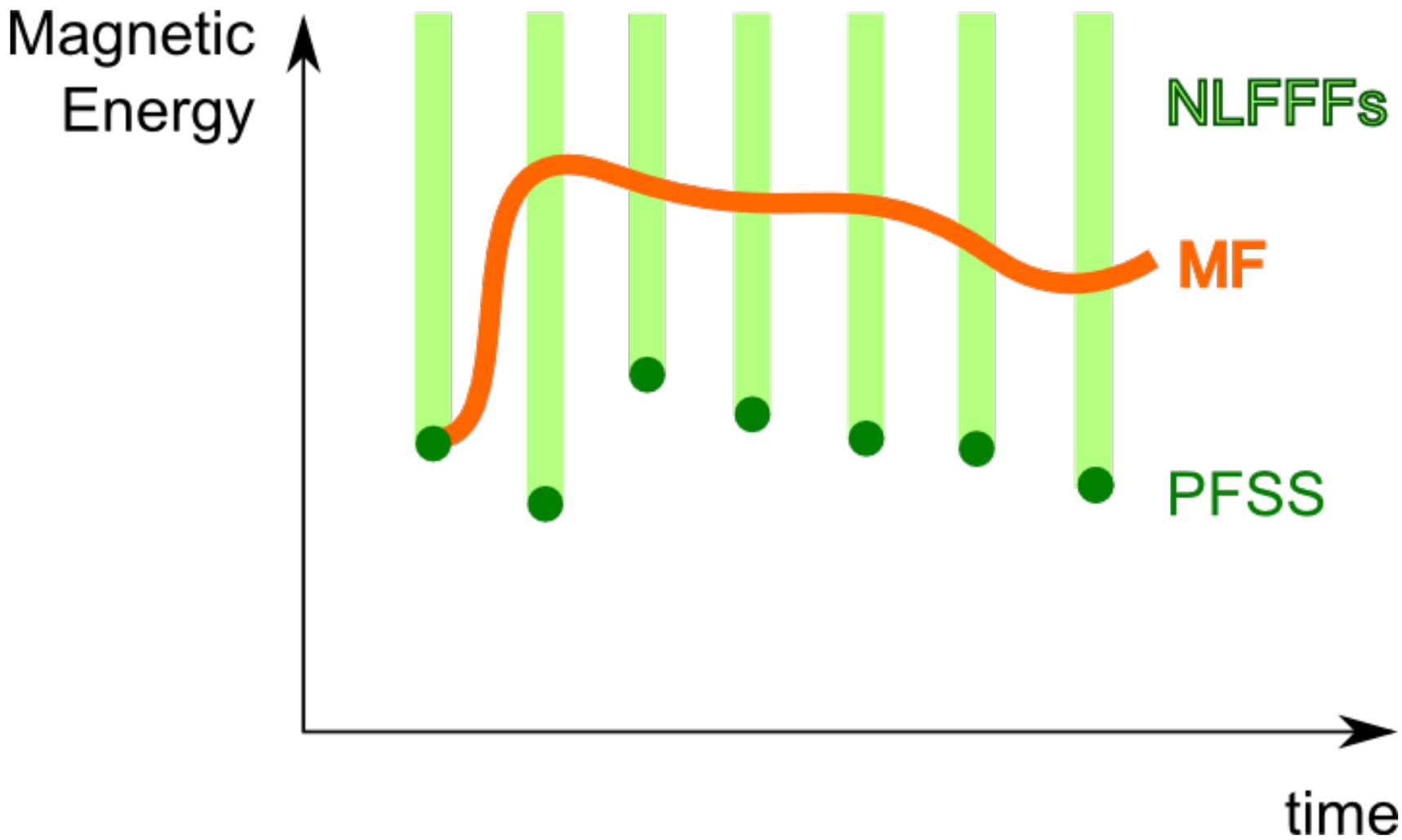
Altschuler & Newkirk, *Sol Phys* 1969
Schatten, Wilcox & Ness, *Sol Phys* 1969

Nonlinear Force-free field

$$\Longrightarrow \quad \mathbf{j} = \alpha\mathbf{B}$$



Problem: NLFFF solution not unique.



Hysteresis - state depends on memory.

e.g. Amari, Luciani, Mikic & Linker, *ApJ* 2000
MacNeice et al., *ApJ* 2004
Santos, Büchner & Otto, *A&A* 2011
Lionello, Linker, Mikic & Riley, *ApJ* 2006
Feng, Jiang, Xiang, et al, *ApJ* 2012

The **magneto-frictional** method solves the induction equation with a fictitious velocity:

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \eta \nabla^2 \mathbf{B}$$

$$\nu \mathbf{v} = \mathbf{j} \times \mathbf{B}$$

Yang, Sturrock & Antiochos, *ApJ* 1986
Craig & Sneyd, *ApJ* 1986

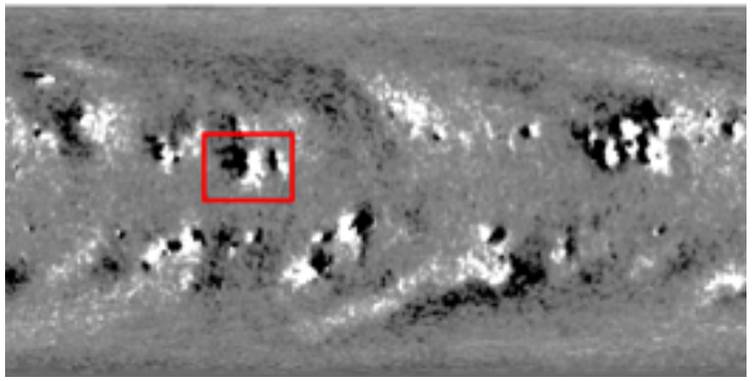
energy decreases monotonically until force-free

