COLLAGE 2019

Active Region Magnetic Fields I

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Outline

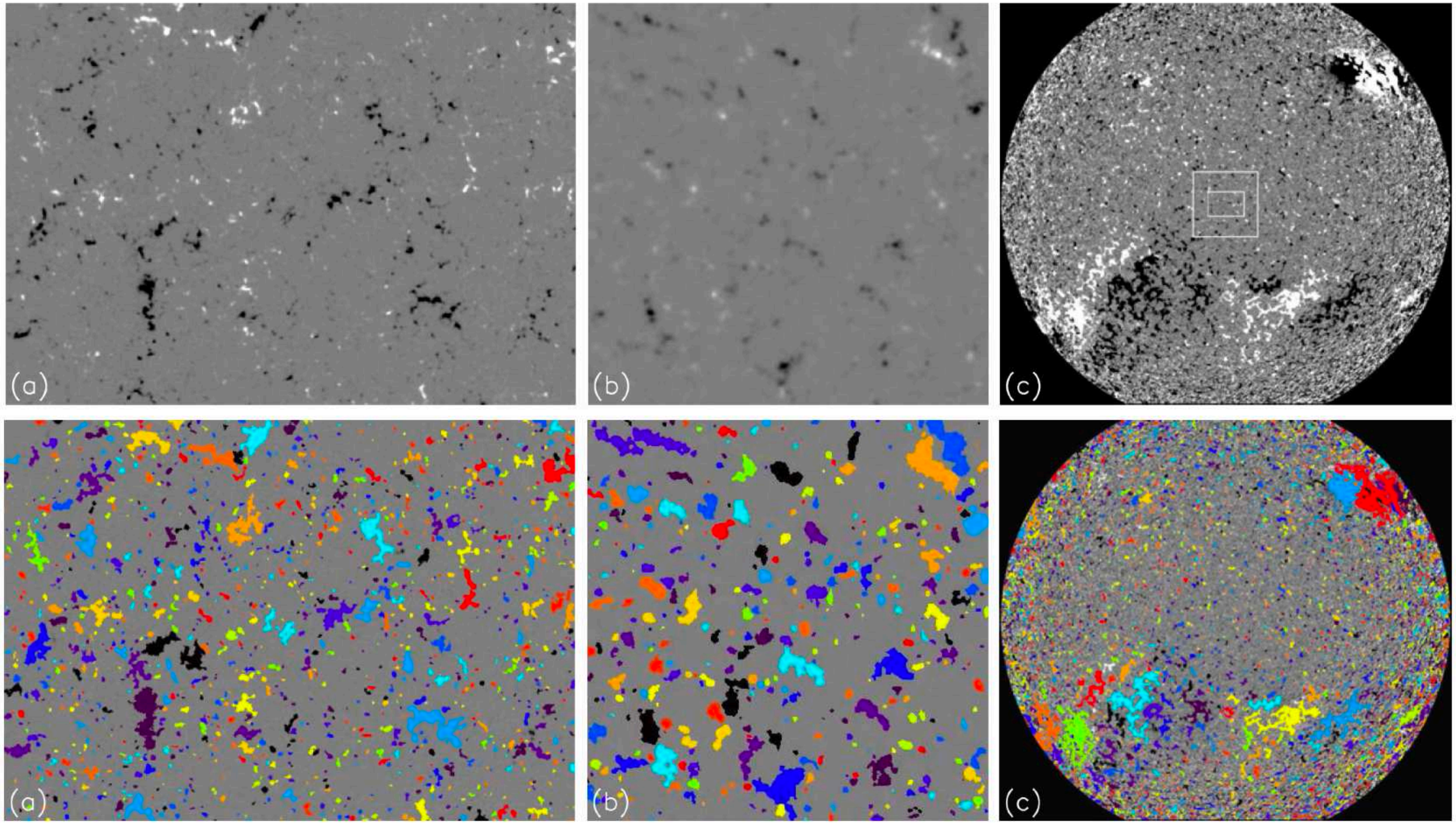
- Crash course on flux emergence
- Flare/CME basics

Crash Course on Flux Emergence

See Cheung & Isobe (2014) for review

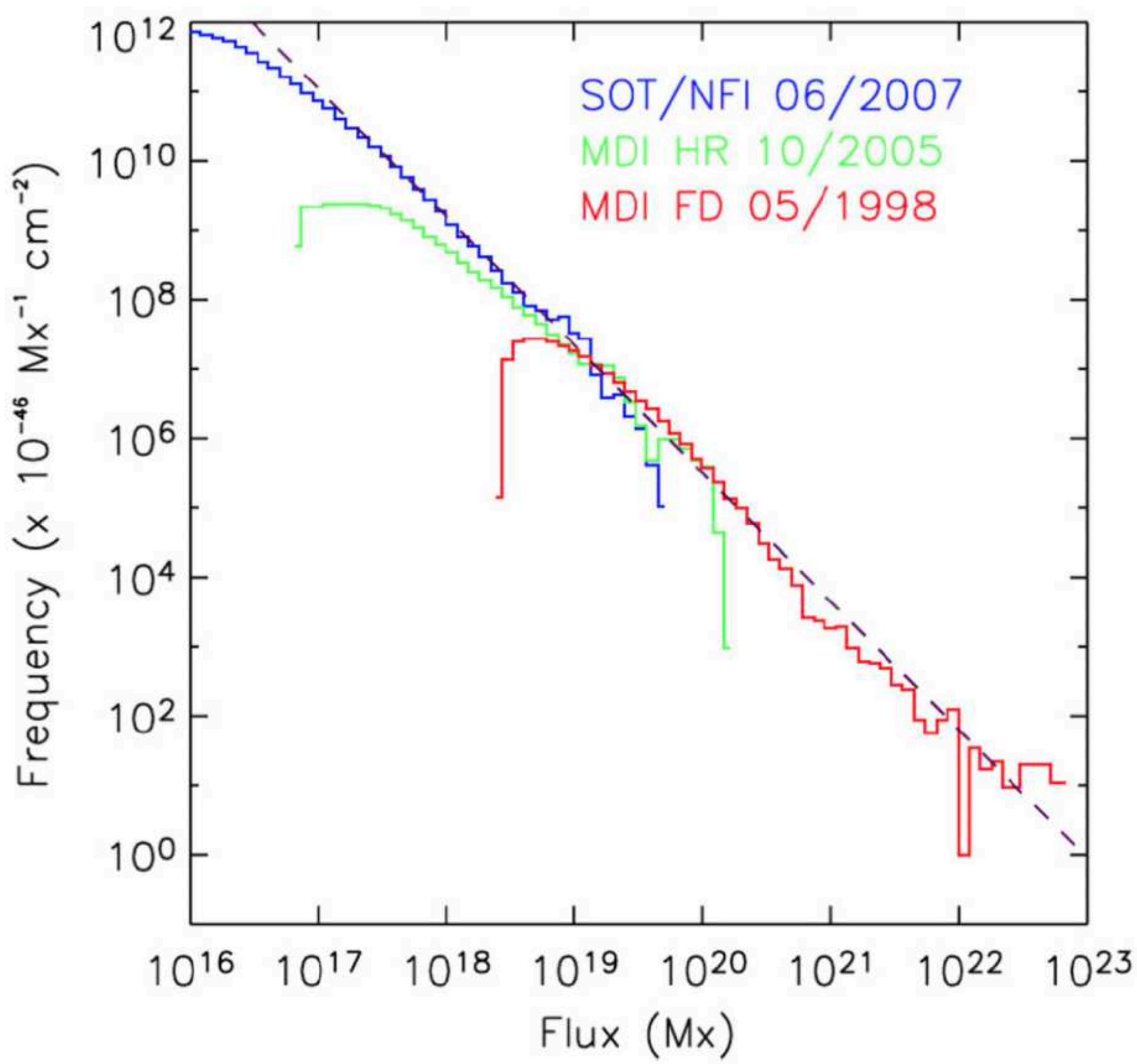
Flux Emergence: Two Dynamos?

- AR flux is highly cycle dependent; quiet Sun flux less so
- Are global & surface dynamo two different processes?



Parnell et al. (2009)

Flux Emergence: Continuous Scales

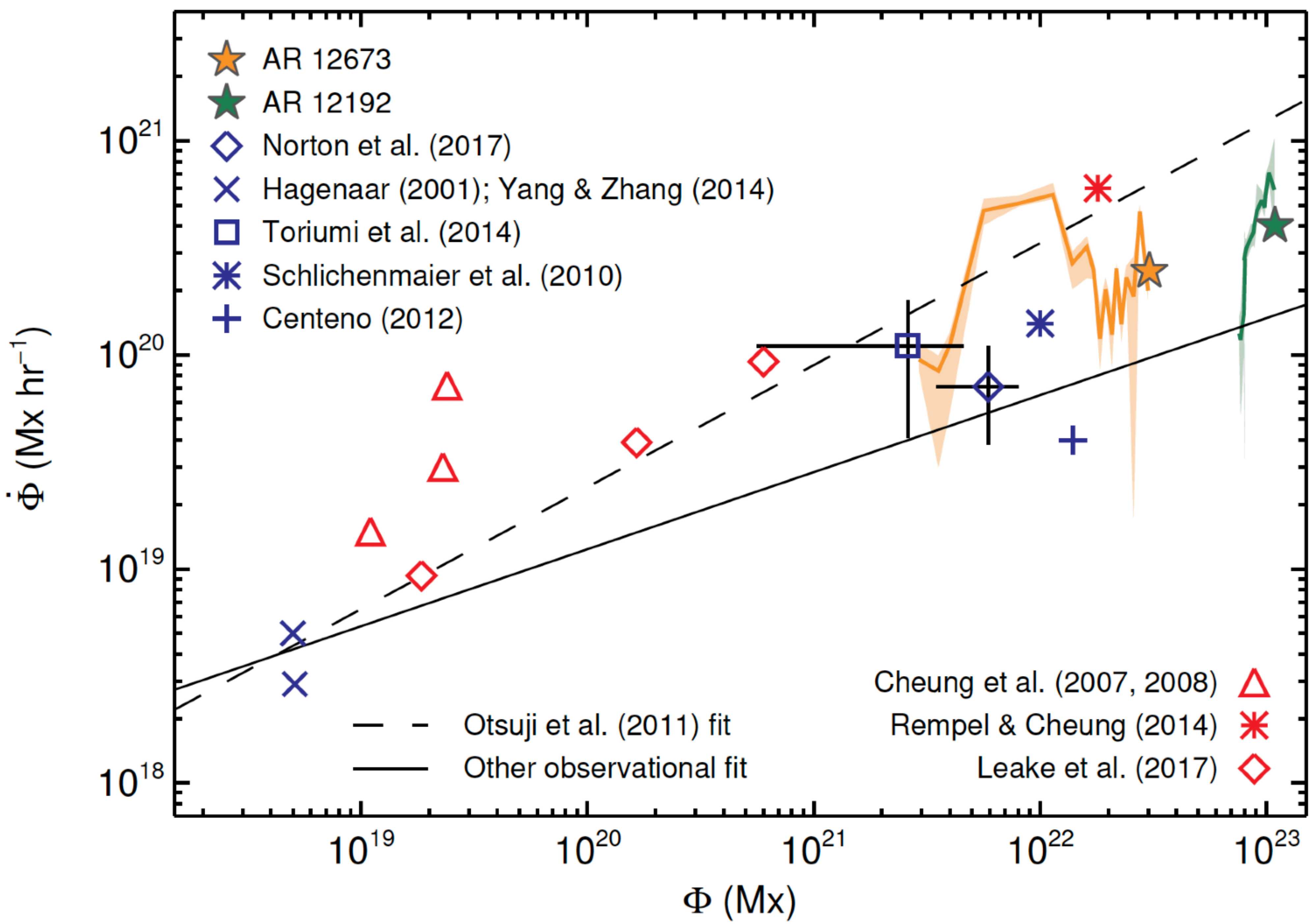


Harvey (1993); Hagenaar et al. (2003)
Parnell et al. (2009); Thornton & Harvey (2011)

- Continuous power law: slope -1.85
- QS flux dominates: 10^4 x AR!
- Continuous dynamo process with different Rossby numbers:

$$Ro = \frac{P_{\rm rot}}{\tau_{\rm conv}}$$

AR Flux Emergence Rate



Norton et al. (2017); Sun & Norton (2017)

Buoyant Rise of Flux Tubes

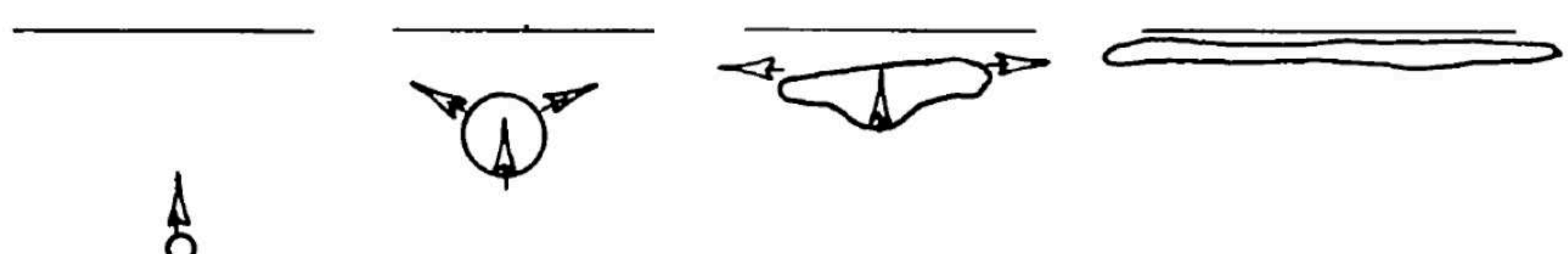
- Density deficiency due to increased magnetic field

$$p_i + \frac{B^2}{8\pi} = p_o$$

- Steep stratification leads to decreasing pressure scale height: flattening

$$H_p = \left(\frac{d\ln p}{dz}\right)^{-1} \sim 150\ \mathrm{km}\ (z=0)$$

- Large field (super-equipartition) needed to rise: ~ 10 kG



Spruit (1987)

