COLLAGE 2019

Active Region Magnetic Fields II

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Apr 16 2019

Outline

- Energy & helicity consideration
- Pre-eruption magnetic fields
- Many modes of eruption

Energy & Helicity Consideration

Magnetic Energy & Helicity

- Coronal time scale is short compared to photosphere: quasi-static

$$t_A = L/v_A \approx 30 \text{ Mm} \ / \ 300 \text{ km s}^{-1} = 100 \text{ s}$$

- Low plasma beta: force-free

$$(\nabla \times \boldsymbol{B}) \times \boldsymbol{B} = 0$$

- Energy accumulation, preferably in filament channel

$$E_f = \int \frac{B^2}{8\pi} dV - \int \frac{B_p^2}{8\pi} dV$$

- Helicity accumulation, preferably in filament channel (global variable)

$$H = \int \boldsymbol{A} \cdot \boldsymbol{B} dV$$

Magnetic Energy & Helicity

- Helicity is gauge dependent

$$\nabla \times \boldsymbol{A} = \nabla \times (\boldsymbol{A} + \nabla \psi) = \boldsymbol{B}$$

- Relative helicity is gauge independent

$$H_R = \int (\boldsymbol{A} + \boldsymbol{A}_p) \cdot (\boldsymbol{B} - \boldsymbol{B}_p) dV$$

- *Faraday*'s Law (underdetermined from magnetic field)

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\nabla \times c\boldsymbol{E}, \text{ but, } \nabla \times \boldsymbol{E} = \nabla \times (\boldsymbol{E} + \nabla \psi)$$

- Ideal electric field (c.f. ideal induction equation)

$$c\boldsymbol{E} = -\boldsymbol{v} \times \boldsymbol{B}$$

Berger & Field (1984)

Poynting & Helicity Flux

- Poynting flux through photosphere

$$S_z = \frac{c}{4\pi}\boldsymbol{E}_h \times \boldsymbol{B}_h \cdot \hat{\boldsymbol{z}}$$

$$= [v_z B_h^2 - (\boldsymbol{v}_h \cdot \boldsymbol{B}_h) B_z]/4\pi$$

- Helicity flux through photosphere

$$\frac{dH_R}{dt} = -2\int (\boldsymbol{A}_p \times \boldsymbol{E}) \cdot \hat{\boldsymbol{z}} da$$

$$= -2\int (\boldsymbol{A}_p \cdot \boldsymbol{v}_h) B_z da + 2\int (\boldsymbol{A}_p \cdot \boldsymbol{B}_h) v_z da$$

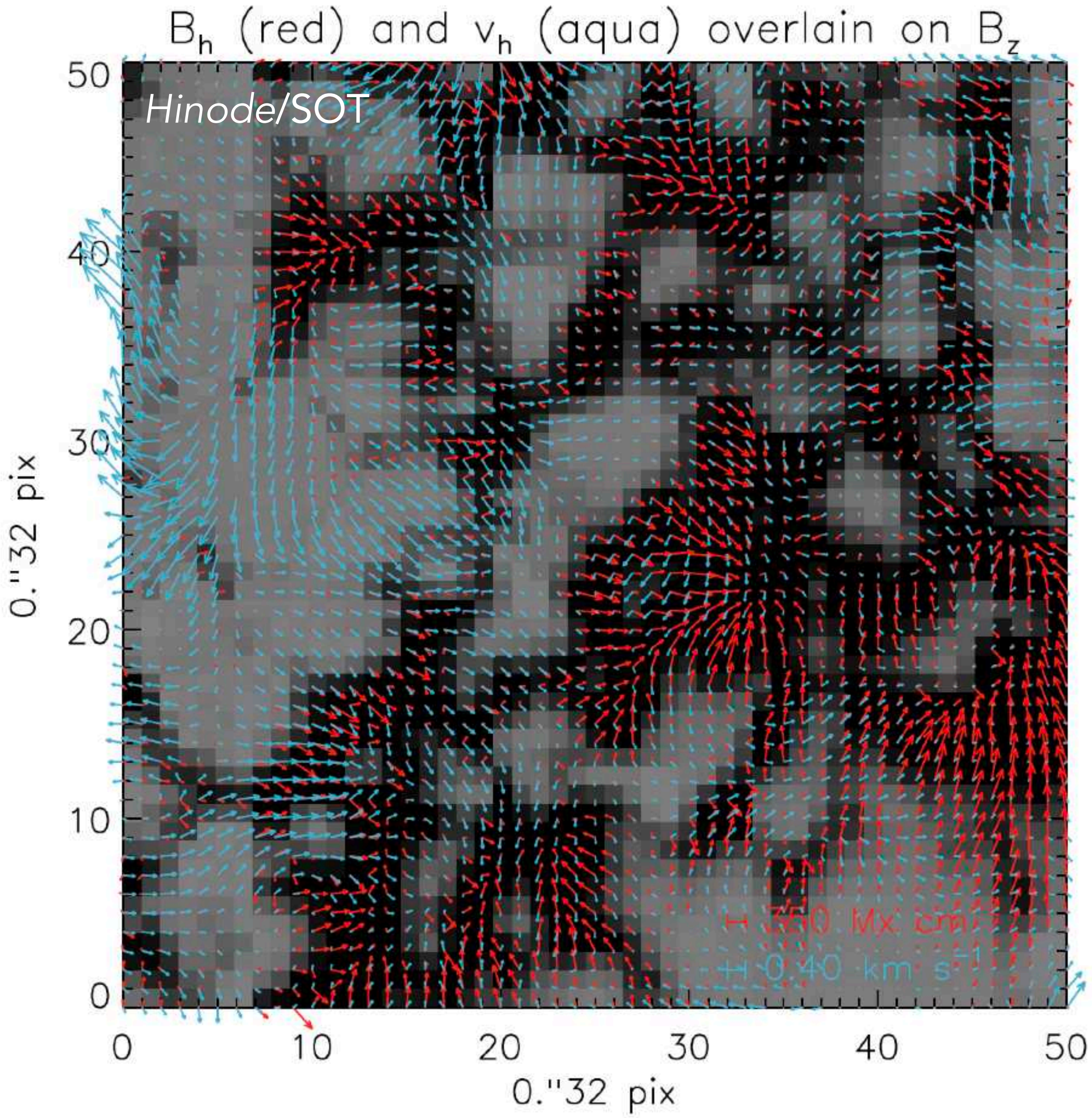
- There may be an upper limit of energy and helicity before eruption sets in

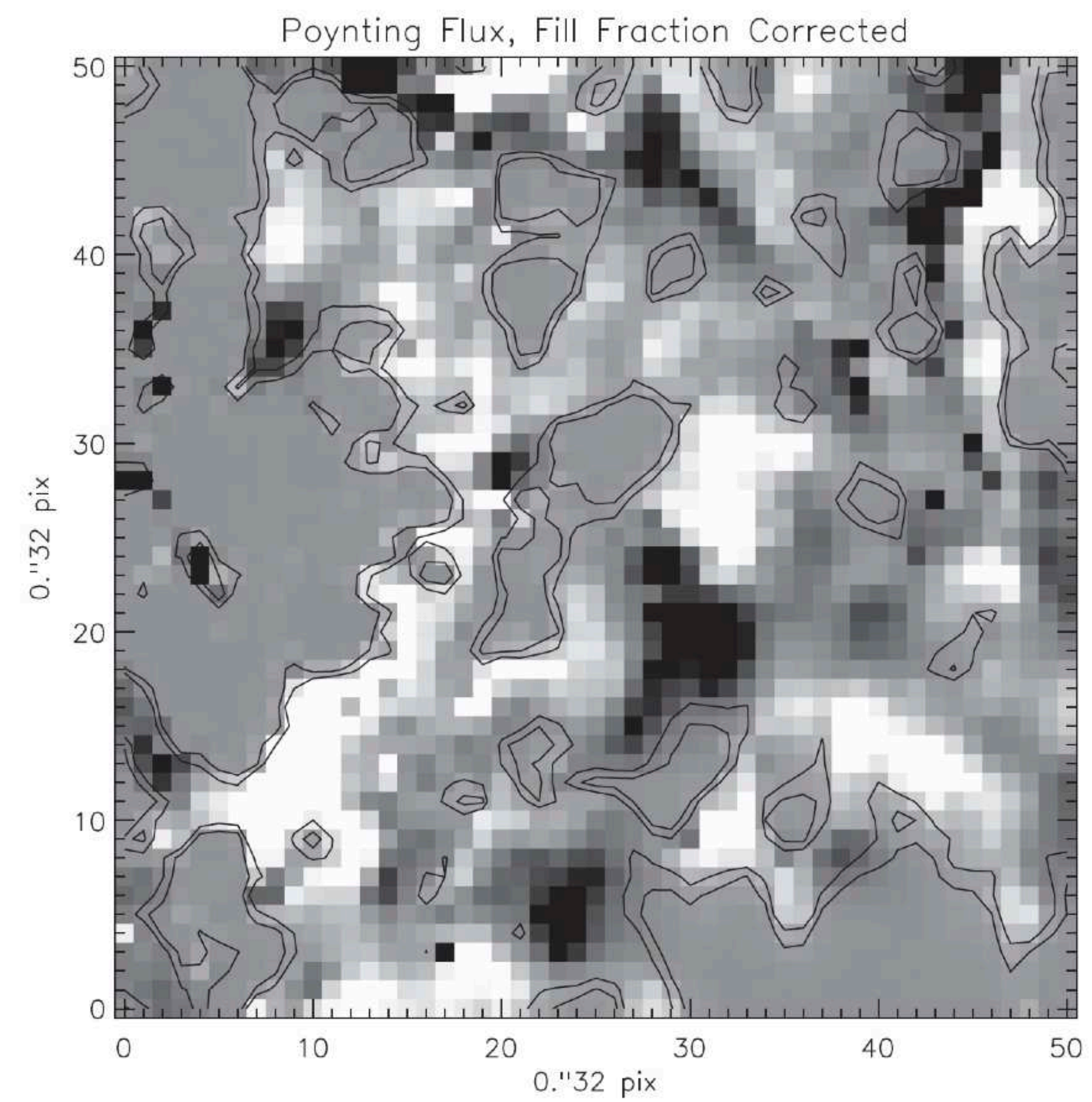
Fisher et al. (2012); Kazachenko et al. (2014)

Surface Velocity Estimate

$S_z = [v_z B_h^2 - (\boldsymbol{v}_h \cdot \boldsymbol{B}_h) B_z]/4\pi$

Q: Which term is more important for plage? What happens for 0 inclination?



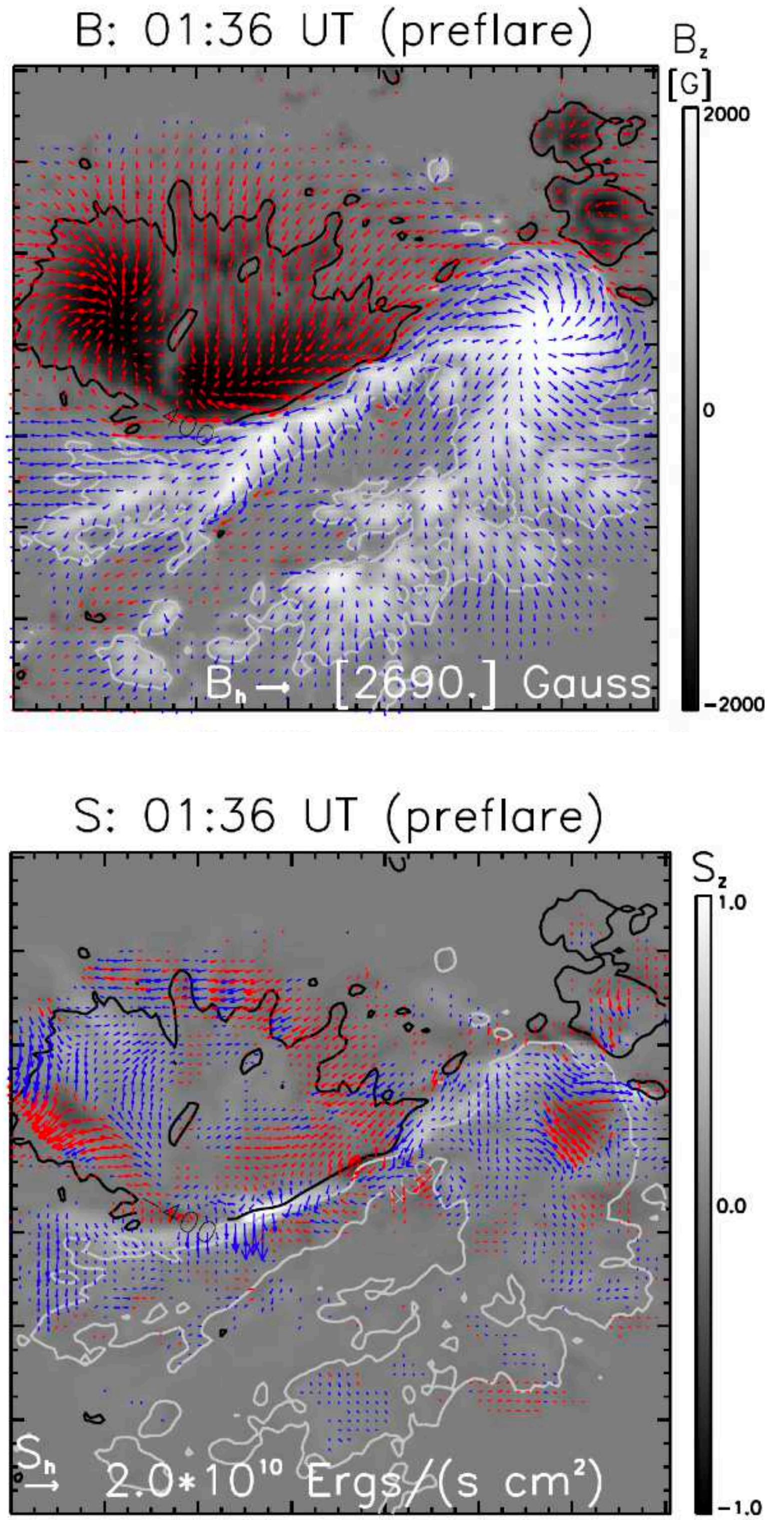


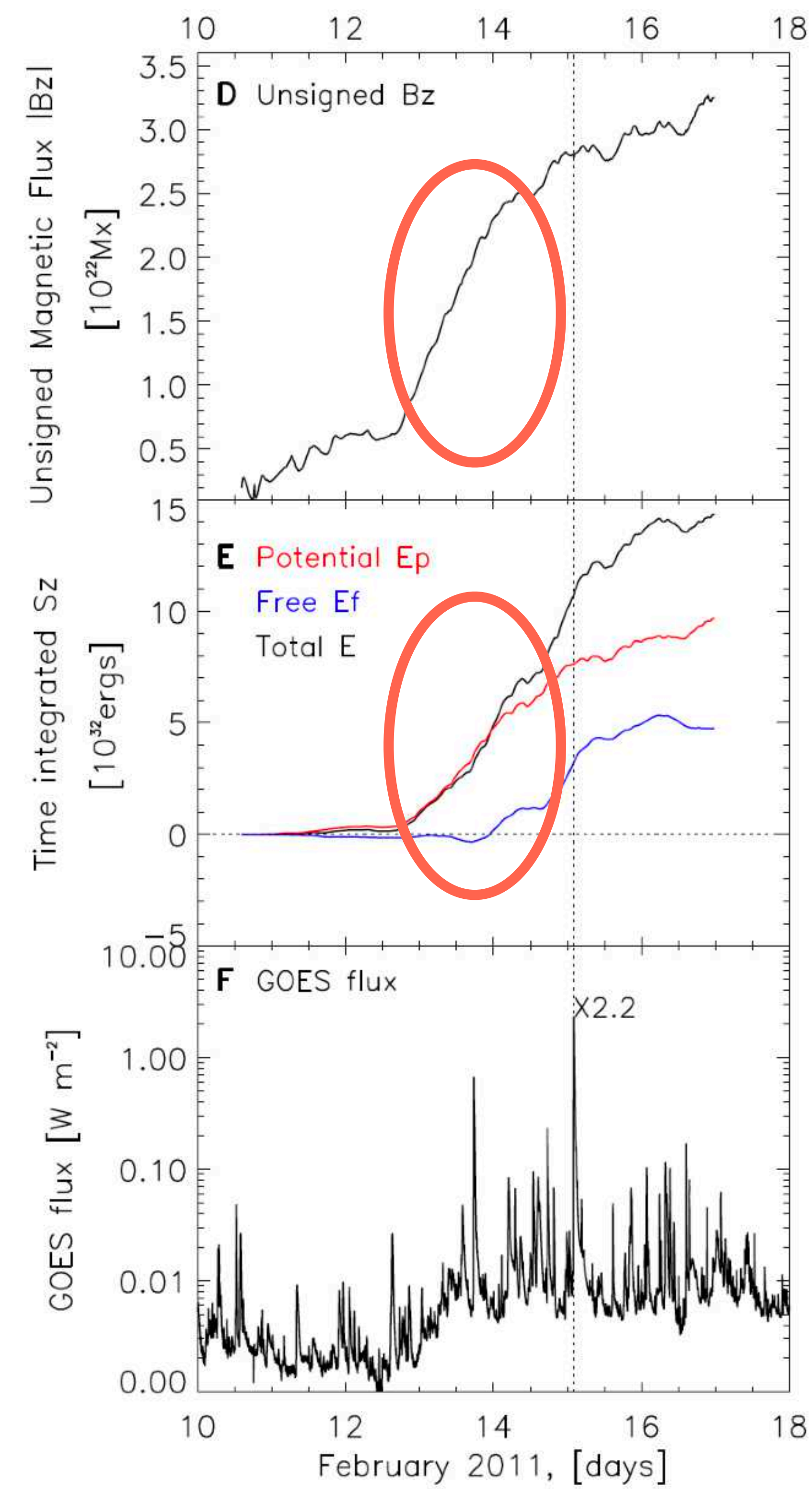
Welsch (2015)

Fourier local correlation tracking (FLCT; Fisher & Welsch 2008)

Differential Affine Velocity Estimator for Vector Magnetograms (DAVE4VM; Schuck 2008)

