COLLAGE 2019

Misc Topics on Magnetic Fields

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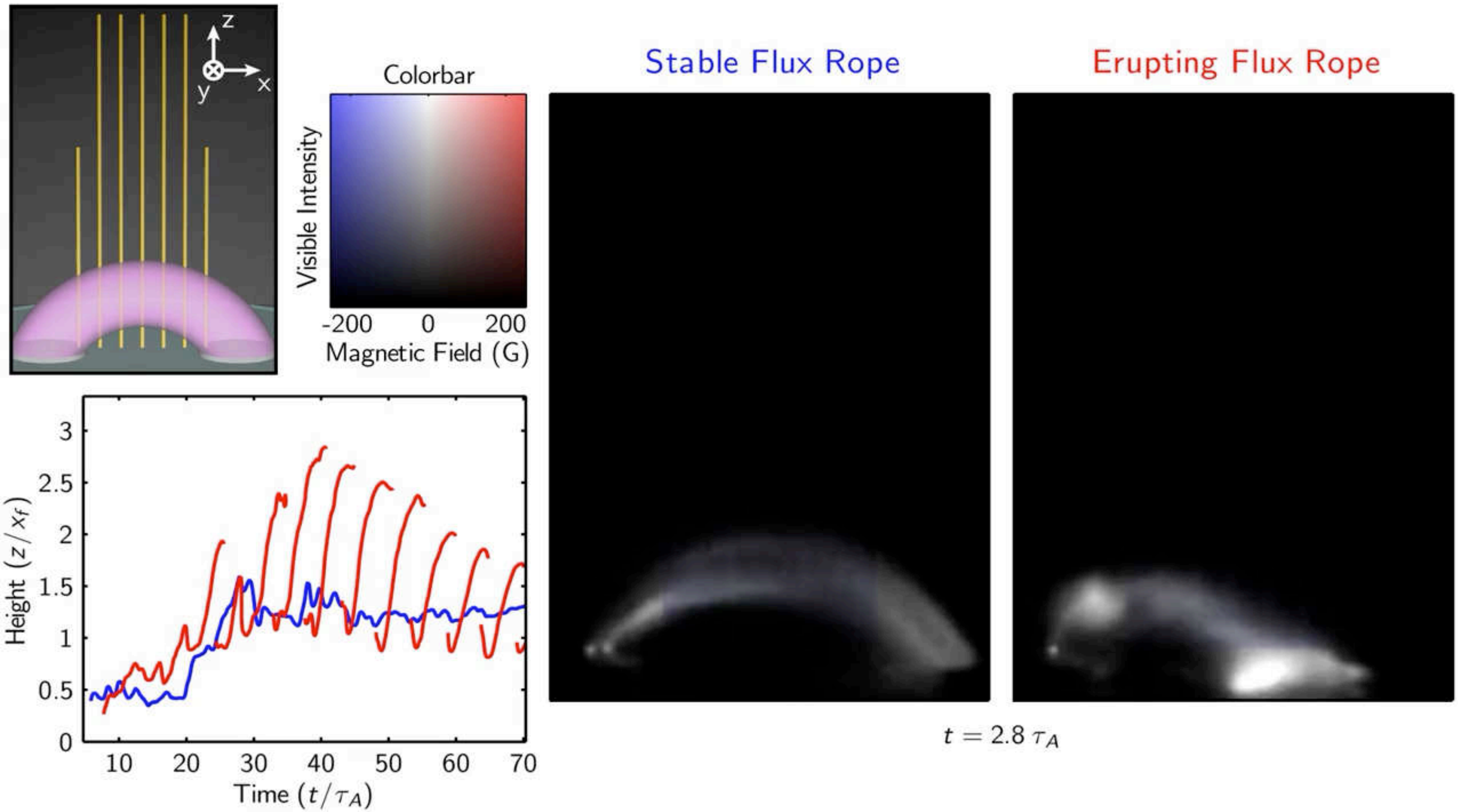
Apr 18 2019

Outline

- Many Modes of Eruption (cont’d)
- Flare/CME prediction
- Misc topics

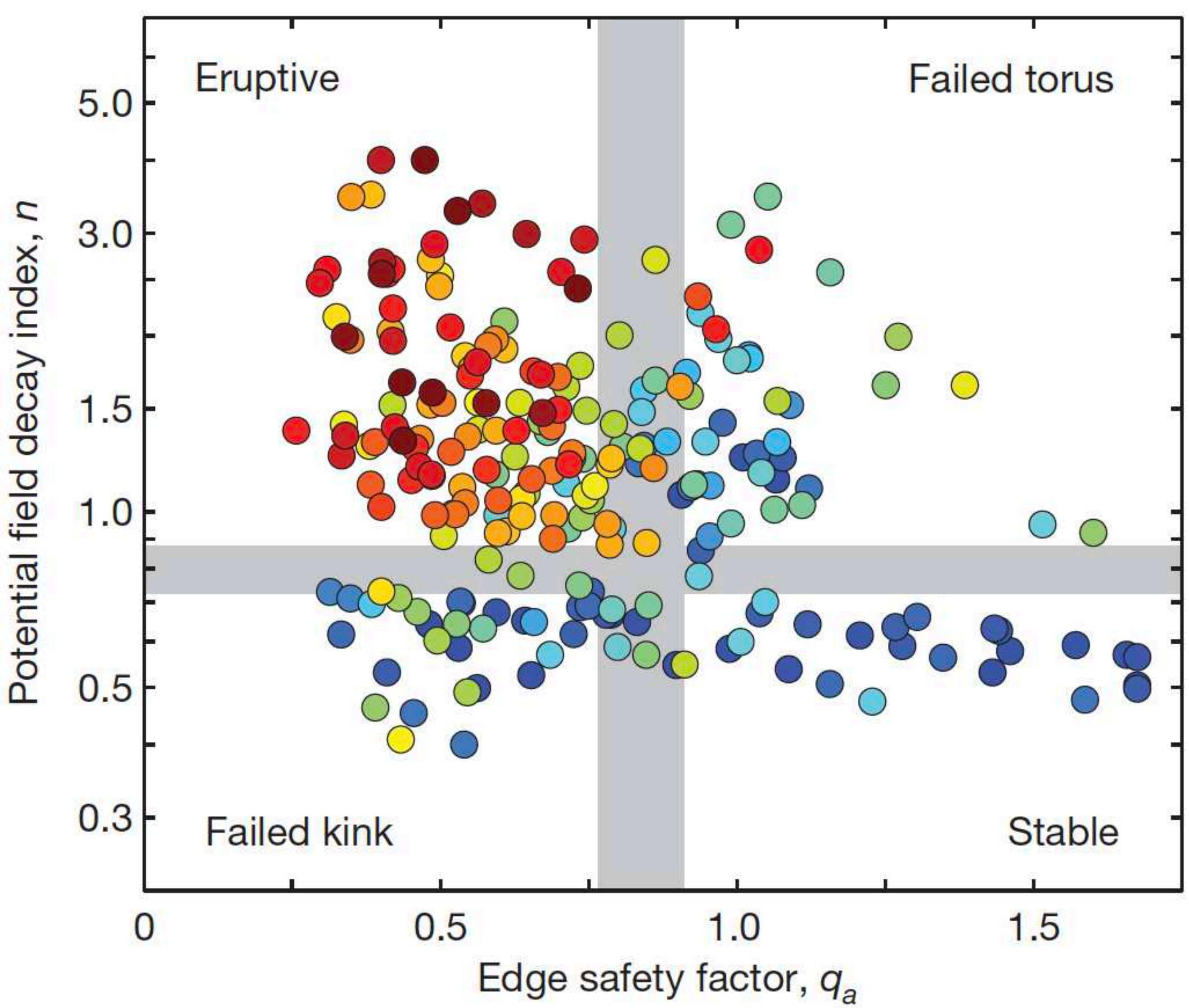
Many Modes of Eruption

Eruption Plasma Experiments

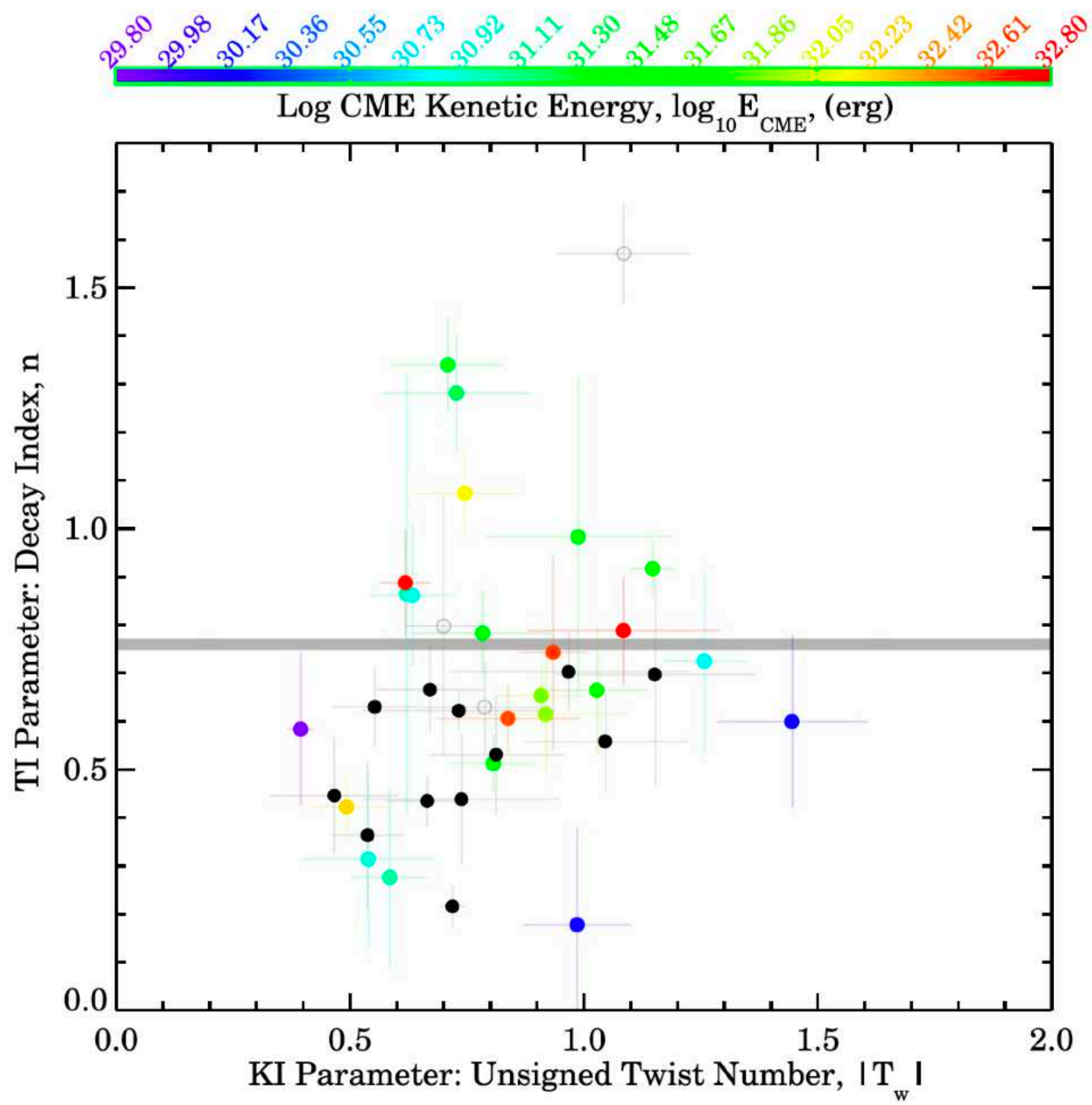


Myers et al. (2015)

Kink vs Torus Instability

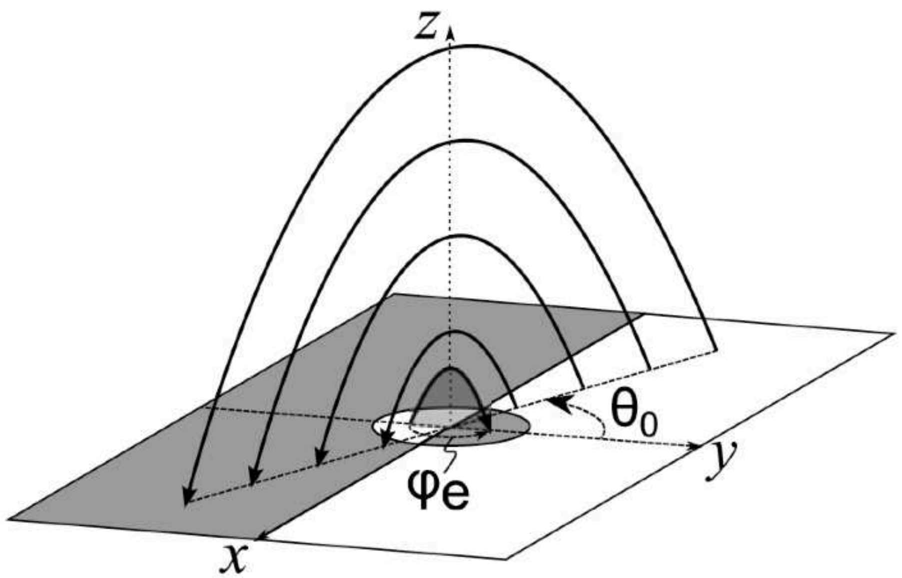


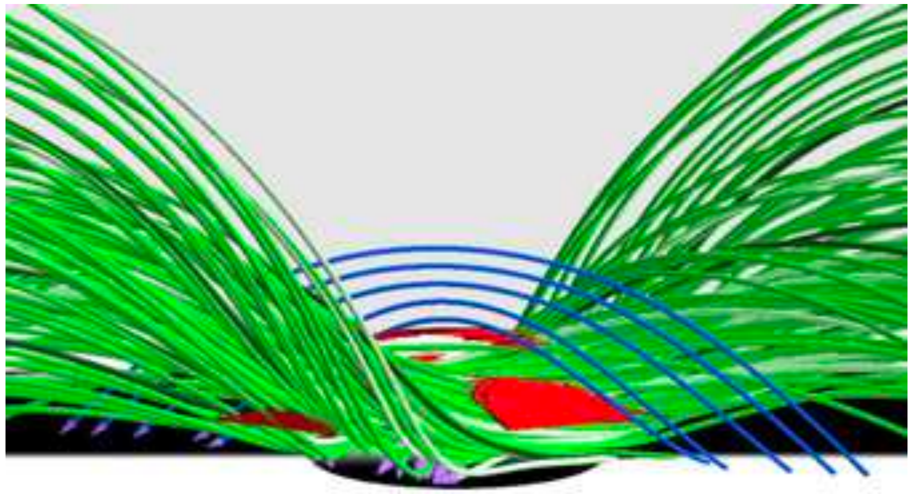
Experiment: Myers et al. (2015)



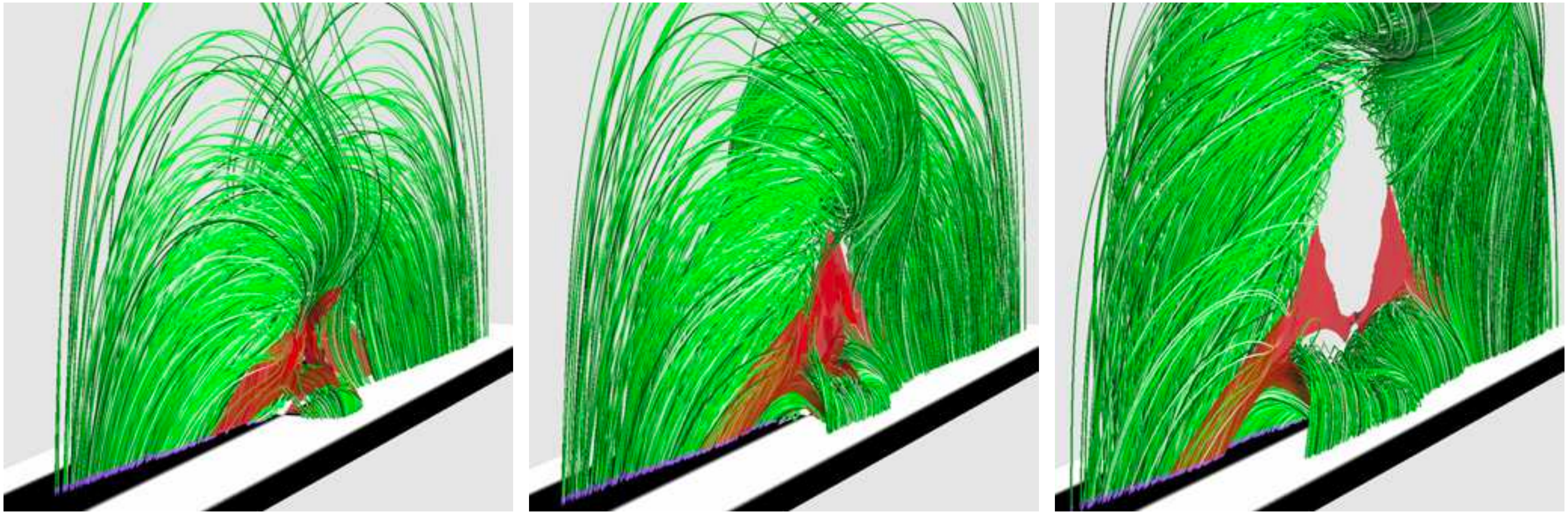
Observation + modeling: Jing et al. (2018)