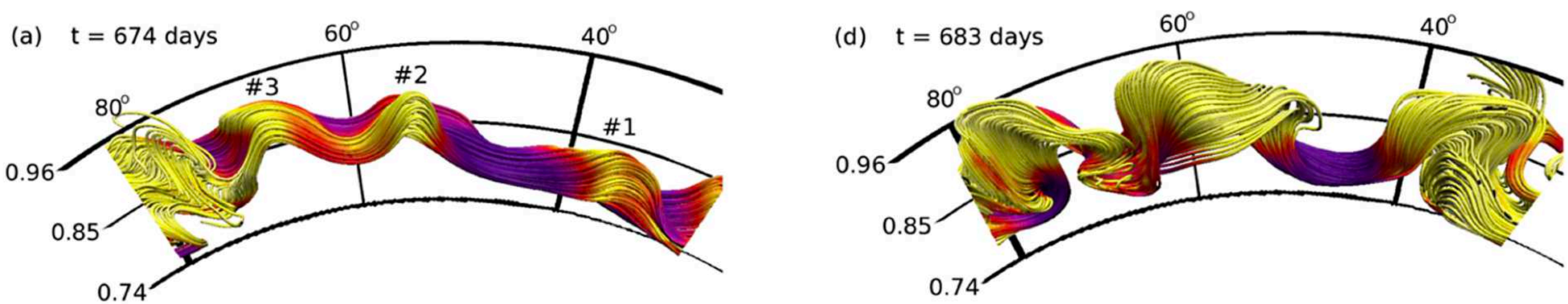
Buoyant Rise of Flux Tubes

- Stratification unstable to convective perturbation near surface i.e., superadiabatic

$$\frac{\partial \rho_{\text{ad}}}{\partial z} < \frac{\partial \rho}{\partial z}, \quad \text{or} \quad \left.\frac{d \ln T}{d \ln p}\right|_s < \frac{d \ln T}{d \ln p}$$

- Susceptible to various magnetic buoyancy instabilities

- Horizontal expansion needs to be suppressed: e.g. with twist



Nelson et al. (2014)

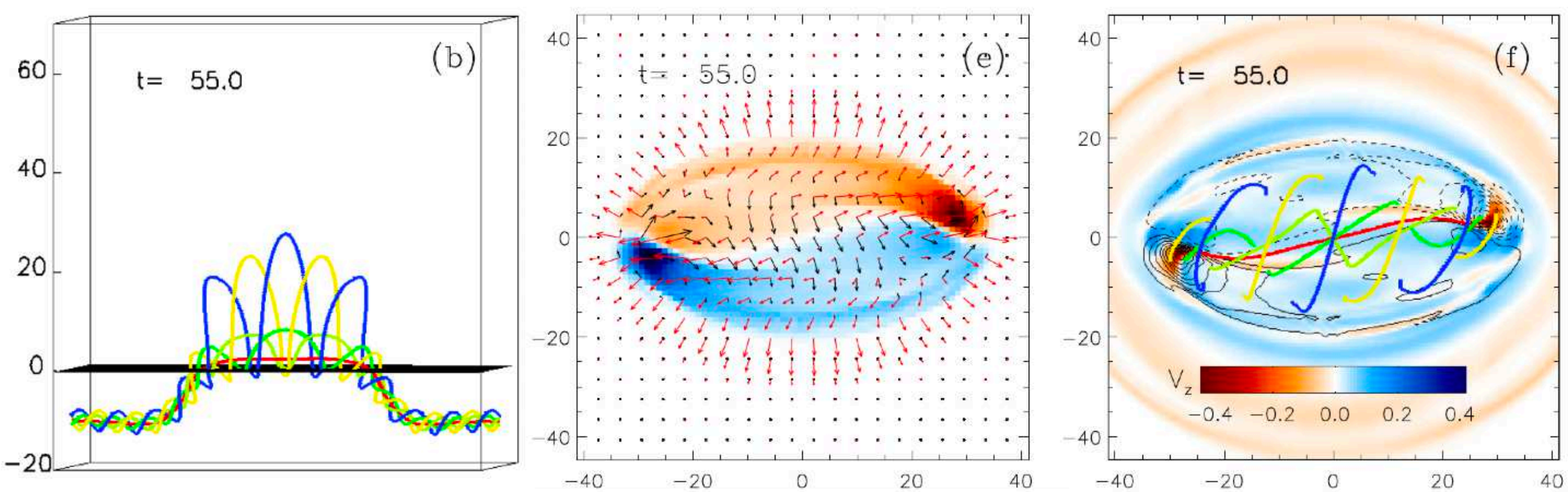
Twist and Writhe of Flux Tubes

- Large scale structure (small *Ro*) modulated by Coriolis force

- Can develop twist/writhe due to interaction with turbulence & kinetic helicity, i.e. Σ-effect (Longcope & Klapper 1997; Longcope et al. 1998)

$$H_m = \int_V \boldsymbol{A} \cdot \boldsymbol{B} dV = \frac{\Phi^2}{2\pi}(T_w + W_r)$$

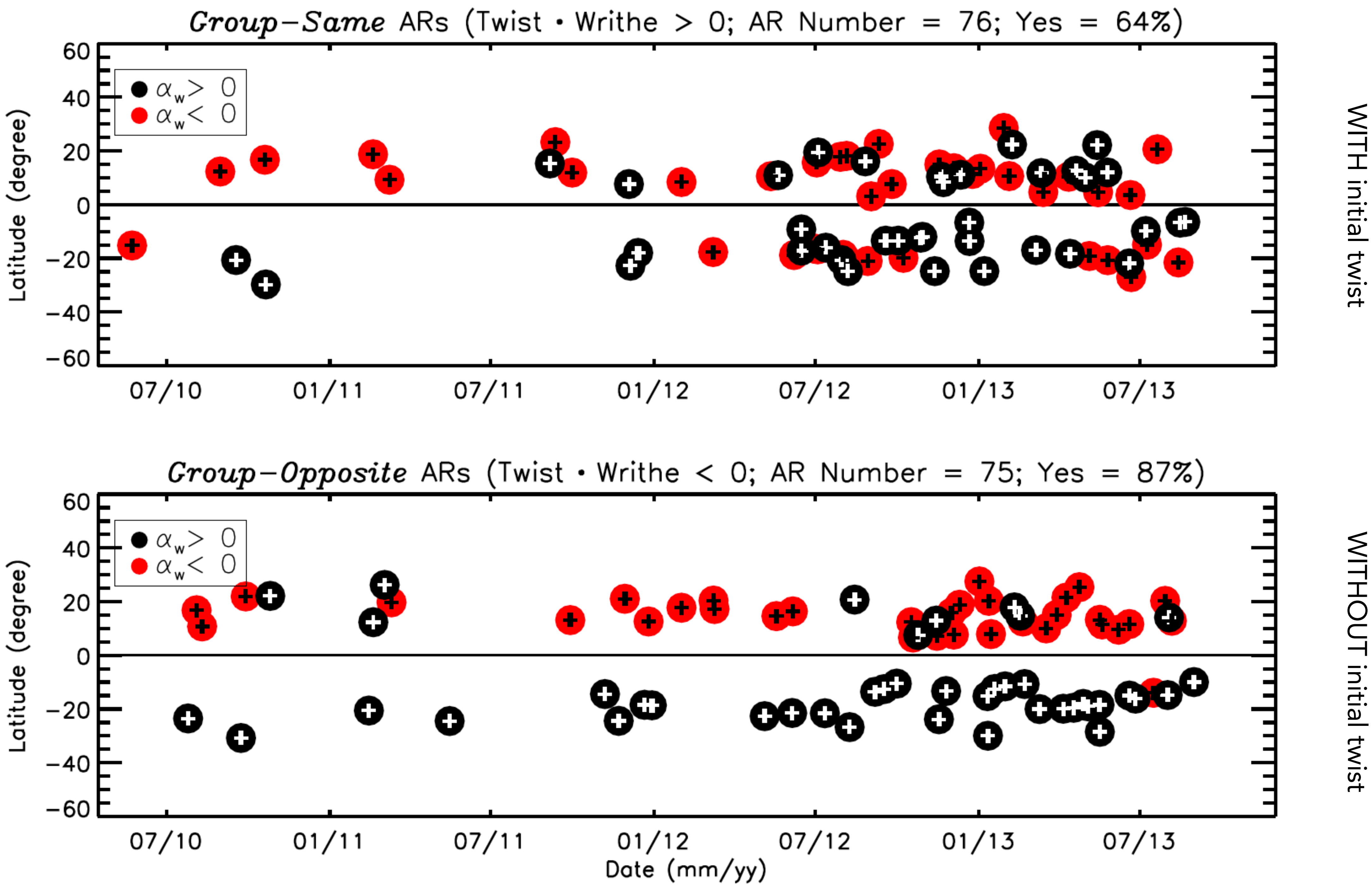
- Helical kink instability; shear & twist as source of space weather



Fan (2001)