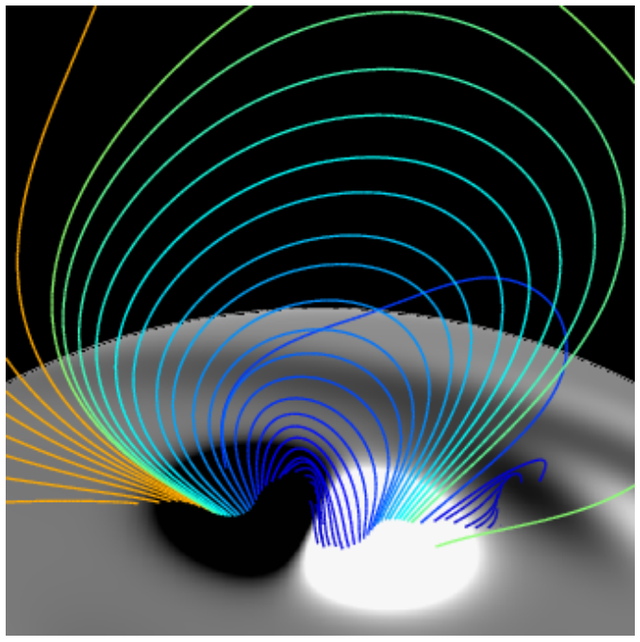
Continual driving by photospheric footpoint motions produces a continuous sequence of force-free equilibria.