Flux Emergence as Trigger

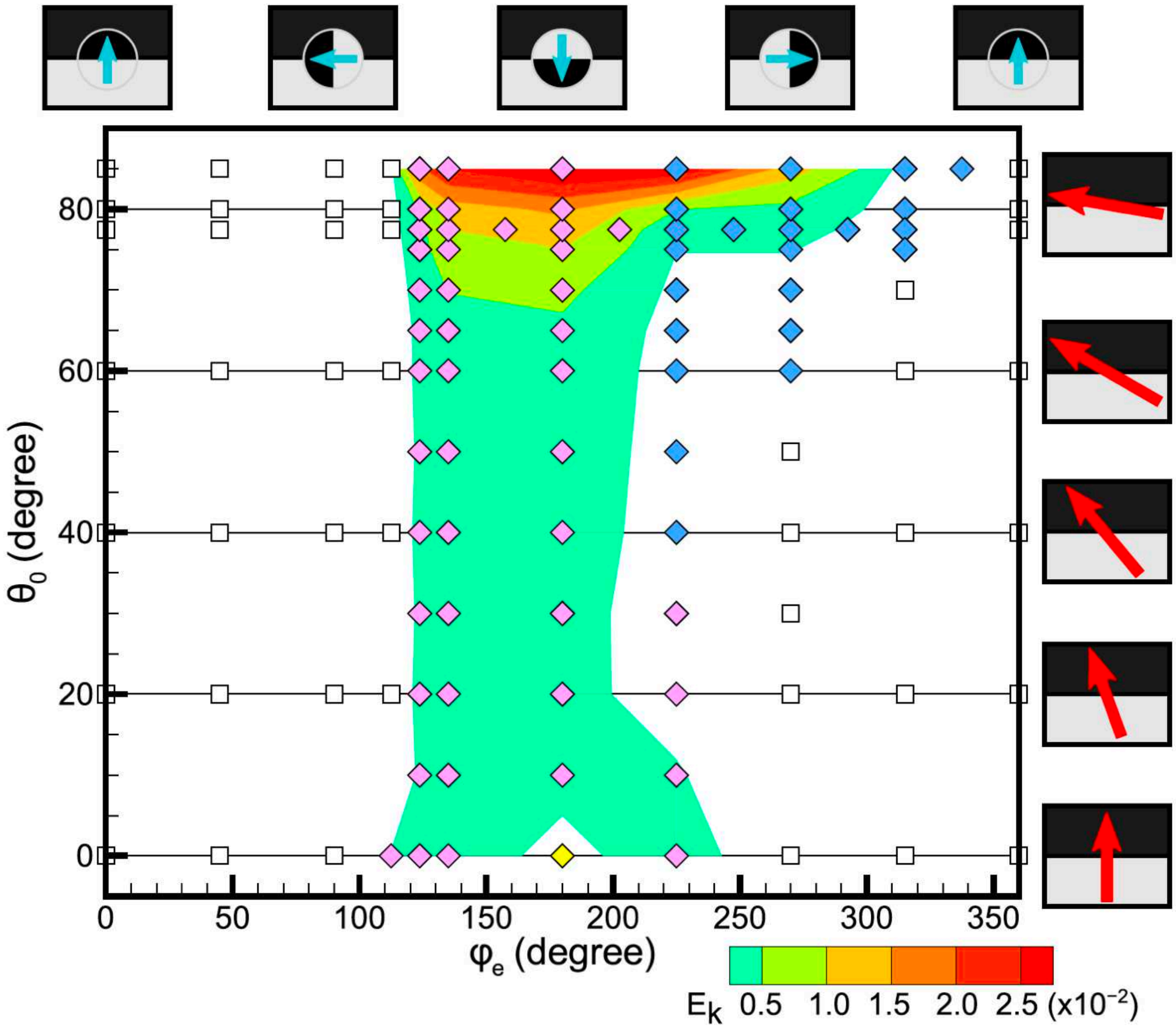




Kusano et al. (2012)



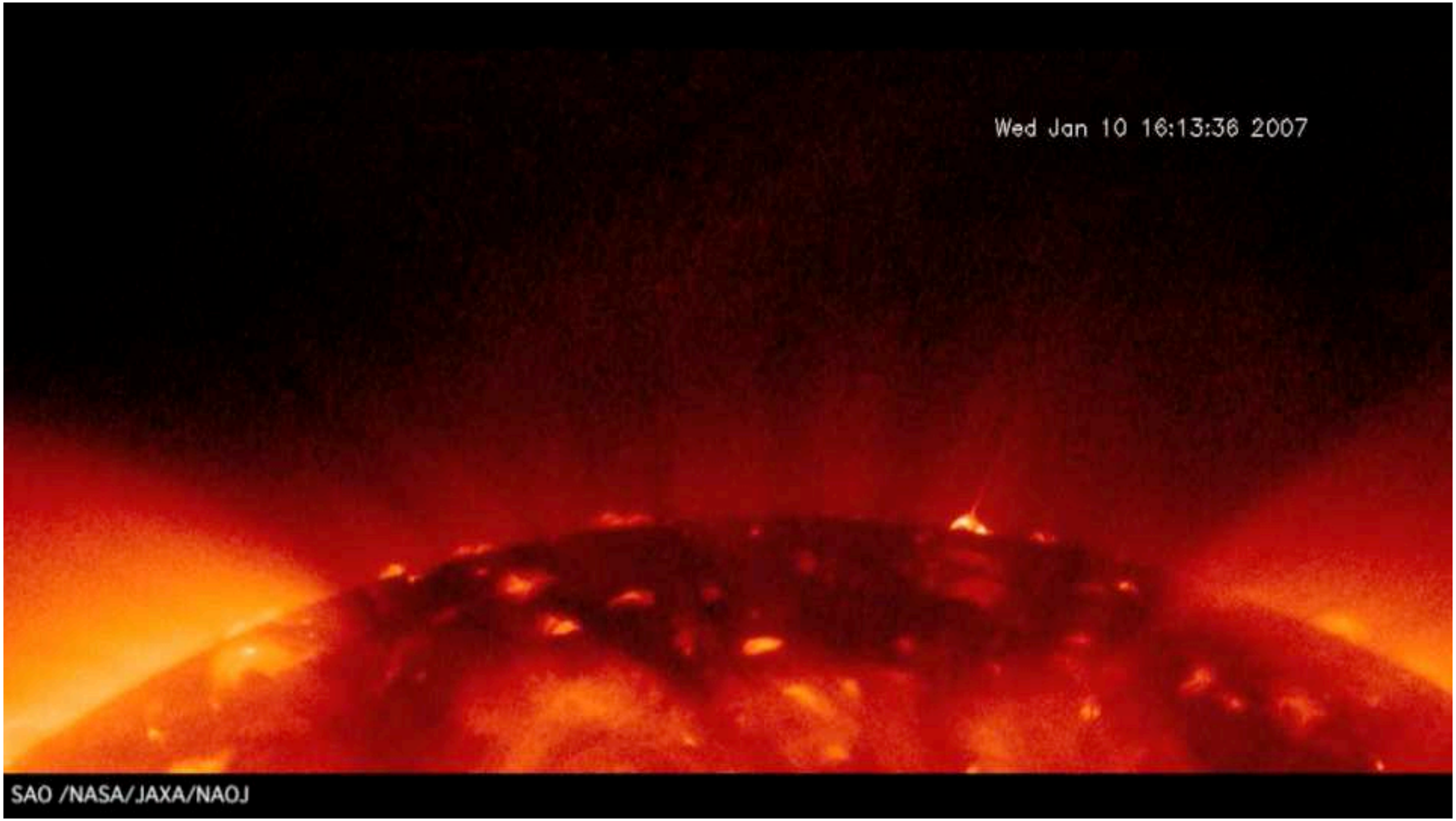
Importance of Field Orientation



Kusano et al. (2012)

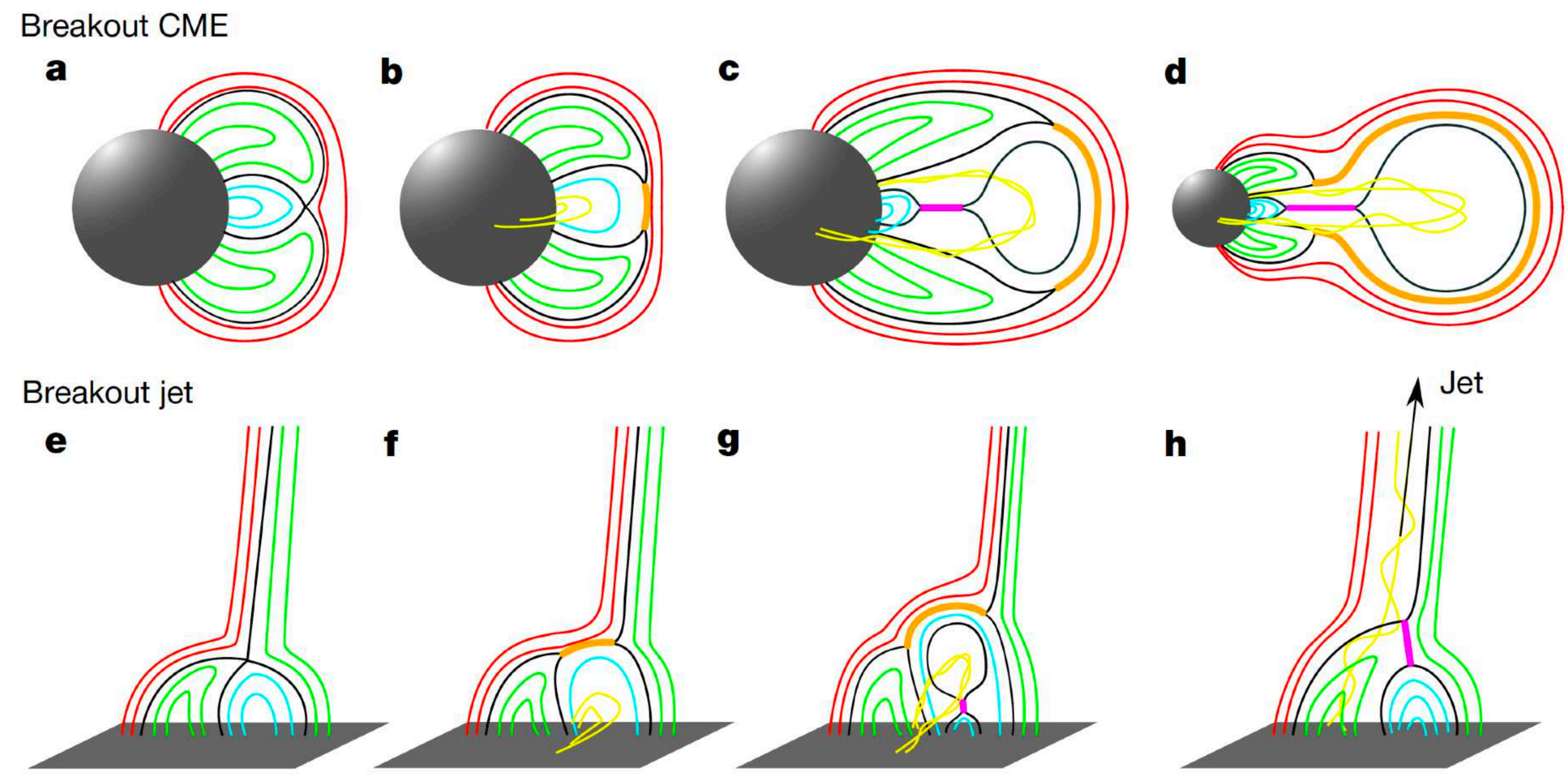
Jets

Hinode/XRT



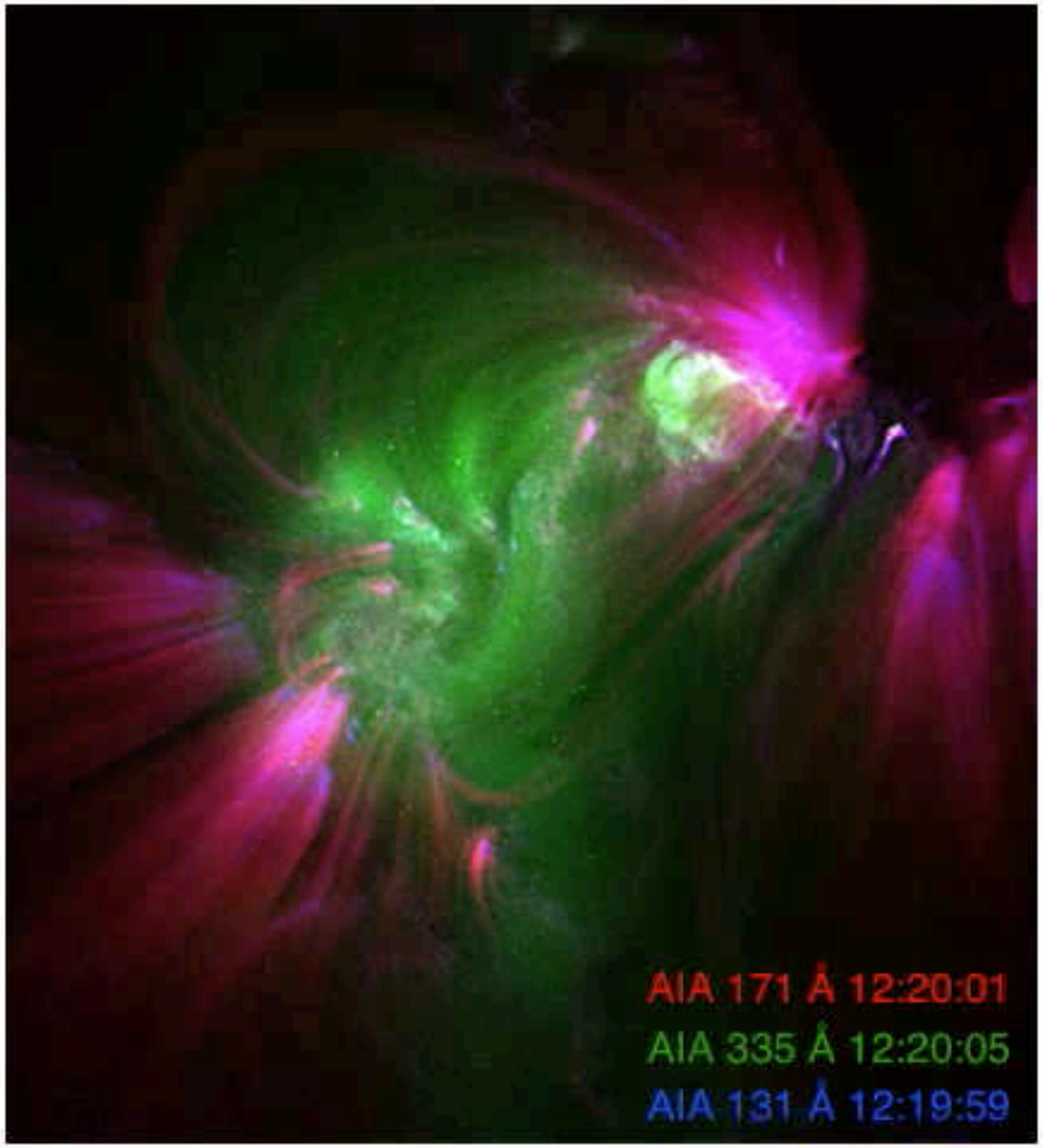
Cirtain et al. (2007)