Magnetic Energy Injection

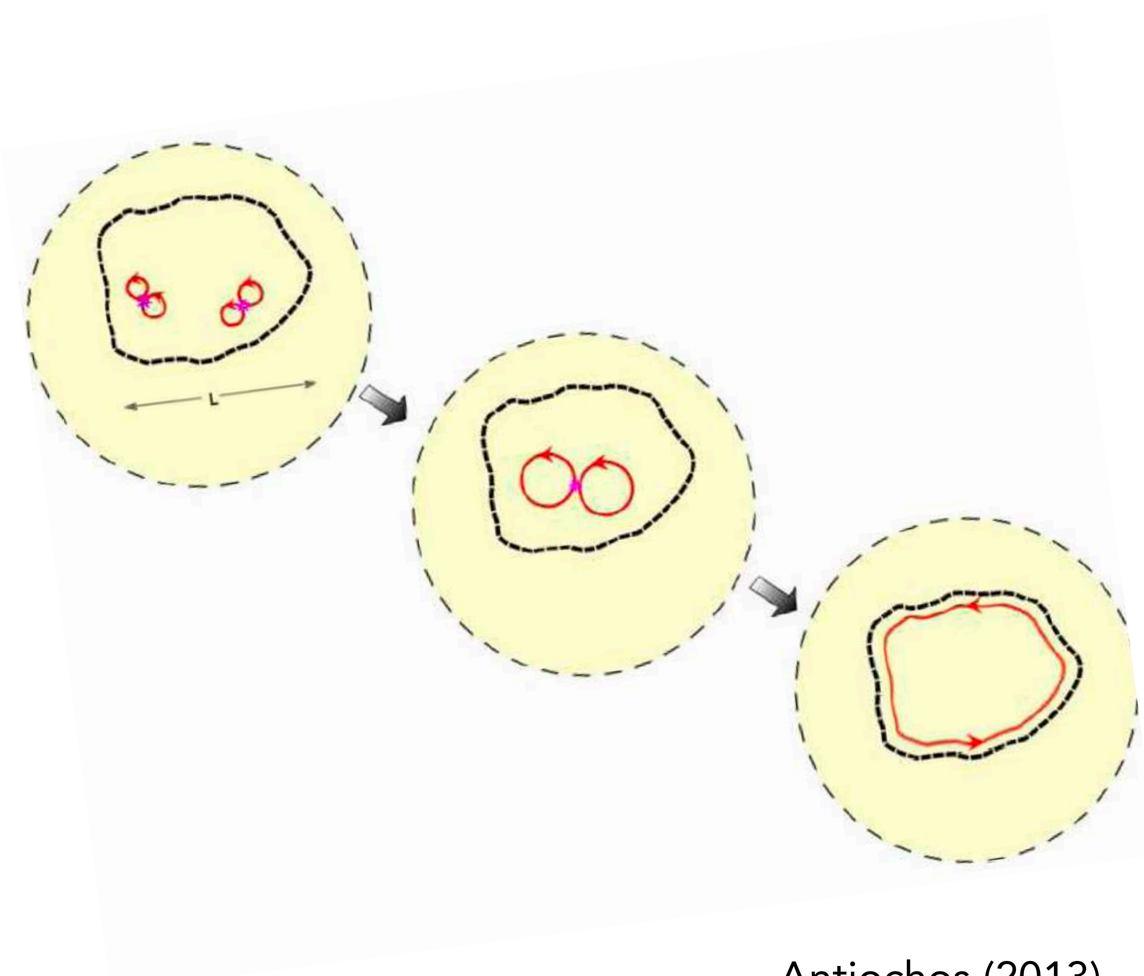




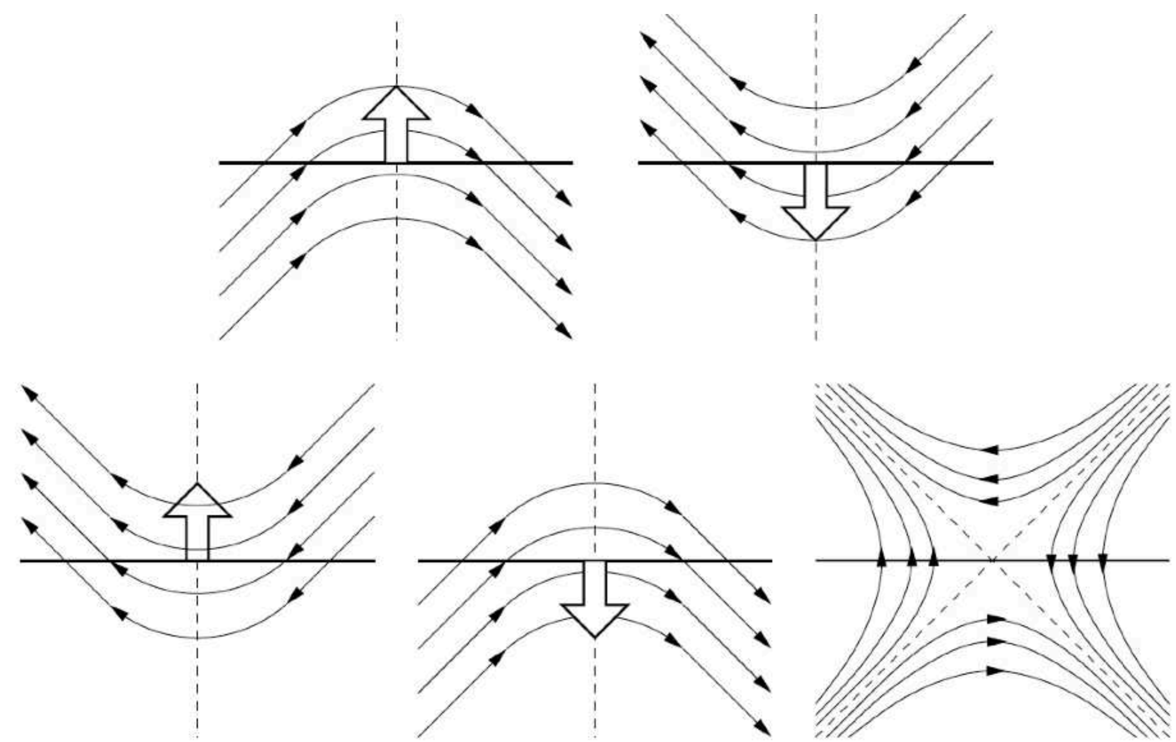
Kazachenko et al. (2015)

Magnetic Polarity Inversion Line (PIL)

- Magnetic flux emergence & submergence
- Energy accumulation in filament channel
- Helicity condensation (inverse cascade) in filament channel



Antiochos (2013)

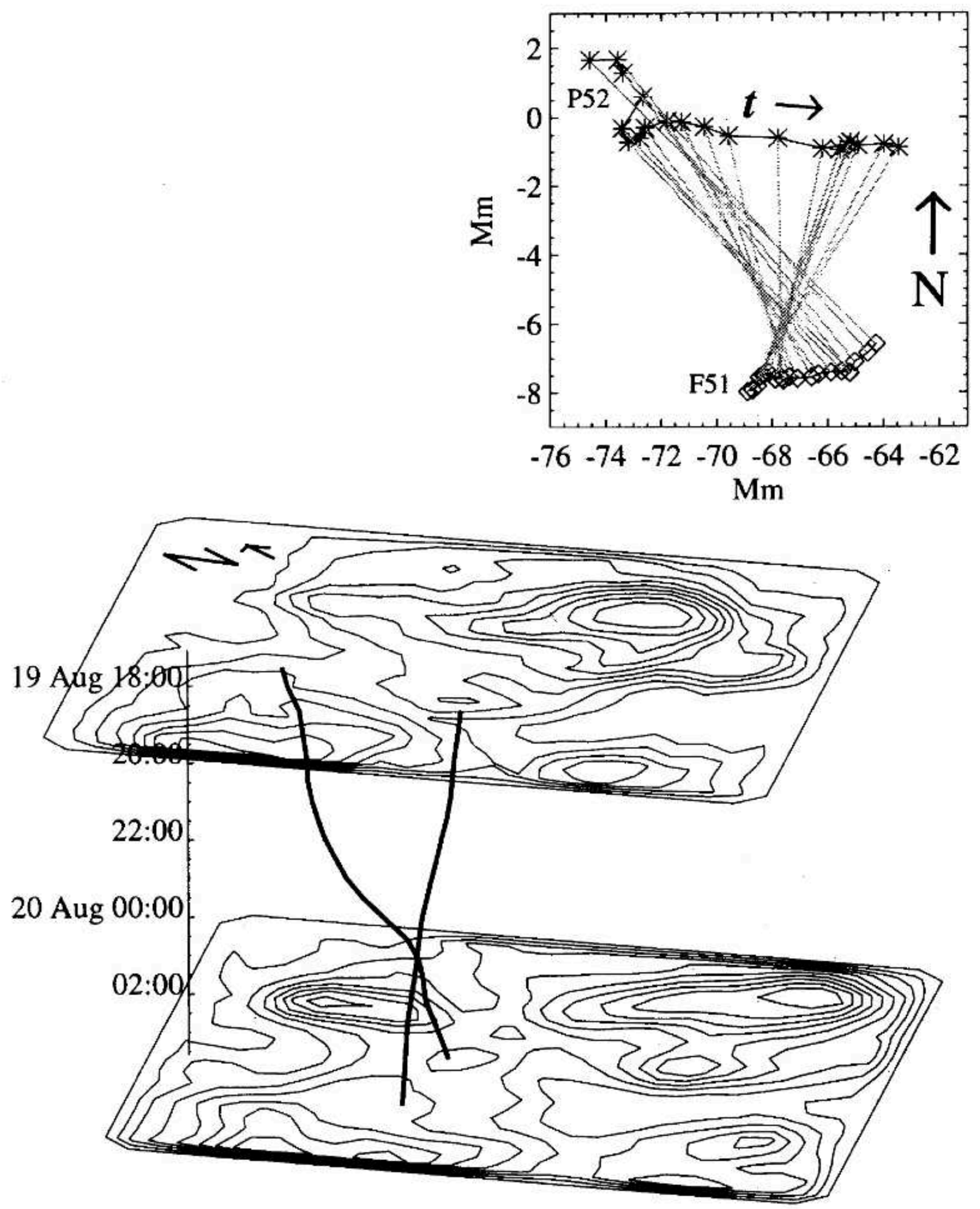


Welsch et al. (2013)

Pre-eruption Magnetic Fields

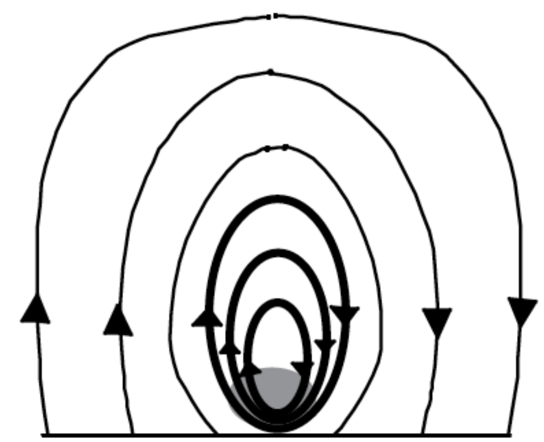
Observation: Magnetogram

Mees/*IVM*; Fe I 656.9 nm



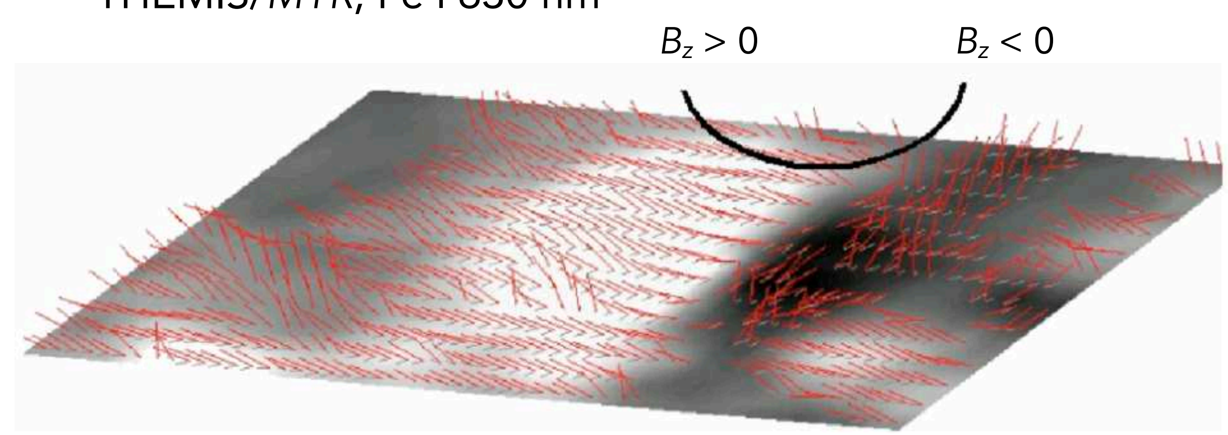
Leka et al. (1996)

"Bald patch"



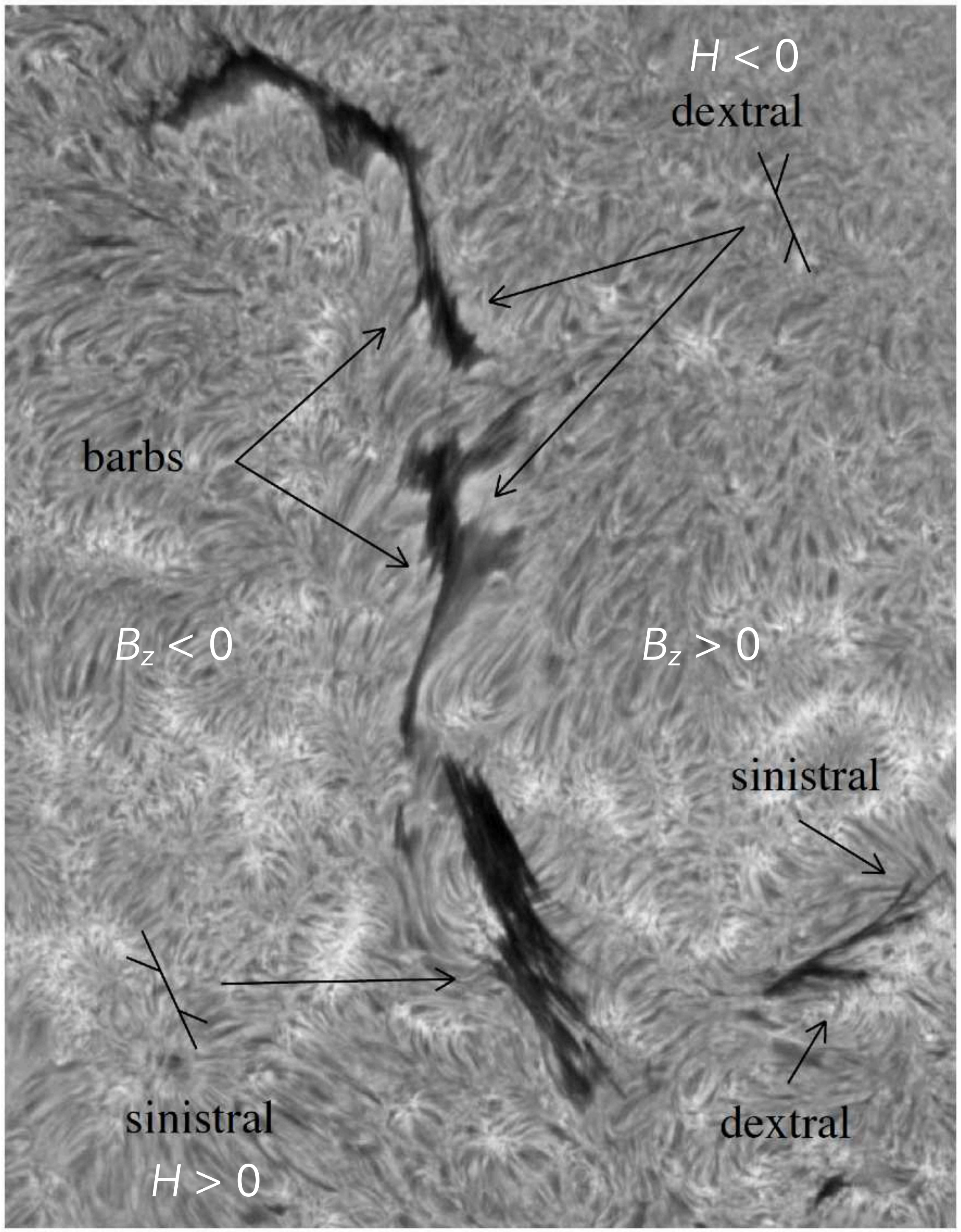
Titov et al. (1993); Gibson & Fan (2006)

THÉMIS/*MTR*; Fe I 630 nm

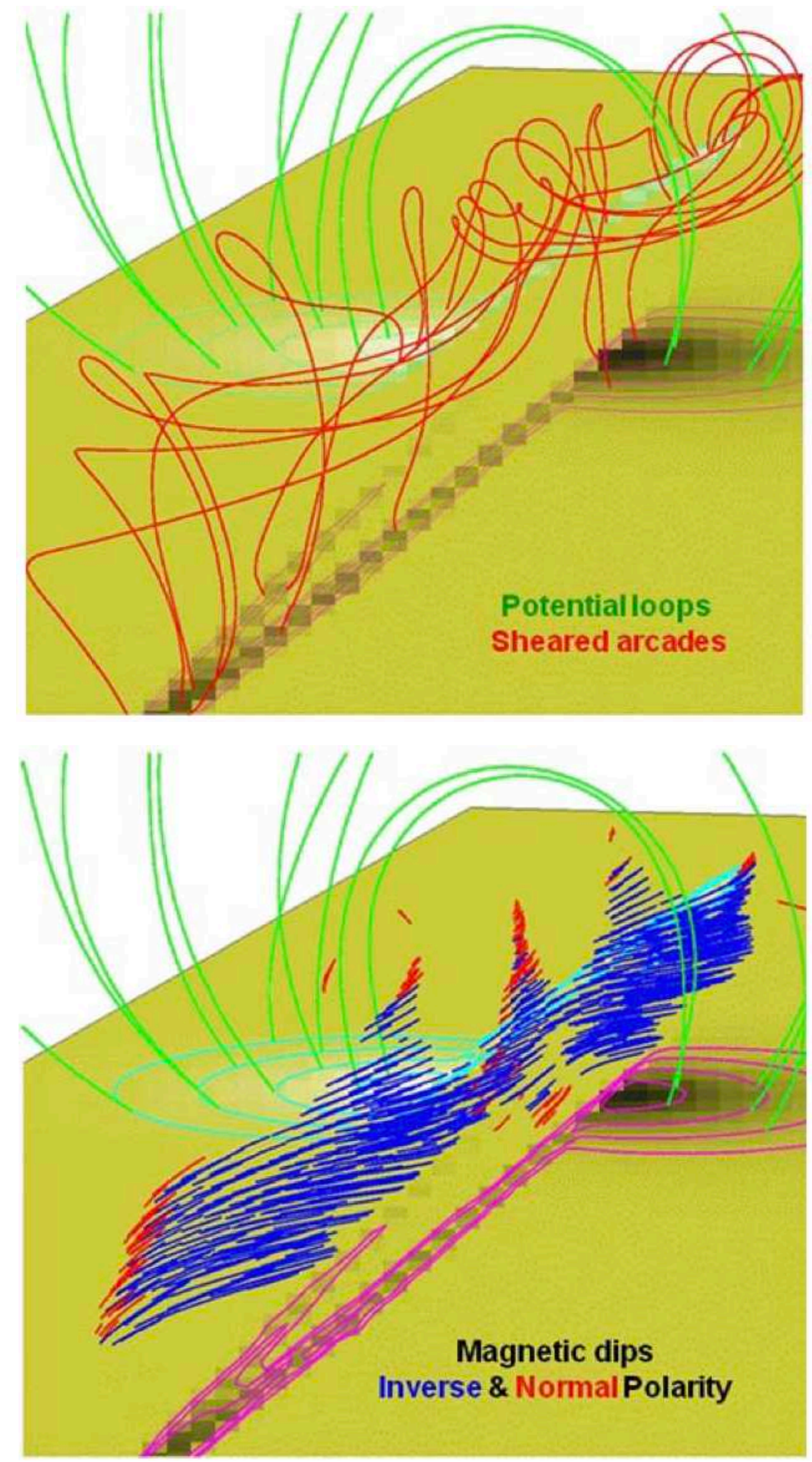


López Ariste et al. (2006)