van Ballegooijen, Priest & Mackay, *ApJ* 2000

Yeates, Mackay & van Ballegooijen, *Sol Phys*, 2007, 2008

+ flux emergence





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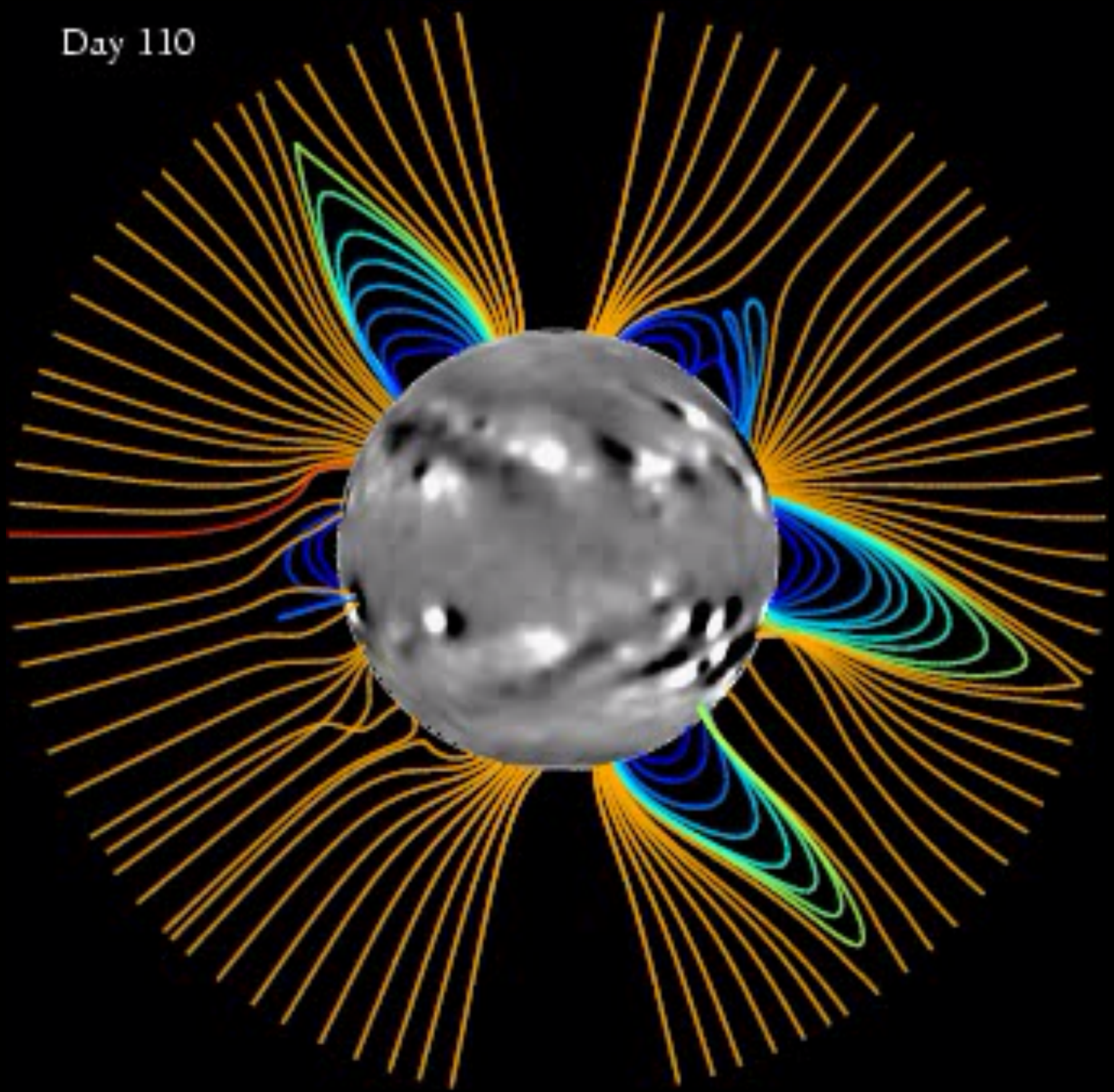
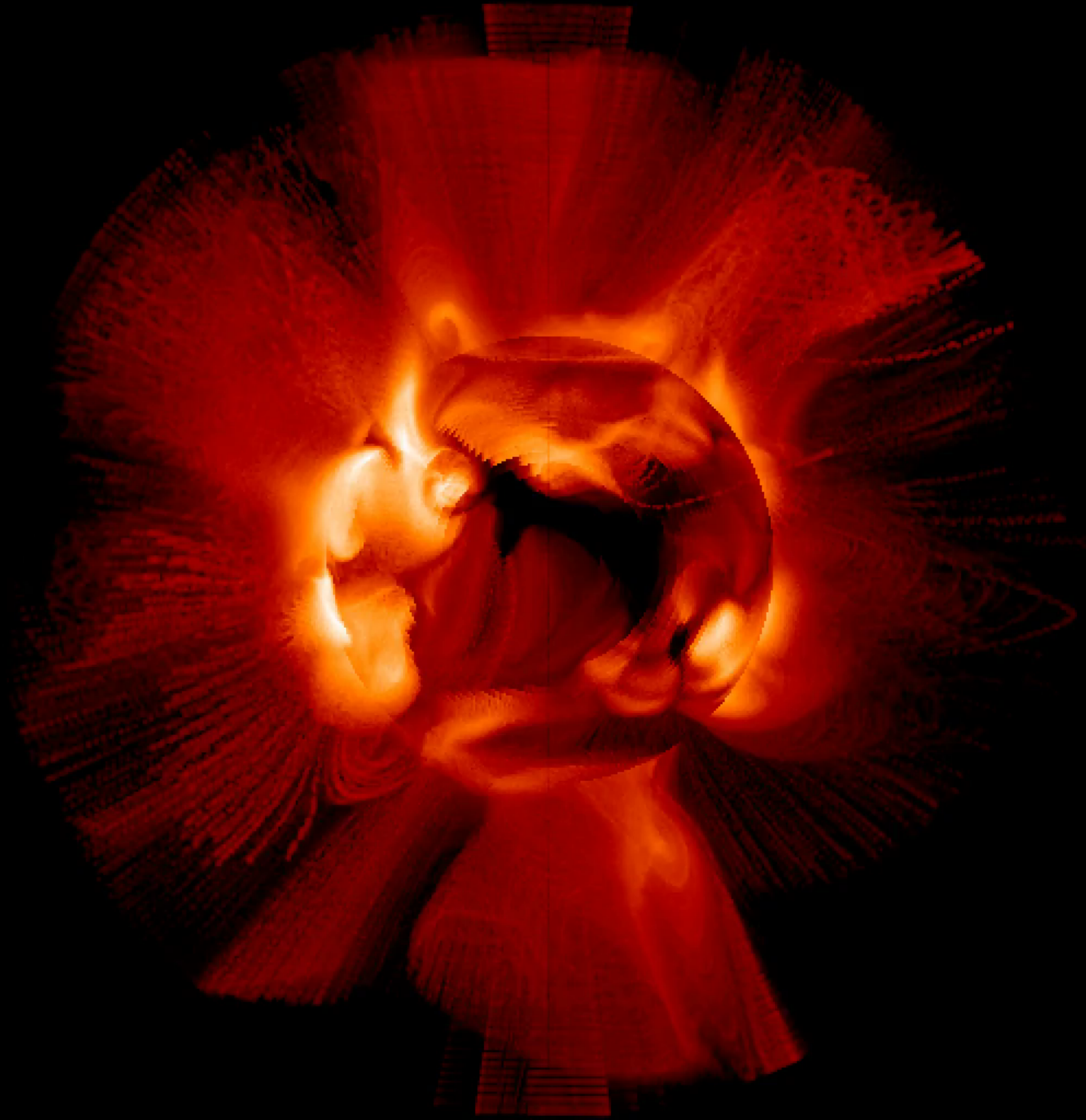
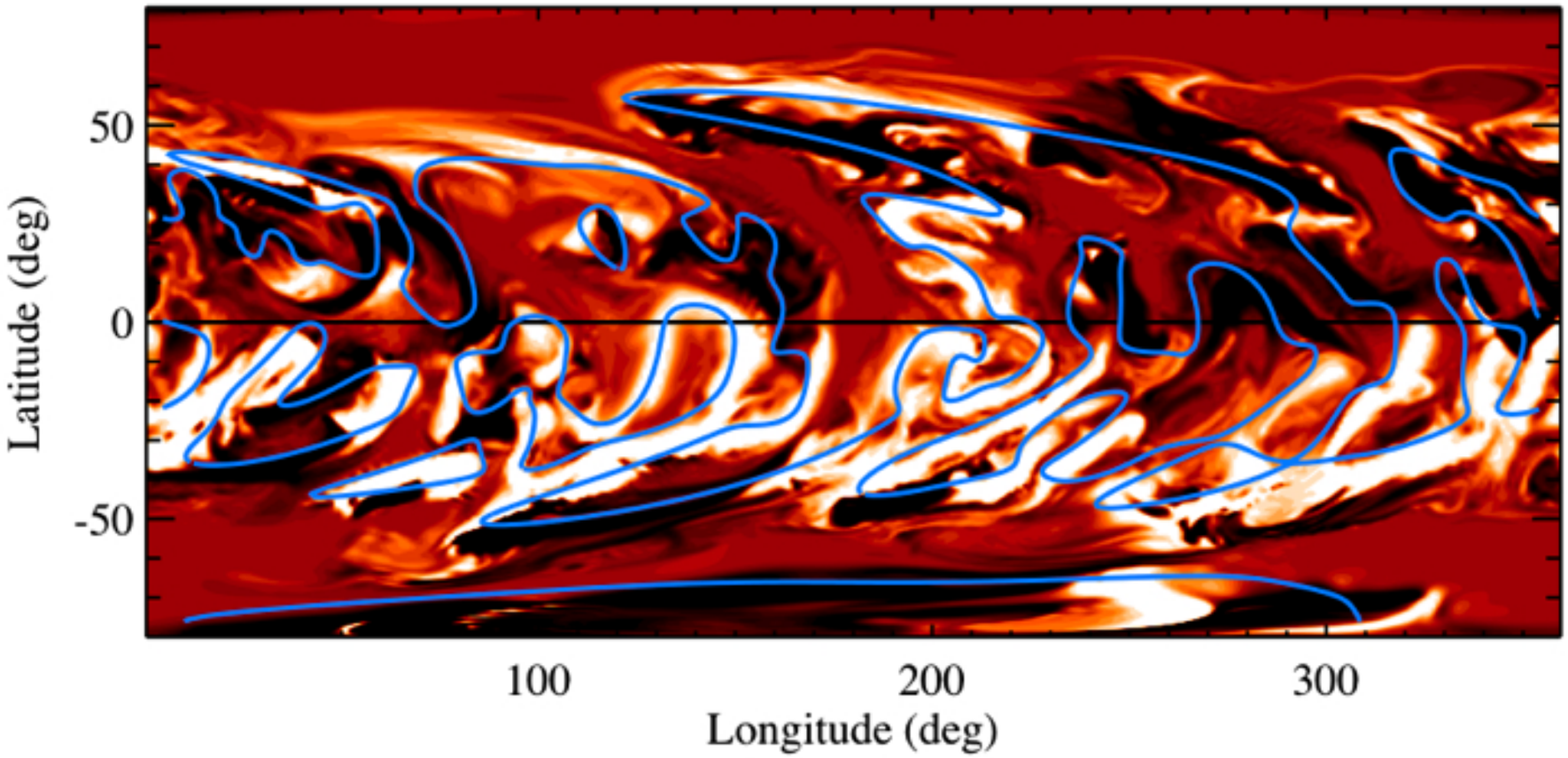