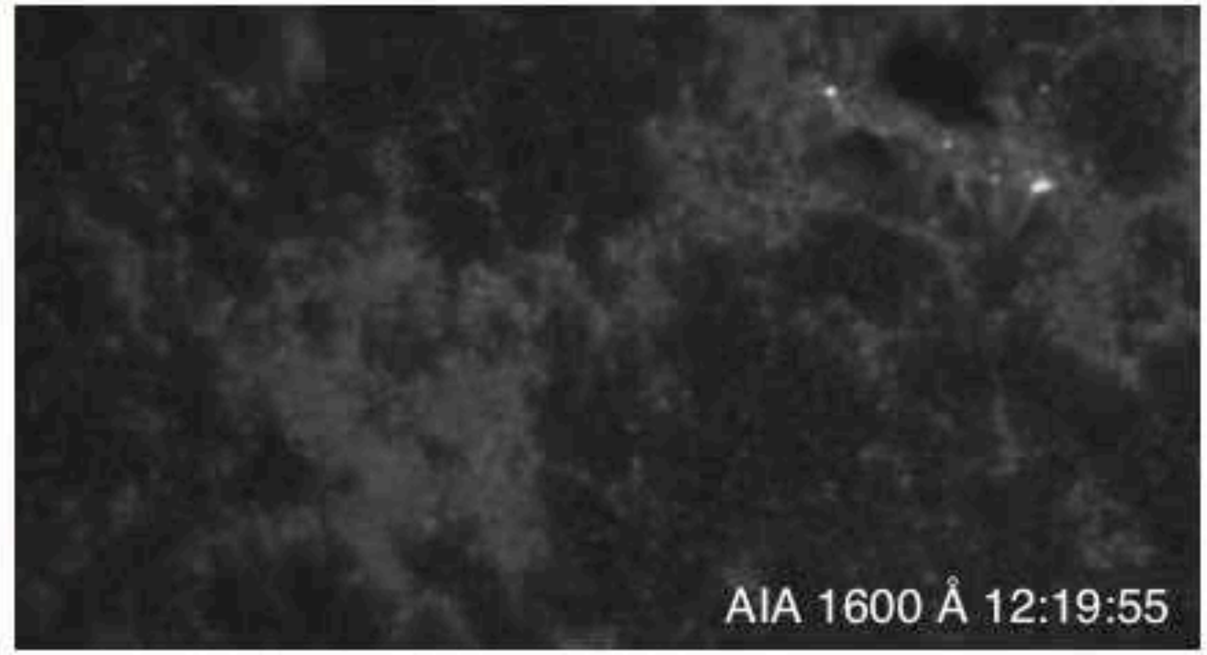
(One of) Jet Mechanism

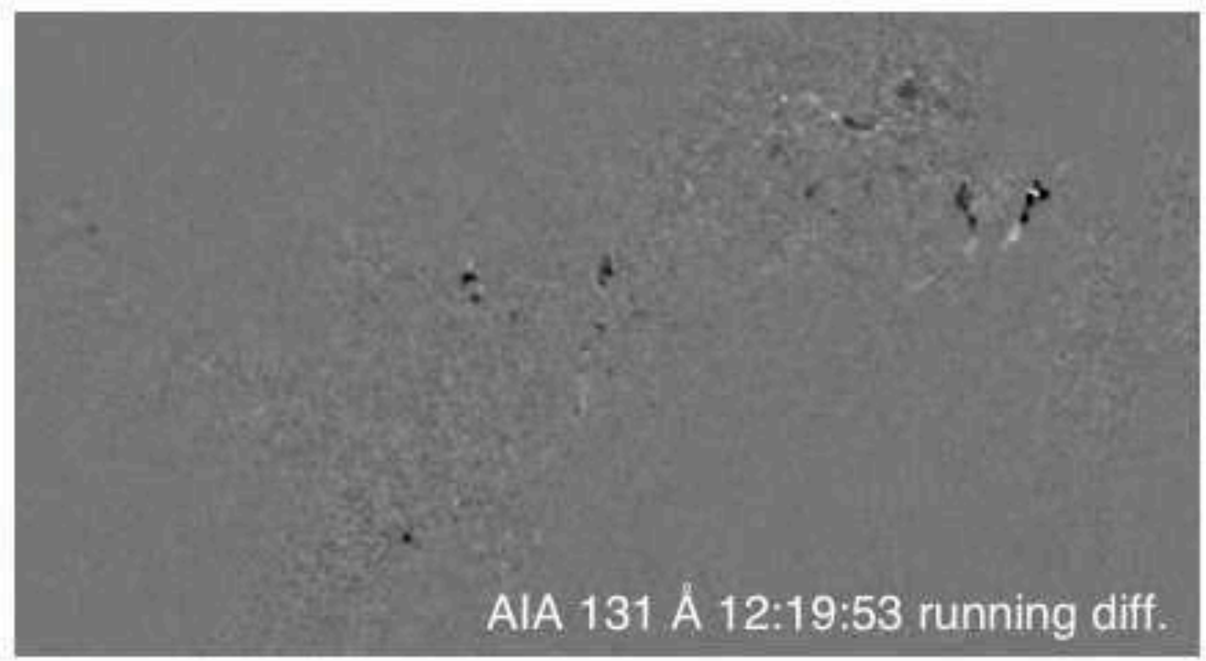


Wyper et al. (2017)

Circular Ribbon Flare

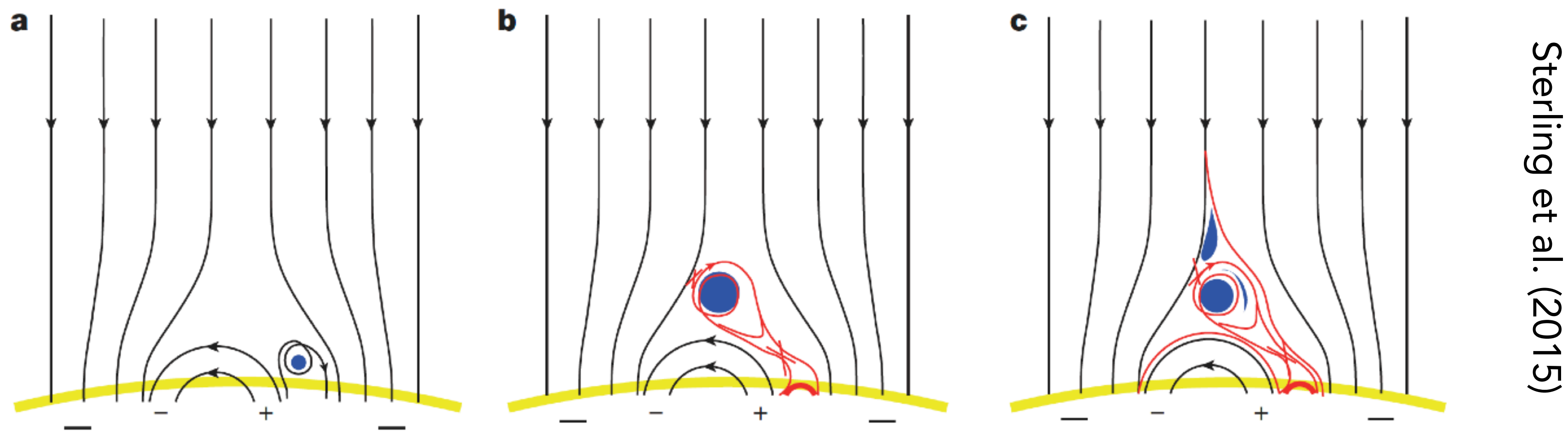


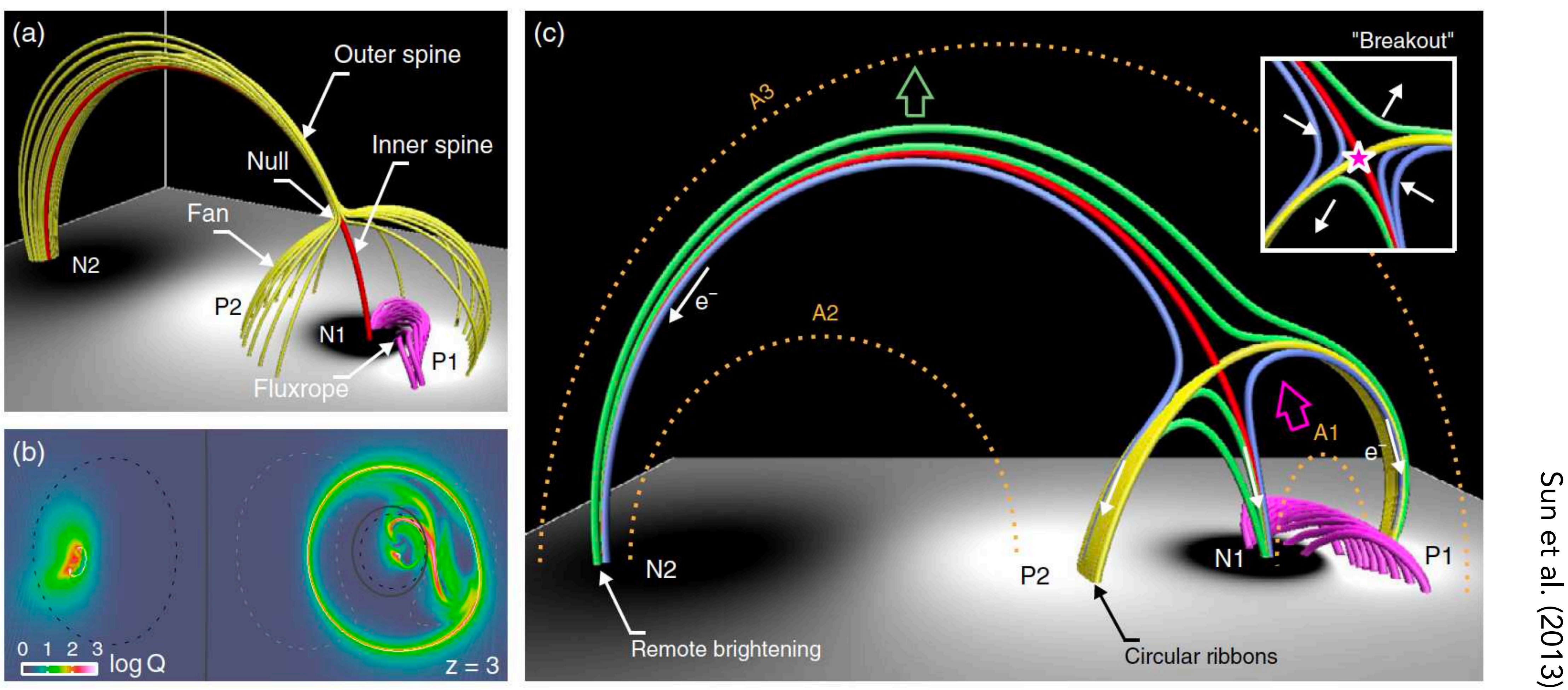




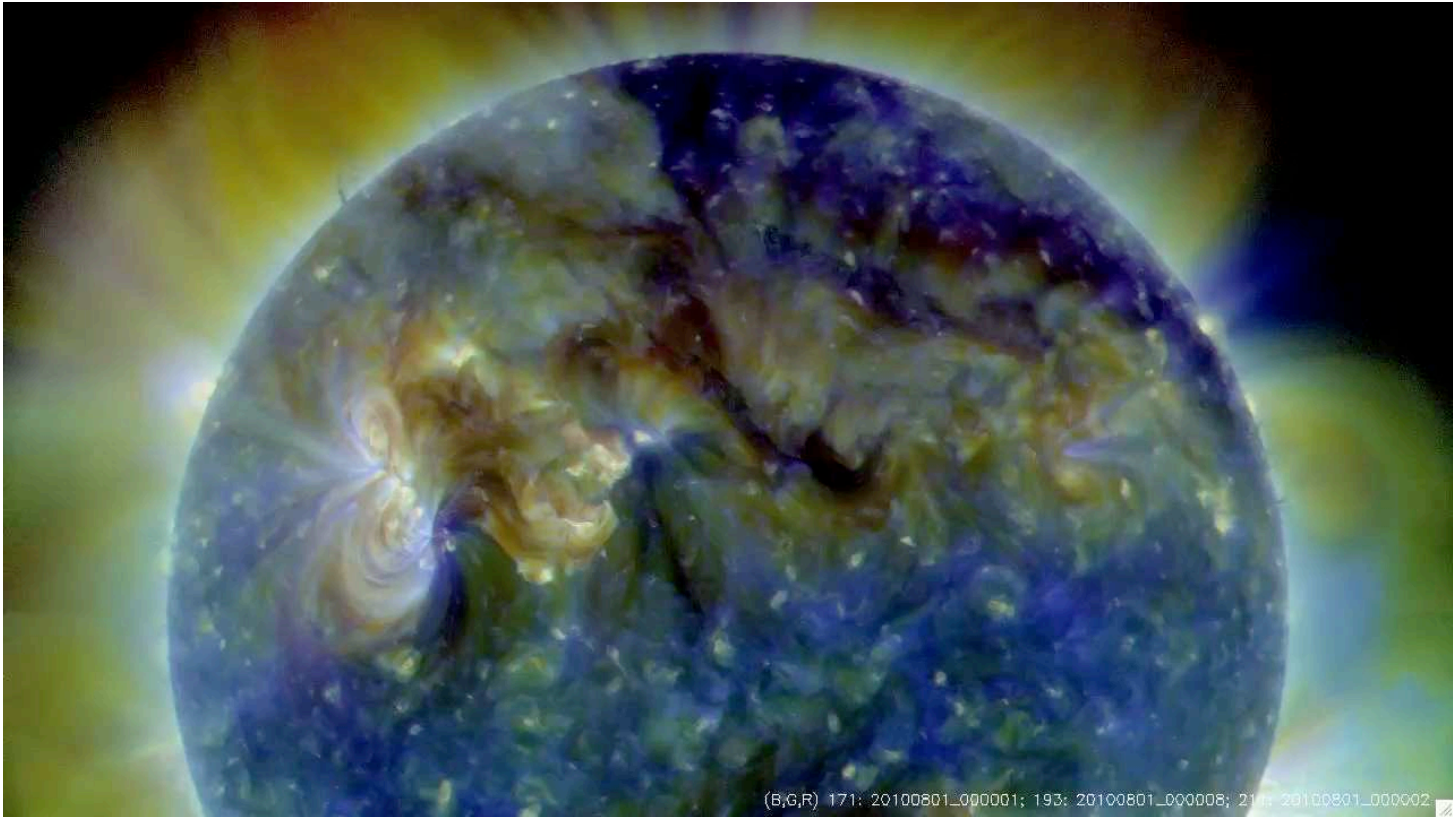
Masson et al. (2009); Wang & Liu (2012); Sun et al. (2013)

Fan-Spine Topology



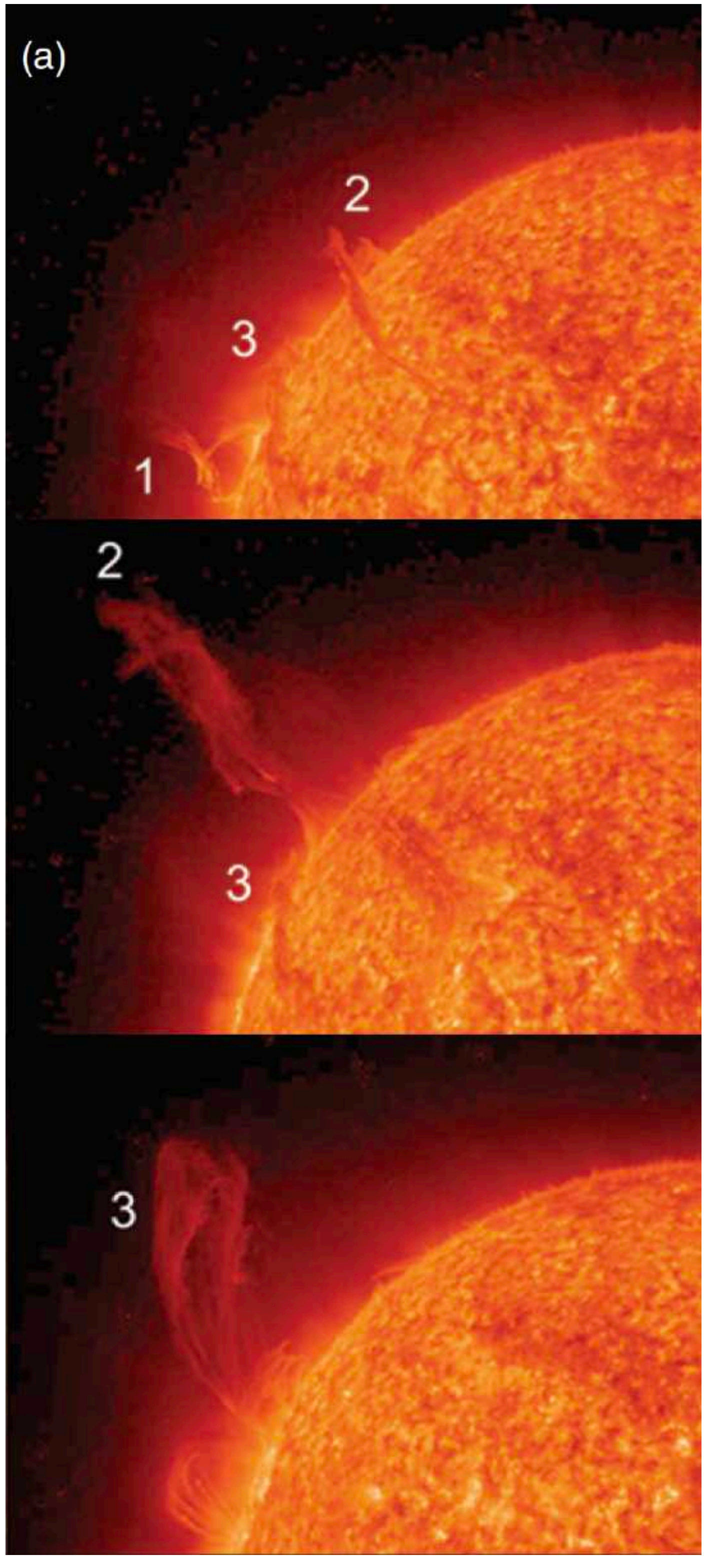


Sympathetic Eruptions



Schrijver & Title (2011)