Filament

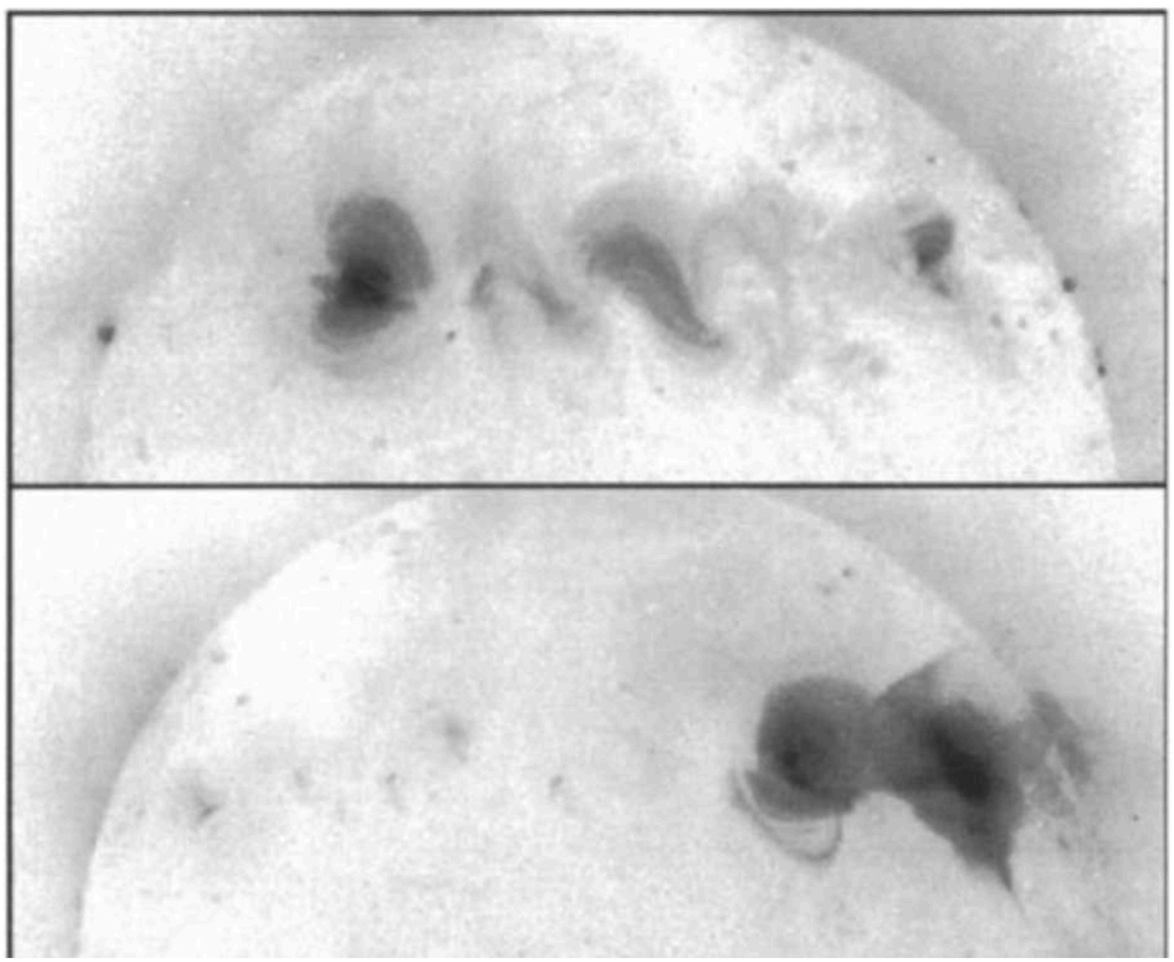


Pevtsov (2003)

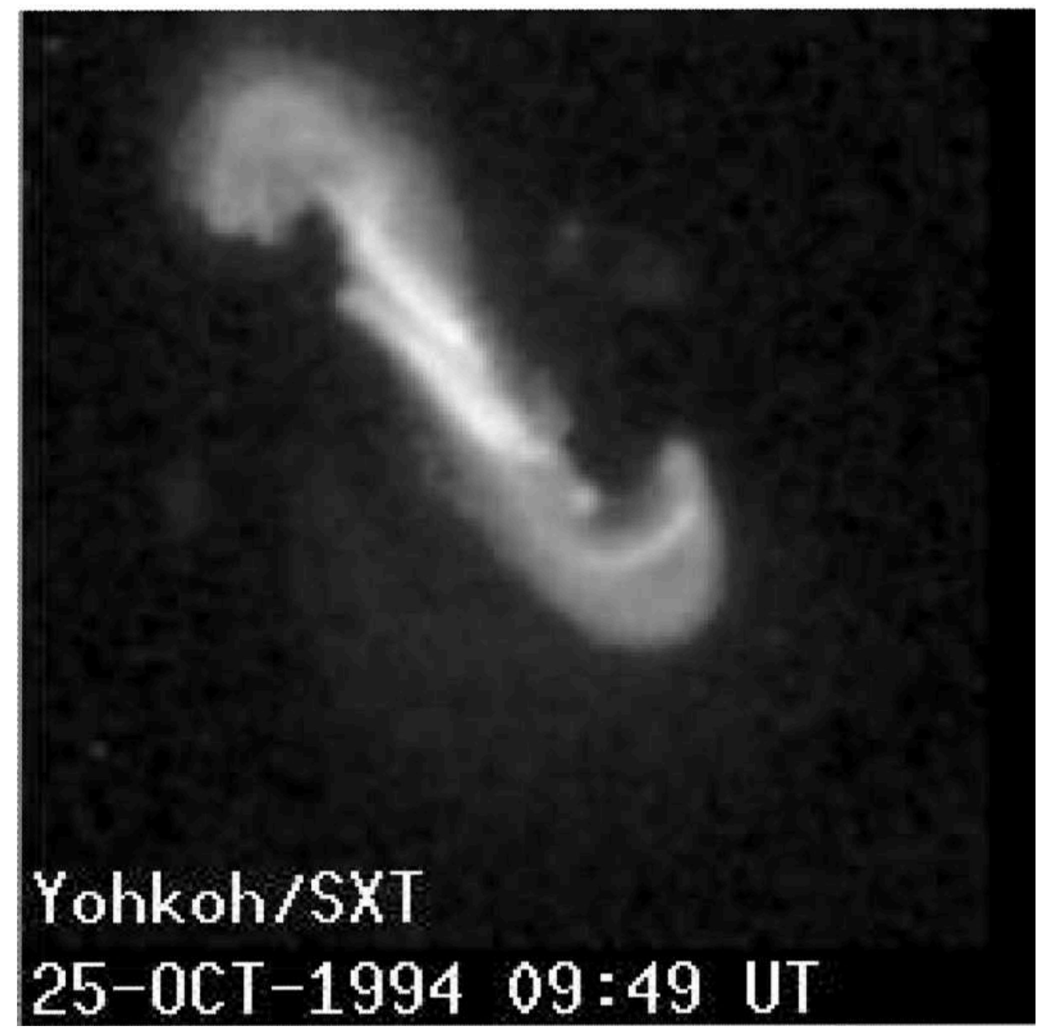


Aulanier et al. (2002)

Sigmoid

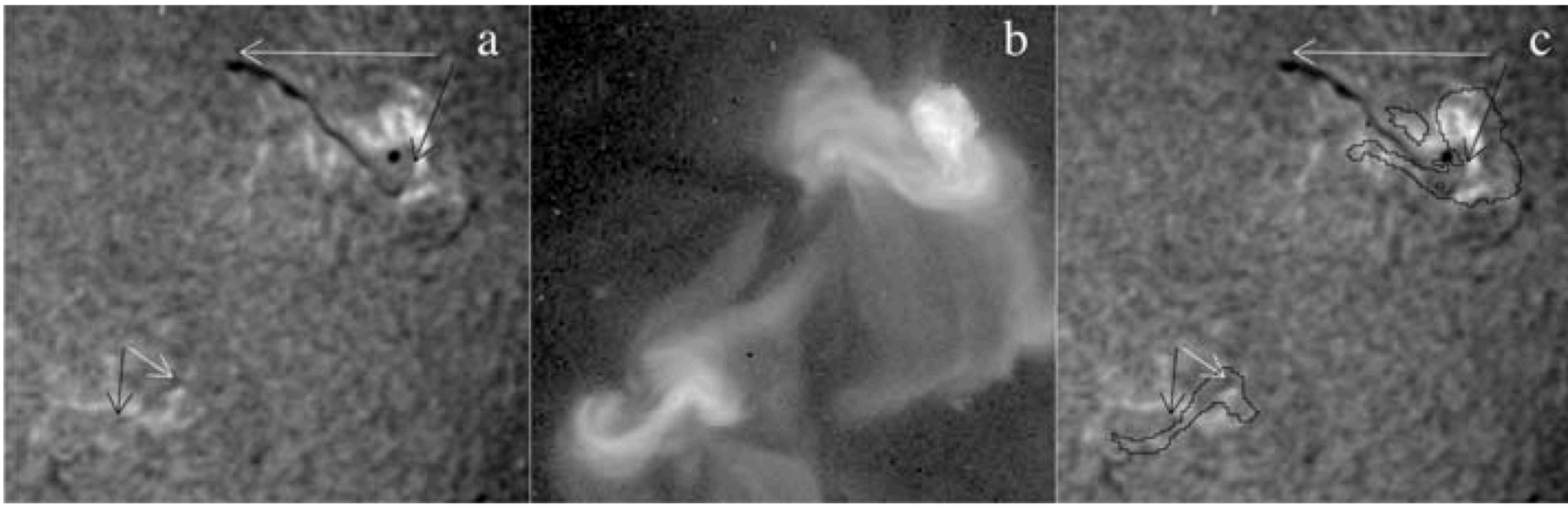


Canfield et al. (1999)



Titov & Démoulin (1999)

Filament + Sigmoid

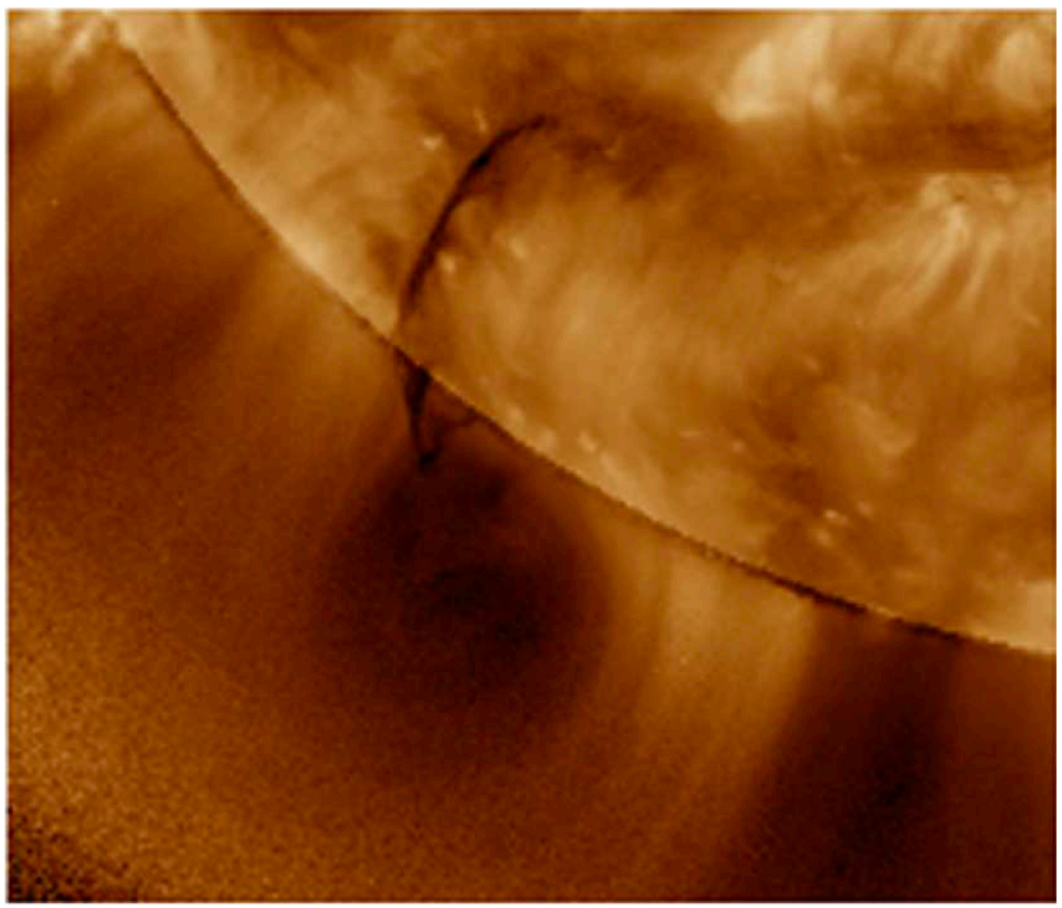


Pevtsov (2002)

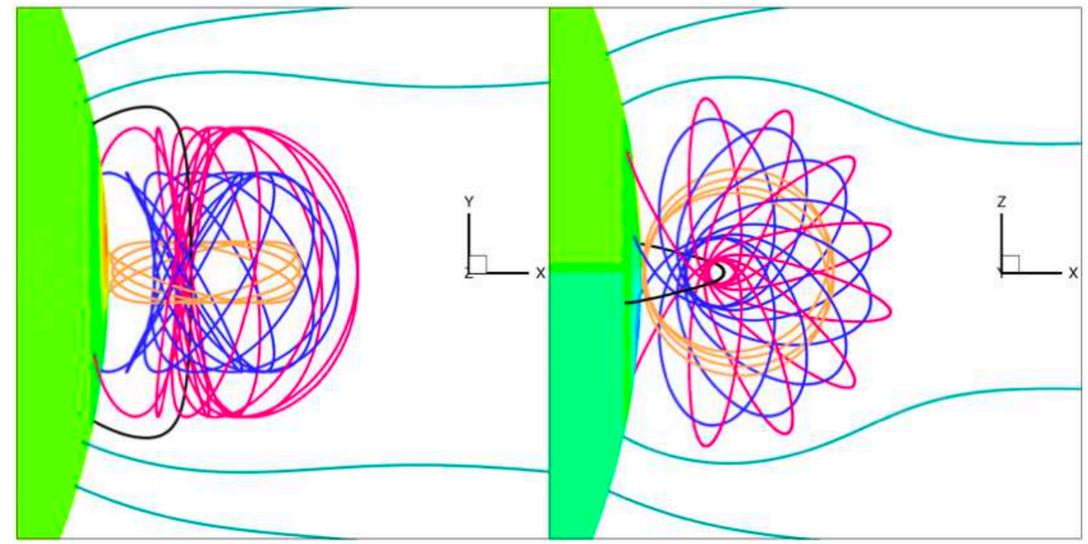
Coronal Cavity

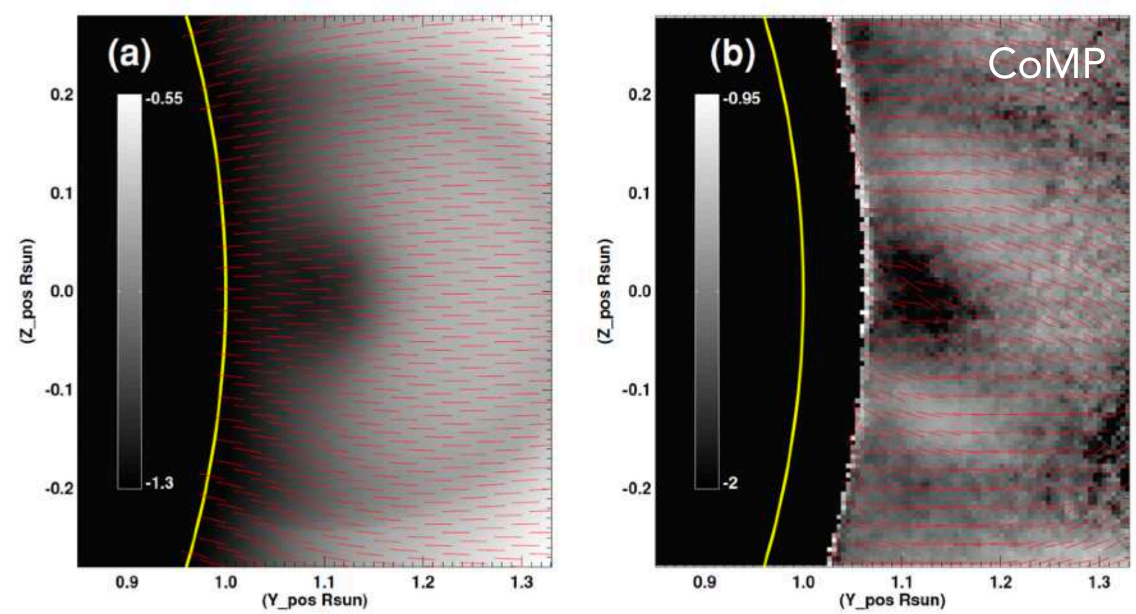
Coronal polarization + FORWARD modeling

Under-dense & hotter (!)