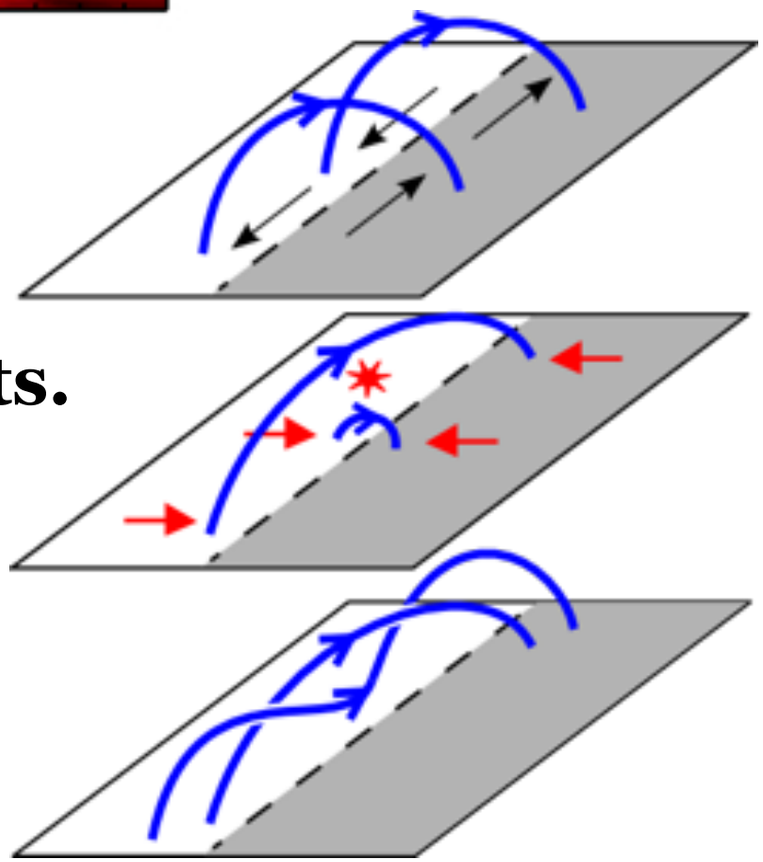


Proxy emissivity Cheung & DeRosa, *ApJ*, 2012

Leads to concentration of **magnetic helicity** above polarity inversion lines.