Twist and Writhe of Flux Tubes

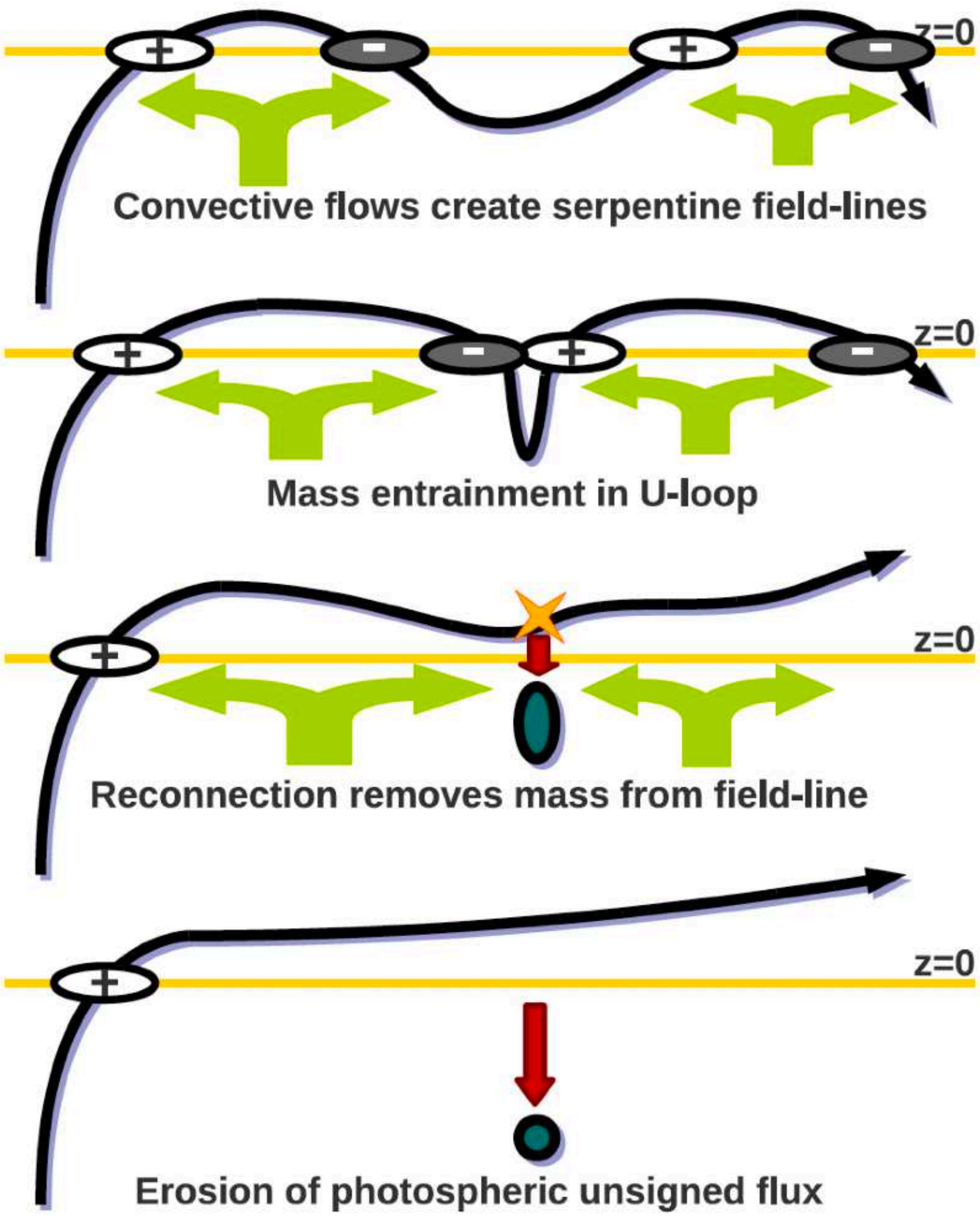
Hemispheric rule of twist

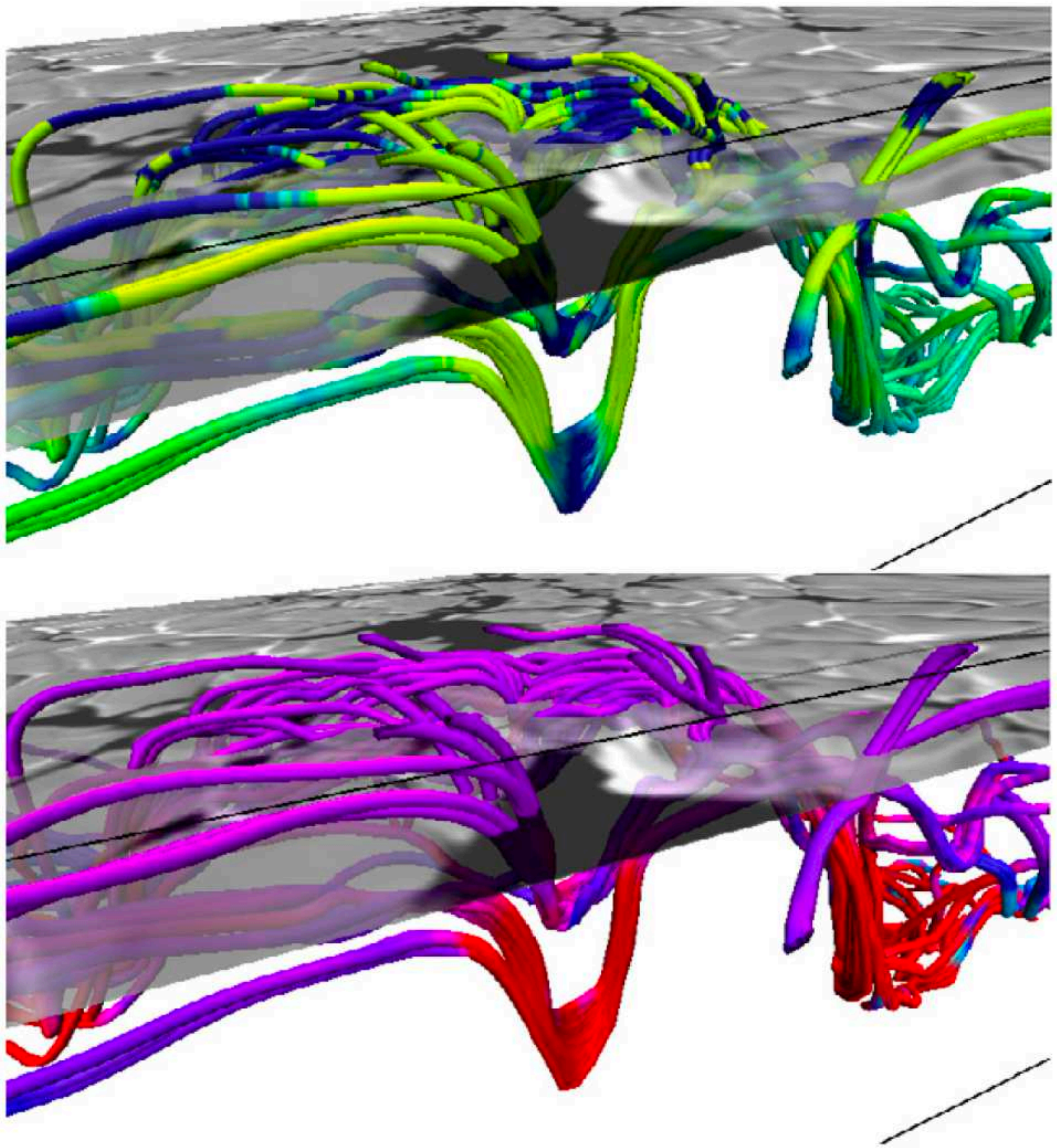


Liu et al. (2014)

Interaction with Convection

Interaction with surface convection & mass discharge

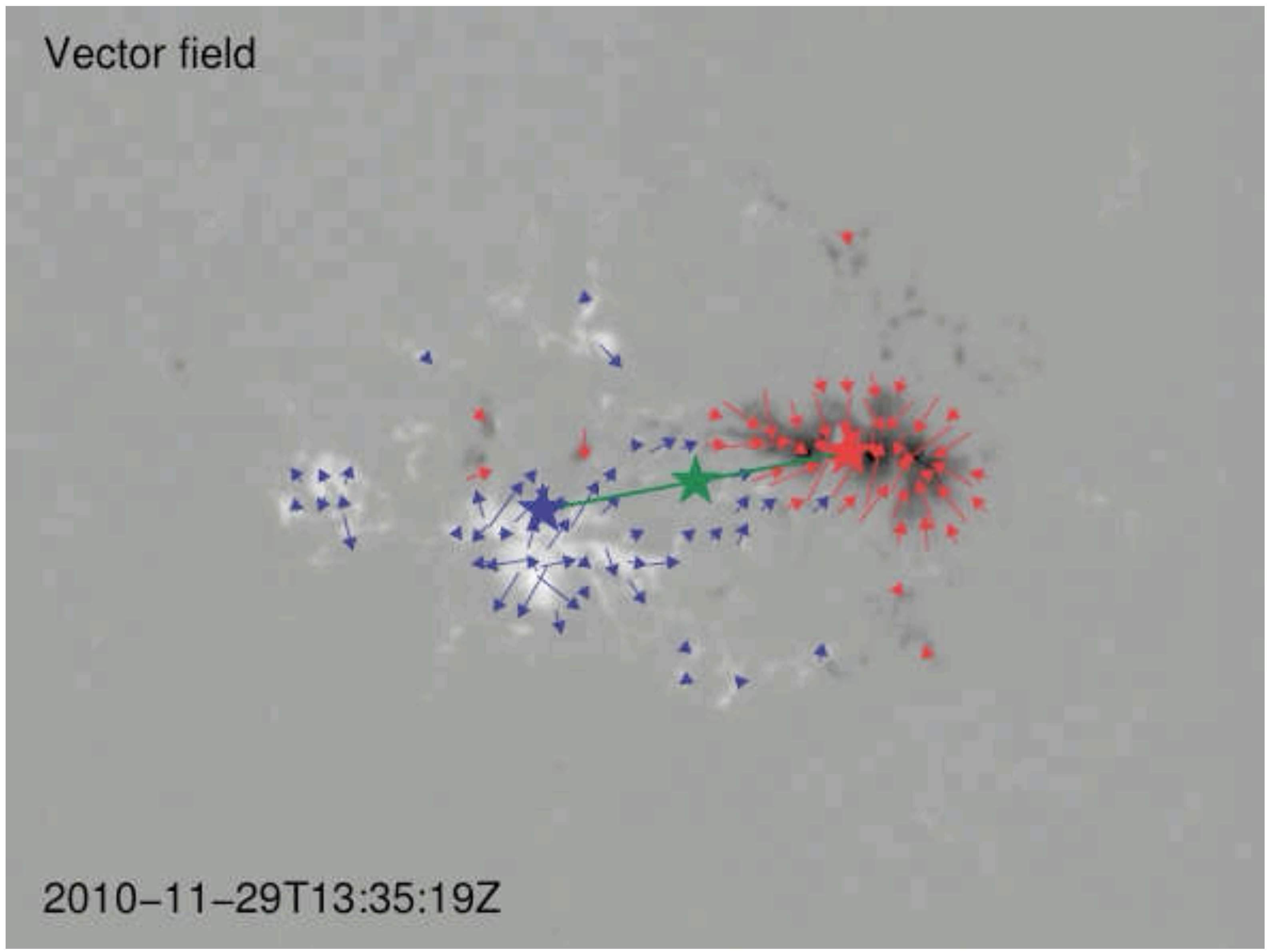




Cheung et al. (2010)

Flux Emergence Observation

HMI; AR 11130



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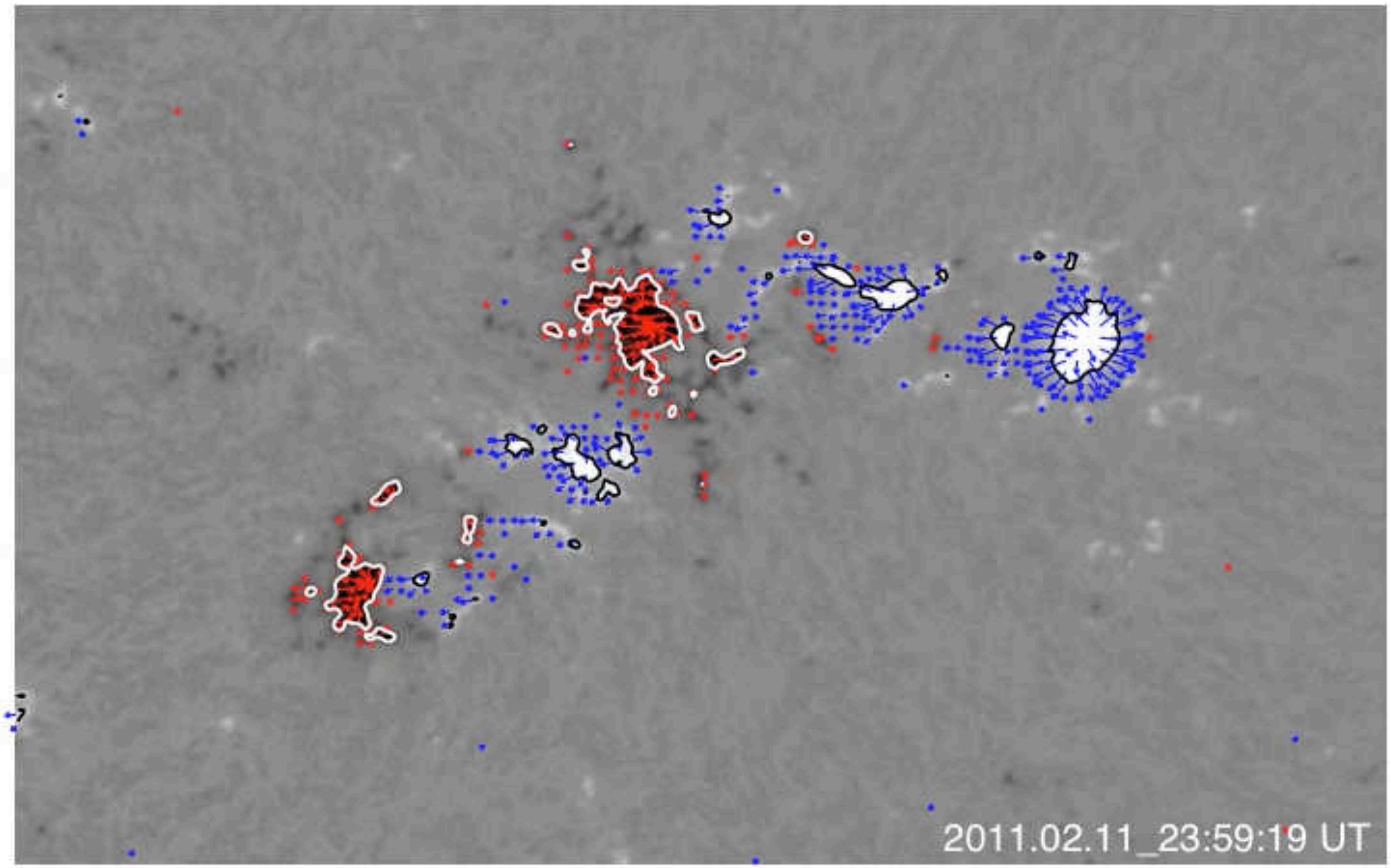
Flux Emergence Observation

HMI; AR 11158

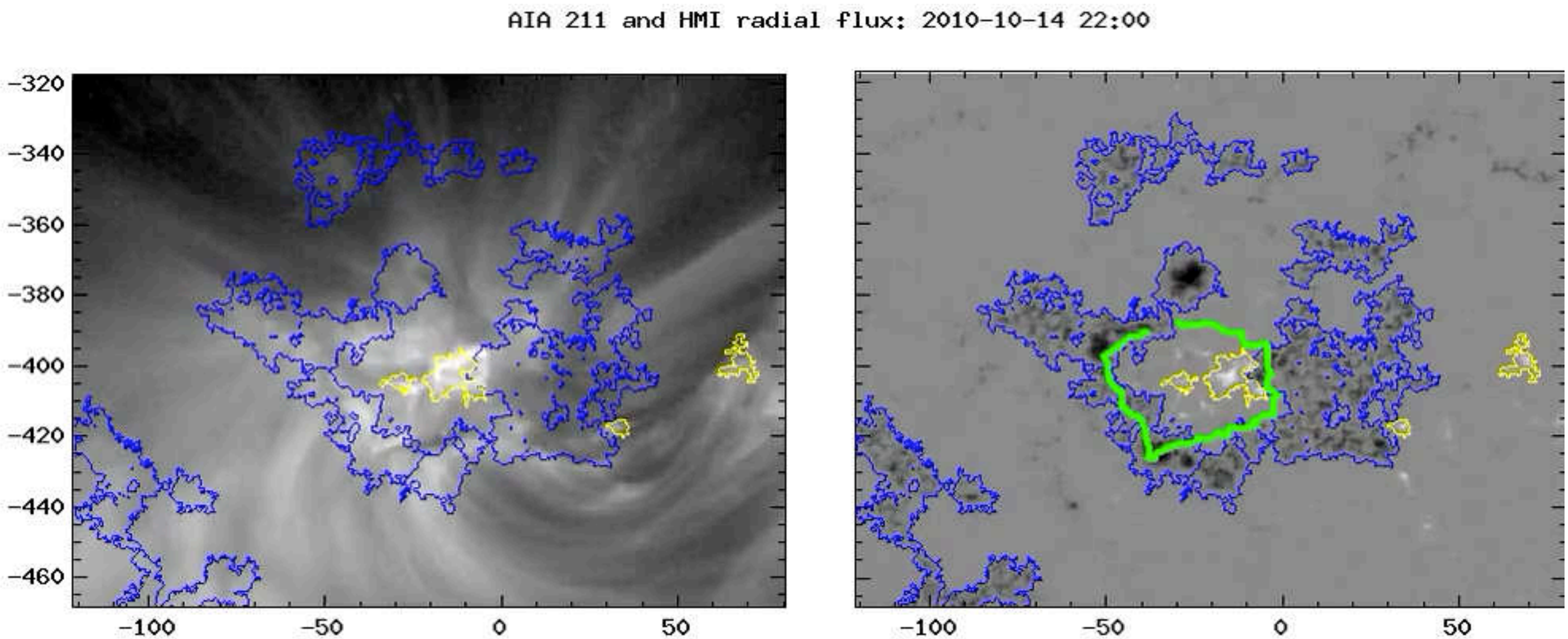


Q: Which AR is more likely to produce flare? AR 11158 or 11130?