Karna et al. (2017)





Dove et al. (2011)

UFO

Two Massive UFO Refueling At The Sun (Formation)

63,881 views

551 52 SHARE SAVE

UFOvni2012
Published on Aug 1, 2017

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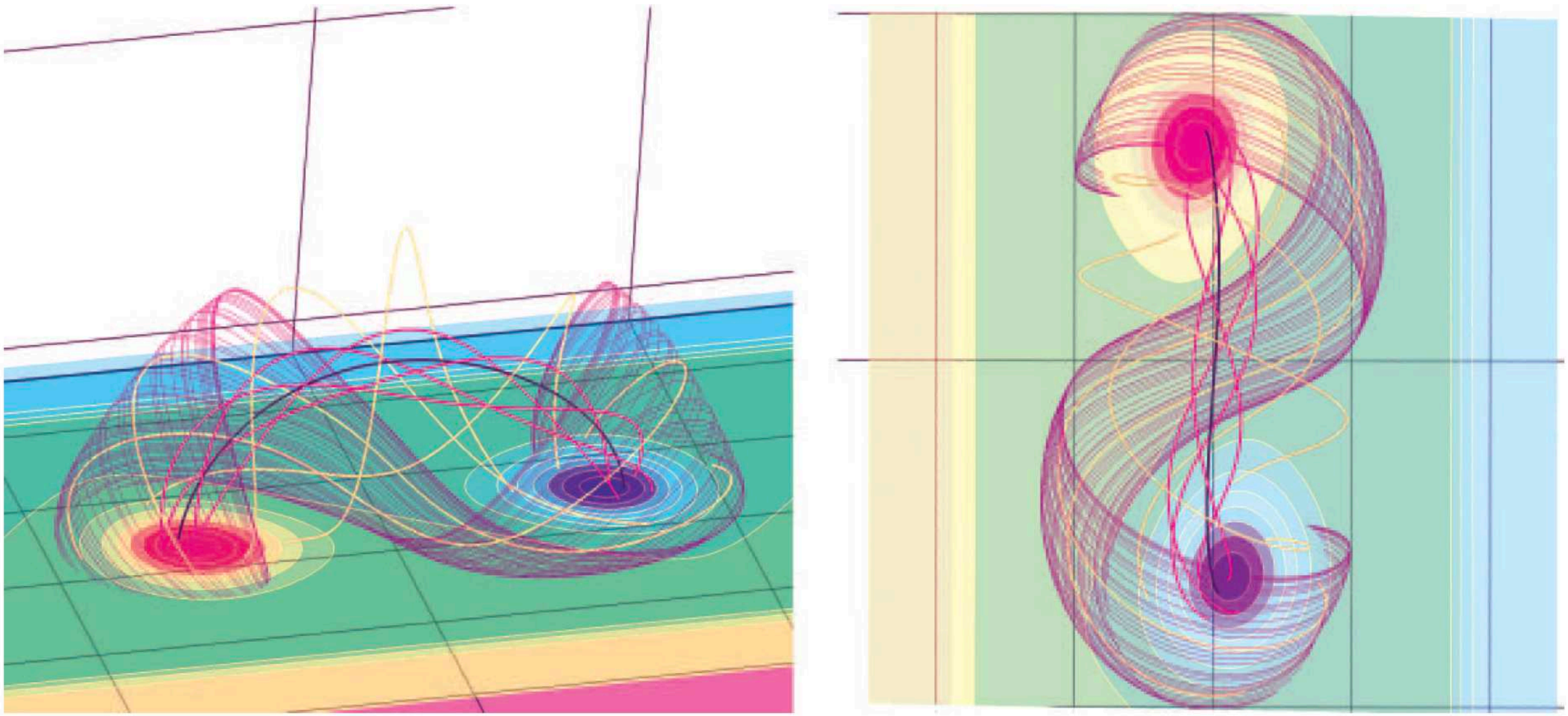
Sheared Arcade & Flux Rope

Separatrix surface



Gibson et al. (2004)

Force-Free Field Modeling

- Statement of problem:

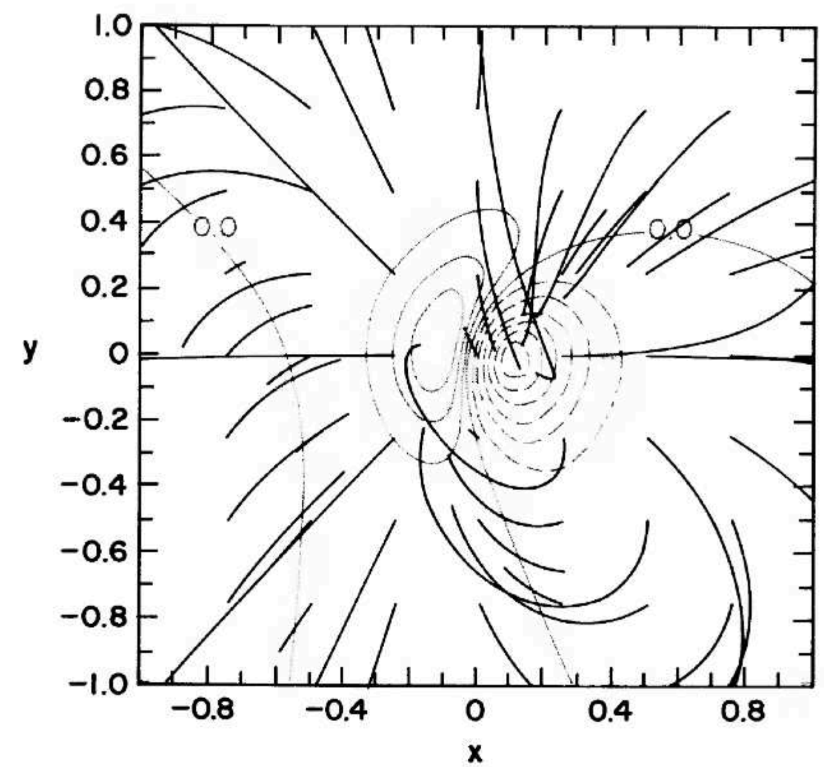
$$\nabla \times \boldsymbol{B} = \alpha \boldsymbol{B}$$

$$\boldsymbol{B}(z=0) = \boldsymbol{B}_{\text{obs}}$$

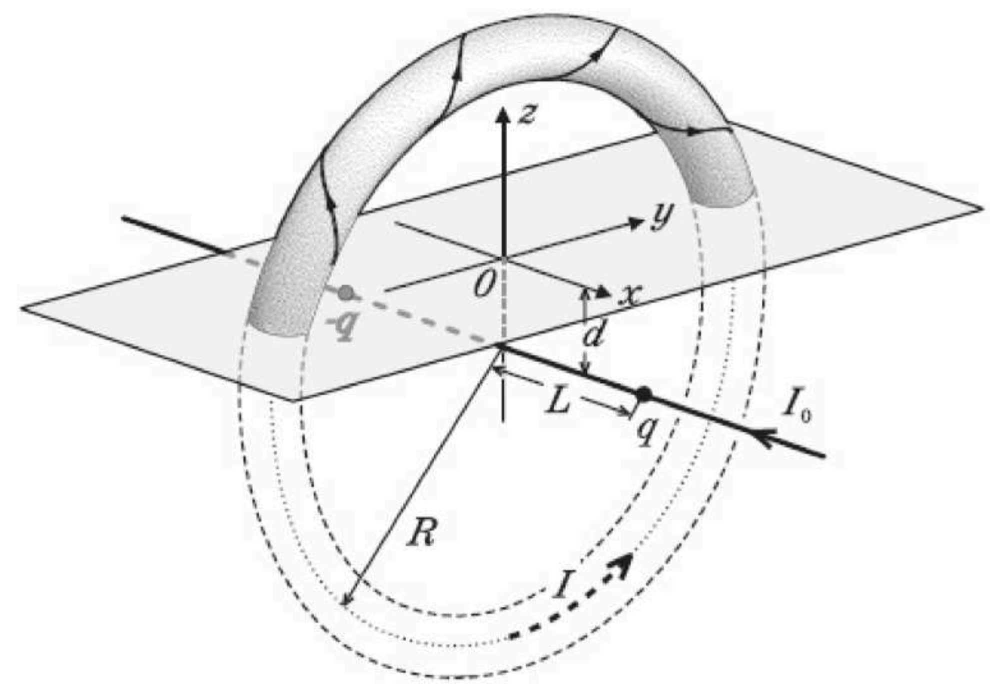
- Non-linear force-free field (NLFFF): α varies in space

- Generally an ill-posed problem; photosphere (high β) non-force-free

- Solutions need to be interpreted with care

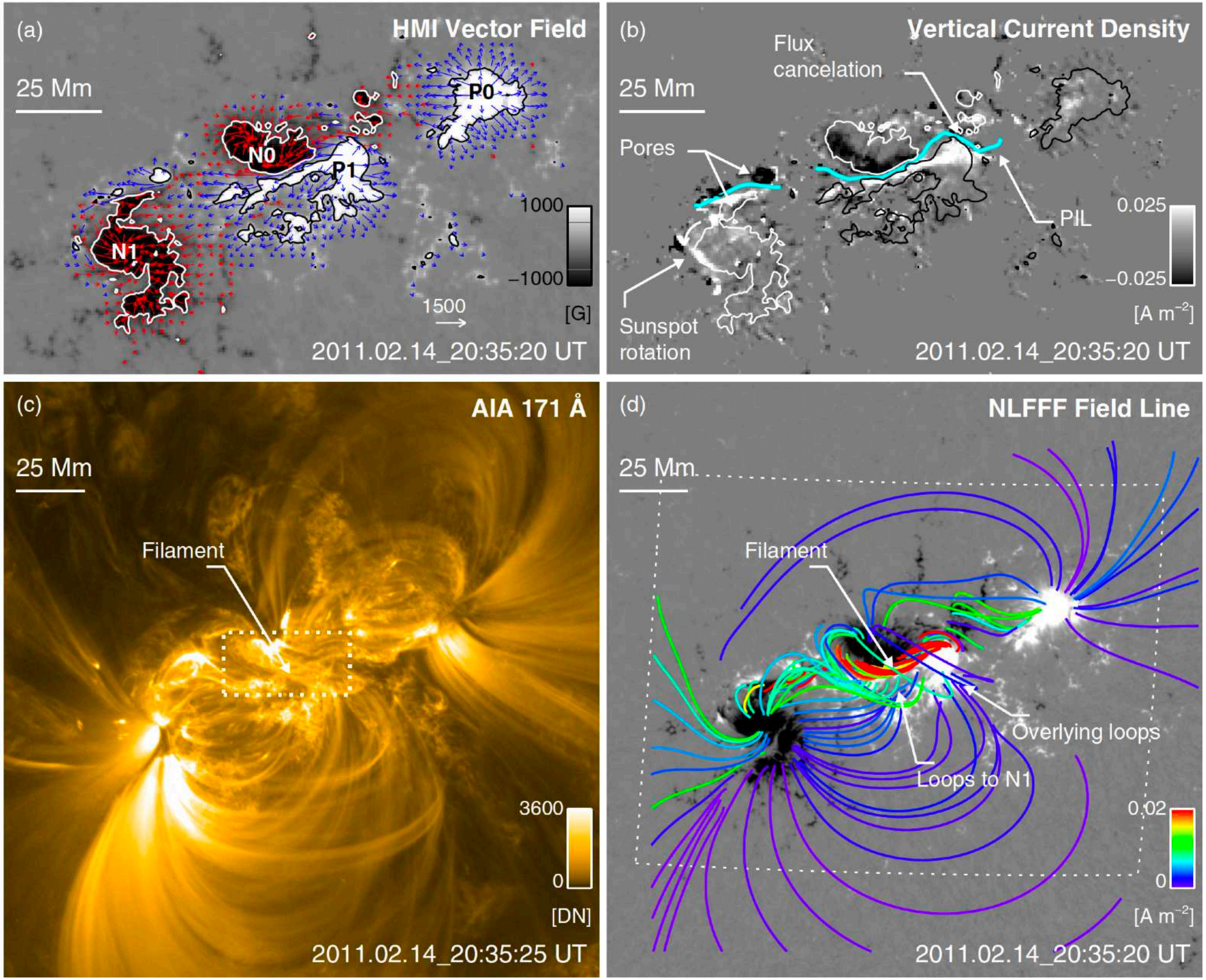


Low & Lou (1990)



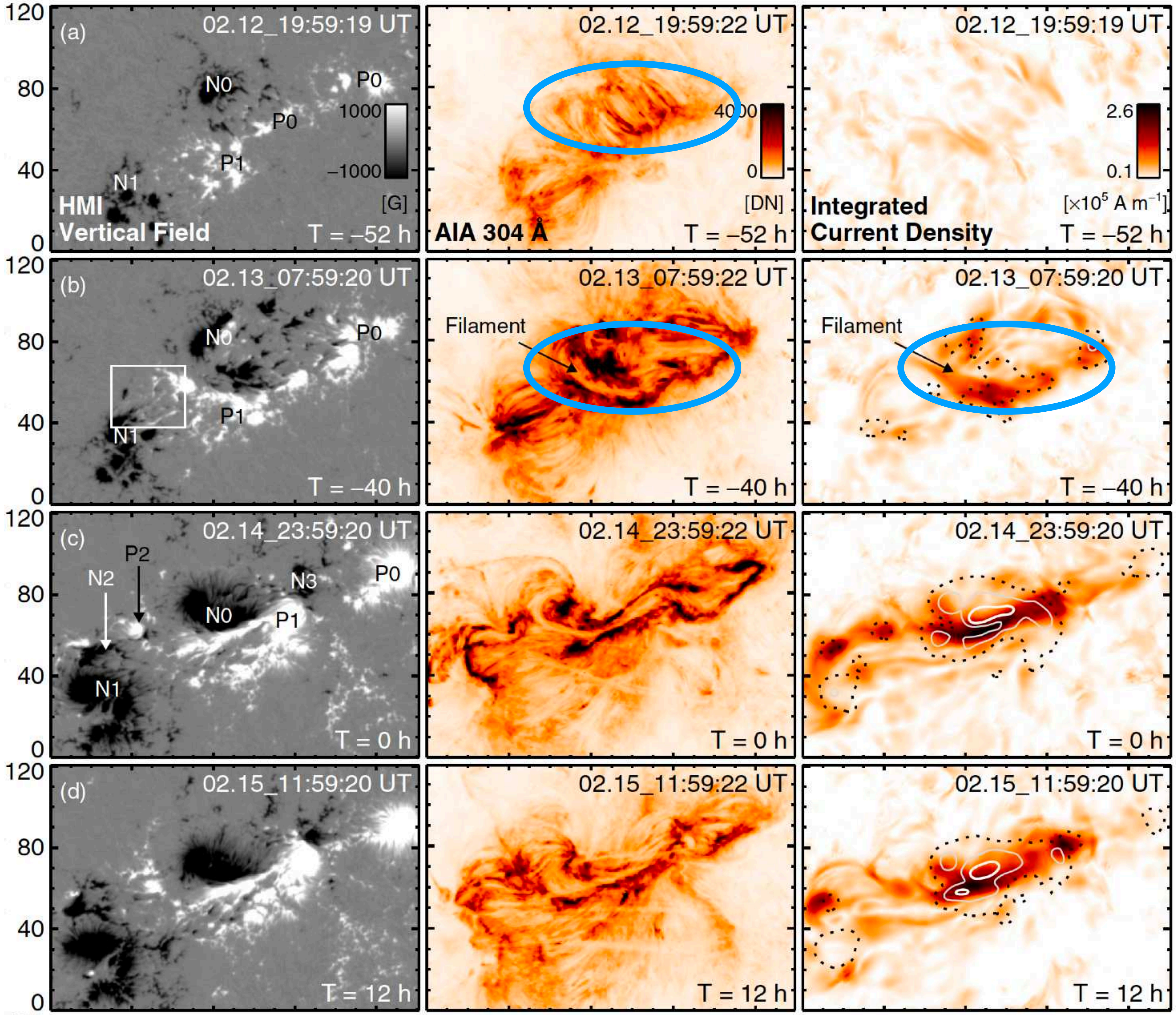
Titov & Démoulin (1999)

Solutions



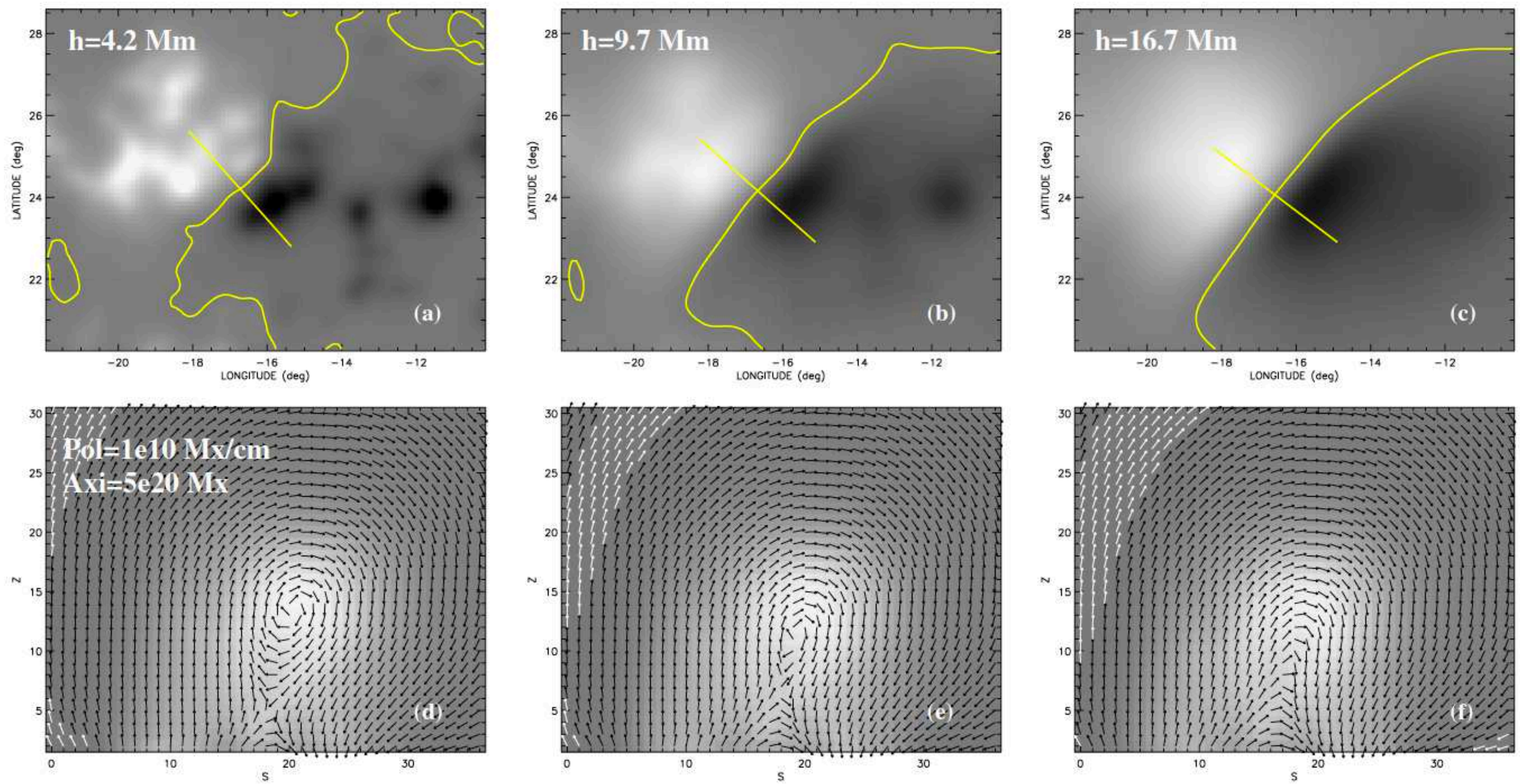
Sun et al. (2012)