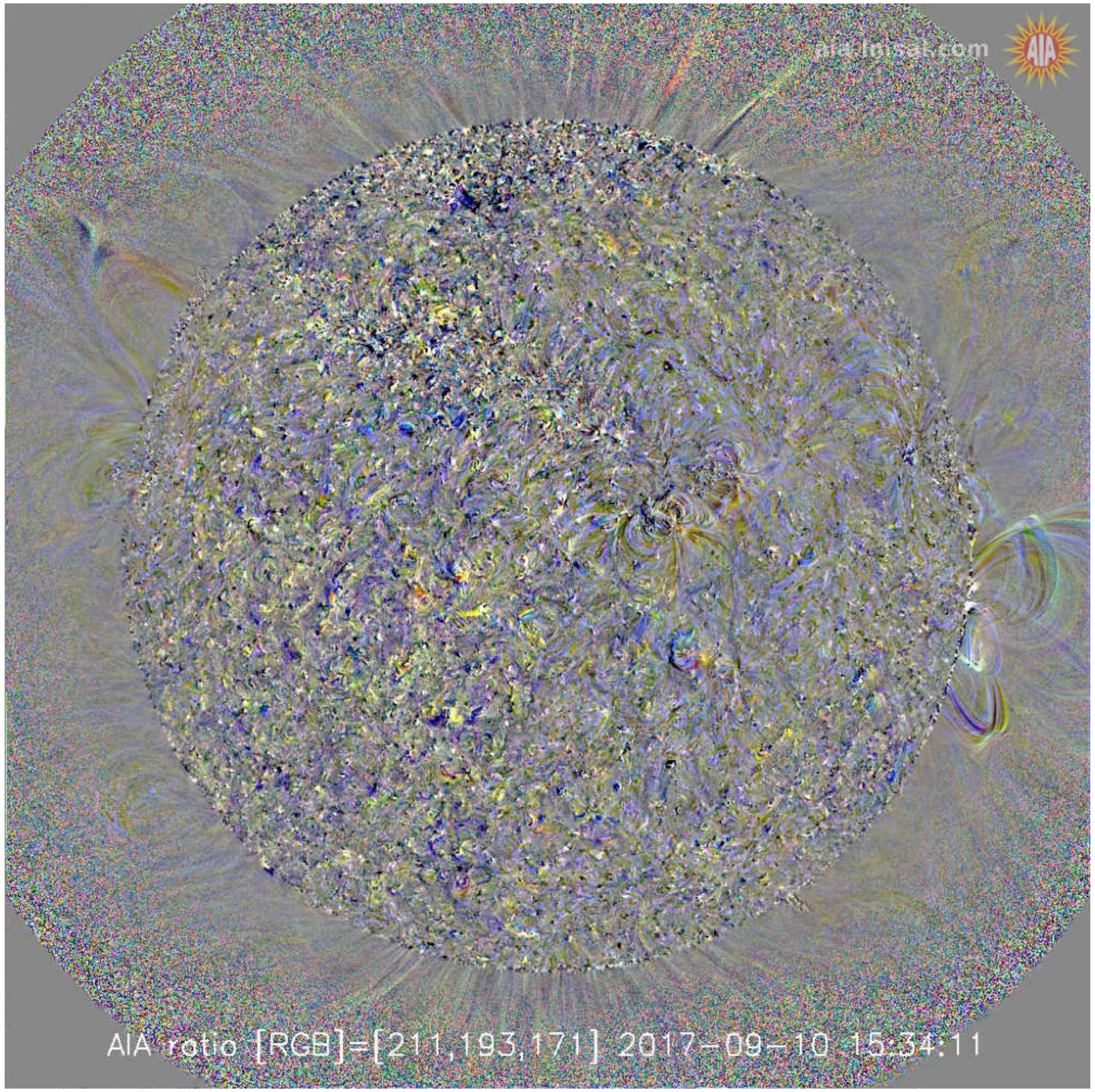
Long-Range Coupling: Reconnection

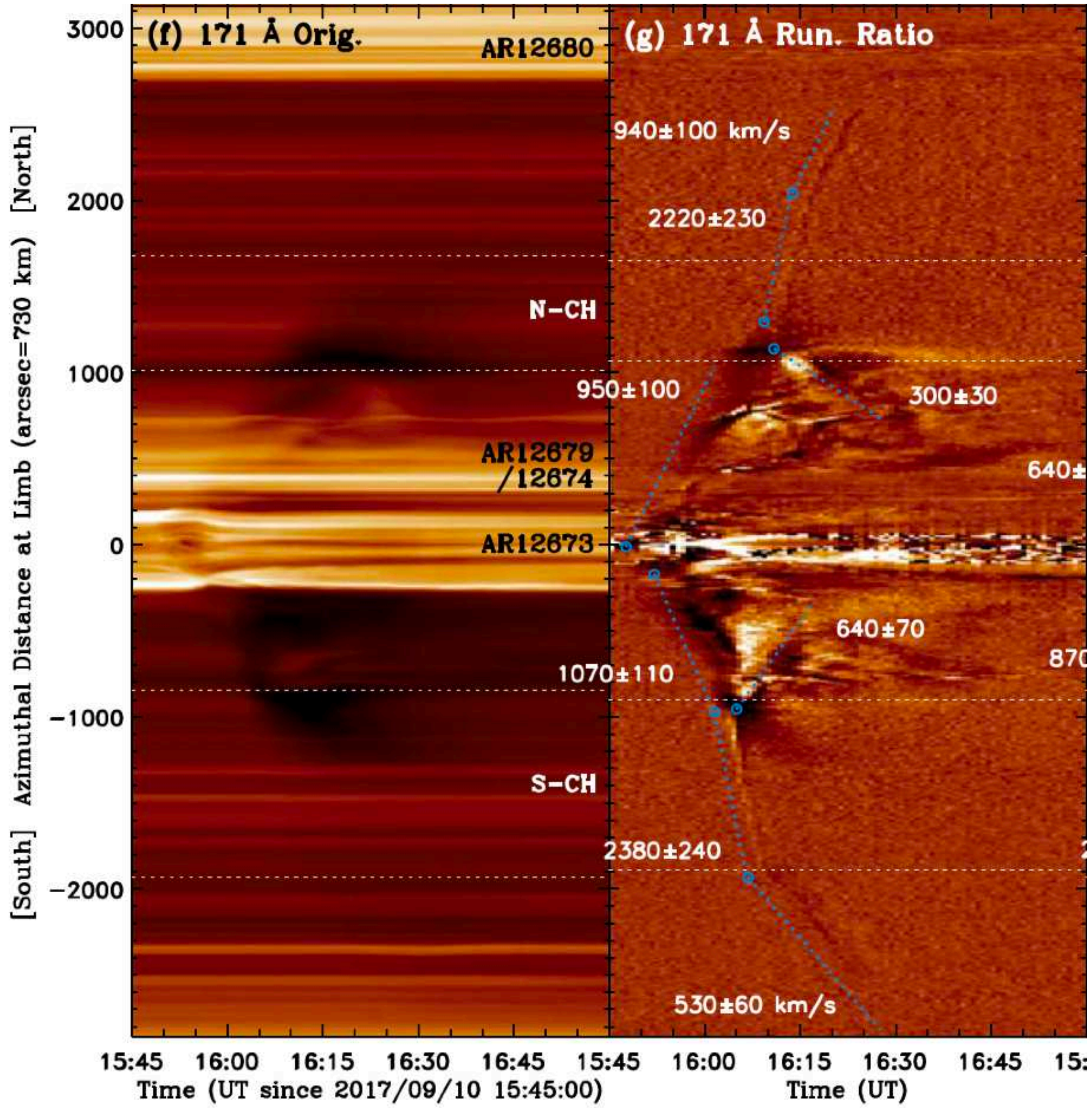


Török et al. (2011); Titov et al. (2012)

Long-Range Coupling: Waves

"Coronal seismology"



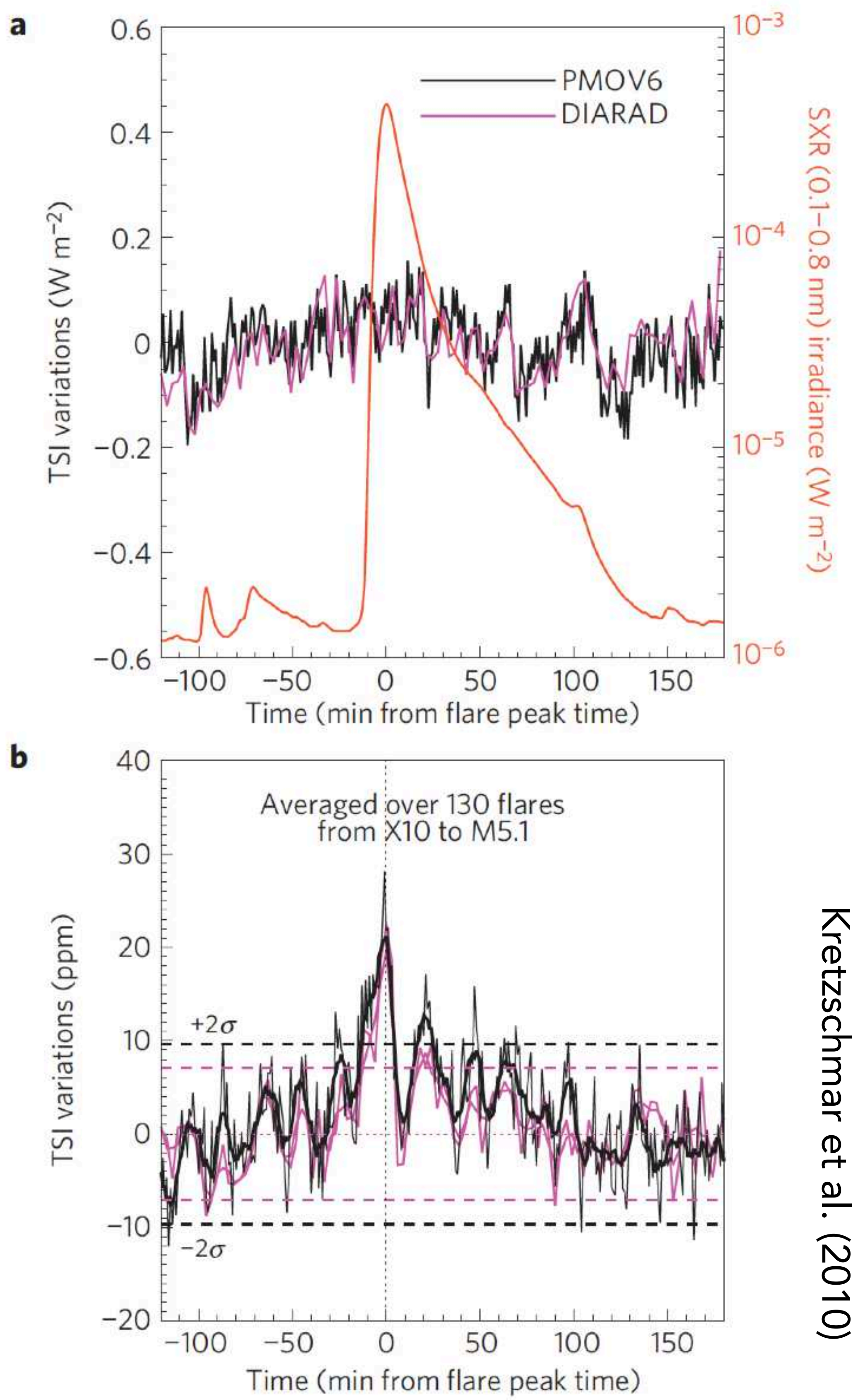


Liu et al. (2018)

Flare/CME Prediction

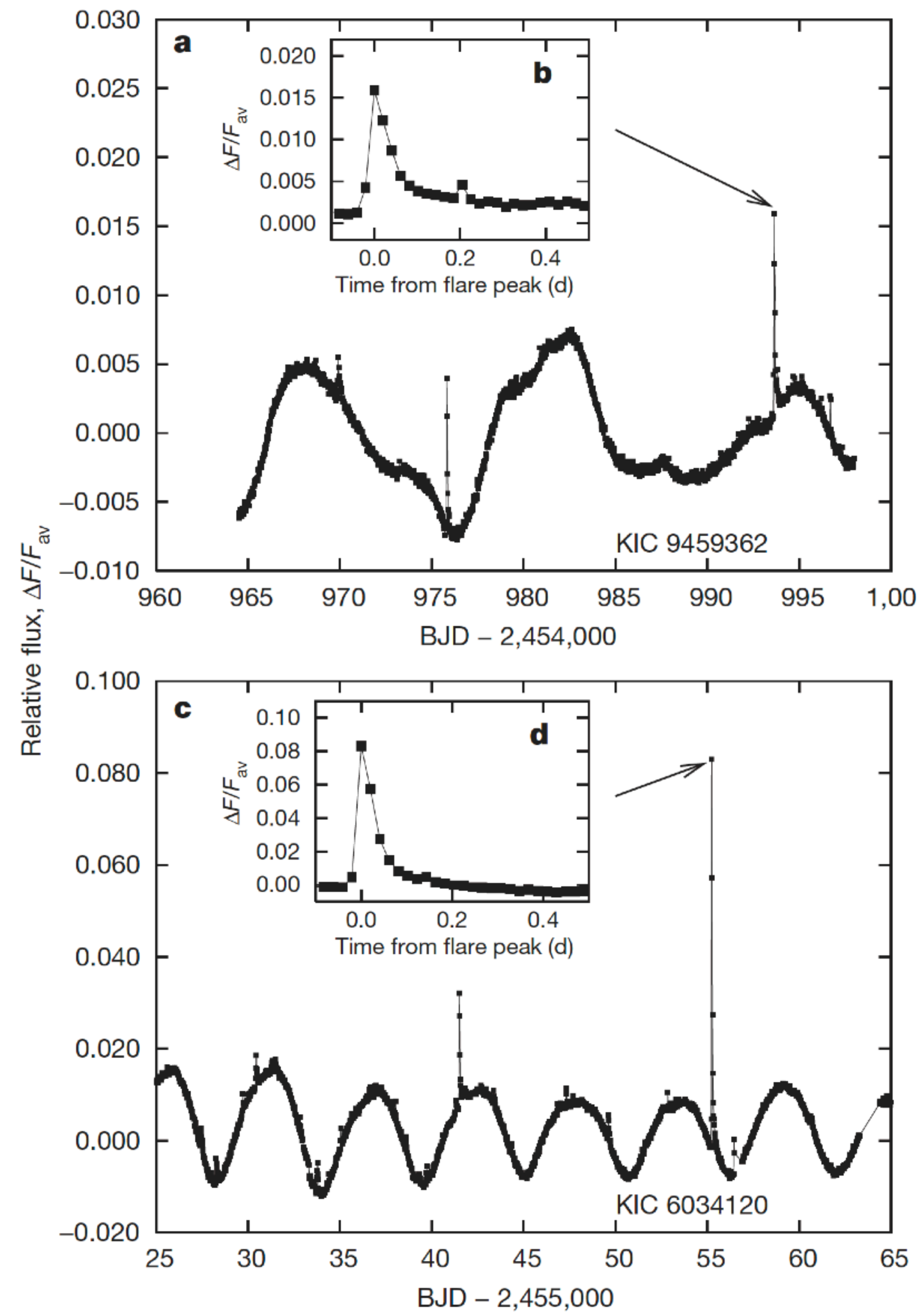
Solar vs Stellar Super Flares

SoHO/VIRGO



Kretzschmar et al. (2010)