Sun et al. (2012)

Energization of Corona

AR 11112: Topology change $\Delta E = 7 \times 10^{30}$ erg

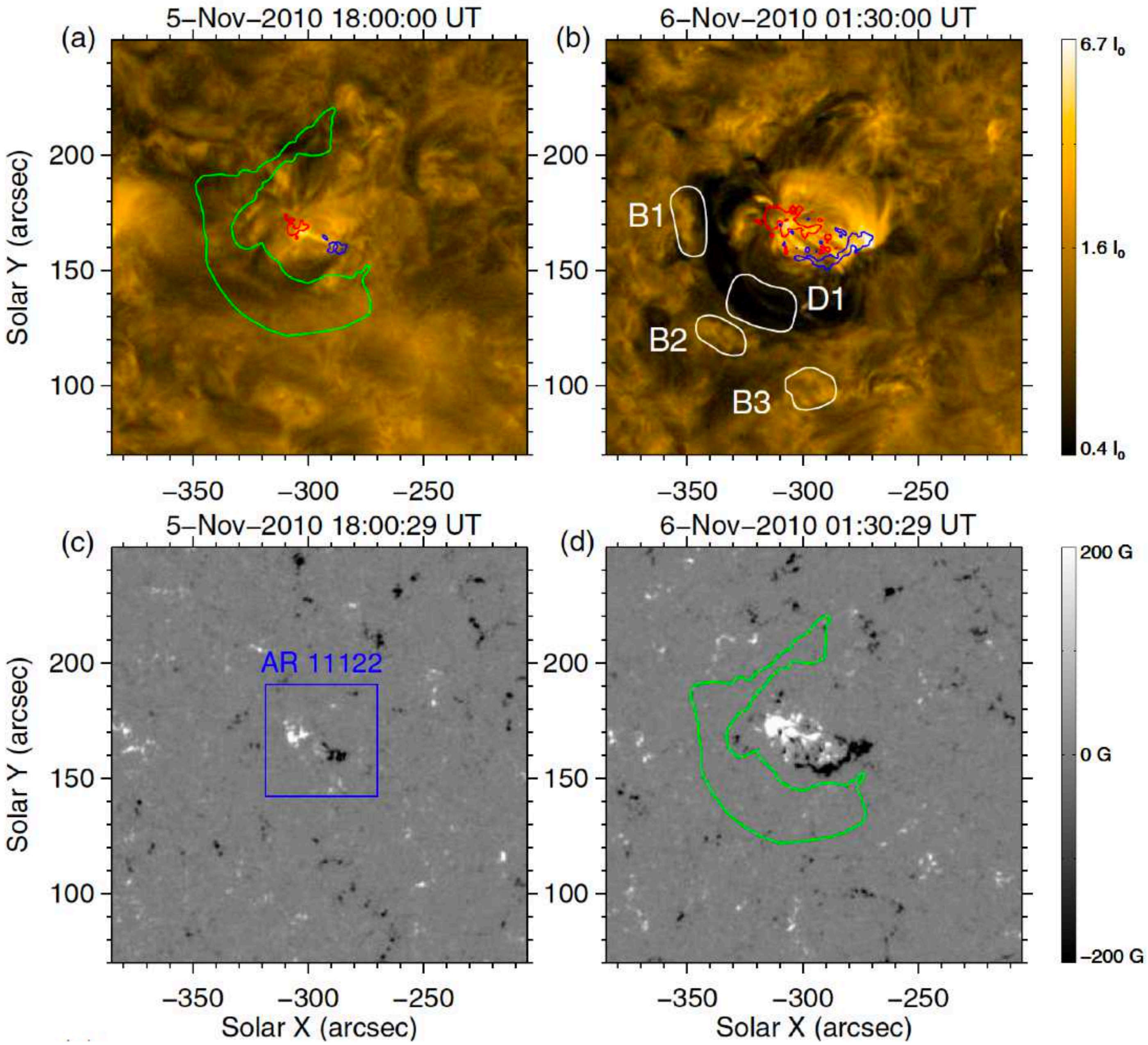


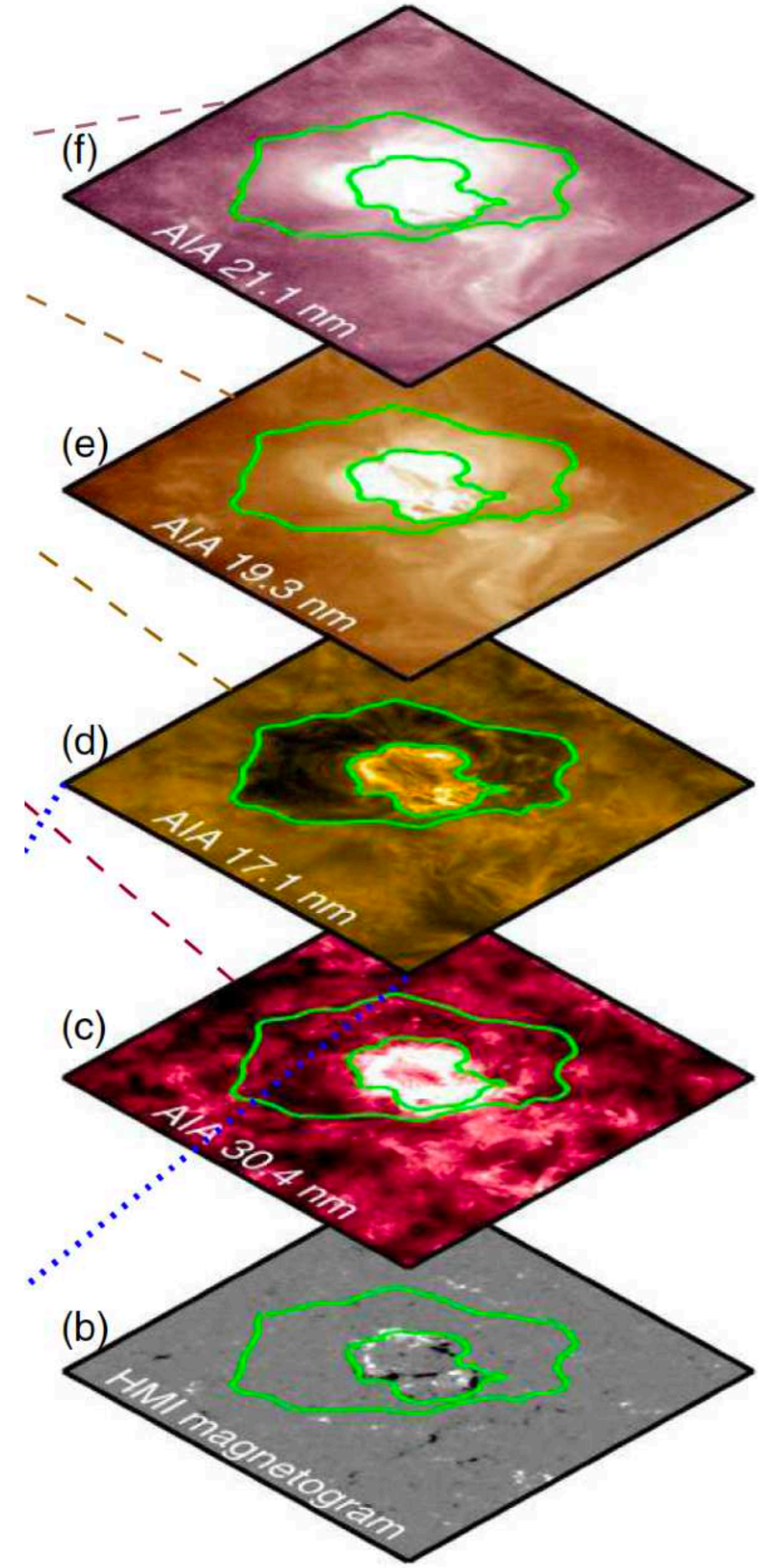
Tarr et al. (2014)

Q: Is AR flux emergence important to coronal heating?

Energization of Corona

"Emerging Dimming"



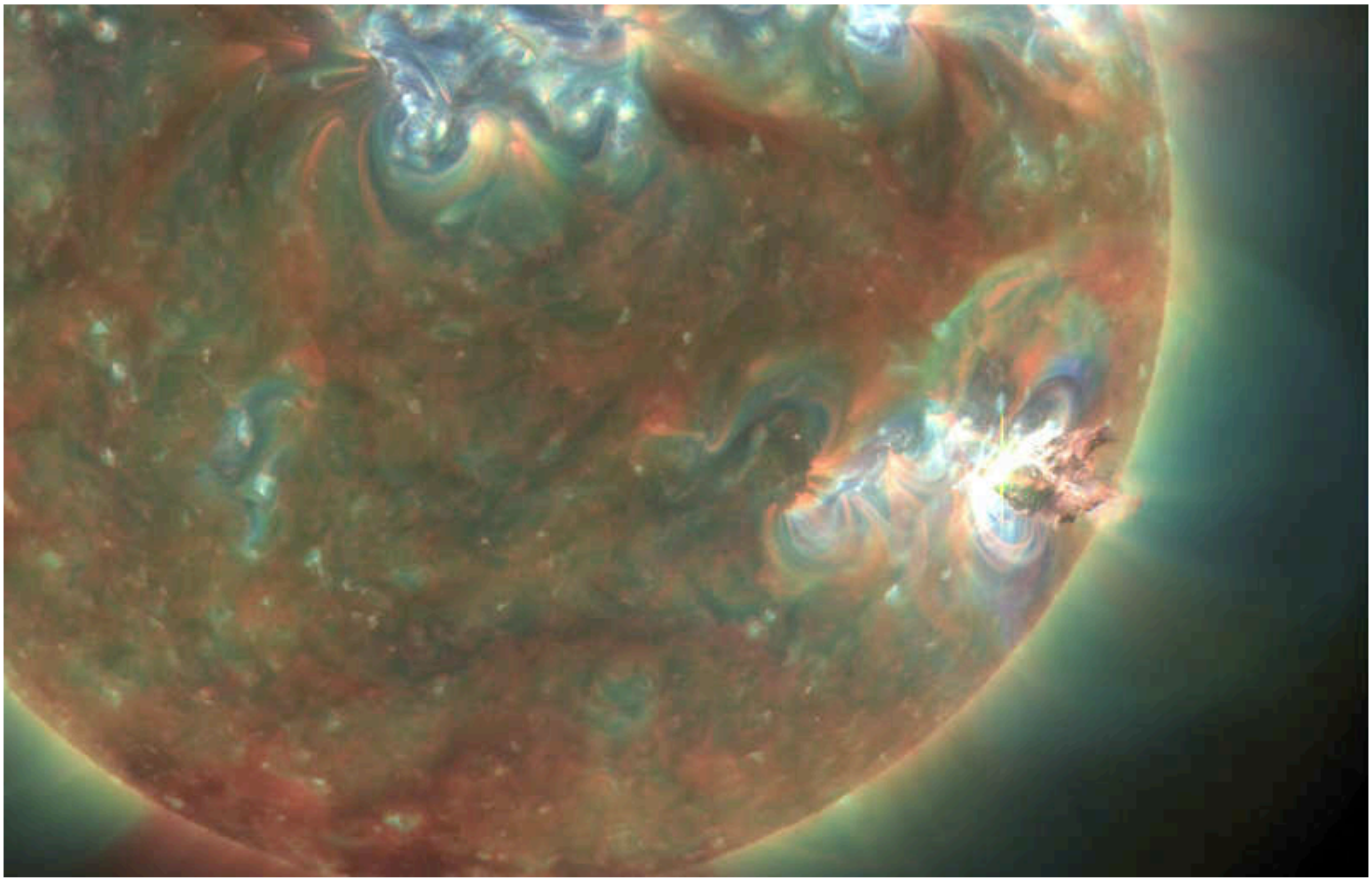


Zhang et al. (2012)