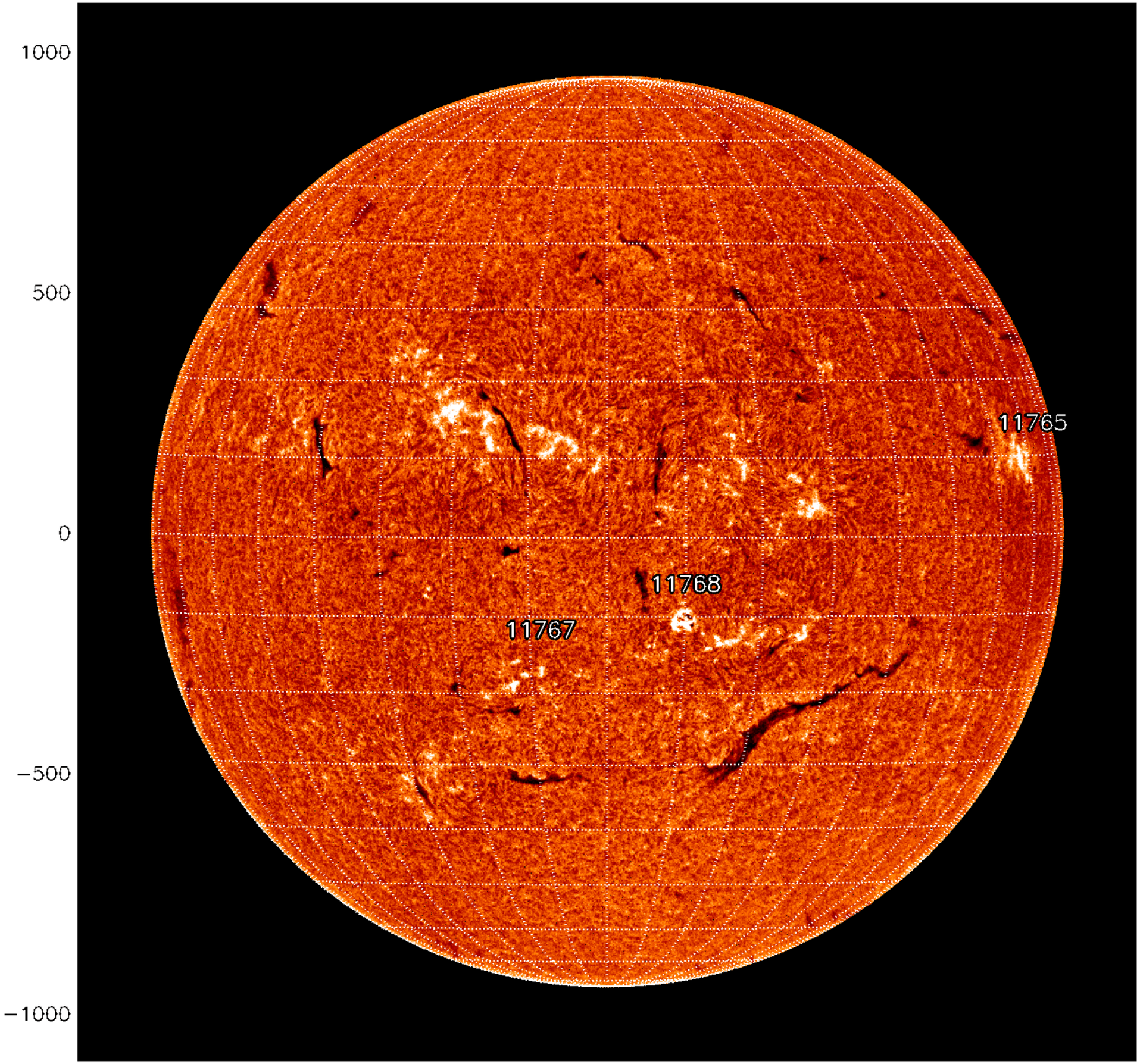
$$\alpha = \frac{\mathbf{j} \cdot \mathbf{B}}{B^2}$$