Energy Storage



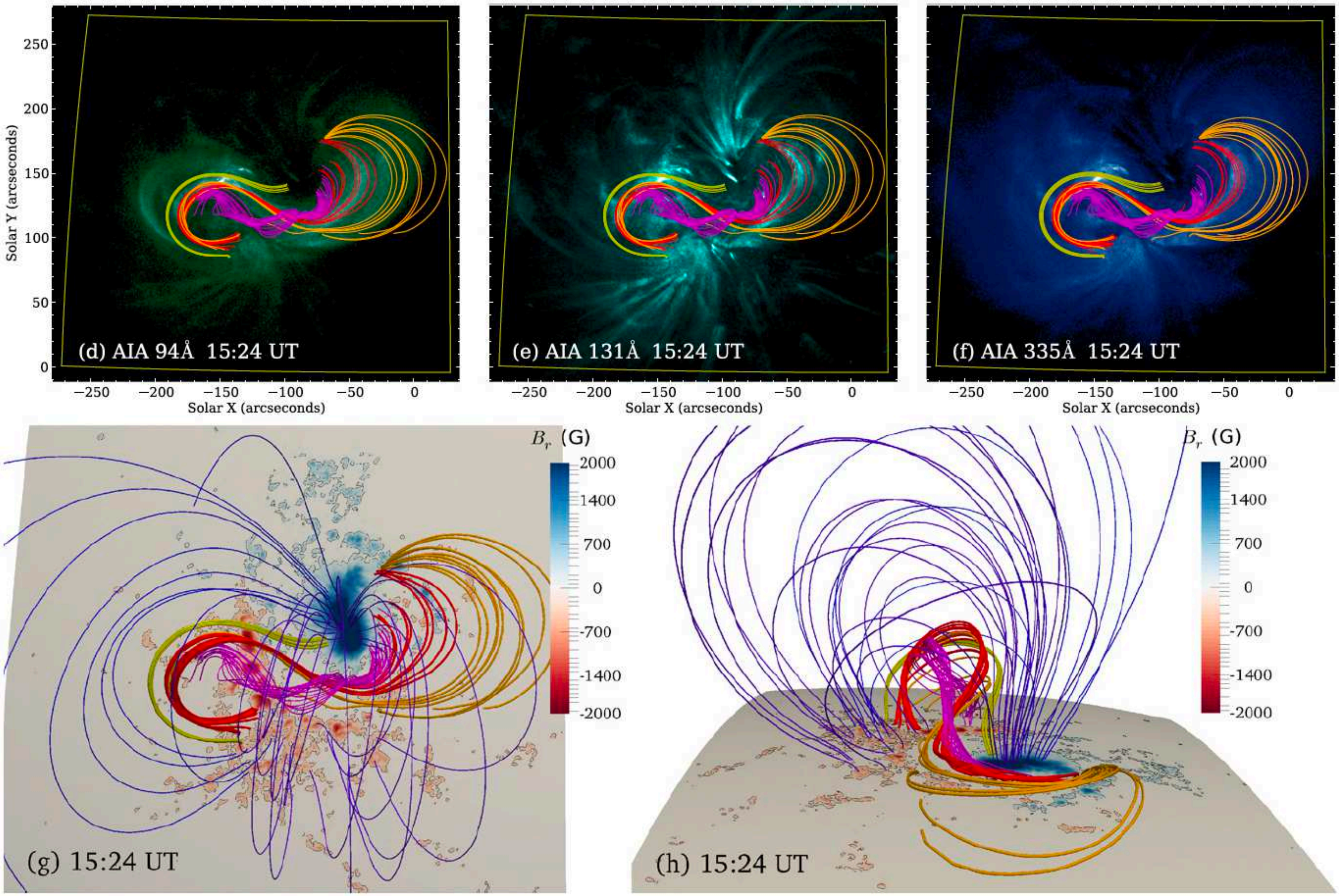
Sun et al. (2012)

Flux Rope in NLFFF



Su et al. (2011)

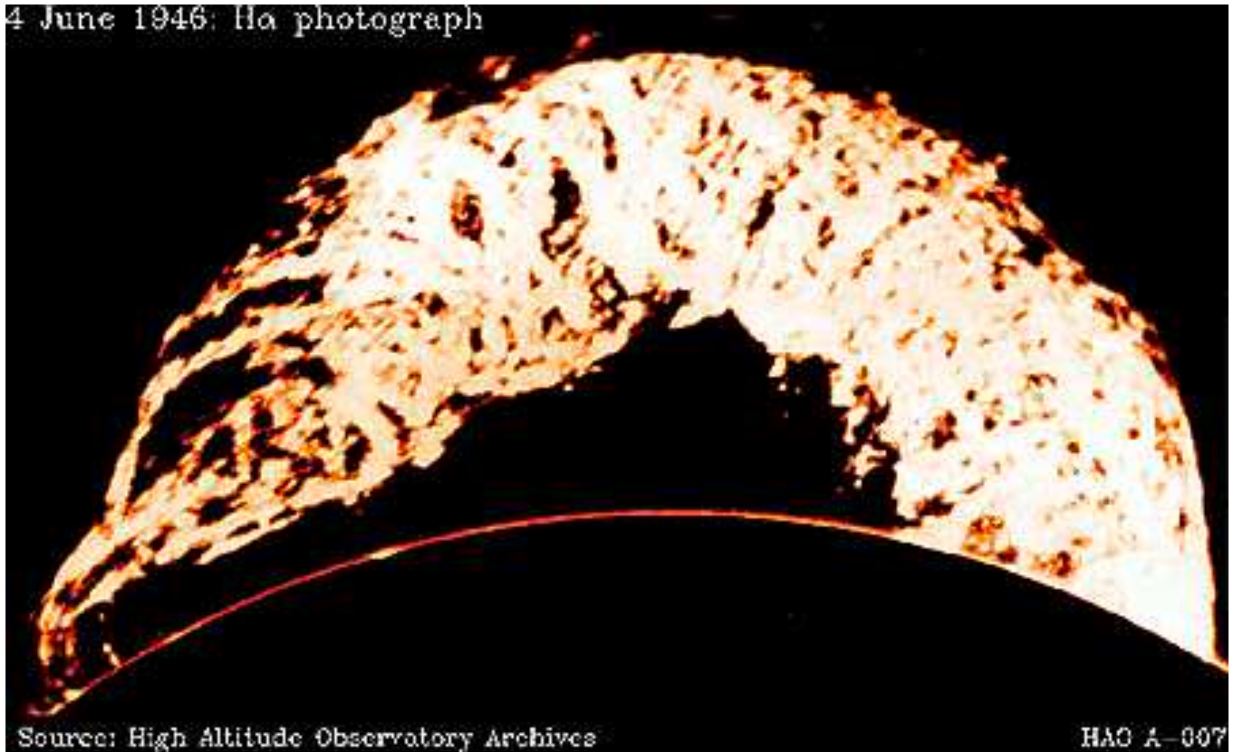
Flux Rope in NLFFF



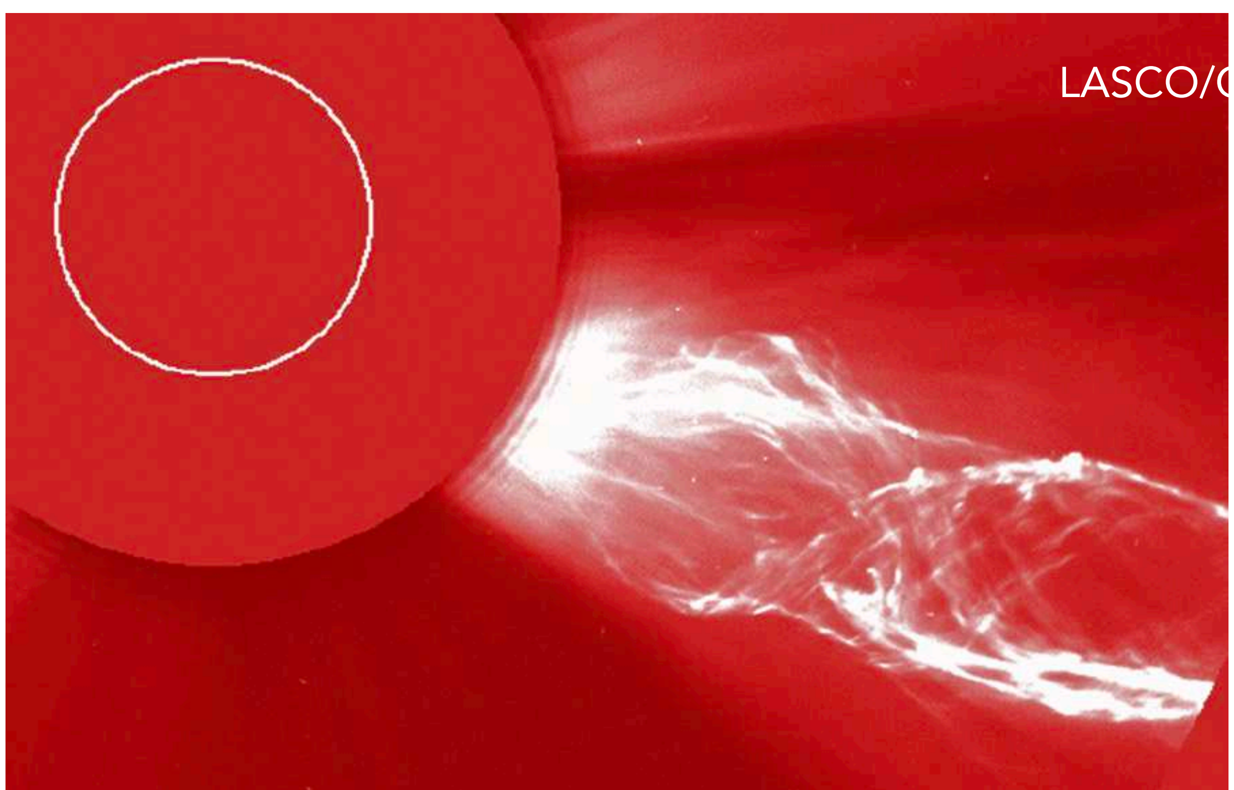
Zhao et al. (2016)

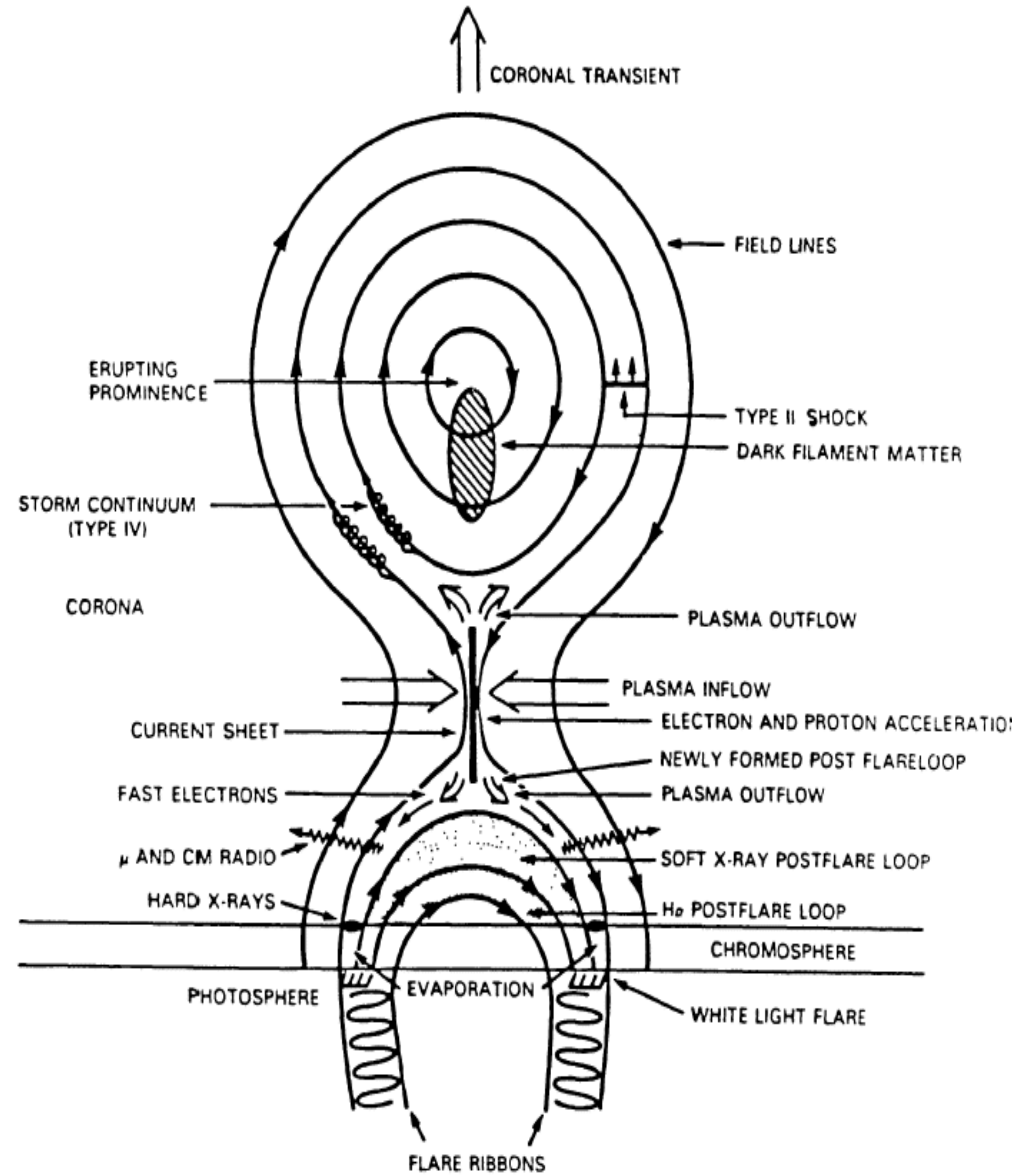
Many Modes of Eruption

CME Observation



"Grand daddy"

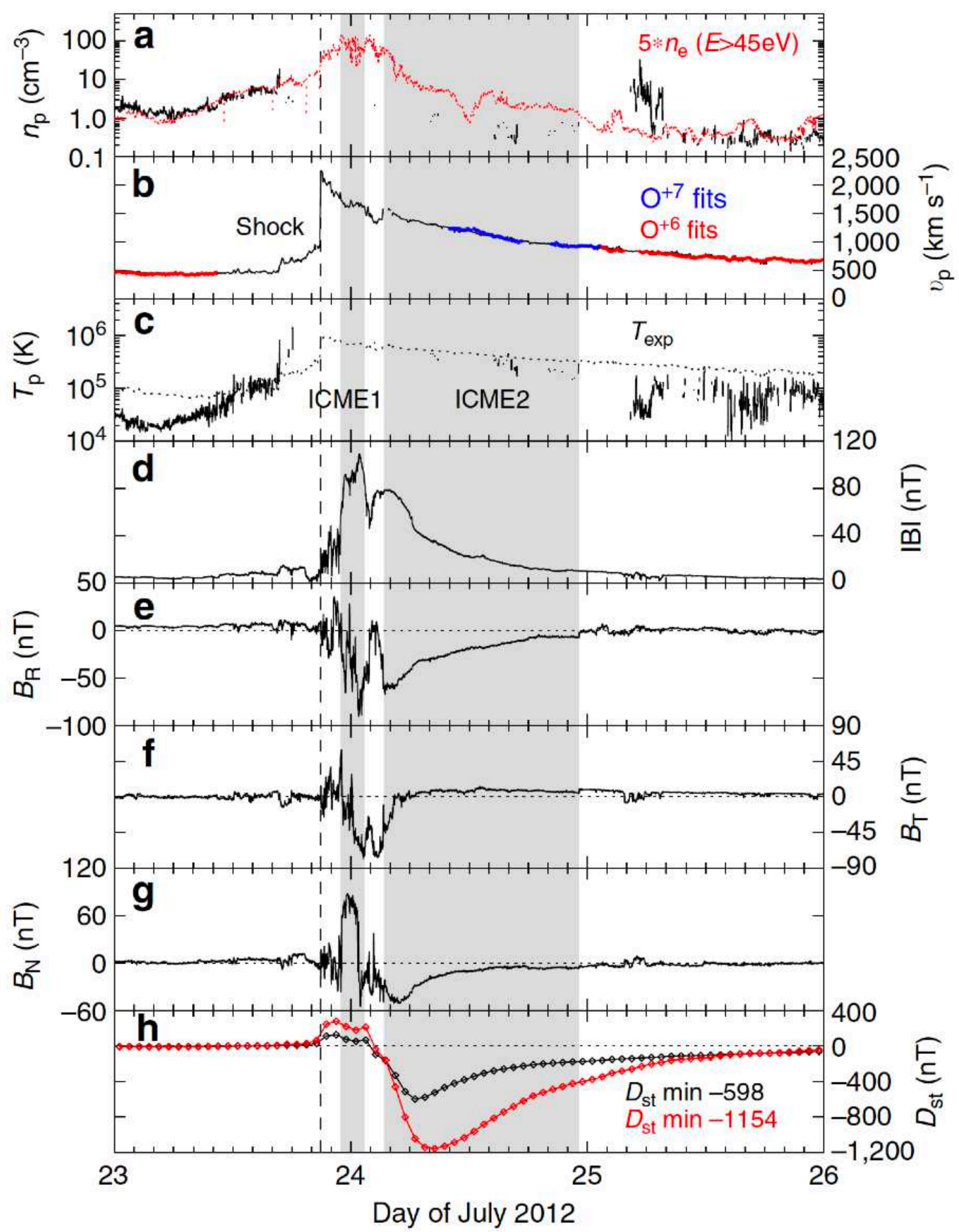




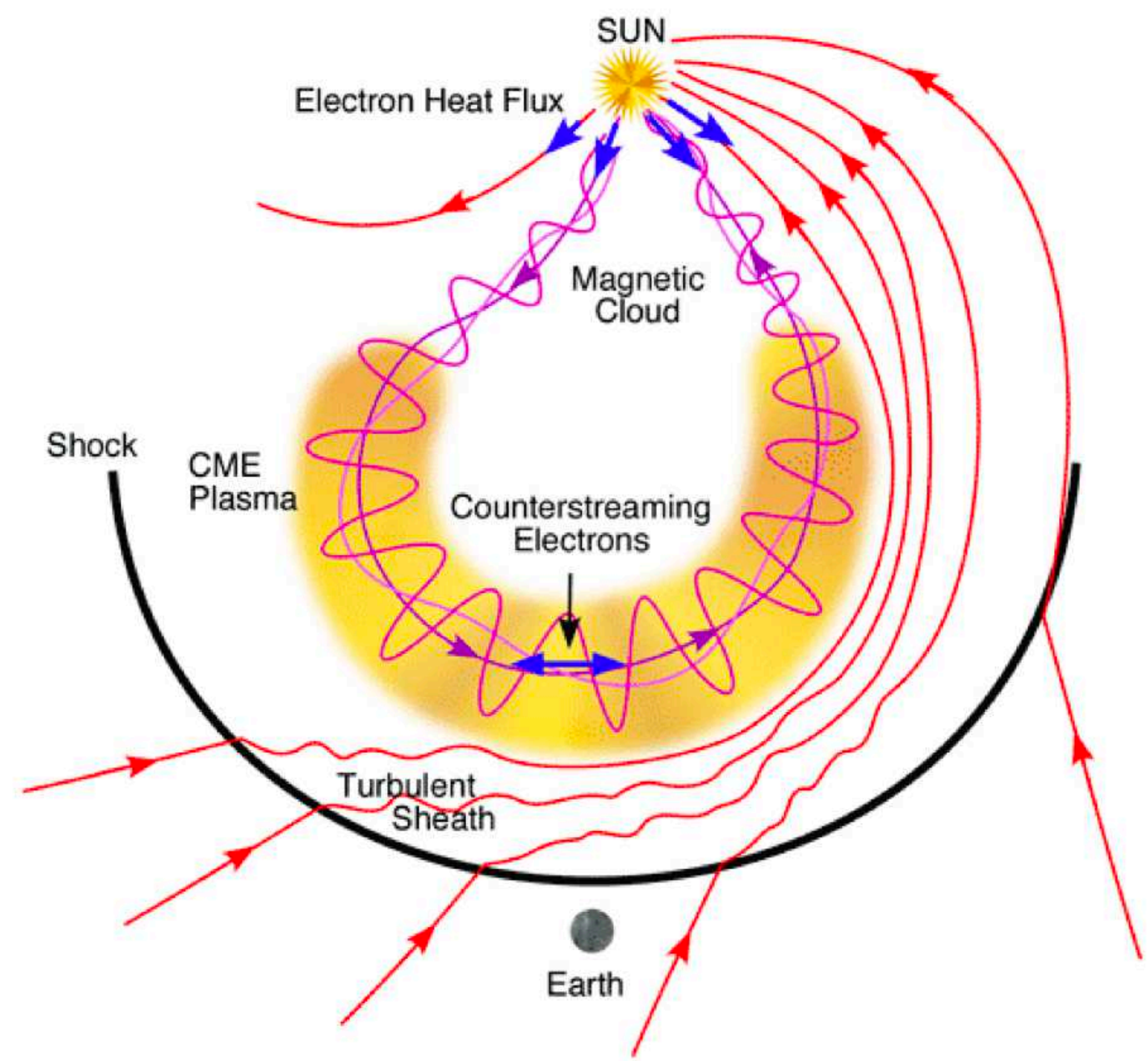
Martens & Kuin (1989)