Flare/CME Basics

See Shibata & Magara (2011); Schrijver (2009) for review

A Spectacular Phenomenon



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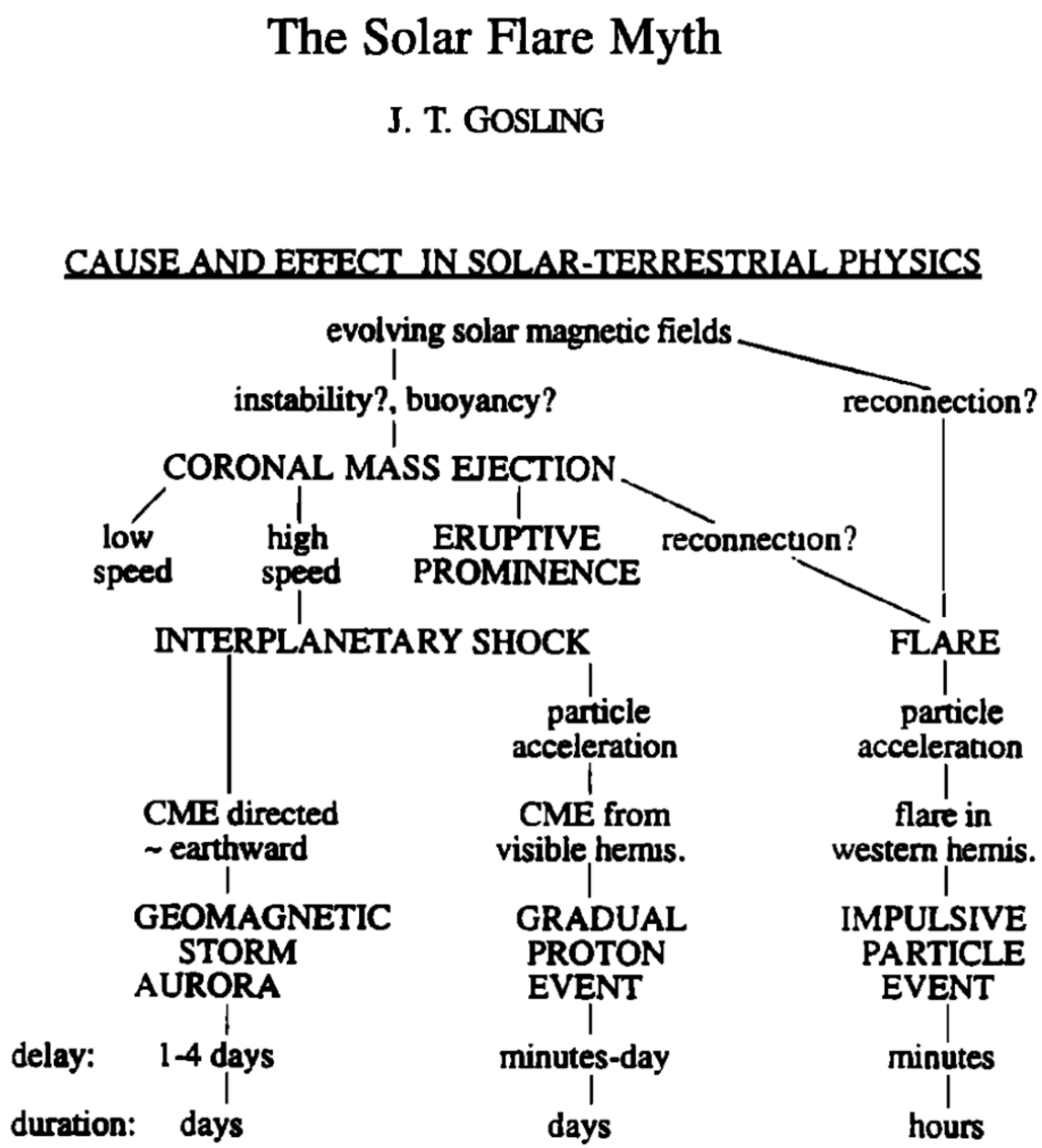
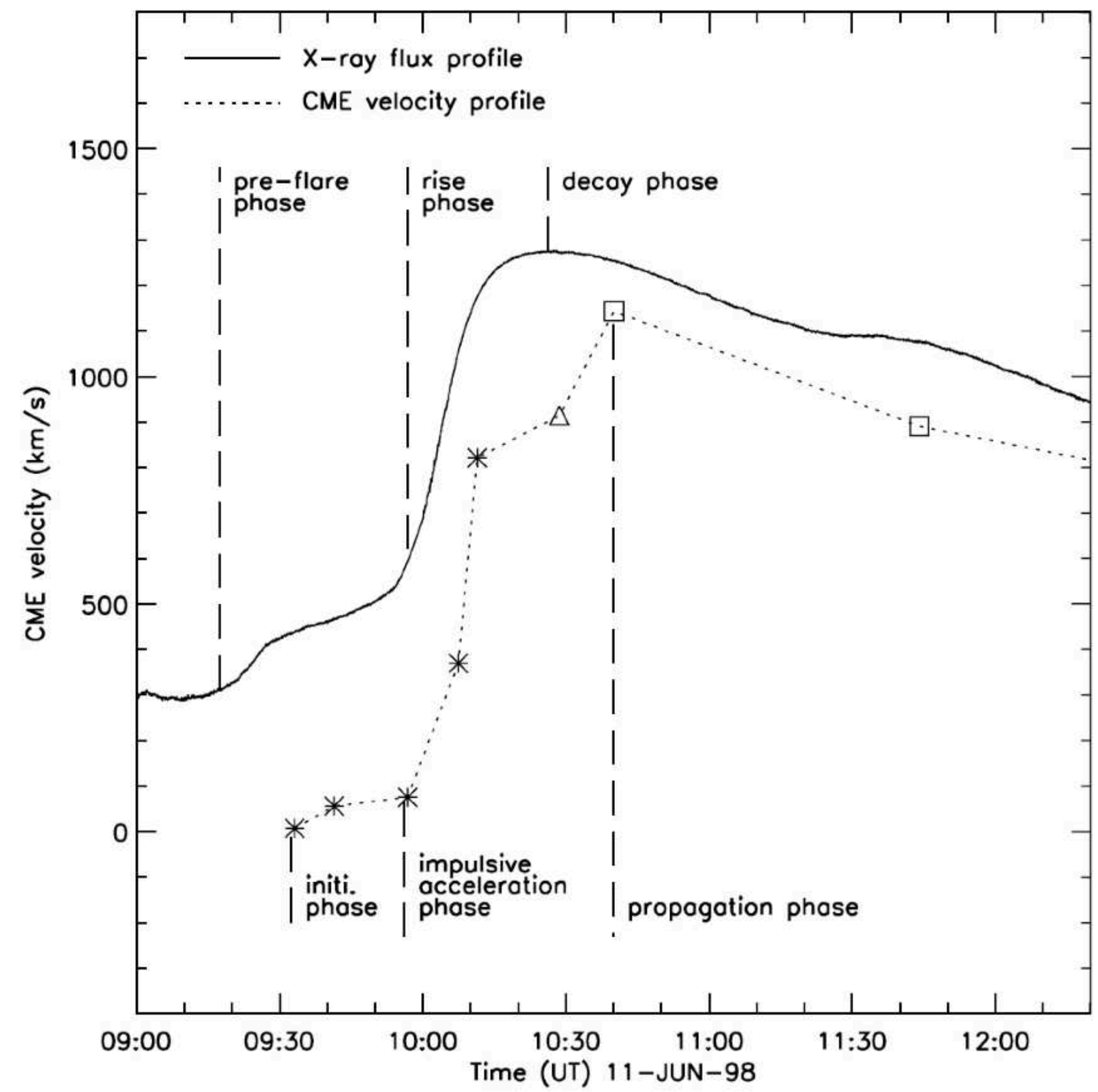
Flare & CME as One Process



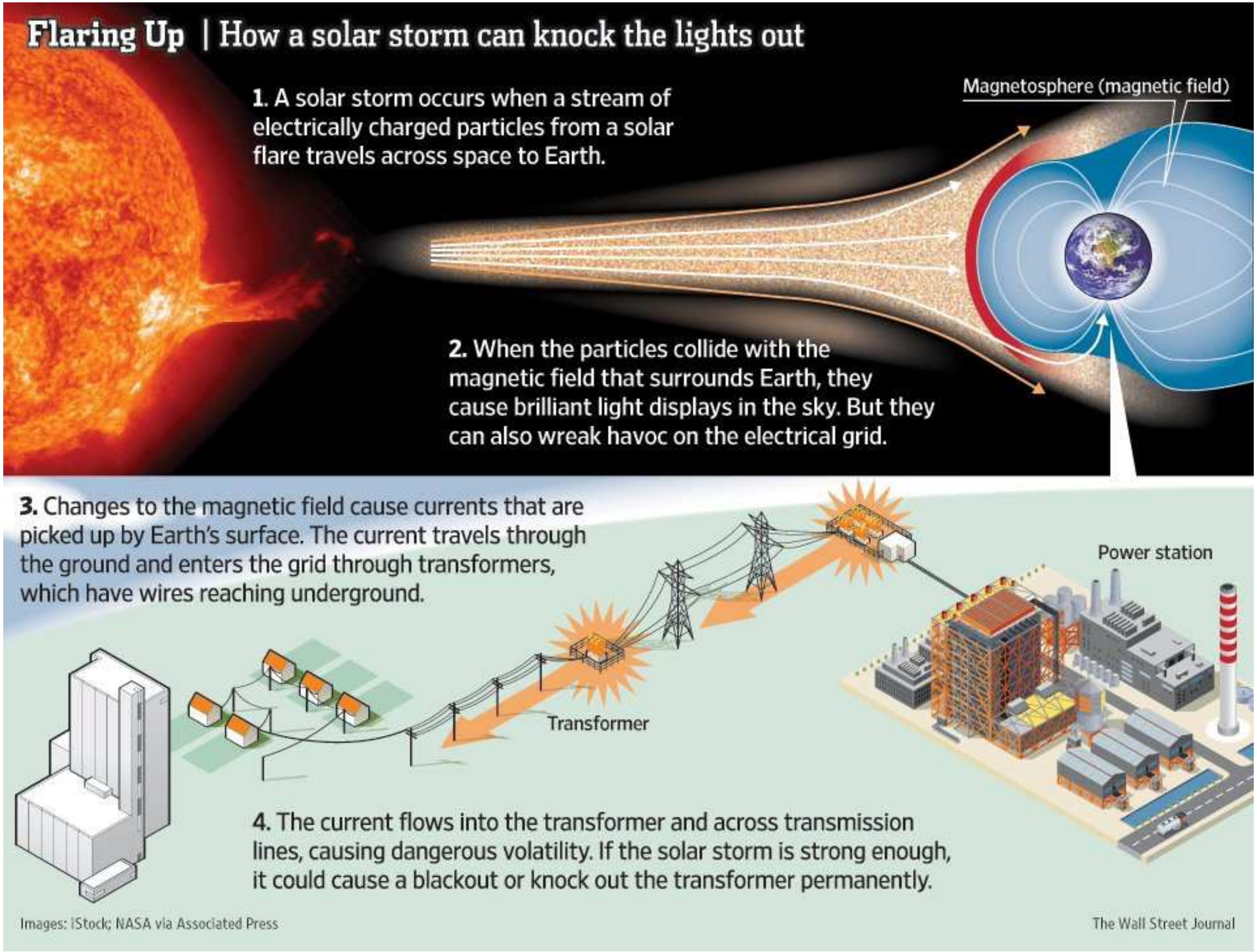
Synchronized evolution



Gosling (1993)

Zhang et al. (2001)

Driver of Space Weather



A Magnetically Driven Phenomenon

- Magnetic field is the only viable energy source

$$E \approx \frac{B^2}{8\pi} L^3 = 10^{33} \left(\frac{B}{10^3\,\mathrm{G}}\right)^2 \left(\frac{L}{3\times 10^9\,\mathrm{cm}}\right)^2 \mathrm{erg}$$

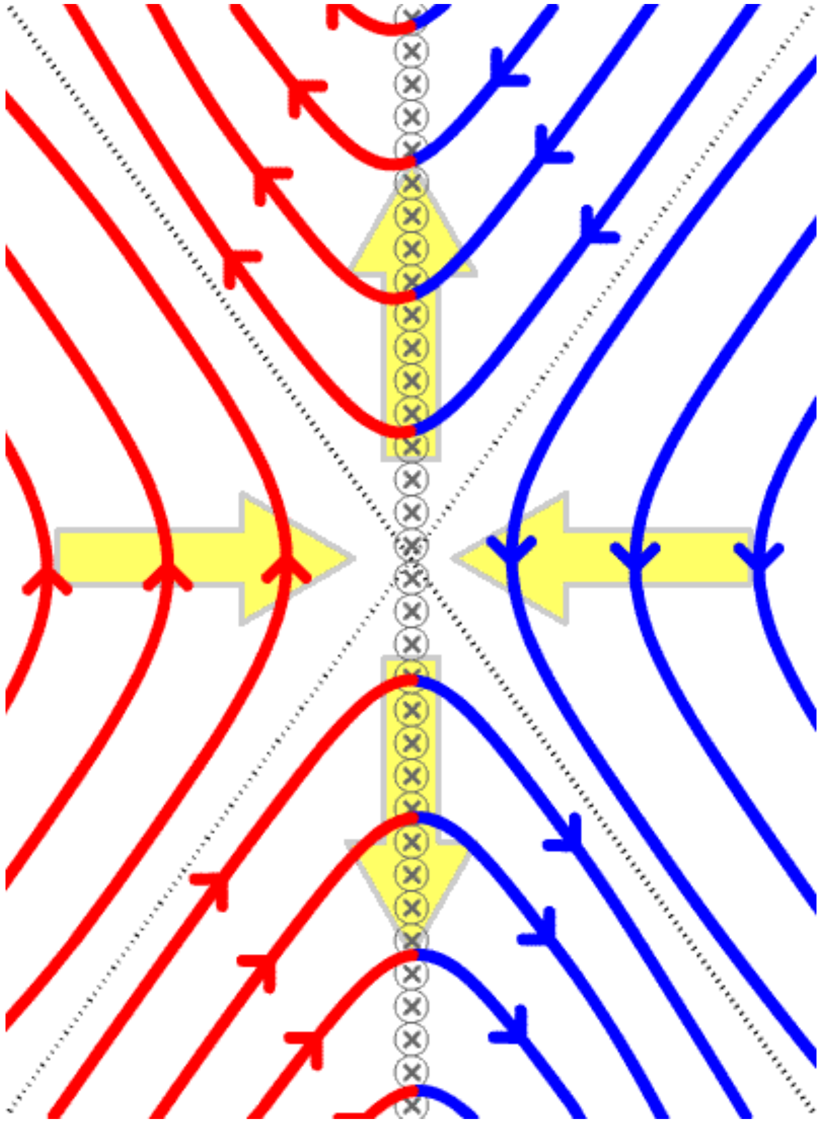
- Gradual energy injection & storage

- Rapid release (~100 s): diffusion region is *local*

$$\tau_{\mathrm{dif}} \approx \frac{L^2}{\eta} = 10^{14} \left(\frac{L}{10^9\,\mathrm{cm}}\right)^2 \left(\frac{T}{10^6\,\mathrm{K}}\right)^2 \mathrm{s}$$

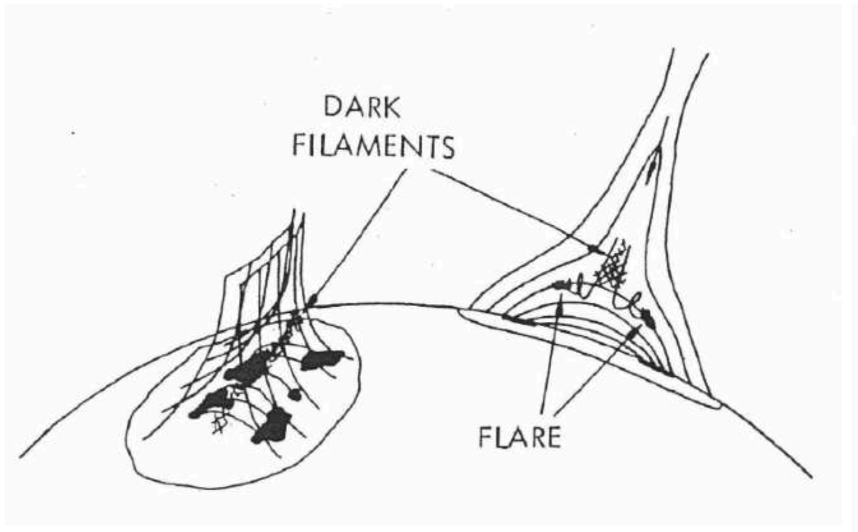
$$L \approx 10^3\,\mathrm{cm}$$

- Global reconfiguration: via Lorentz force?