Kepler

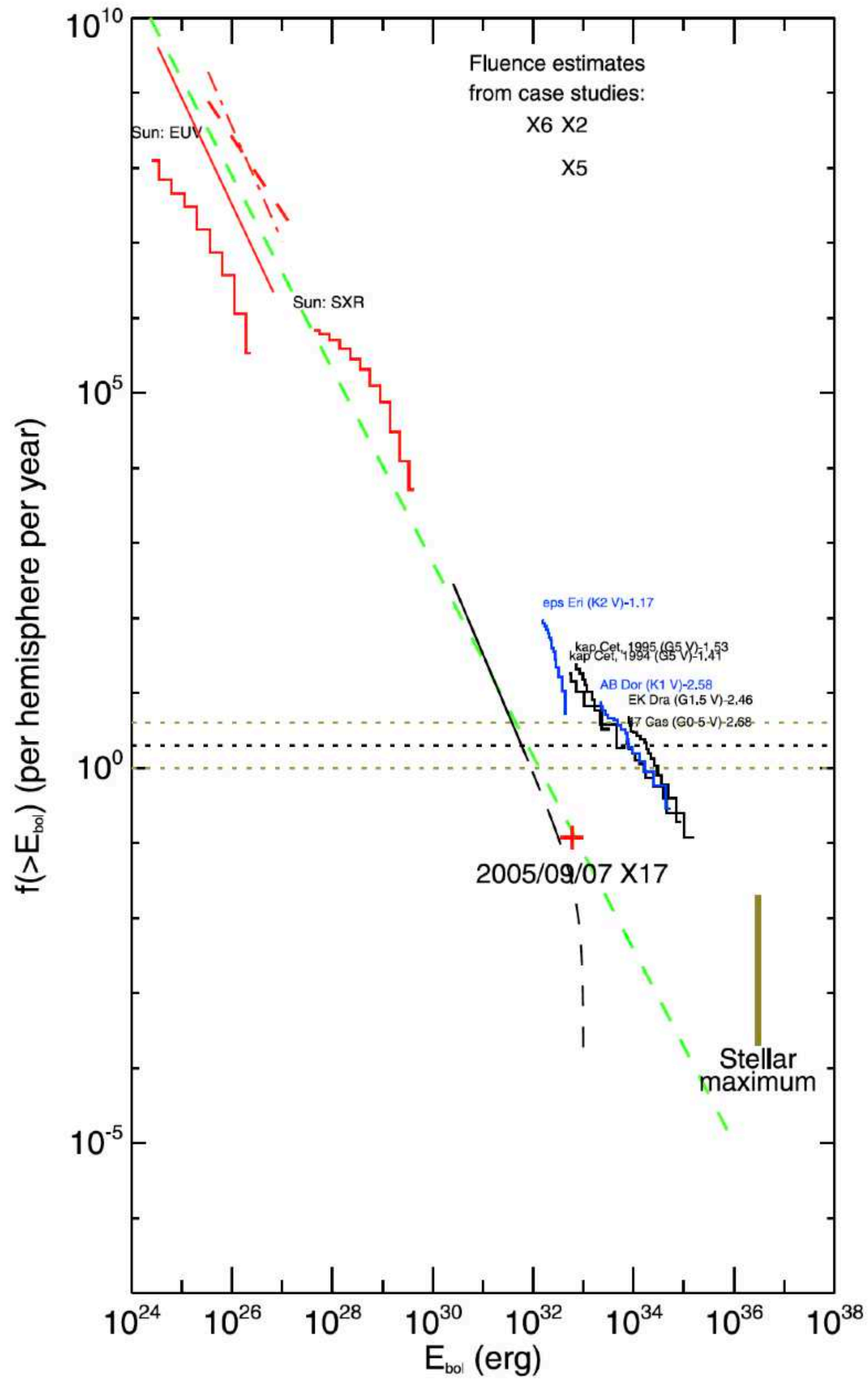


Maehara et al. (2012)

Flare Statistics

- Power law for frequency, etc.
- Stochasticity involved: deterministic prediction difficult
- Need to catch the “big guys”

> "Because the likelihood of flares larger than approximately X30 remains empirically unconstrained, we present indirect arguments, based on records of sunspots and on statistical arguments, that solar flares in the past four centuries have likely not substantially exceeded the level of the largest flares observed in the space era, and that there is at most about a 10% chance of a flare larger than about X30 in the next 30 years."

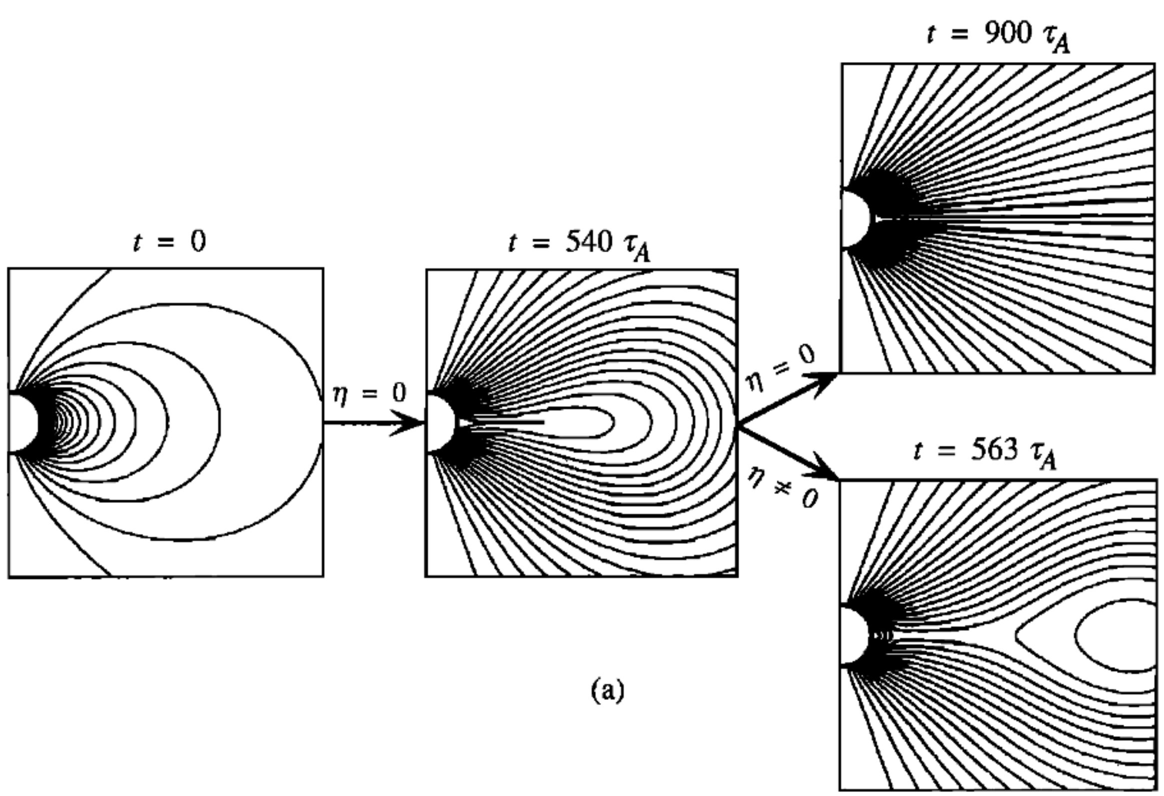


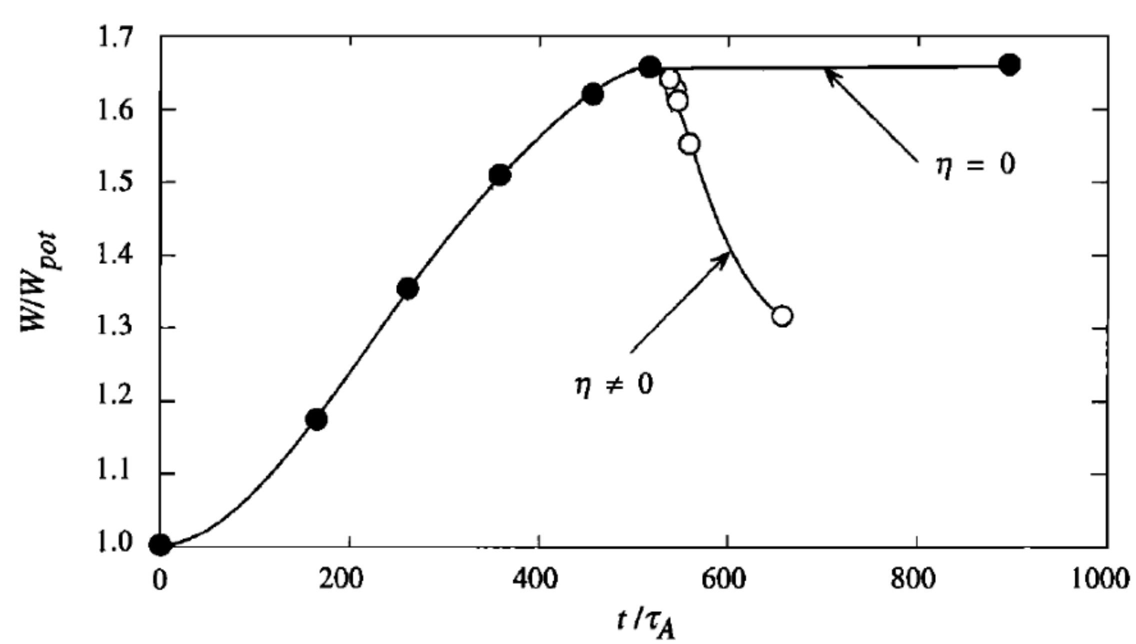
Schrijver et al. (2012)

Aly-Sturrock Conjecture

- For a simply connected field, the fully opened field has a higher magnetic energy than the corresponding force-free field (Aly 1984; Sturrock 1991)
- Way out: resistive processes; partially open field; multi-polar field; non-force-free field, etc.

Q: What problem does the conjecture create for eruption?





Mikić & Linker (1994)

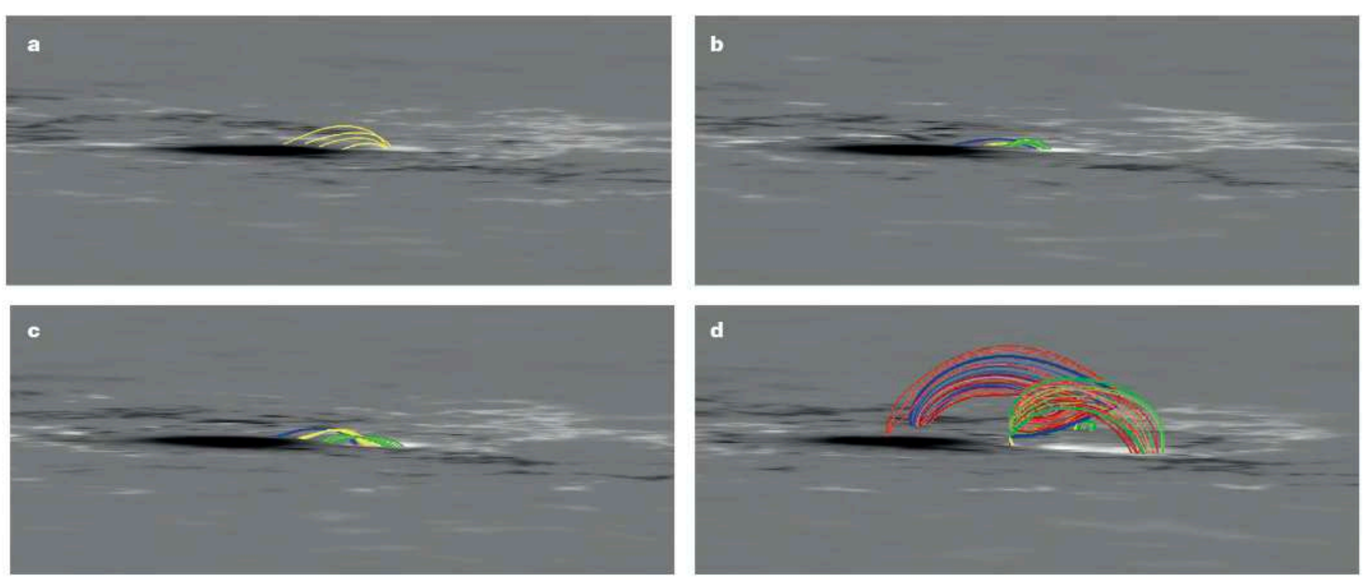
Threshold of Magnetic Energy

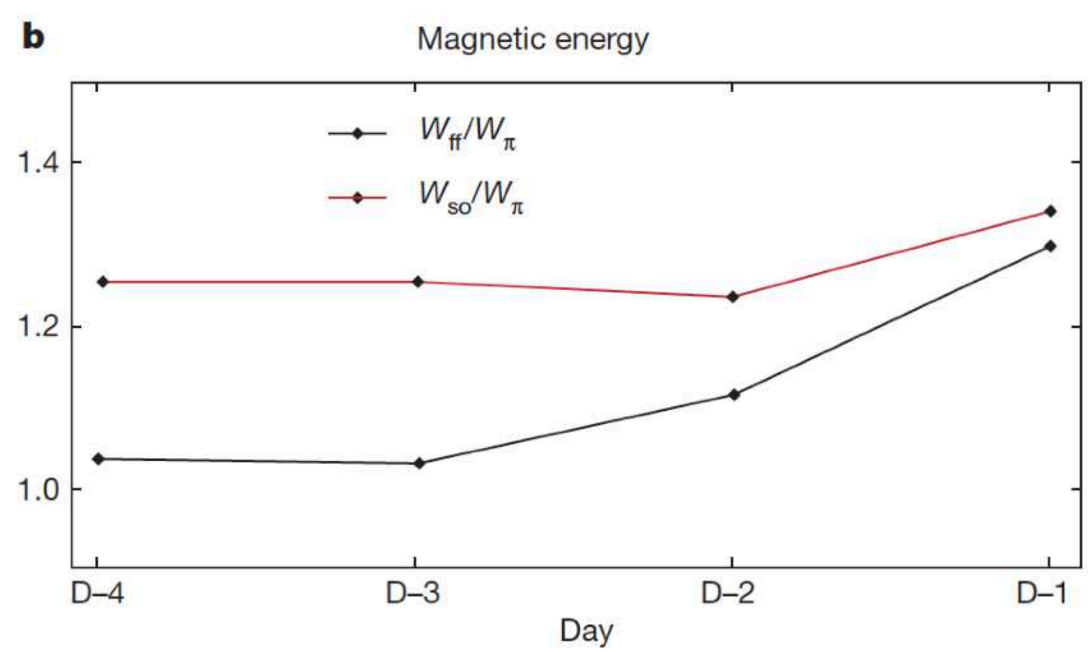
- Magnetic *Virial Theorem*: Energy of FFF is determined by boundary condition (see HW3 Q2):

$$E_{\rm ff} = \frac{R_\odot^3}{8\pi} \oint (B_r^2 - B_\theta^2 - B_\phi^2)\,|_{r=R_\odot}\, d\Omega$$

- Free magnetic energy from extrapolation rarely exceeds ~0.5E_p

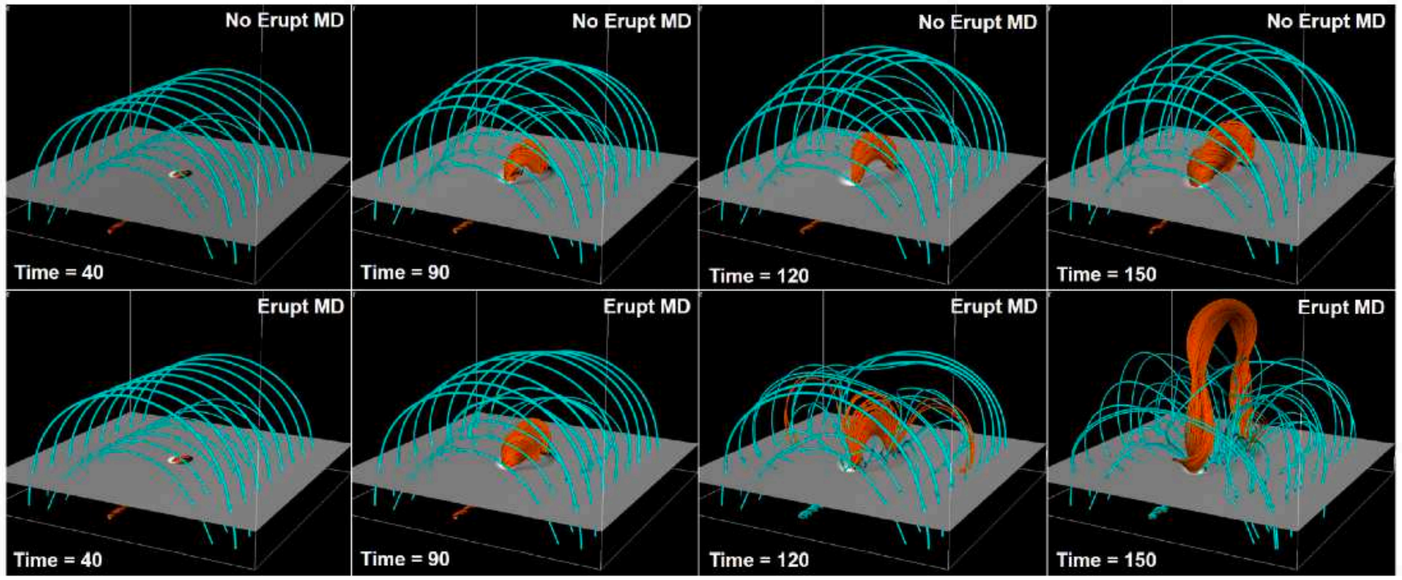
- "Partially open field" energy as upper bound? (e.g., Amari et al. 2011)