CME Observation

"The Perfect Storm": Carrington level event



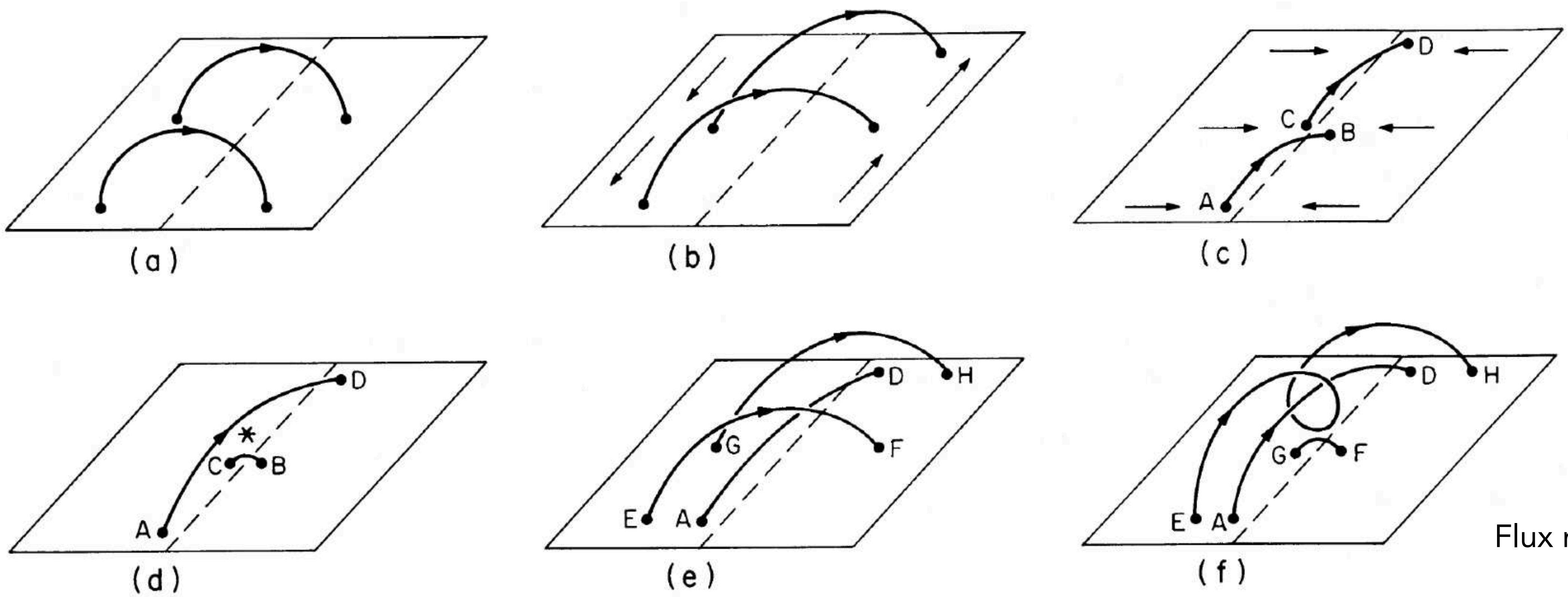
Liu et al. (2014)



Courtesy N. Murphy

Formation of Flux Rope

Sheared arcade

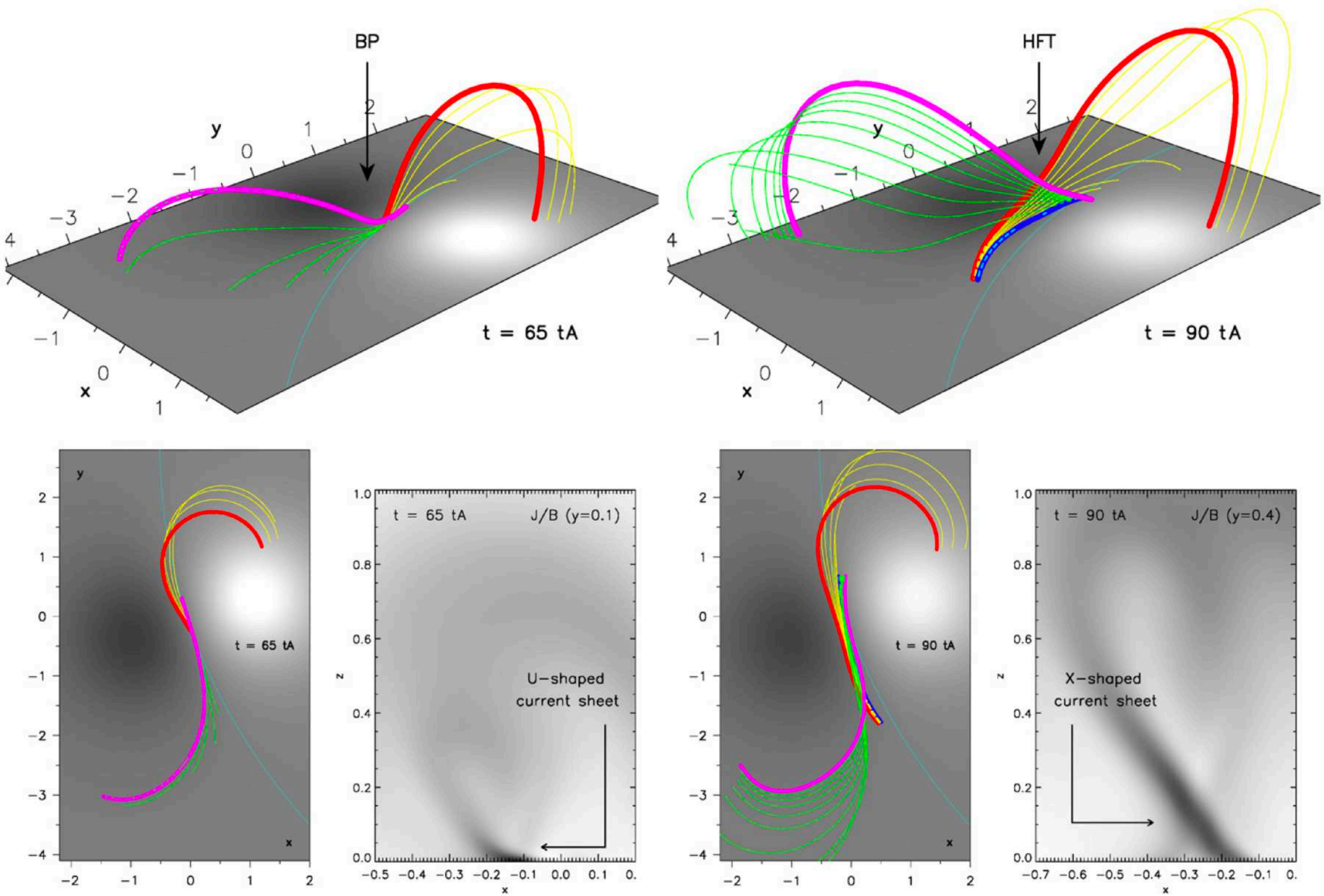


Flux rope

FIG. 1.—Flux cancellation in a sheared magnetic field. The rectangle represents the solar photosphere, and the dashed line is the neutral line separating two regions of opposite magnetic polarity. (*a*) Initial potential field; (*b*) sheared magnetic field produced by flows along the neutral line; (*c*) magnetic shear is increased further due to flows toward the neutral line; (*d*) reconnection produces long loop AD and a shorter loop CB which subsequently submerges; (*e*) overlying loops EF and GH are pushed to the neutral line; (*f*) reconnection produces the helical loop EH and a shorter loop GF which again submerges.

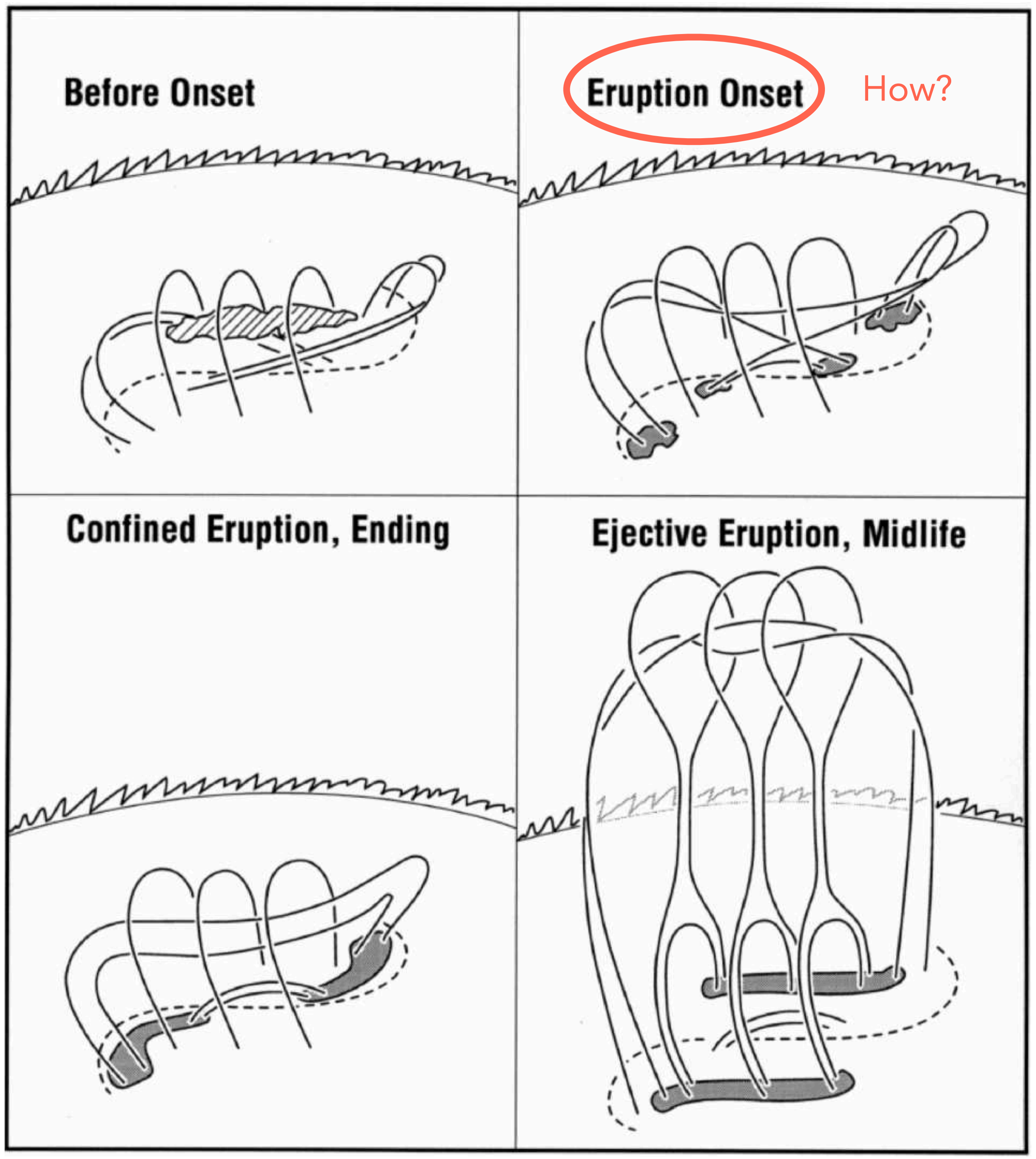
van Ballegooijen & Martens (1989)

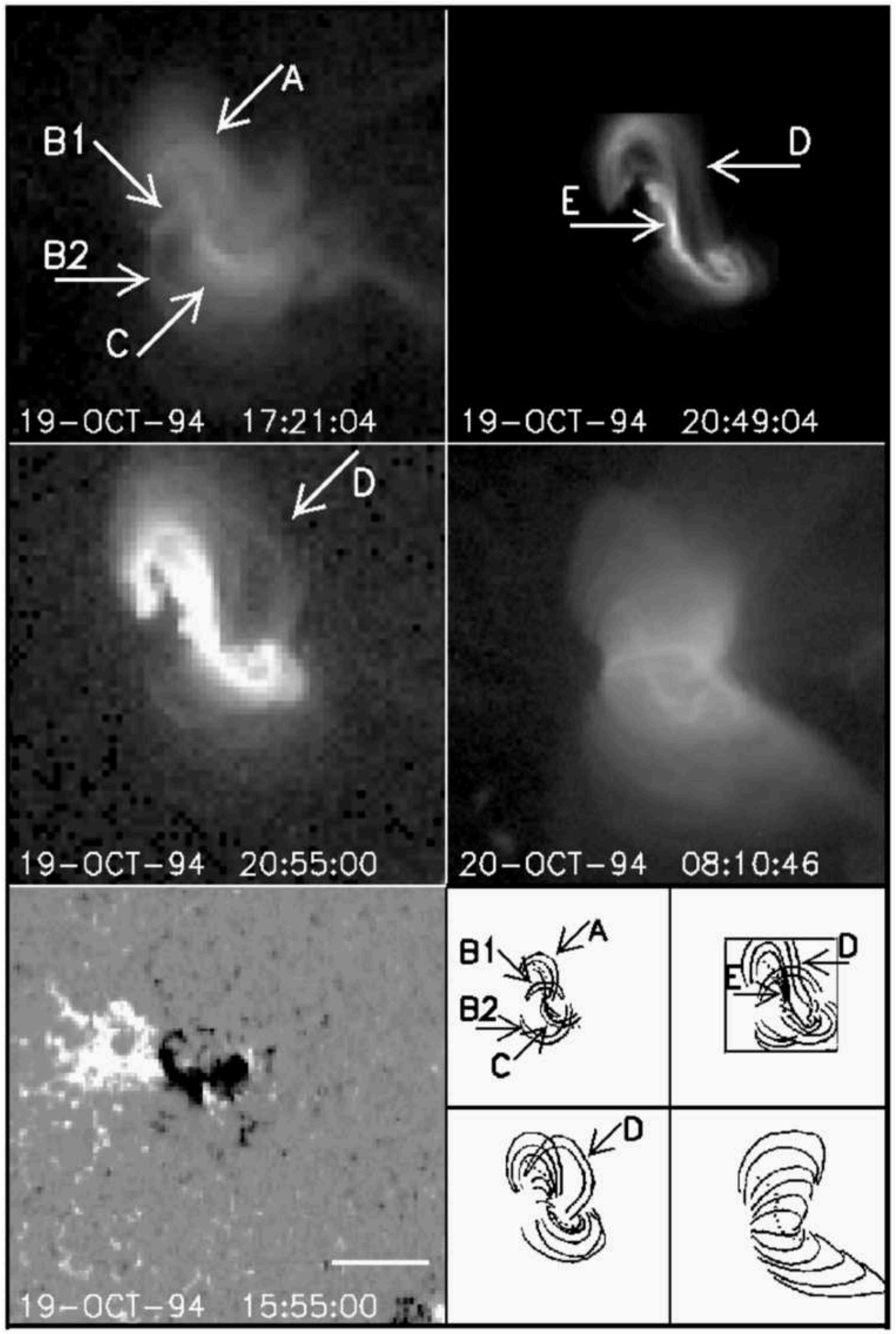
Formation of Flux Rope



Aulanier et al. (2010)

"Tether-Cutting" Reconnection

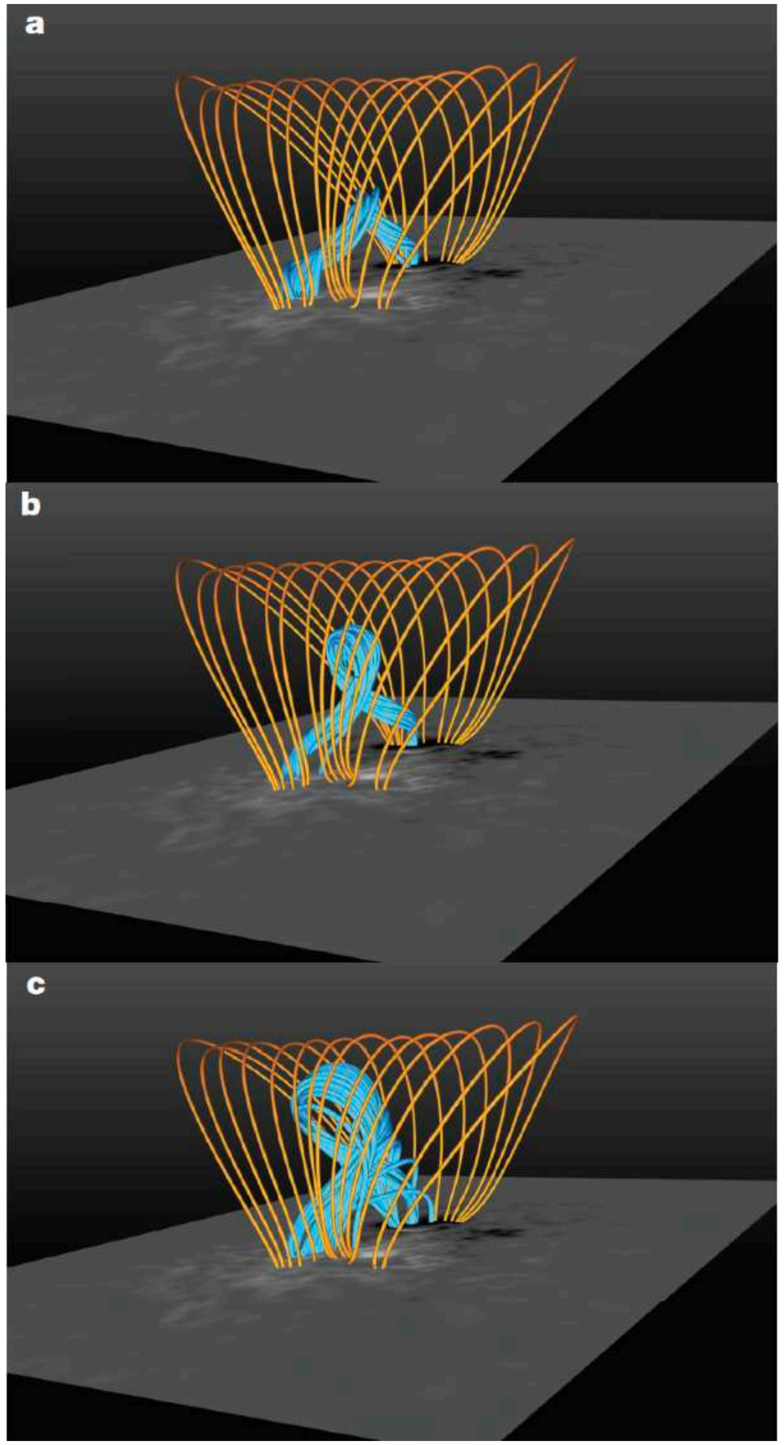




Moore et al. (2001)