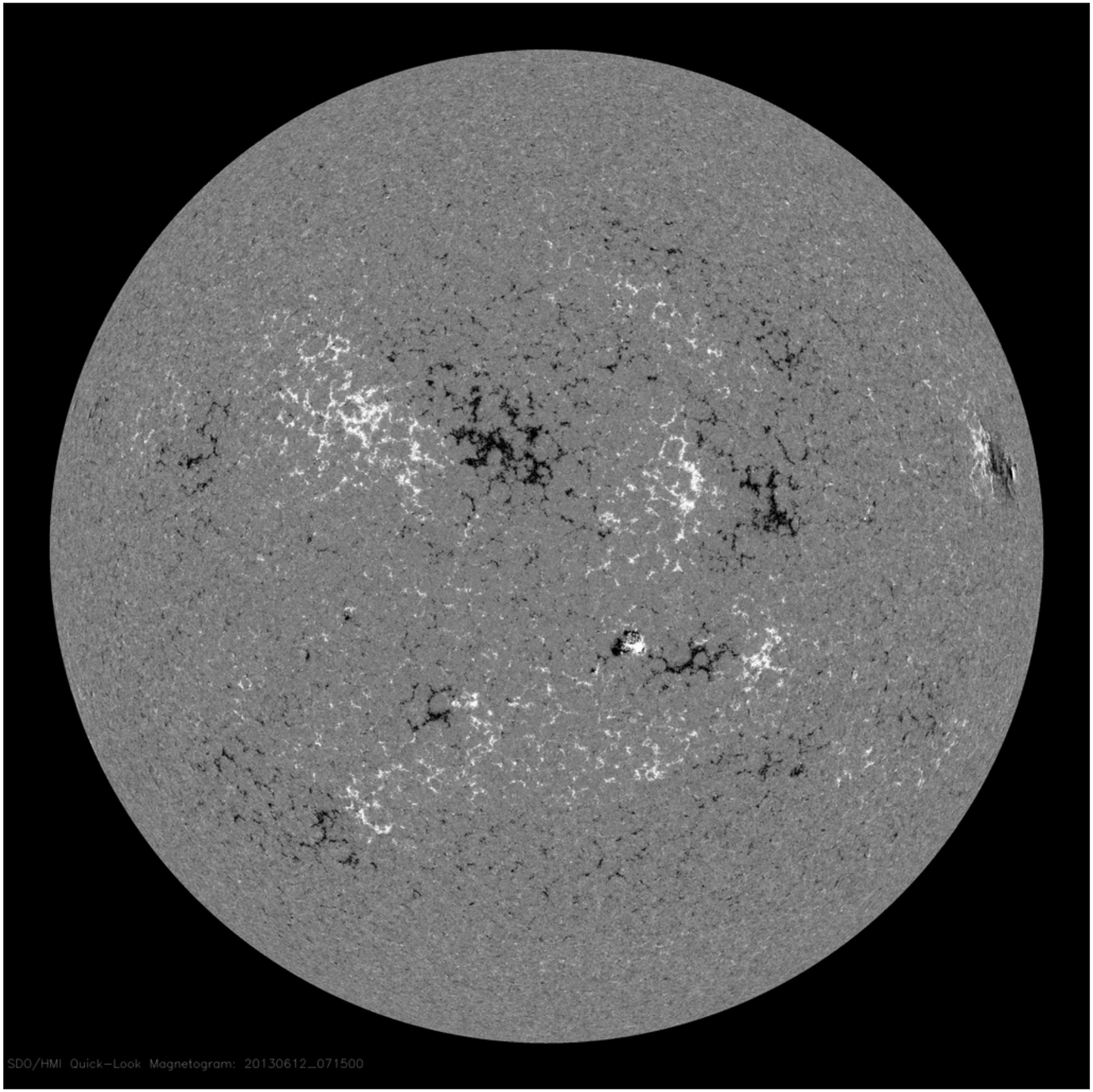


Model for formation of **prominences/filaments.**

van Ballegooijen & Martens, *ApJ* 1989

Kanzelhoehe H−alpha 12−Jun−2013 07:20:17.000

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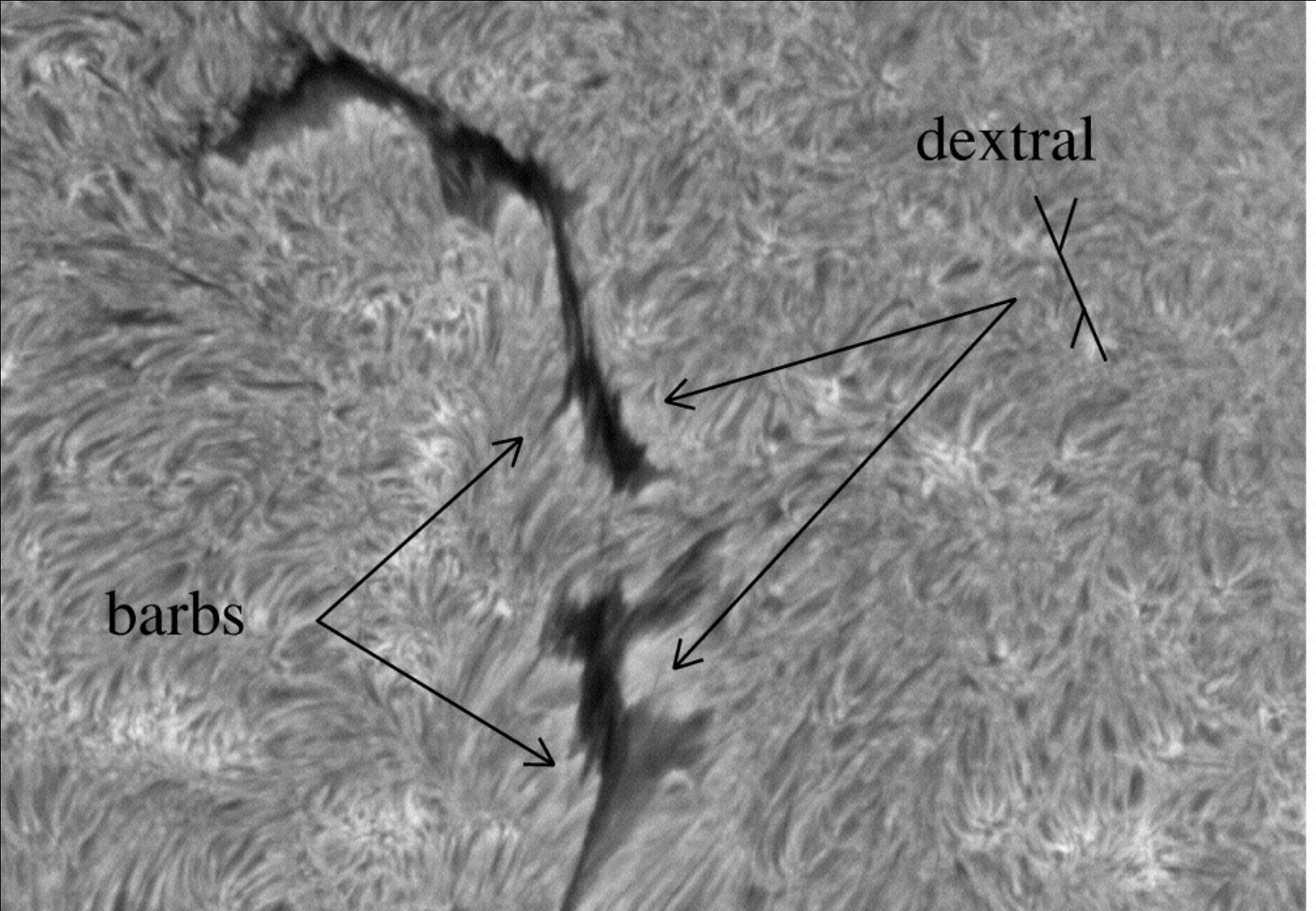
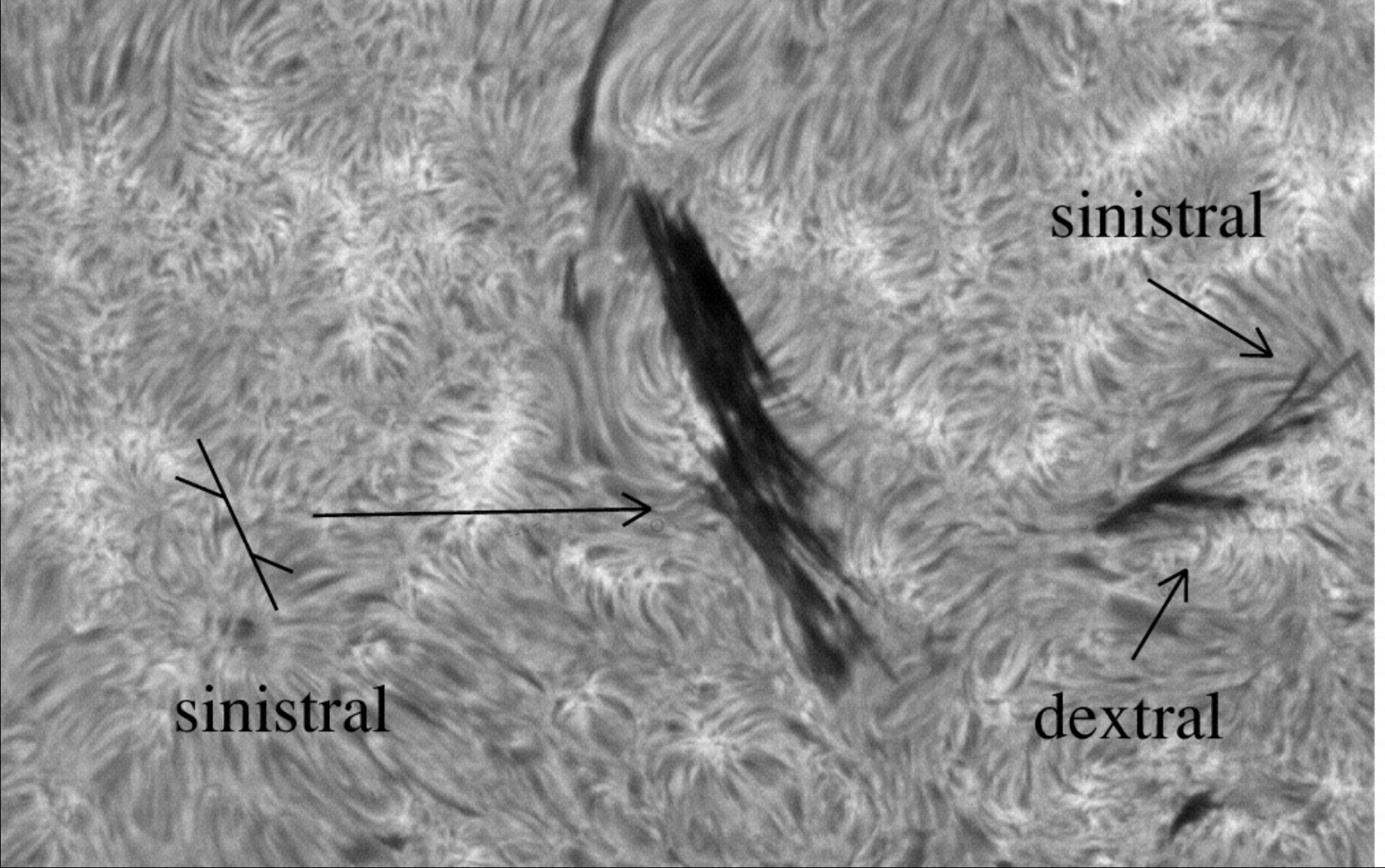


The axial field direction can be tested using only Hα observations.