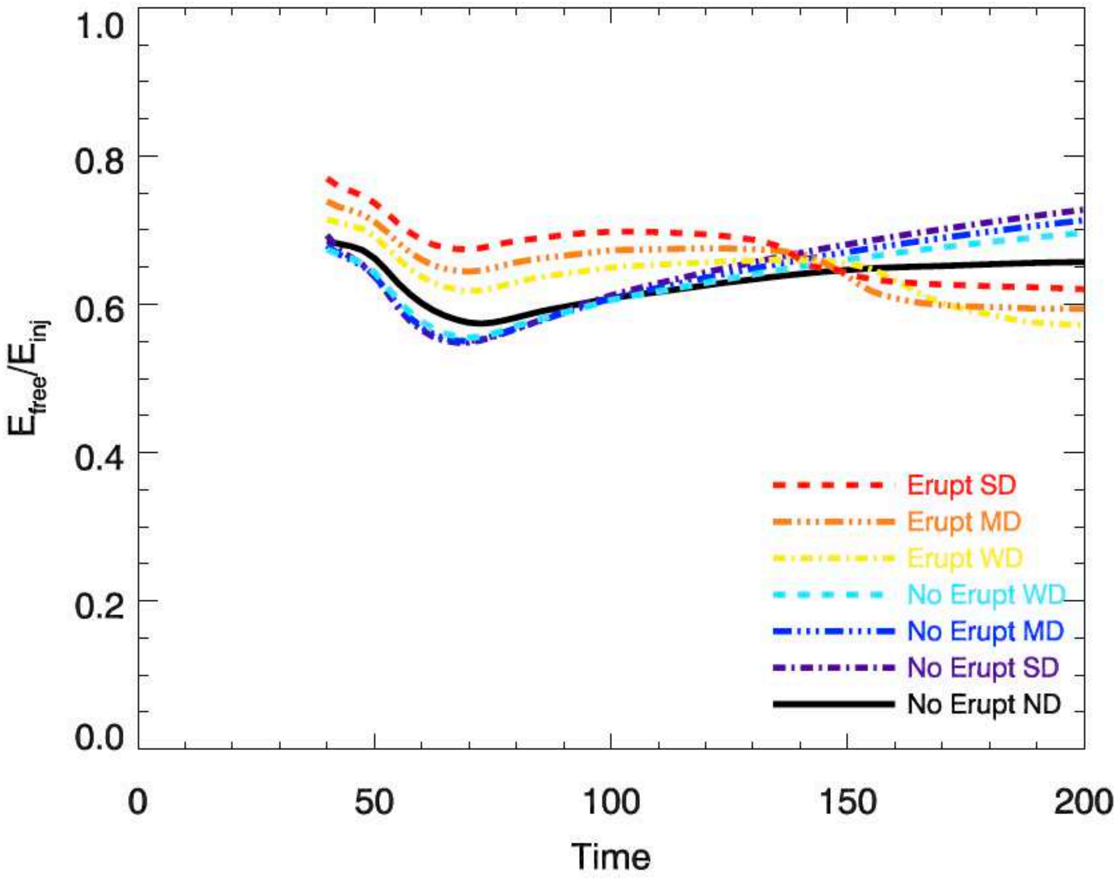
Amari et al. (2014)

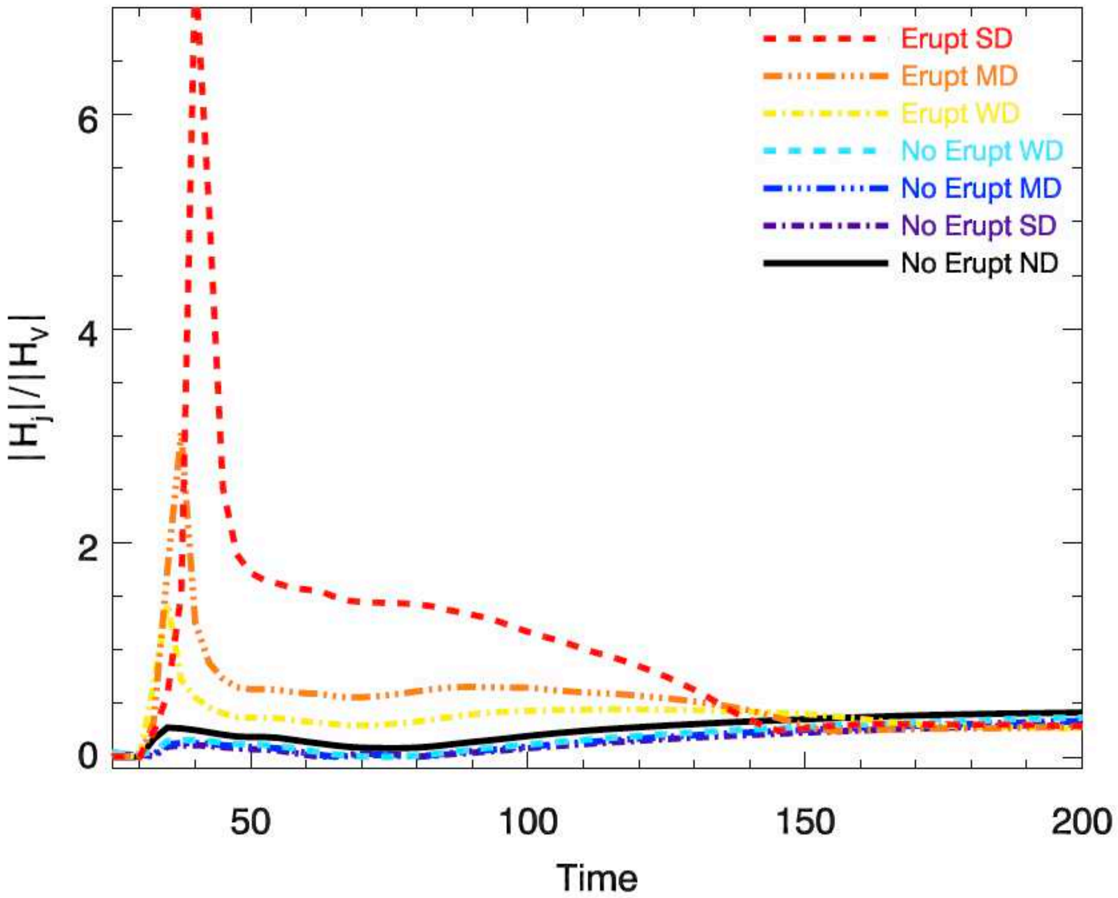
Threshold of Magnetic Helicity



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

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





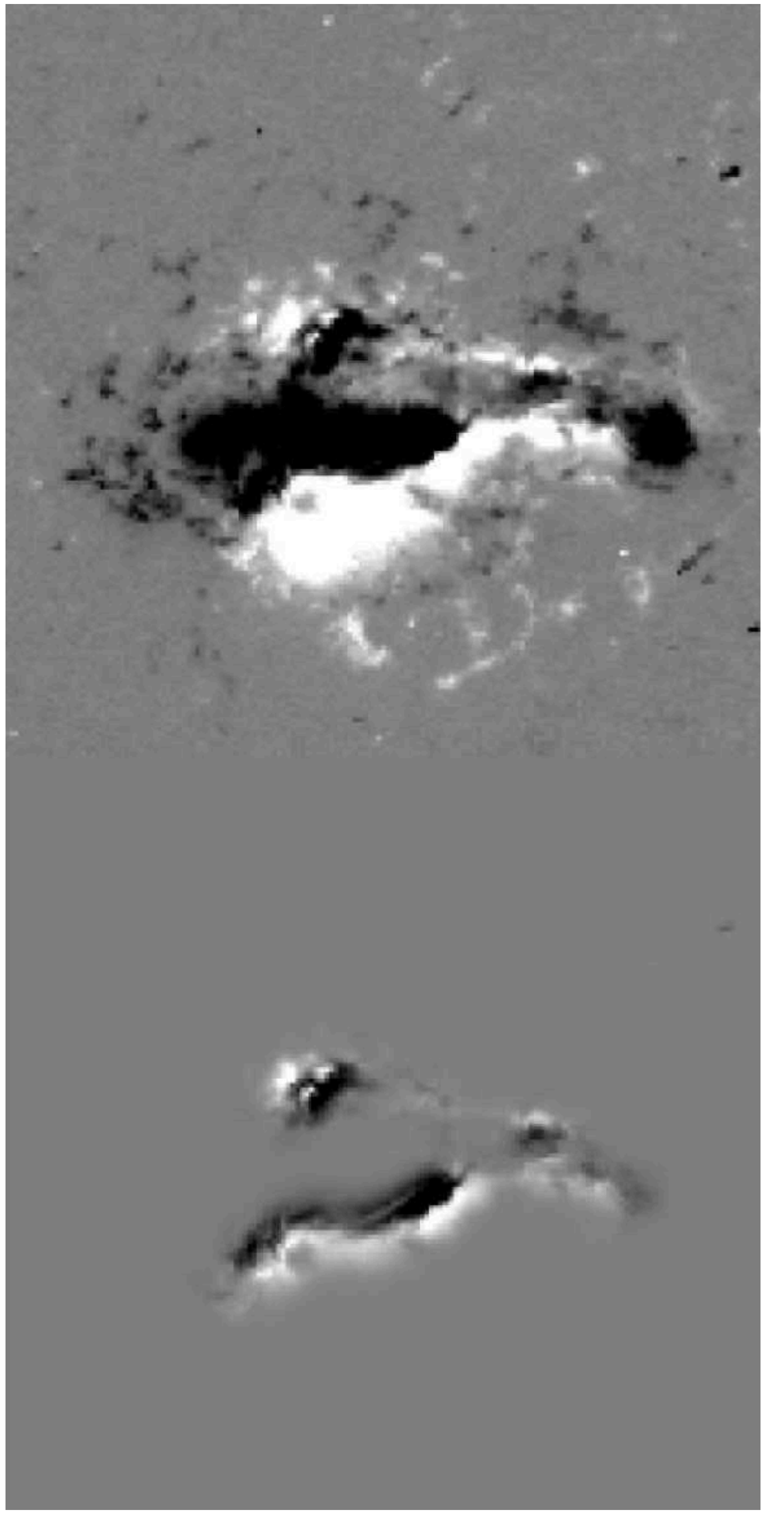
Pariat et al. (2017)

Magnetic Field Proxies

TABLE 3
PARAMETERS USED IN THE DISCRIMINANT ANALYSIS

Description	Formula	Variable
Atmospheric Seeing		
Median of the granulation contrast	$s = \mathrm{median}(\Delta I)$	s
Distribution of Magnetic Fields		
Moments of vertical magnetic field	$B_z = \boldsymbol{B} \cdot \boldsymbol{e}_z$	$\mathcal{M}(B_z)$
Total unsigned flux	$\Phi_{\mathrm{tot}} = \sum \lvert B_z \rvert \, dA$	Φ_{tot}
Absolute value of the net flux	$\lvert \Phi_{\mathrm{net}} \rvert = \lvert \sum B_z \, dA \rvert$	$\lvert \Phi_{\mathrm{net}} \rvert$
Moments of horizontal magnetic field	$B_h = \sqrt{B_x^2 + B_y^2}$	$\mathcal{M}(B_h)$
Distribution of Inclination Angle		
Moments of inclination angle	$\gamma = \tan^{-1}(B_z/B_h)$	$\mathcal{M}(\gamma)$
Distribution of the Magnitude of the Horizontal Gradients of the Magnetic Fields		
Moments of total field gradients	$\lvert \nabla_h B \rvert = \sqrt{(\partial B/\partial x)^2 + (\partial B/\partial y)^2}$	$\mathcal{M}(\lvert \nabla_h B \rvert)$
Moments of vertical field gradients	$\lvert \nabla_h B_z \rvert = \sqrt{(\partial B_z/\partial x)^2 + (\partial B_z/\partial y)^2}$	$\mathcal{M}(\lvert \nabla_h B_z \rvert)$
Moments of horizontal field gradients	$\lvert \nabla_h B_h \rvert = \sqrt{(\partial B_h/\partial x)^2 + (\partial B_h/\partial y)^2}$	$\mathcal{M}(\lvert \nabla_h B_h \rvert)$
Distribution of Vertical Current Density		
Moments of vertical current density	$J_z = (\partial B_y/\partial x - \partial B_x/\partial y)/\mu_0$	$\mathcal{M}(J_z)$
Total unsigned vertical current	$I_{\mathrm{tot}} = \sum \lvert J_z \rvert \, dA$	I_{tot}
Absolute value of the net vertical current	$\lvert I_{\mathrm{net}} \rvert = \lvert \sum J_z \, dA \rvert$	$\lvert I_{\mathrm{net}} \rvert$
Sum of absolute value of net currents in each polarity	$\lvert I_{\mathrm{net}}^B \rvert = \lvert \sum J_z(B_z > 0) \, dA \rvert + \lvert \sum J_z(B_z < 0) \, dA \rvert$	$\lvert I_{\mathrm{net}}^B \rvert$
Moments of vertical heterogeneity current density[a]	$J_z^h = (b_y \partial B_x/\partial y - b_x \partial B_y/\partial x)/\mu_0$	$\mathcal{M}(J_z^h)$
Total unsigned vertical heterogeneity current	$I_{\mathrm{tot}}^h = \sum \lvert J_z^h \rvert \, dA$	I_{tot}^h
Absolute value of net vertical heterogeneity current	$\lvert I_{\mathrm{net}}^h \rvert = \lvert \sum J_z^h \, dA \rvert$	$\lvert I_{\mathrm{net}}^h \rvert$
Distribution of Twist Parameter		
Moments of twist parameter[b]	$\alpha = CJ_z/B_z$	$\mathcal{M}(\alpha)$
Best-fit force-free twist parameter[b]	$\boldsymbol{B} = \alpha_{\mathrm{ff}} \nabla \times \boldsymbol{B}$	$\lvert \alpha_{\mathrm{ff}} \rvert$
Distribution of Current Helicity		
Moments of current helicity[c]	$h_c = CB_z(\partial B_y/\partial x - \partial B_x/\partial y)$	$\mathcal{M}(h_c)$
Total unsigned current helicity	$H_c^{\mathrm{tot}} = \sum \lvert h_c \rvert \, dA$	H_c^{tot}
Absolute value of net current helicity	$\lvert H_c^{\mathrm{net}} \rvert = \lvert \sum h_c \, dA \rvert$	$\lvert H_c^{\mathrm{net}} \rvert$
Distribution of Shear Angles		
Moments of three-dimensional shear angle[d]	$\Psi = \cos^{-1}(\boldsymbol{B}^p \cdot \boldsymbol{B}^o / B^p B^o)$	$\mathcal{M}(\Psi)$
Area with shear $>\Psi_0$, $\Psi_0 = 45°, 80°$	$A(\Psi > \Psi_0) = \sum_{\Psi > \Psi_0} dA$	$A(\Psi > 45°)$, $A(\Psi > 80°)$
Moments of three-dimensional neutral-line shear angle	$\Psi_{\mathrm{NL}} = \cos^{-1}(\boldsymbol{B}_{\mathrm{NL}}^p \cdot \boldsymbol{B}_{\mathrm{NL}}^o / B_{\mathrm{NL}}^p B_{\mathrm{NL}}^o)$	$\mathcal{M}(\Psi_{\mathrm{NL}})$
Length of neutral line with shear $>\Psi_0$	$L(\Psi_{\mathrm{NL}} > \Psi_0) = \sum_{\Psi_{\mathrm{NL}} > \Psi_0} dL$	$L(\Psi_{\mathrm{NL}} > 45°)$, $L(\Psi_{\mathrm{NL}} > 80°)$
Moments of horizontal shear angle[e]	$\psi = \cos^{-1}(\boldsymbol{B}_h^p \cdot \boldsymbol{B}_h^o / B_h^p B_h^o)$	$\mathcal{M}(\psi)$
Area with horizontal shear $>\psi_0$	$A(\psi > \psi_0) = \sum_{\psi > \psi_0} dA$	$A(\psi > 45°)$, $A(\psi > 80°)$
Moments of horizontal neutral-line shear angle	$\psi_{\mathrm{NL}} = \cos^{-1}(\boldsymbol{B}_{h,NL}^p \cdot \boldsymbol{B}_{h,NL}^o / B_{h,NL}^p B_{h,NL}^o)$	$\mathcal{M}(\psi_{\mathrm{NL}})$
Length of neutral line with horizontal shear $>\psi_0$	$L(\psi_{\mathrm{NL}} > \psi_0) = \sum_{\psi_{\mathrm{NL}} > \psi_0} dL$	$L(\psi_{\mathrm{NL}} > 45°)$, $L(\psi_{\mathrm{NL}} > 80°)$
Distribution of Photospheric Excess Magnetic Energy Density		
Moments of photospheric excess magnetic energy density[d]	$\rho_e = (\boldsymbol{B}^p - \boldsymbol{B}^o)^2/8\pi$	$\mathcal{M}(\rho_e)$
Total photospheric excess magnetic energy	$E_e = \sum \rho_e \, dA$	E_e