Onset of Eruption

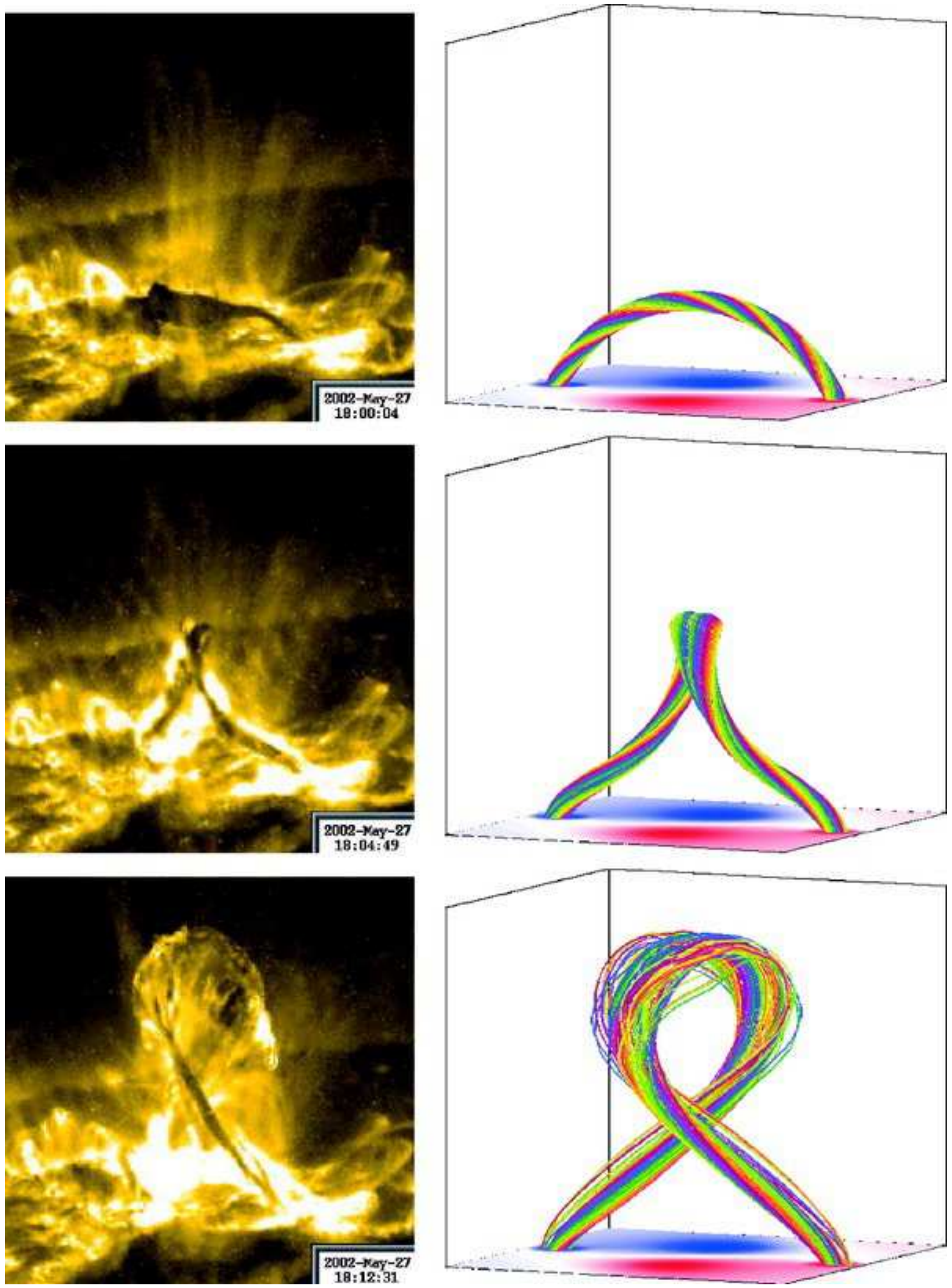
- Possible upper limit of magnetic energy & helicity
- May or may not require pre-eruption FR
- Competition between "hoop force" from energized core field and confinement of overlying field
- Trigger & driver: instability vs reconnection
- Conversion of magnetic energy to kinetic energy



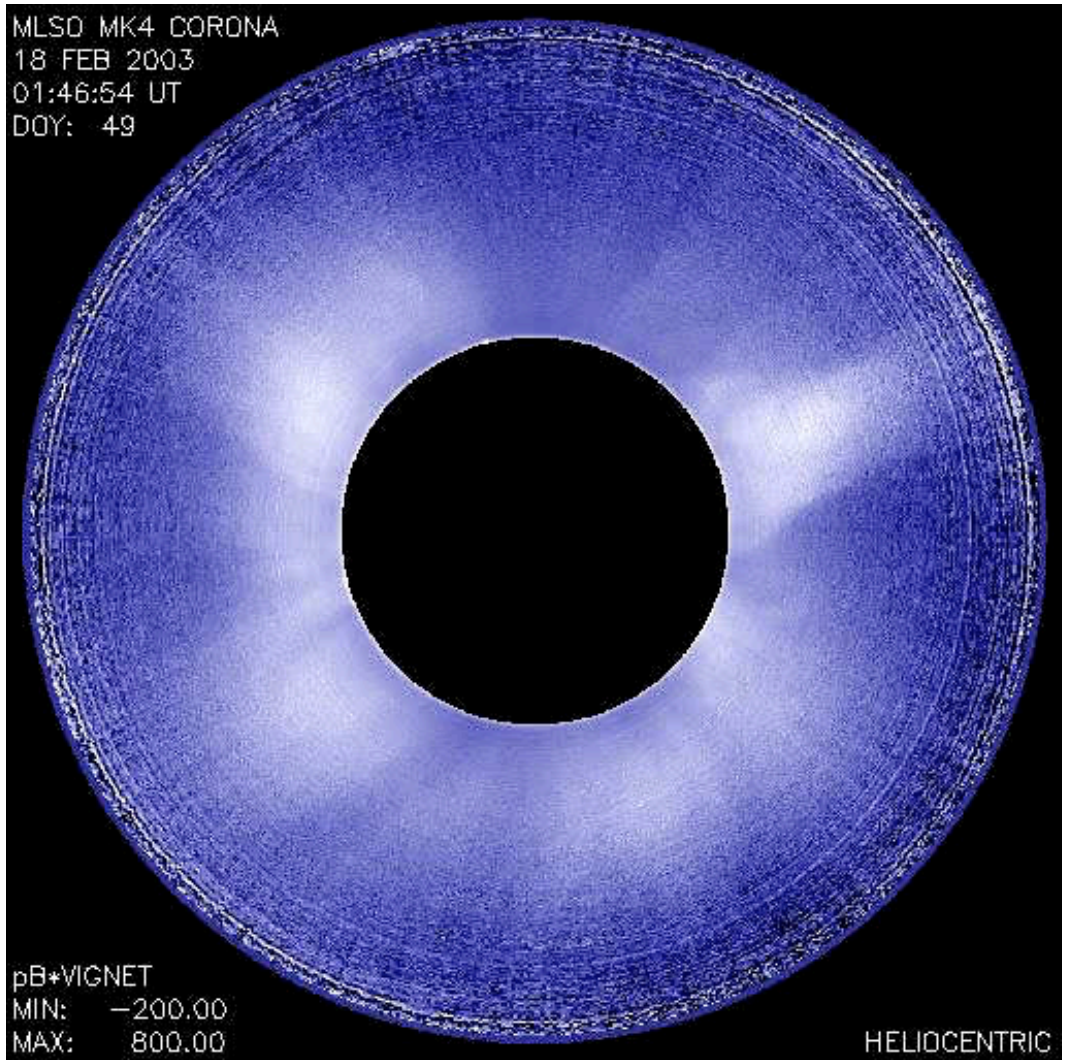
Amari et al. (2018)

Kink Instability

- Twist greater than KI threshold => writhe
- Orientation wrt overlying field changes
- Equilibrium lost



Török & Kliem (2005)

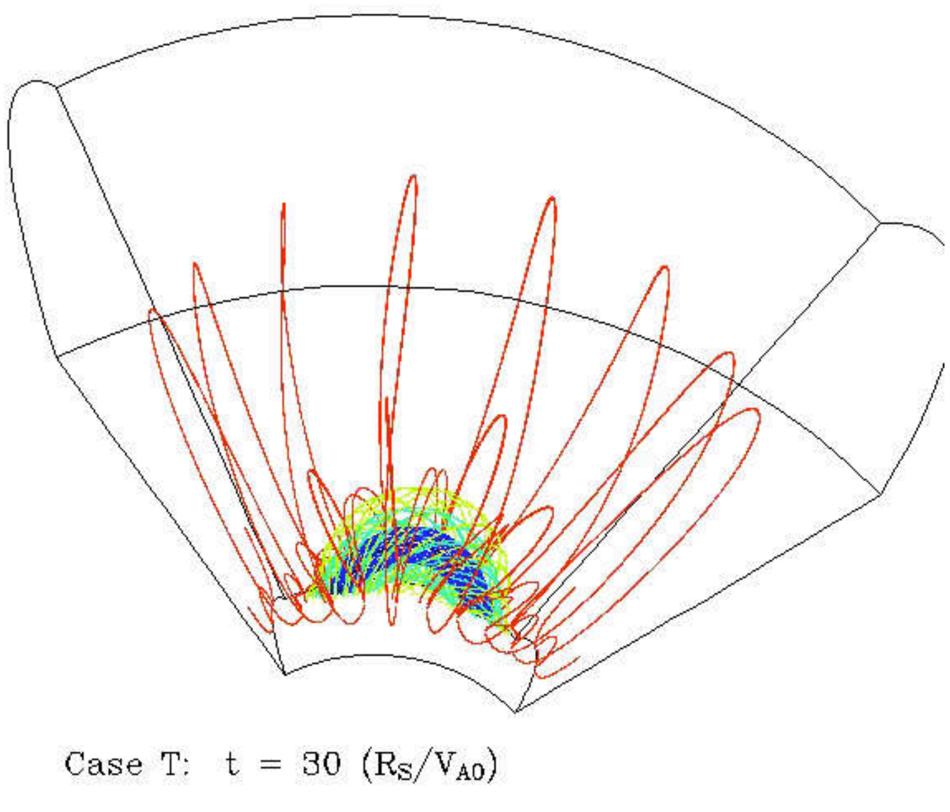


Fan (2005)

Torus Instability

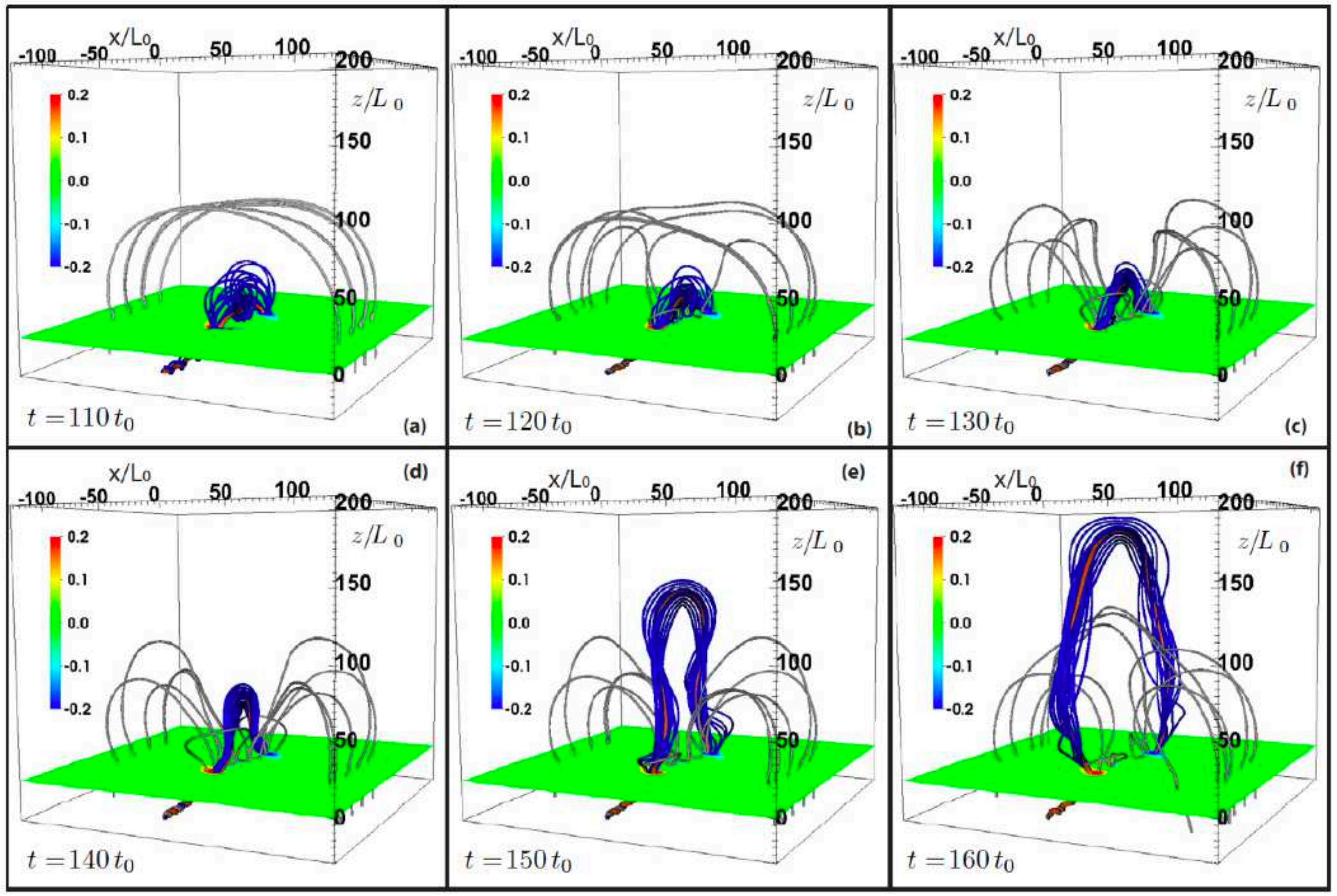
- Overlying field decays fast with height
- Hoop force becomes greater than confinement
- Equilibrium lost

Failed eruption + flux emergence + TI



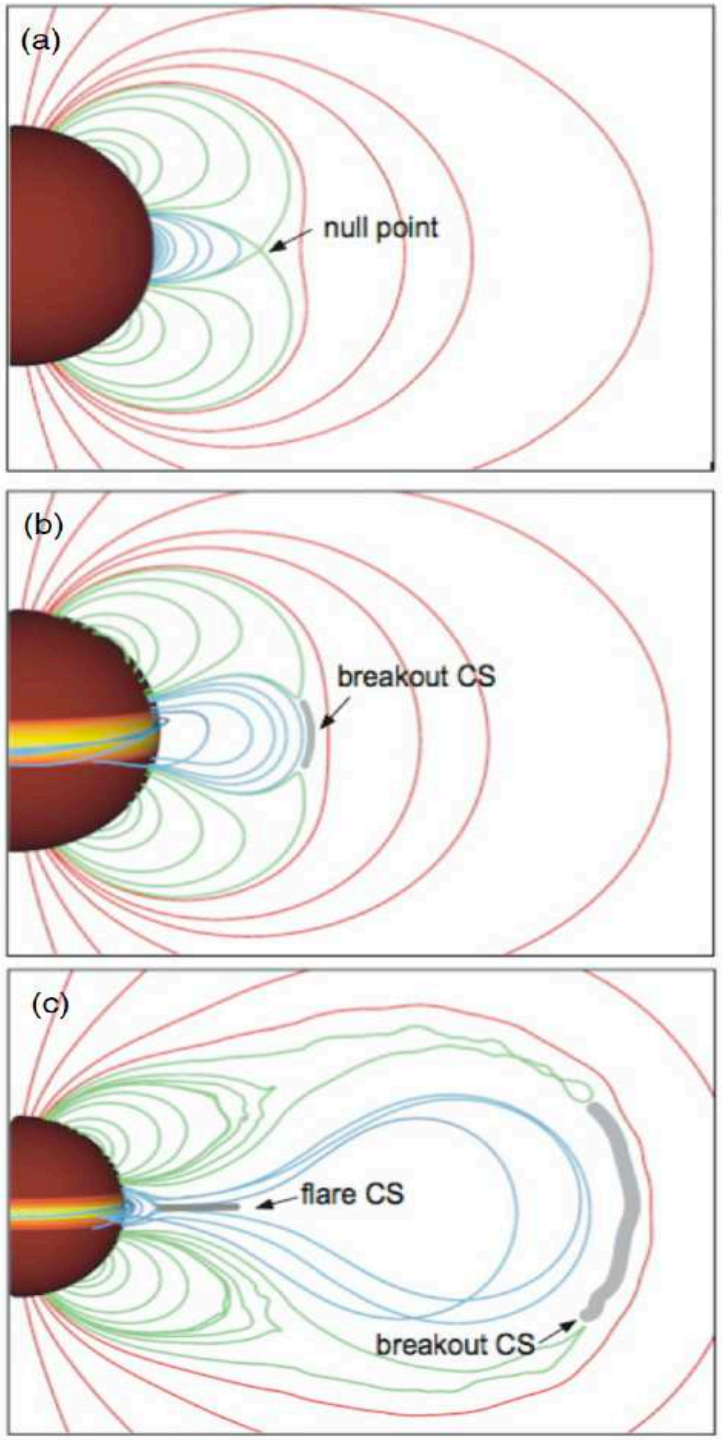
Fan & Gibson (2007)

Flux emergence + breakout reconnection + TI

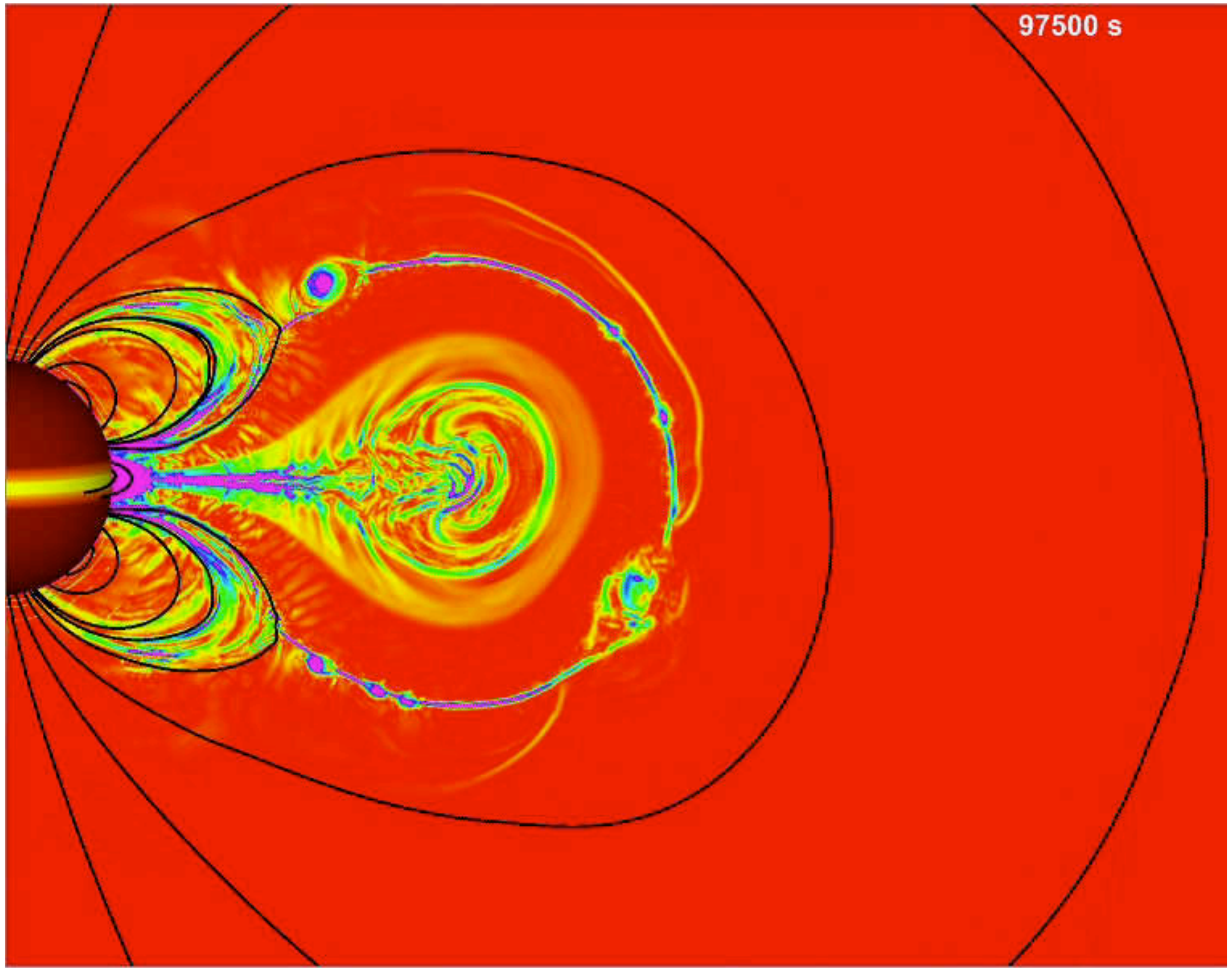


Leake et al. (2014)