Filaments have either **dextral** or **sinistral** chirality.

Martin, Bilimoria & Tracadas, 1994



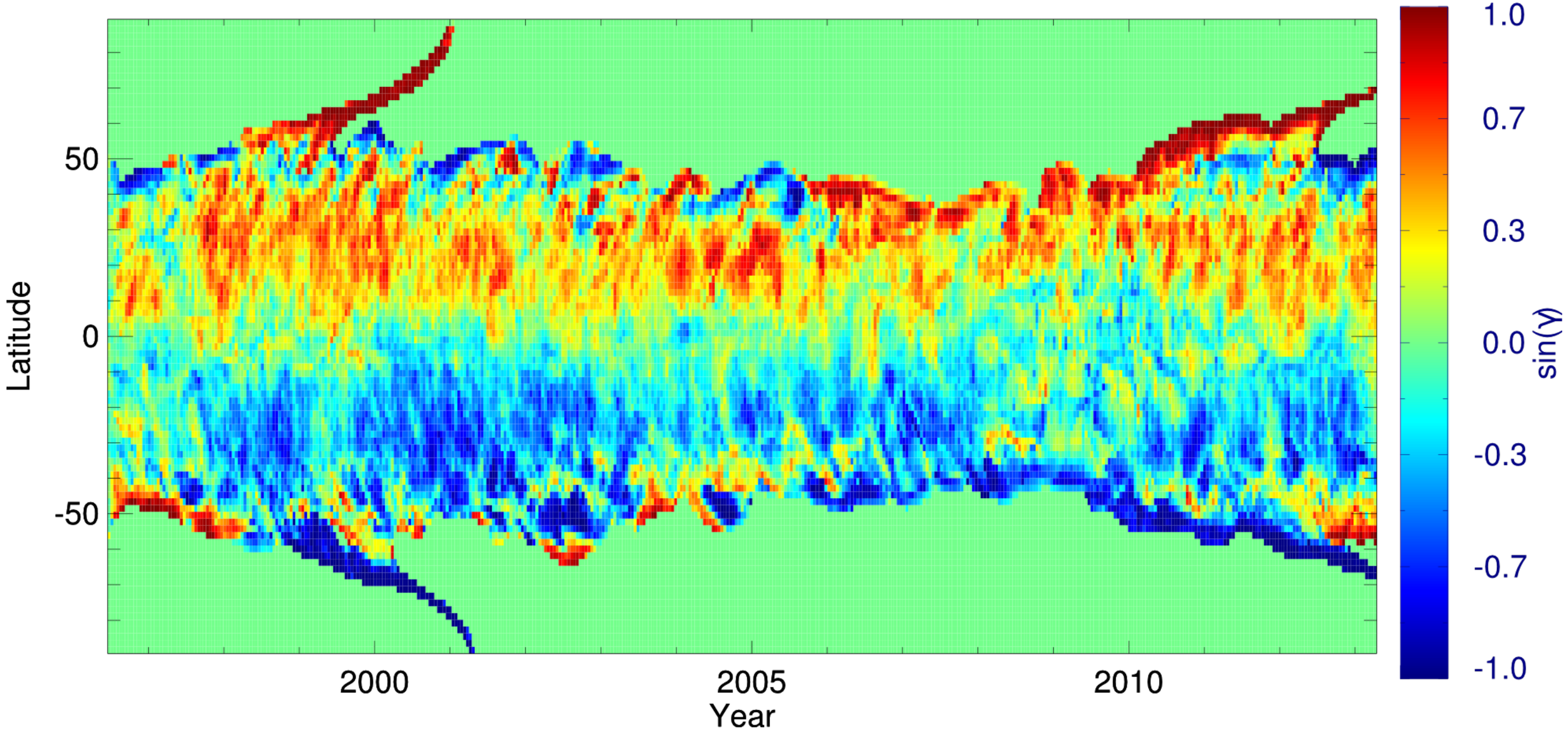
Observed hemispheric pattern of 80% dex/sin in N/S.

Rust, *ApJ* 1967
Leroy, *A&A* 1978
Leroy, Bommier & Sahal-Brechot, *Sol Phys* 1983
Pevtsov, Balasubramaniam & Rogers, *ApJ* 2003
Bernasconi, Rust & Hakim, *Sol Phys* 2005

The model reproduces the observed hemispheric chirality pattern.

Yeates, Mackay & van Ballegooijen, *Sol Phys* 2008

Yeates & Mackay, *ApJL* 2012



2-year + memory required at higher latitudes.

Summary

1. Non-potential reconstruction of the coronal magnetic field needs the time history of magnetogram input.

2. Magneto-frictional method allows global long-term simulation.

3. Can test with H-alpha filaments.

4. Demonstrates the importance of memory for high-latitudes.

Mackay & Yeates, *Living Rev Sol Phys* 2012- **surface/coronal mag fields**
Yeates & Mackay, *ApJL* 2012 - **15-year simulations (chirality)**
Yeates, *Solar Phys*. (pub online) - **15-year simulations (calibration, eruptions)**

Other consequences

- Enhancement of open magnetic flux.
- Flux ropes lose equilibrium and erupt - coronal mass ejections.

Science & Technology Facilities Council

http://www.maths.dur.ac.uk/~bmjg46/

Durham University