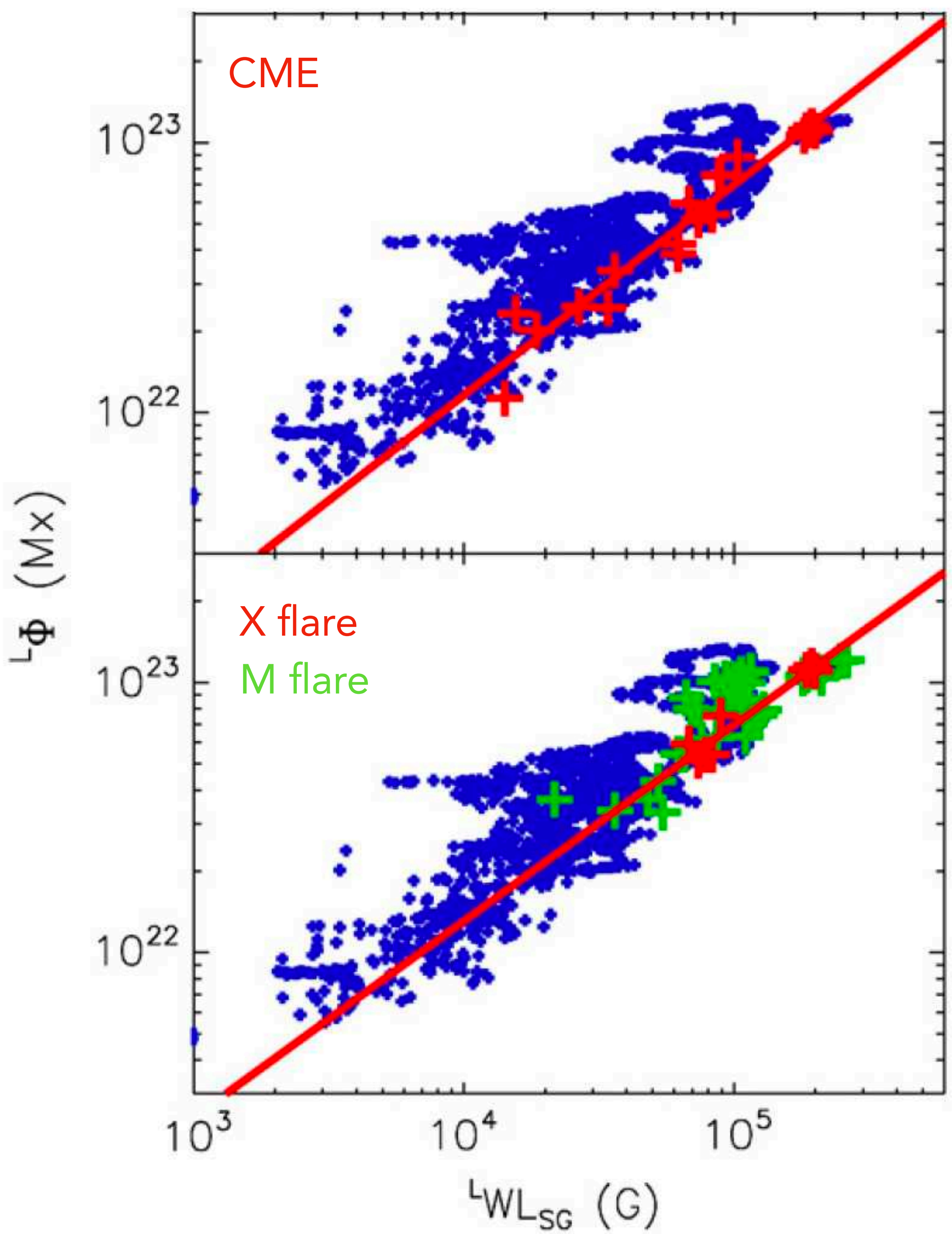
Leka & Barnes (2003)



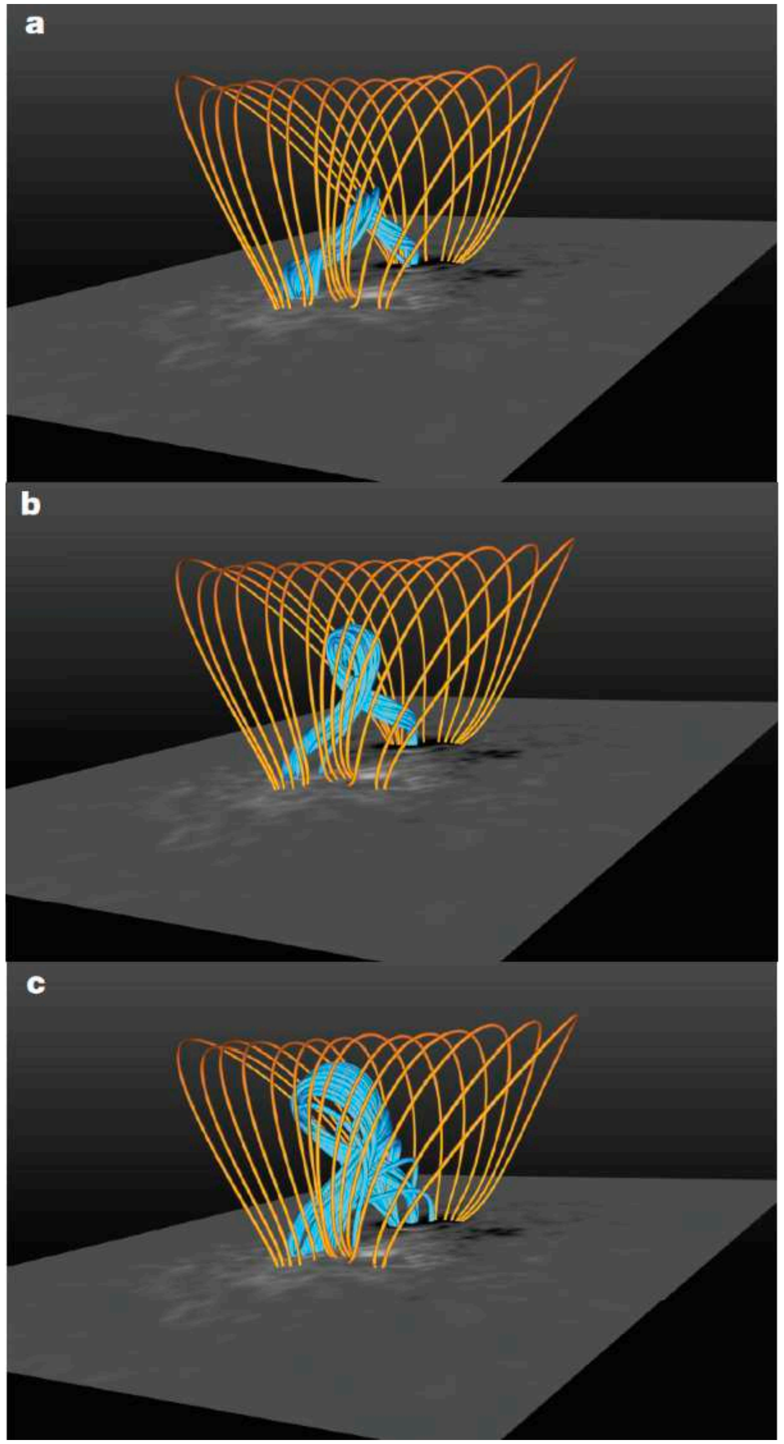
Schrijver (2007)

Hoop Force vs Confinement

"Main sequence" of solar ARs

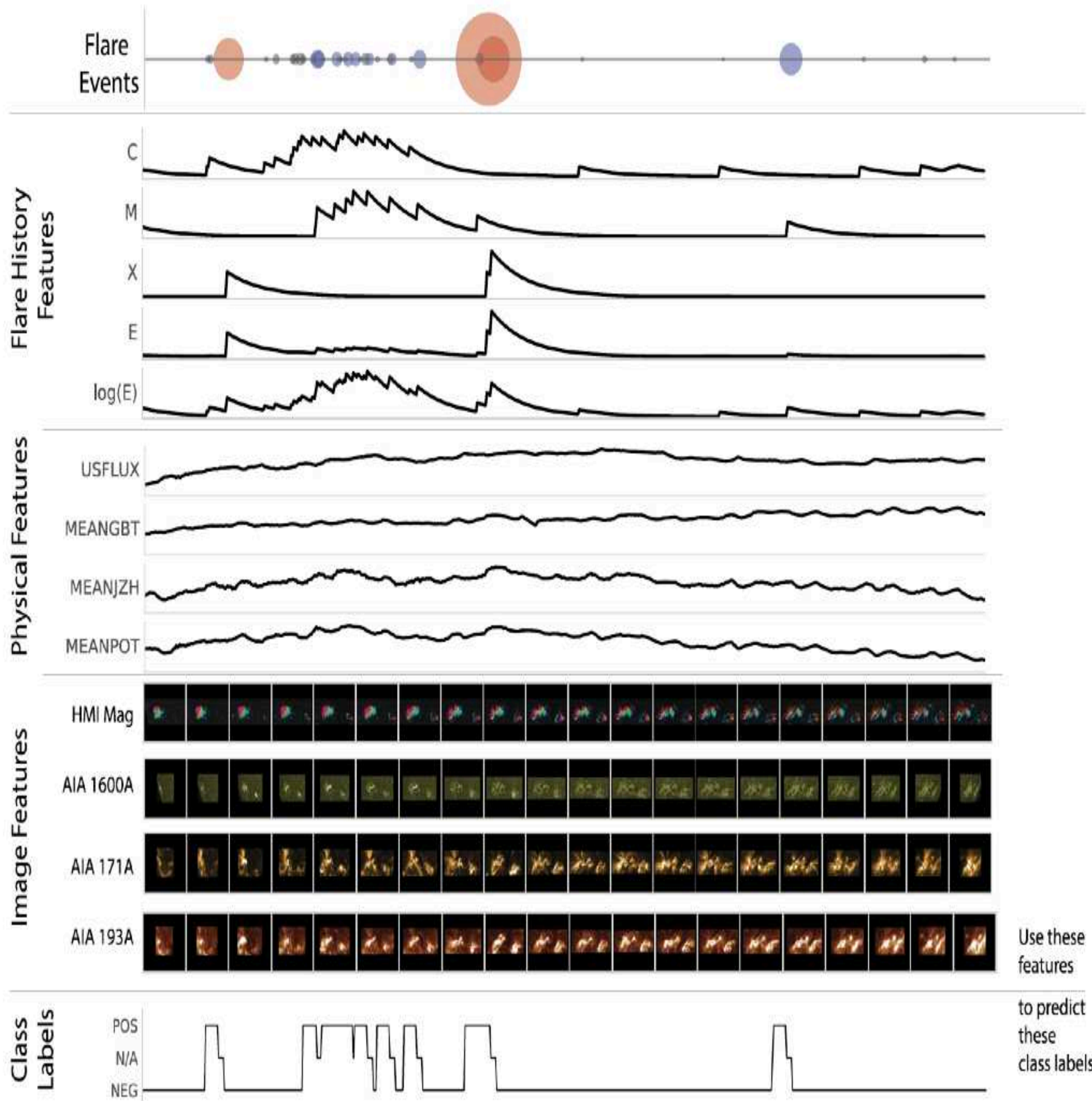


Falconer et al. (2009)

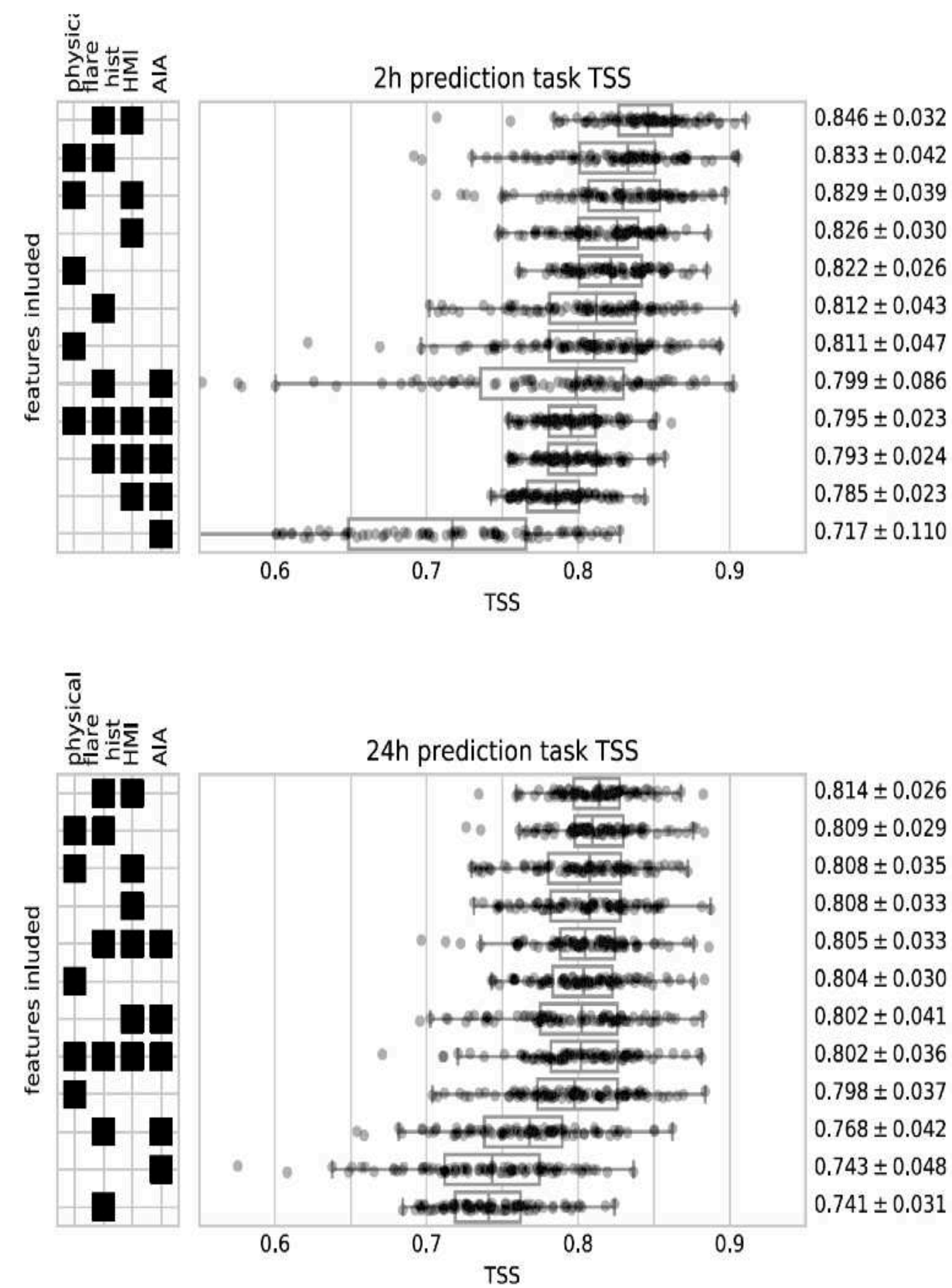


Amari et al. (2018)

Machine Learning



$$\mathrm{TSS} = \frac{\mathrm{TP} \times \mathrm{TN} - \mathrm{FP} \times \mathrm{FN}}{\mathrm{P} \times \mathrm{N}} = \mathrm{recall} - \mathrm{FPR}.$$



Bobra & Couvidat (2015); Jonas et al. (2018)