Magnetic Breakout

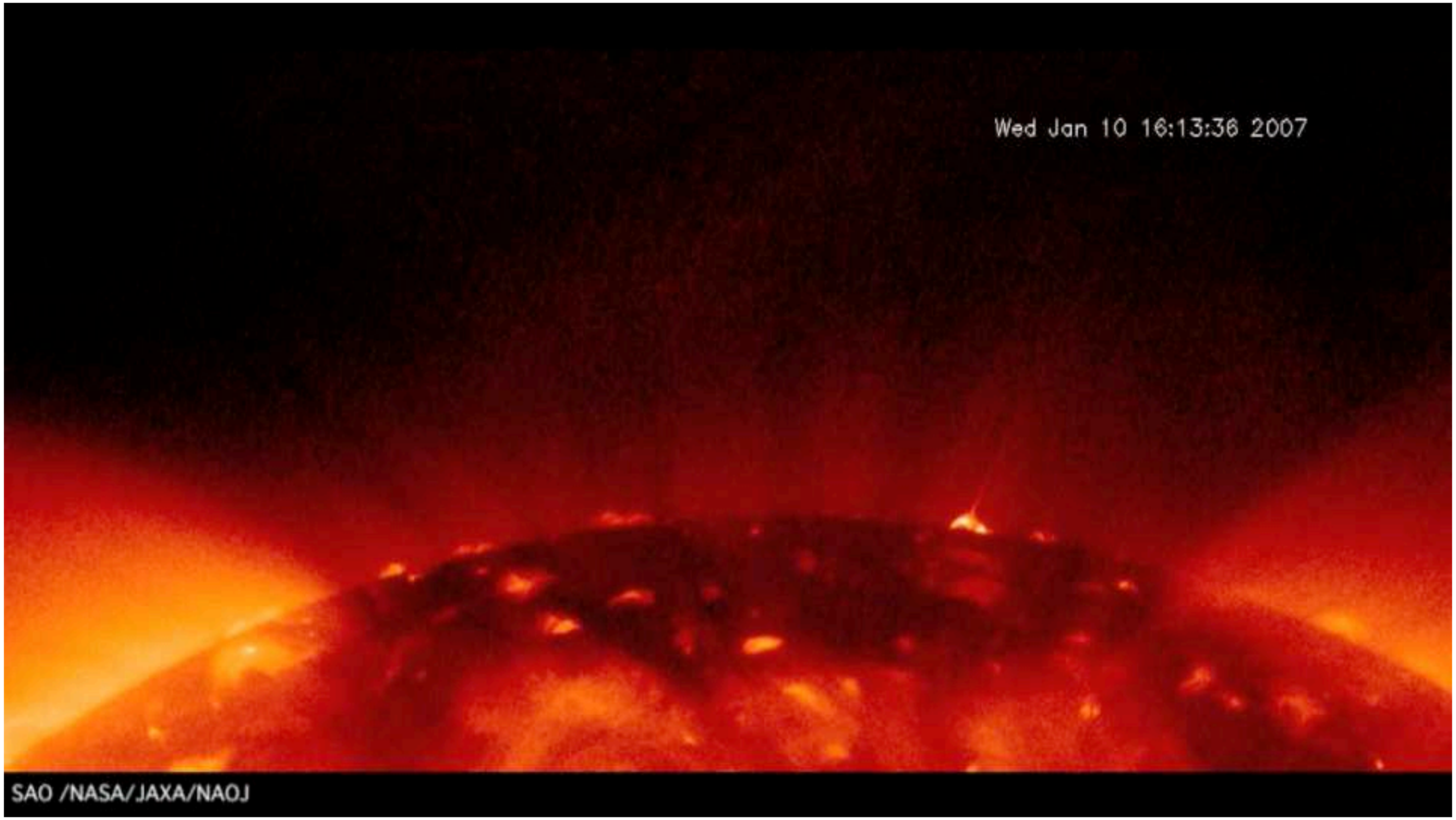


- Multipolar field + shearing needed
- No pre-existing FR required: formed during eruption
- Reconnection essential

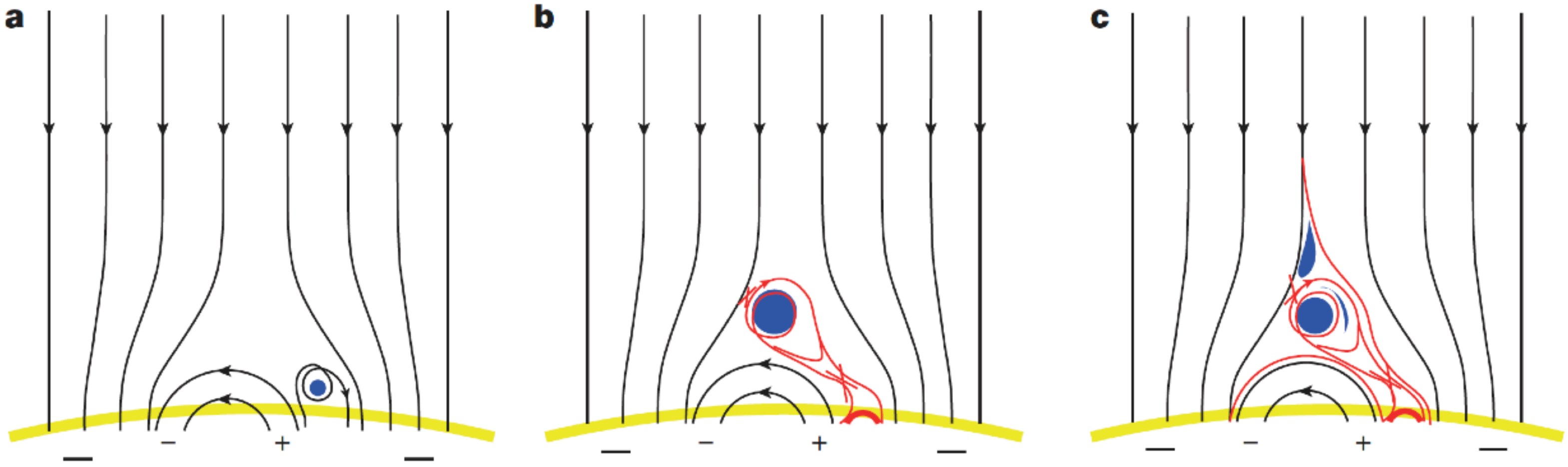


Antiochos et al. (1999); Karpen et al. (2012)

Jet!

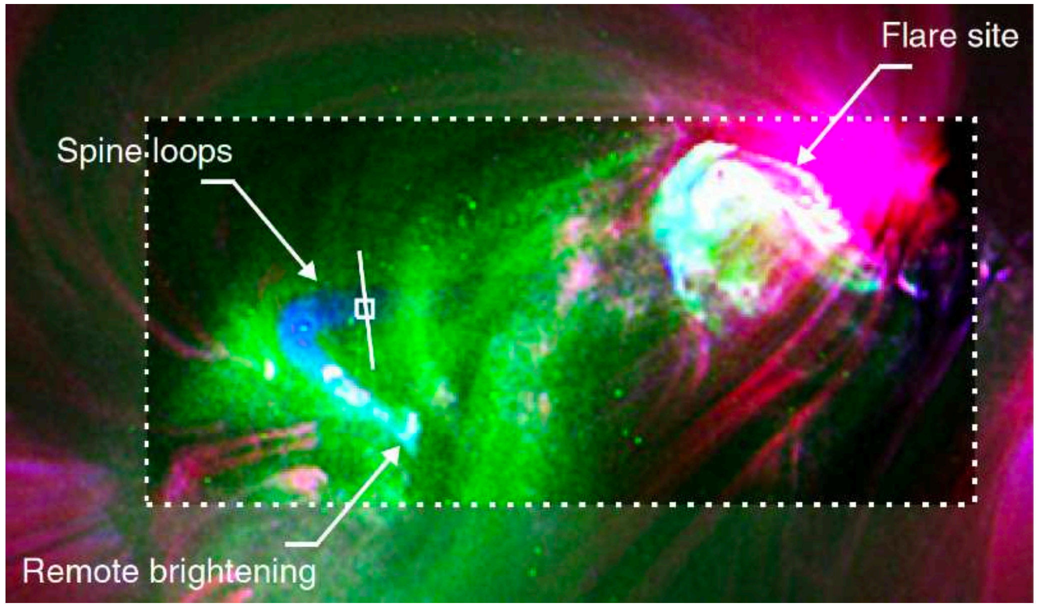


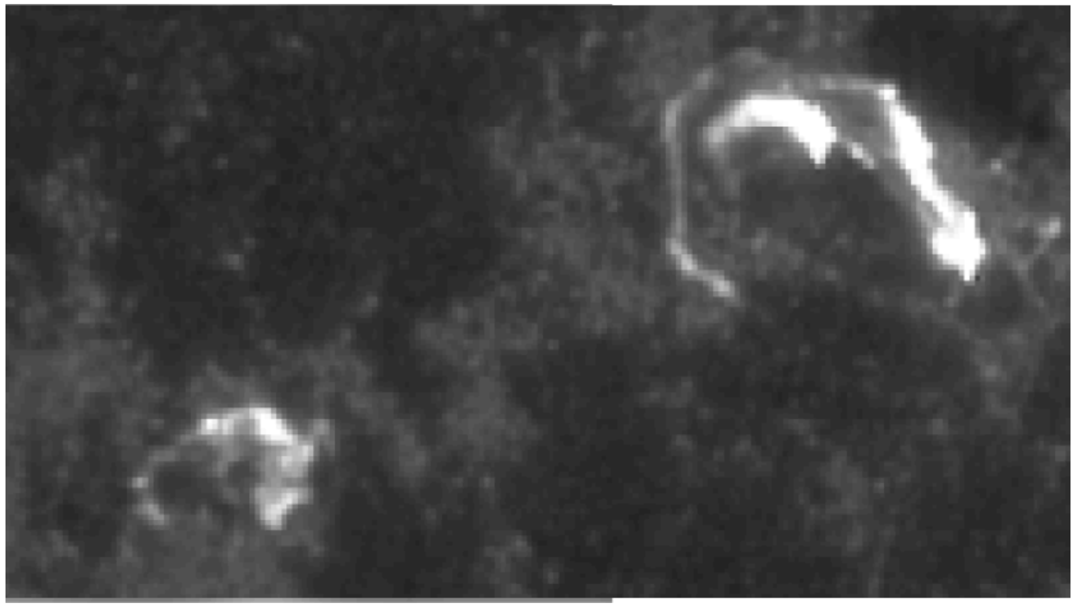
Cirtain et al. (2007)

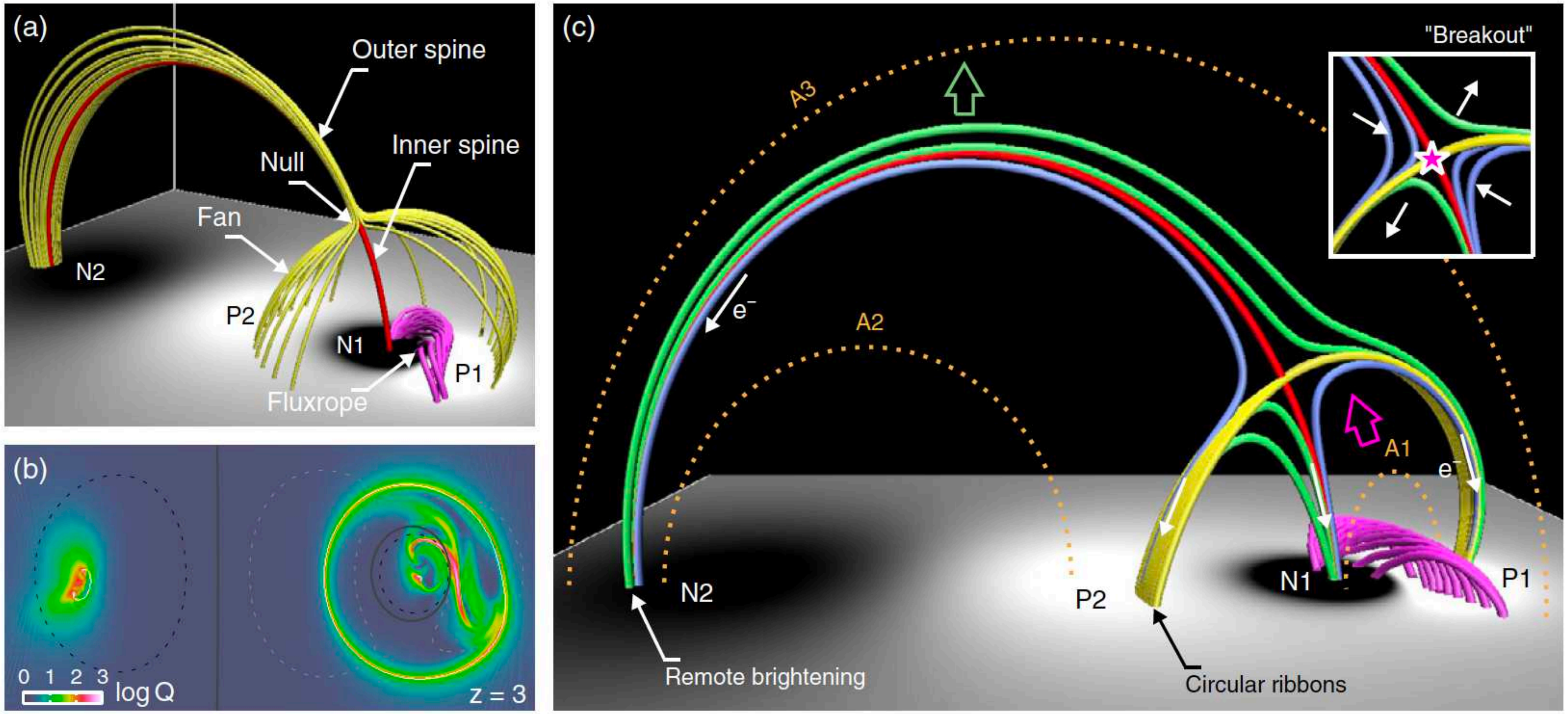


Sterling et al. (2015)

Fan-Spine Topology

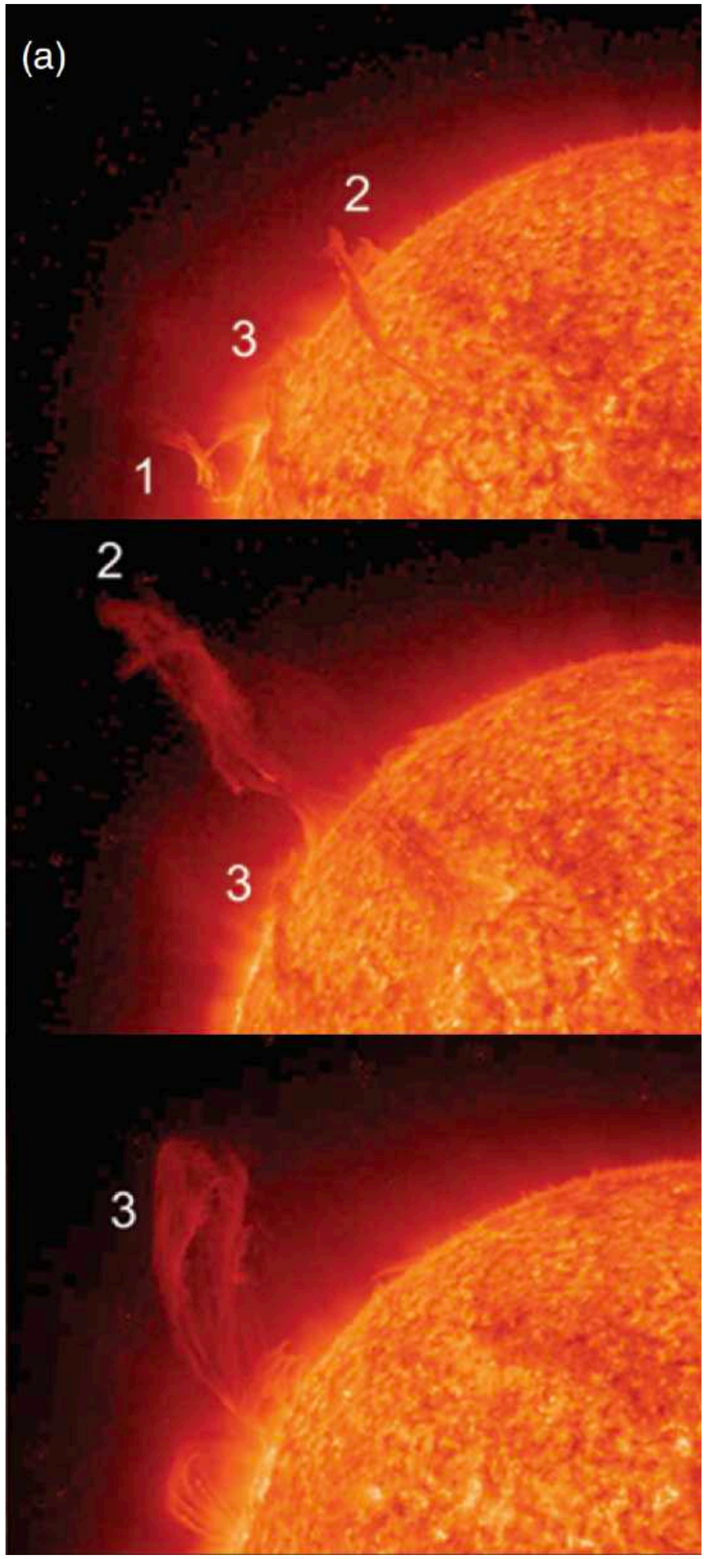






Sun et al. (2013)

Sympathetic Eruptions



Schrijver & Title (2011); Török et al. (2011); Titov et al. (2012)