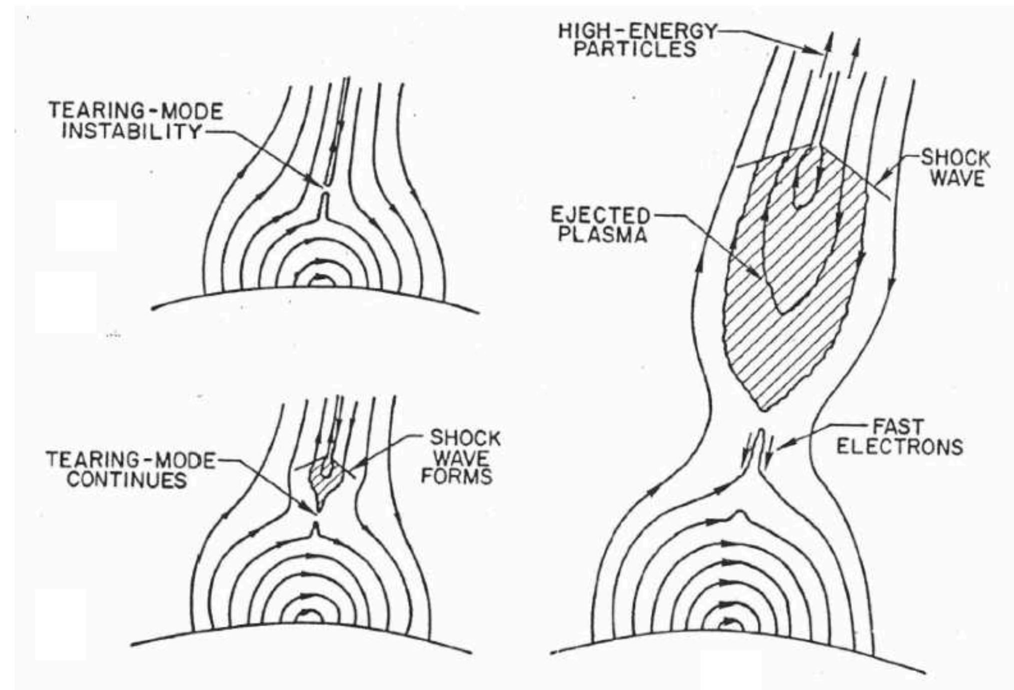


https://en.wikipedia.org/wiki/Magnetic_reconnection

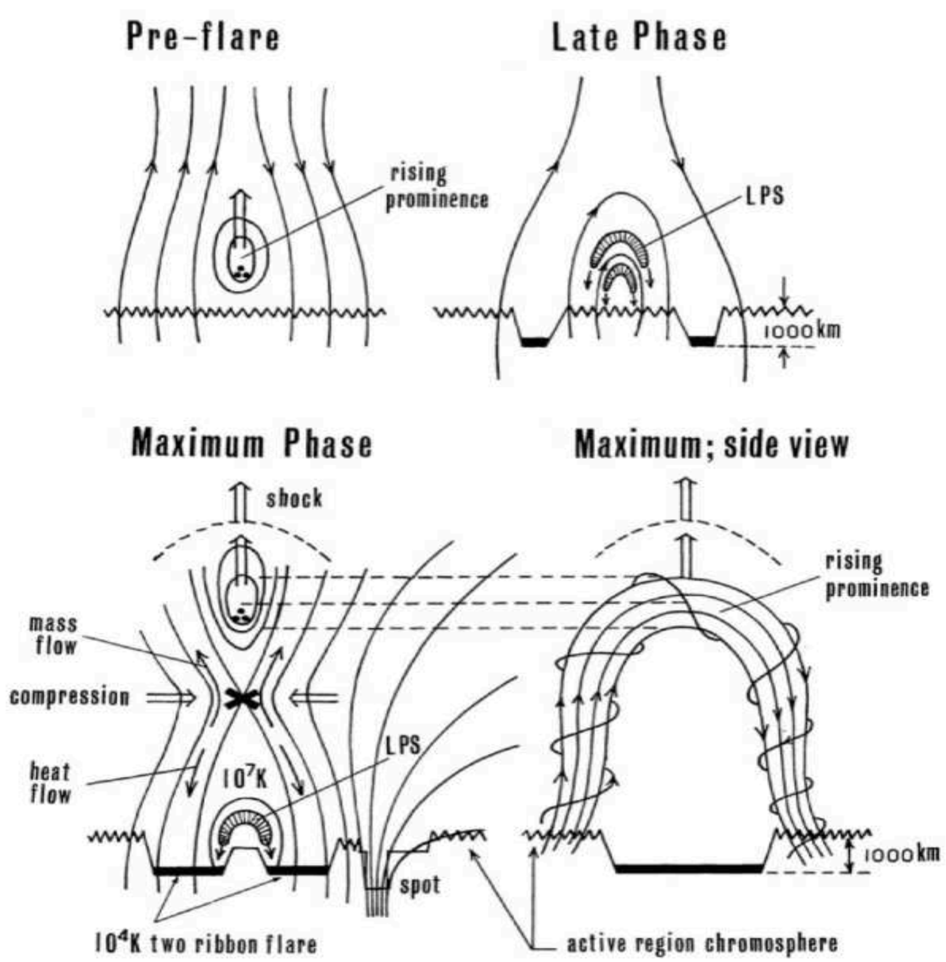
CSHKP Model (or have you read the papers?)



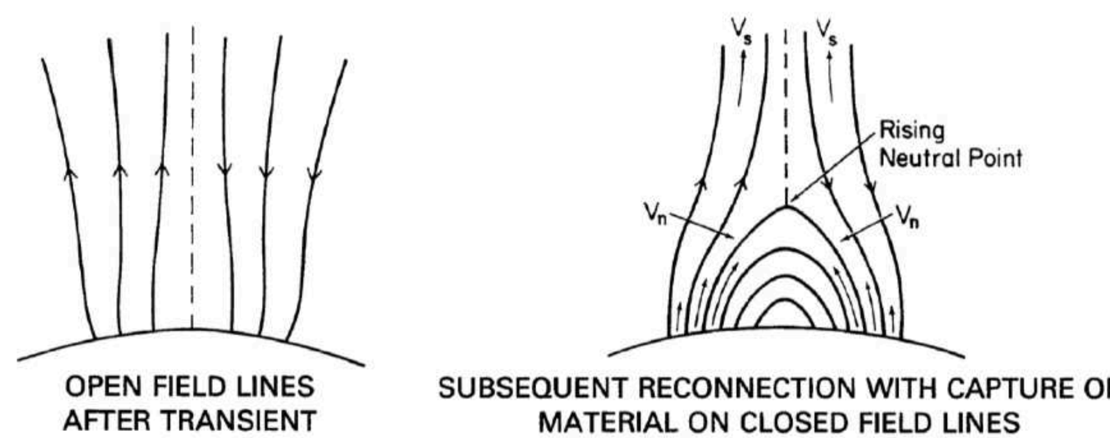
Carmichael (1964)



Sturrock (1966)

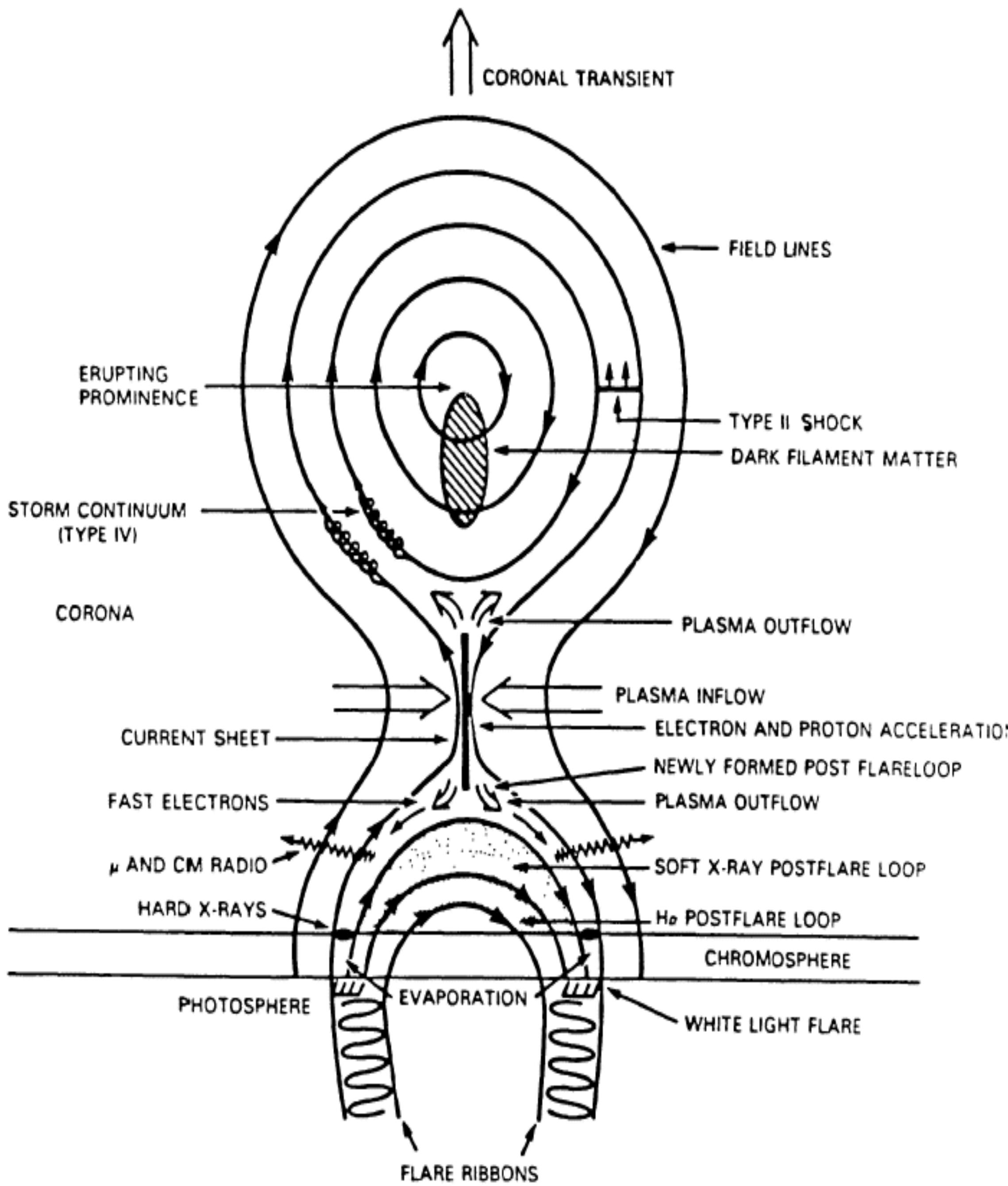


Hirayama (1974)

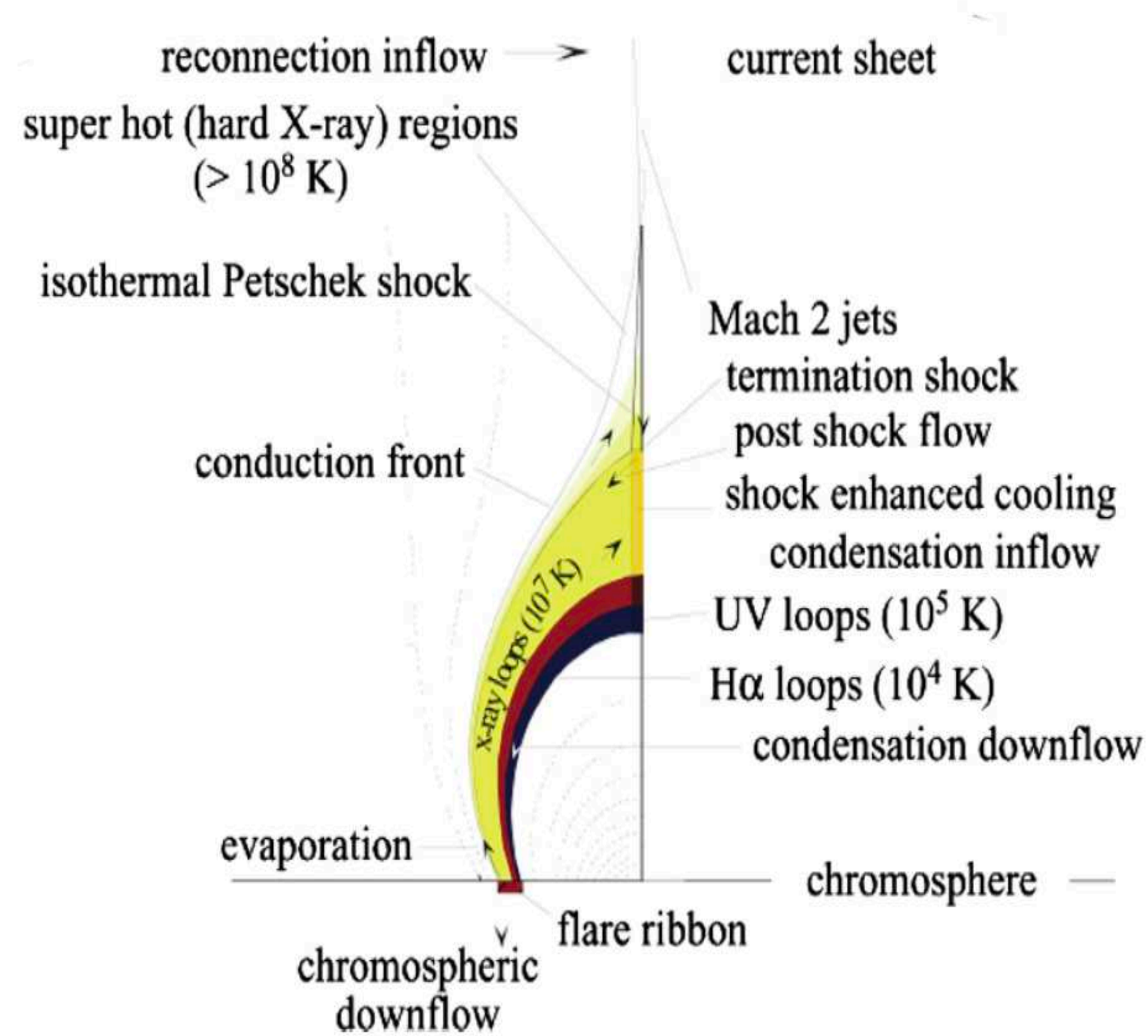


Kopp & Pneuman (1976)

“Standard” Flare Model in 2D



Martens & Kuin (1989)

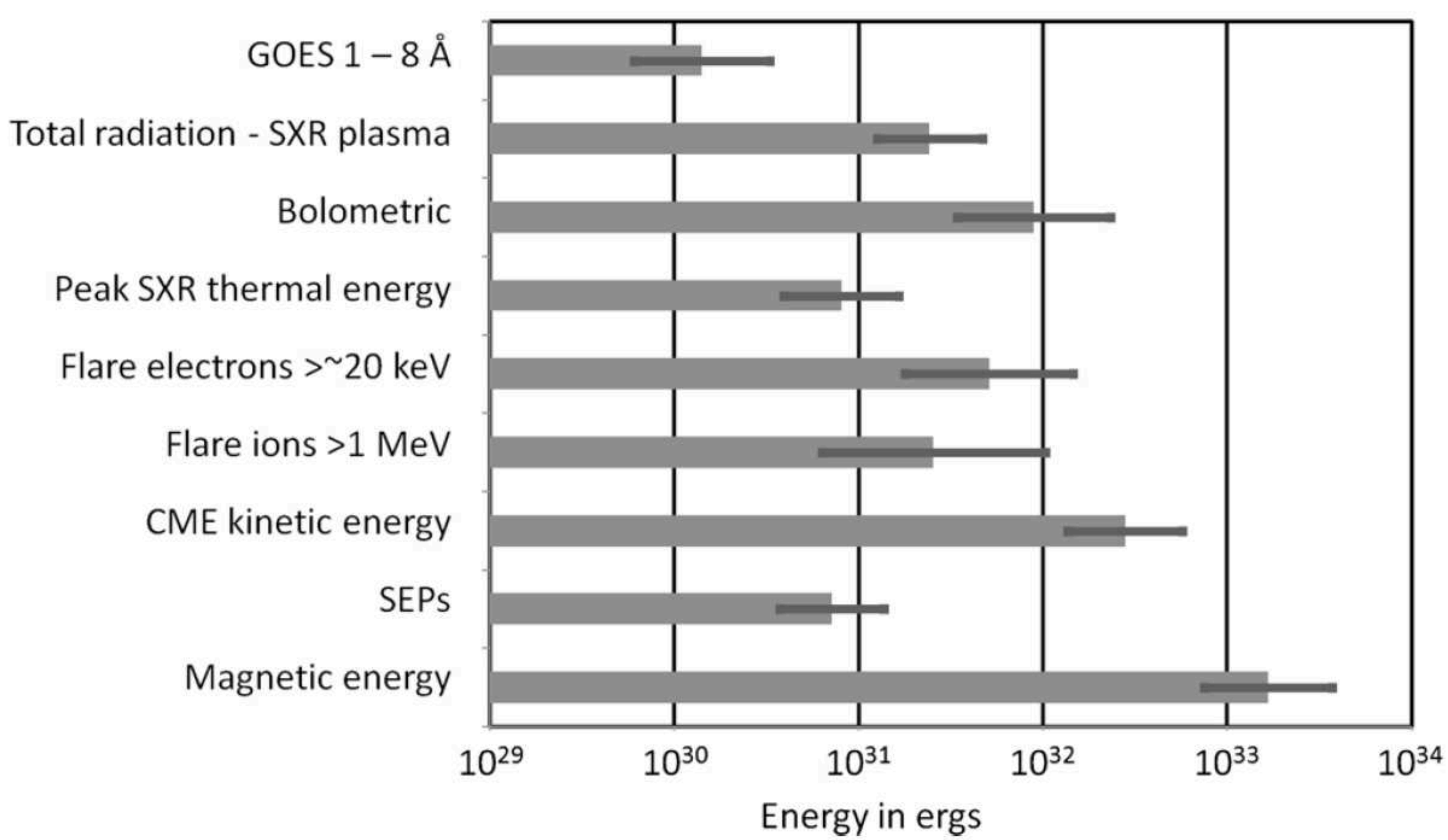


Lin et al. (2015)

Energy Partition

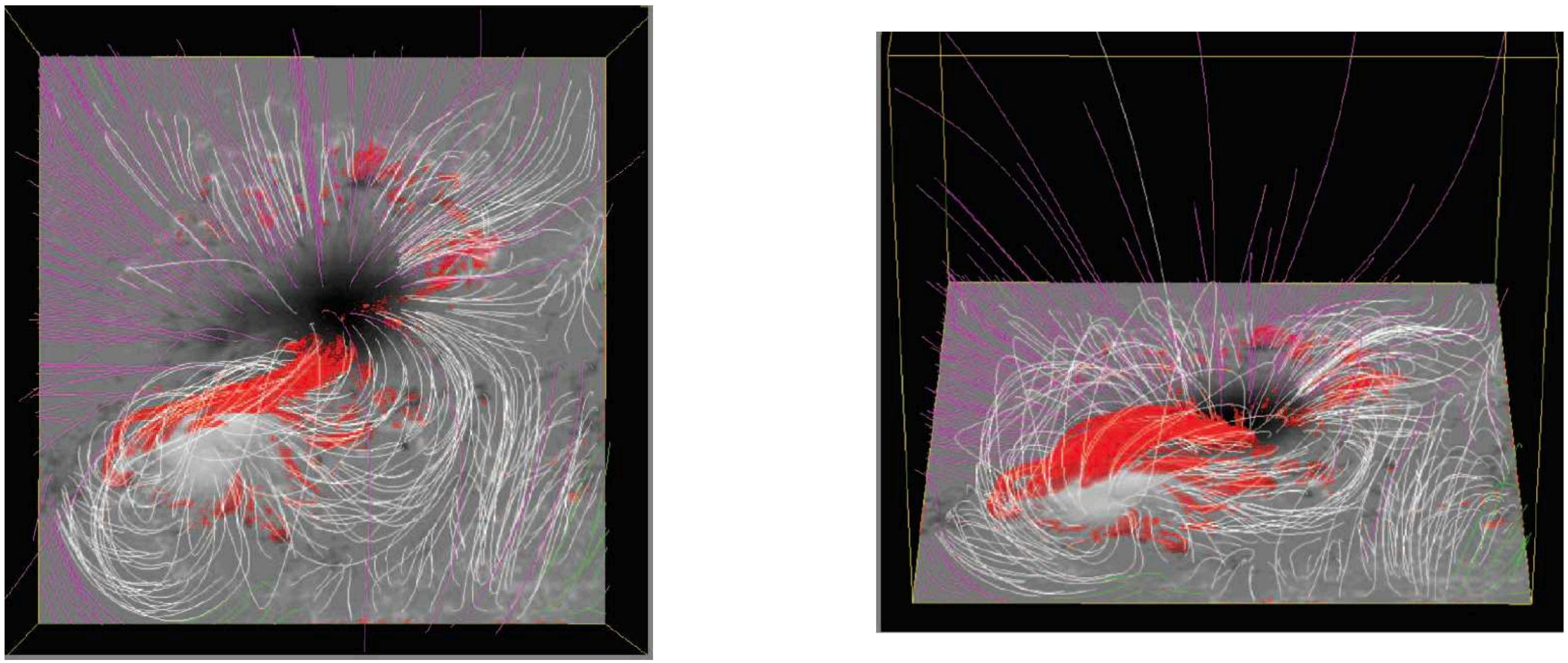
- *Woltjer's theorem*: for closed system with same boundary and helicity, potential field has the lowest energy (see HW3 Q2)

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



Emslie et al. (2012)

“Non-Potentiality”



Schrijver et al. (2008)

- Photosphere to low corona; near PIL (filament channel)
- Shear; twist
- Free energy E_p, E_p/E
- Electric current j
- Helicity H

Momentum Partition (?)

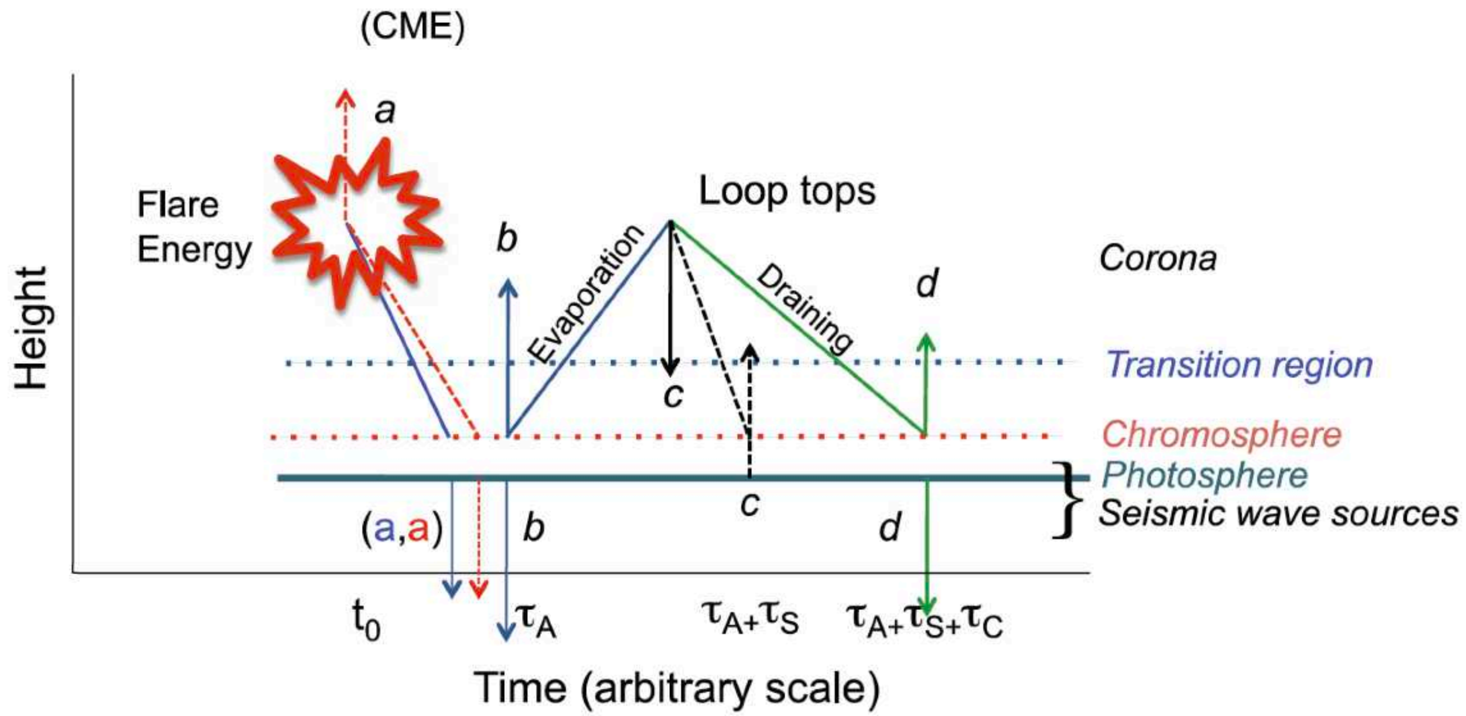
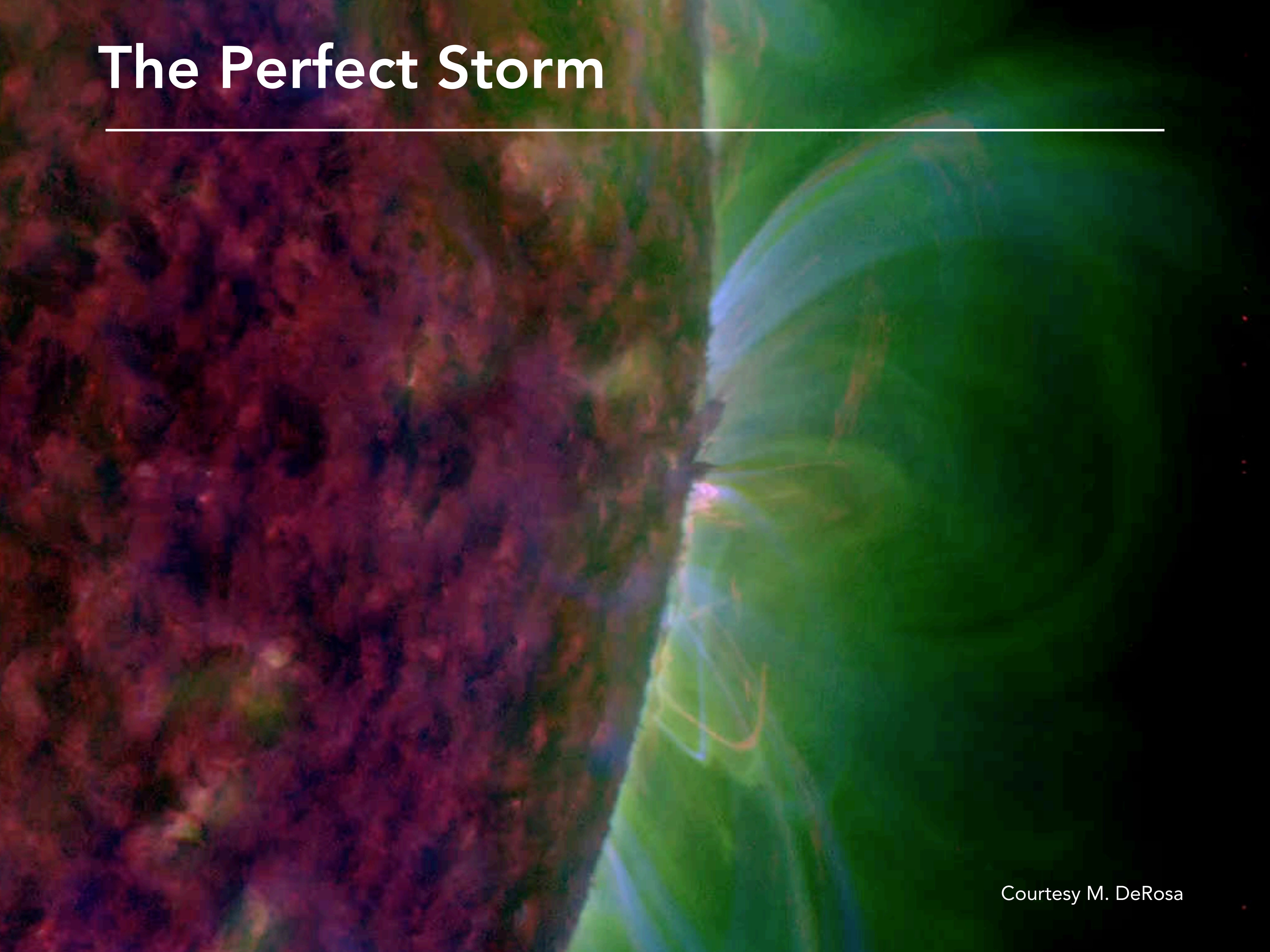


Table 2 Vertical momentum components, representative X-class flare with CME.

Item Figure 1	Phenomenon	Mass g	v $km\,s^{-1}$	Δt s	Momentum $g\,cm\,s^{-1}$	Pressure $dyne\,cm^{-2}$
a	Primary (e^-)[a]	2×10^{11}	c/3	10	2×10^{21}	7×10^{2}
a	Primary (p^+ or H)[a]	1×10^{13}	2×10^{8}	10	1×10^{23}	3×10^{5}
a′	Primary (waves)	–	c/3	10	1×10^{21}	3×10^{2}
b	Evaporation flow	10^{14}	500	10	2×10^{22}	2×10^{3}
b′	Radiation[b]	–	c	10	1×10^{19}	3
c	CME	10^{15}	2000	100	2×10^{23}	?
d	Draining	10^{15}	10	$\approx 10^{4}$	2×10^{21}	0.07
	Seismic wave[c]				8×10^{21}	

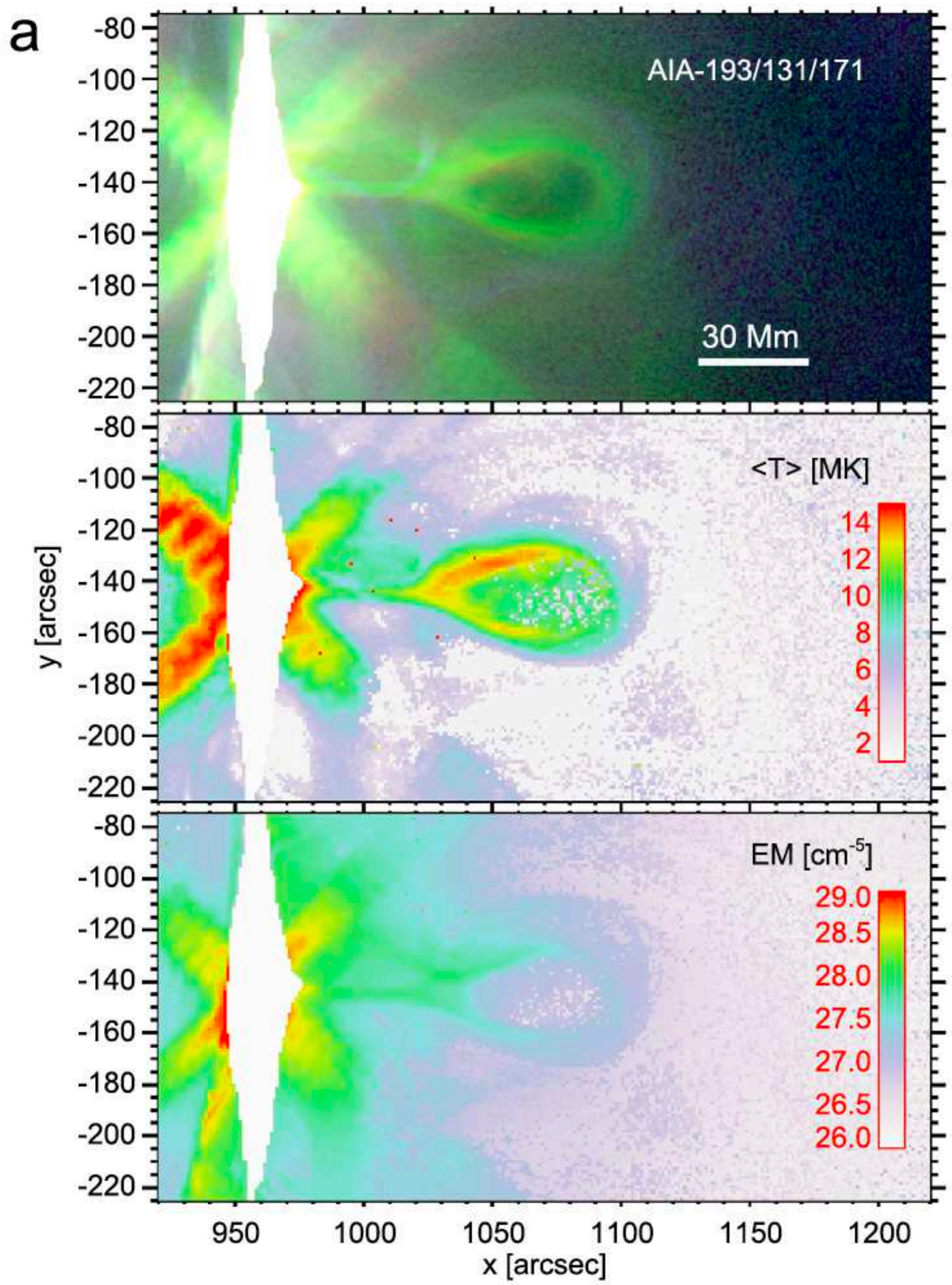
Hudson et al. (2012)

The Perfect Storm

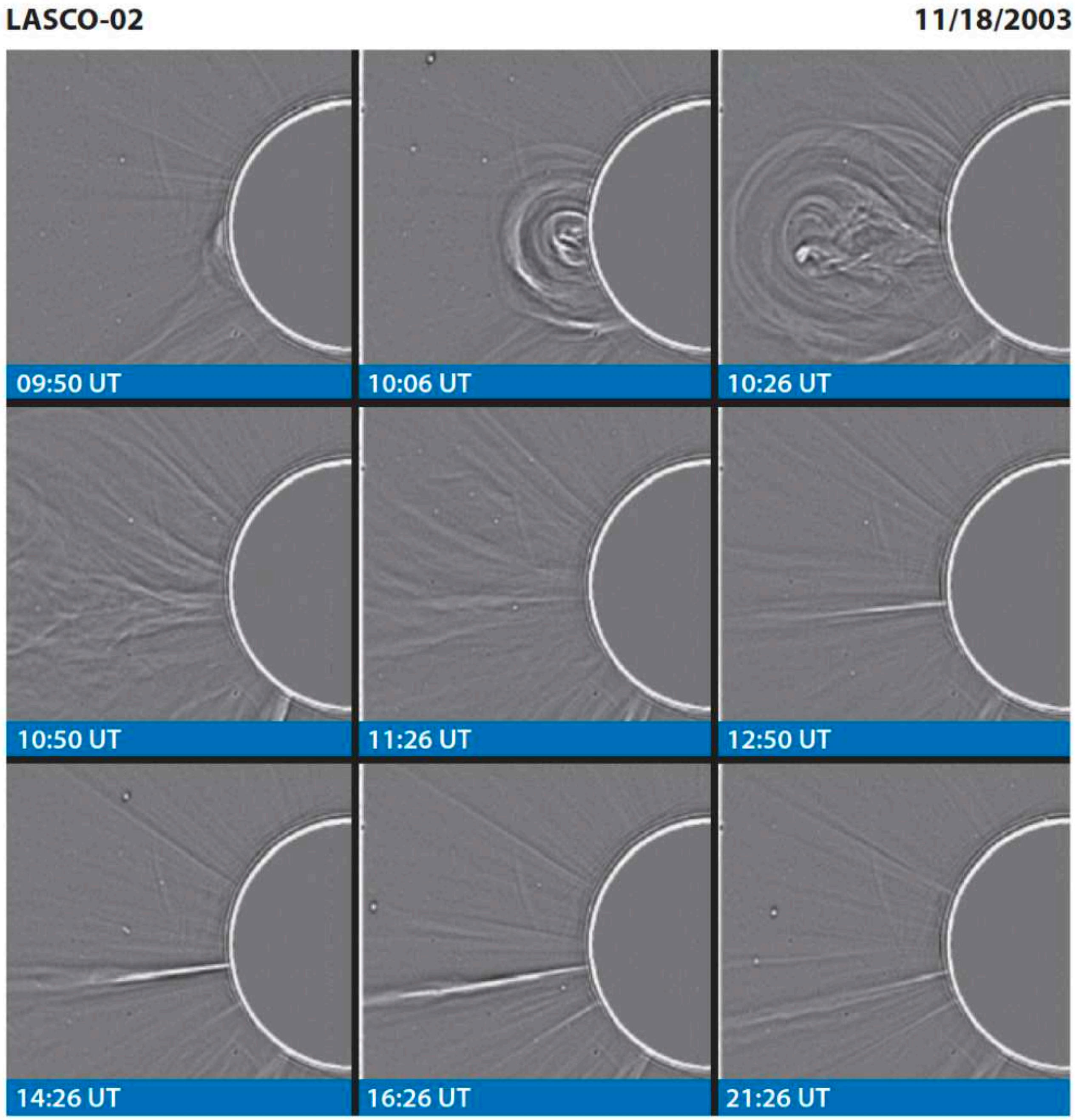


Courtesy M. DeRosa

The Perfect Storm



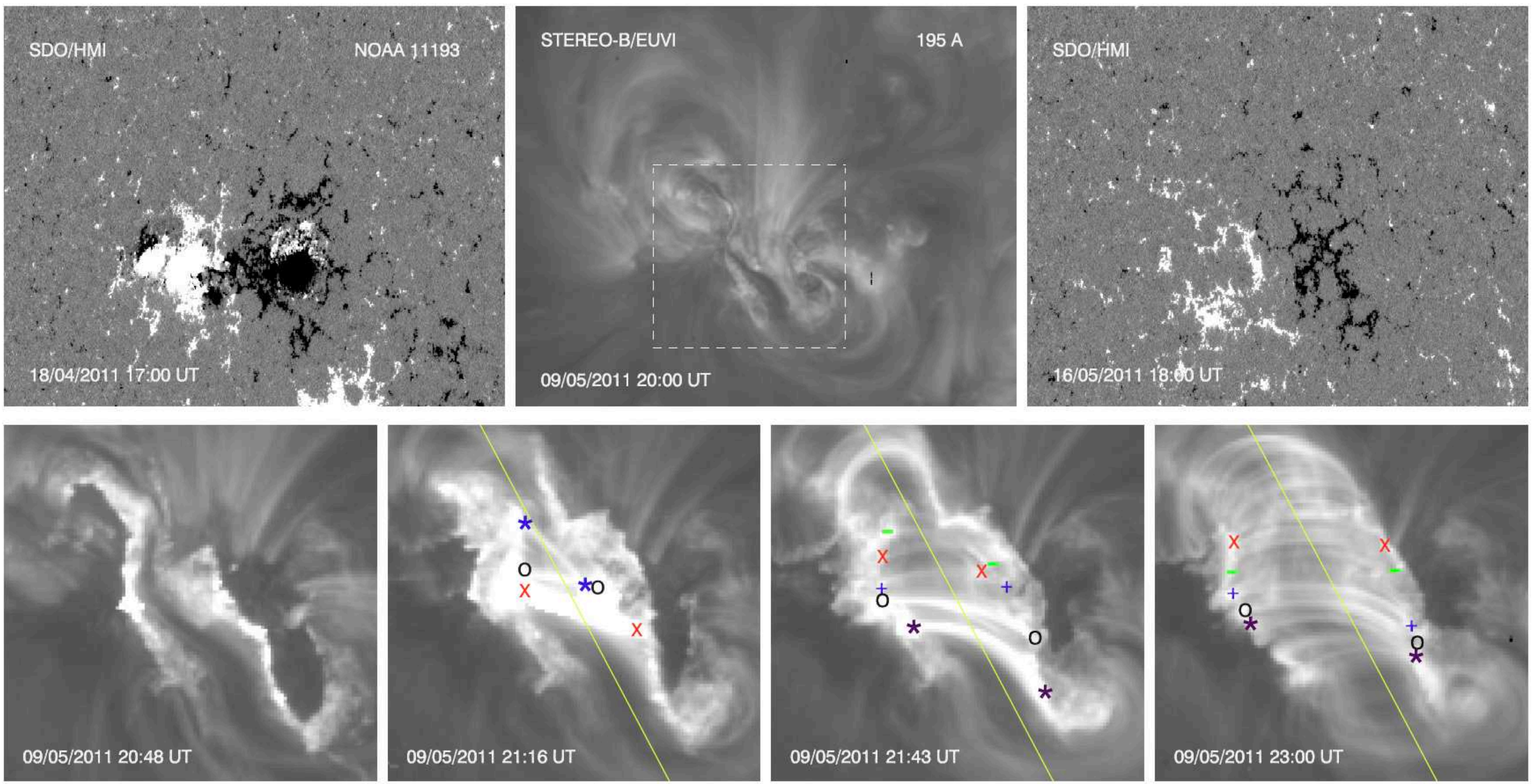
Cheng et al. (2018)



Lin et al. (2005)

The Need to Go to 3D

Important effect in the 3rd dimension



Aulanier et al. (2012)