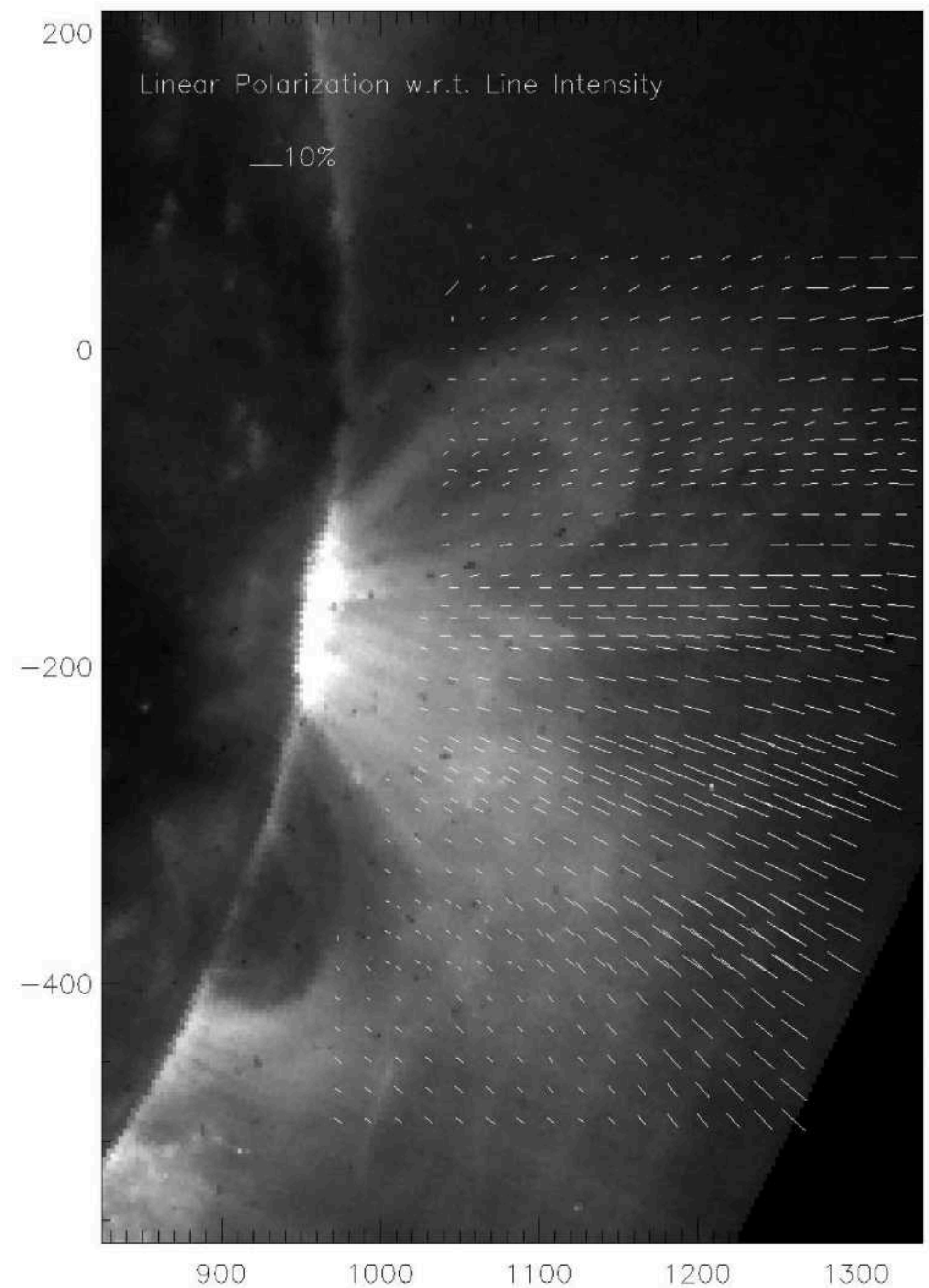
Misc Topics on Magnetic Fields

- Techniques for coronal *B*
- Comets!
- Prediction of Cycle 25

In Pursuit of Coronal *B*

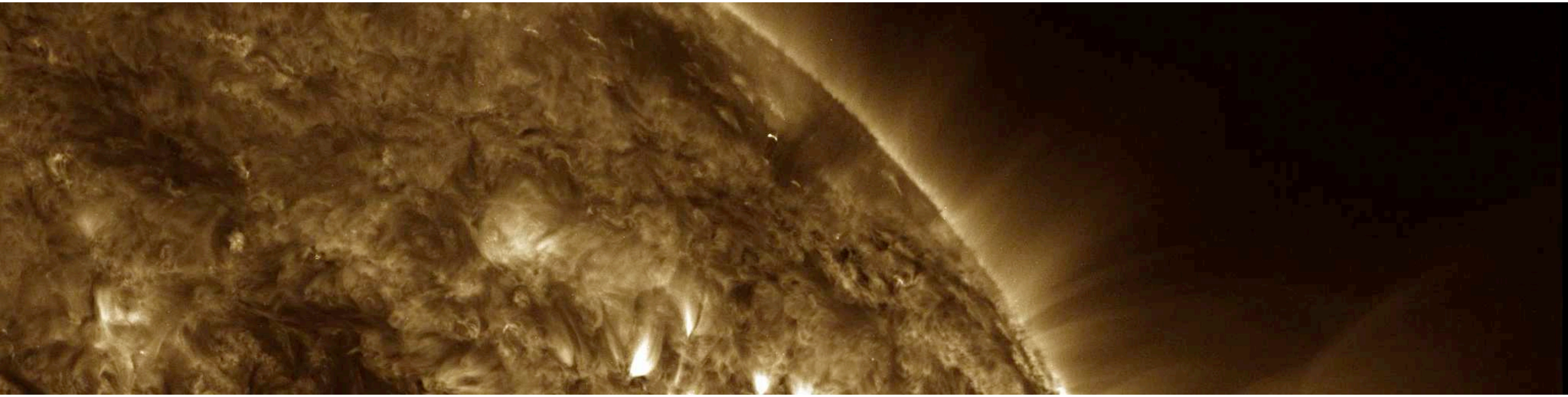
- Zeeman effect at visible & IR lines (*DKIST*)
- Hanle effect at NUV, visible, & IR lines
- Gyroresonance/Free-free emission at radio
- Faraday rotation at radio
- Coronal seismology in EUV
- Coronal stereoscopy & tomography

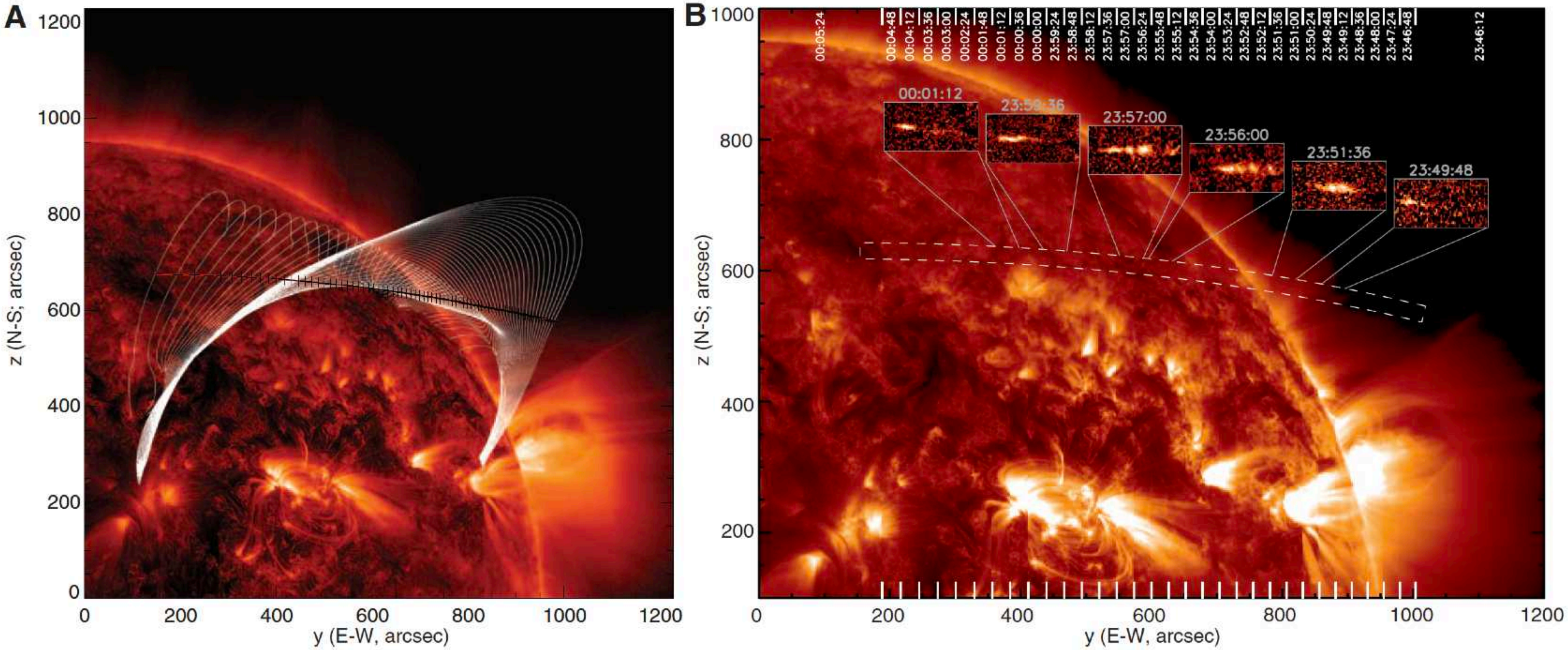
SOLARC; Fe XIII 1075 nm



Lin, Kuhn, & Coulter (2004)

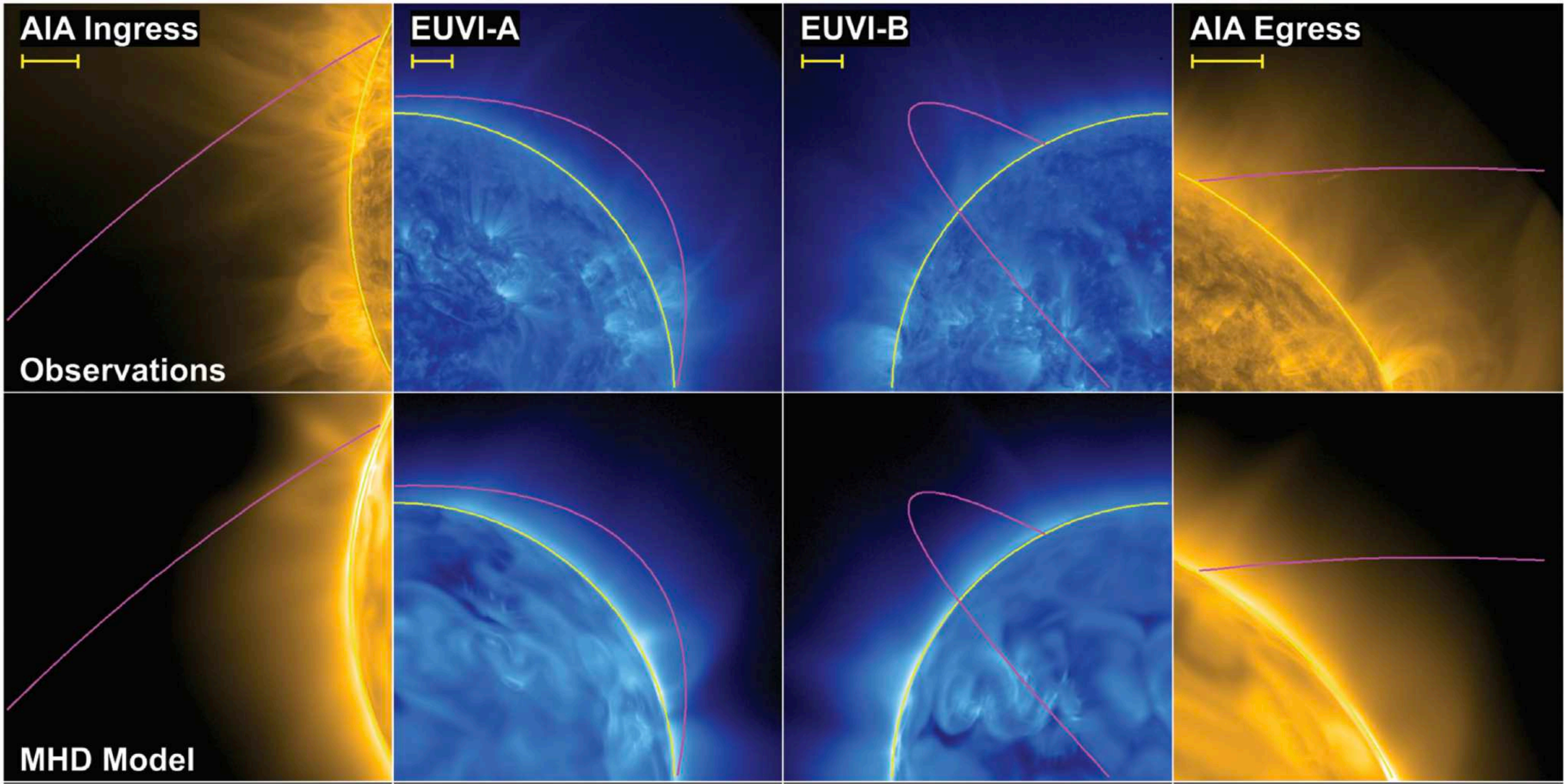
Sun-Grazing Comet: C/2011 N3





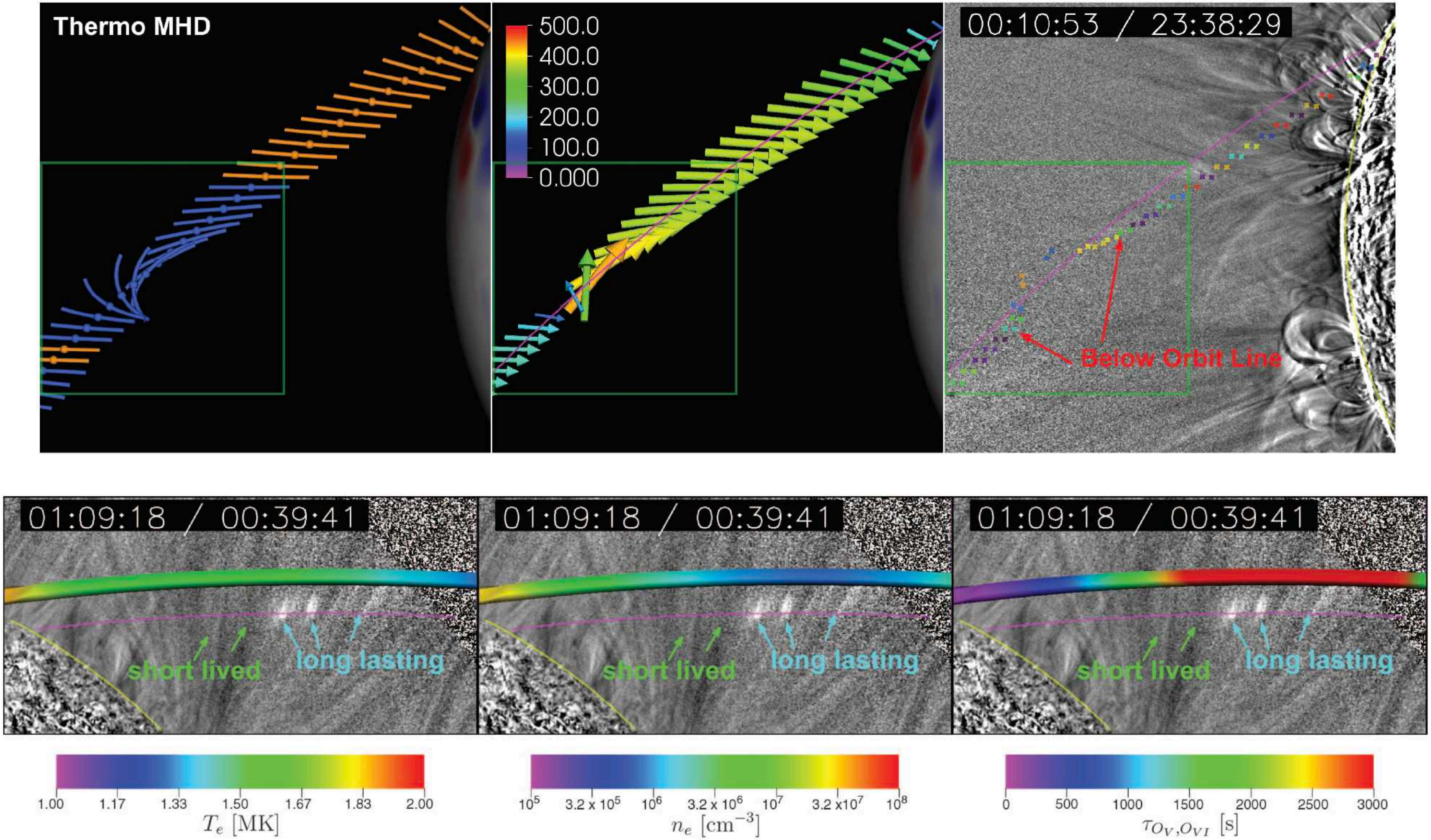
Schrijver et al. (2012)

C/2011 W3 (Comet Lovejoy)



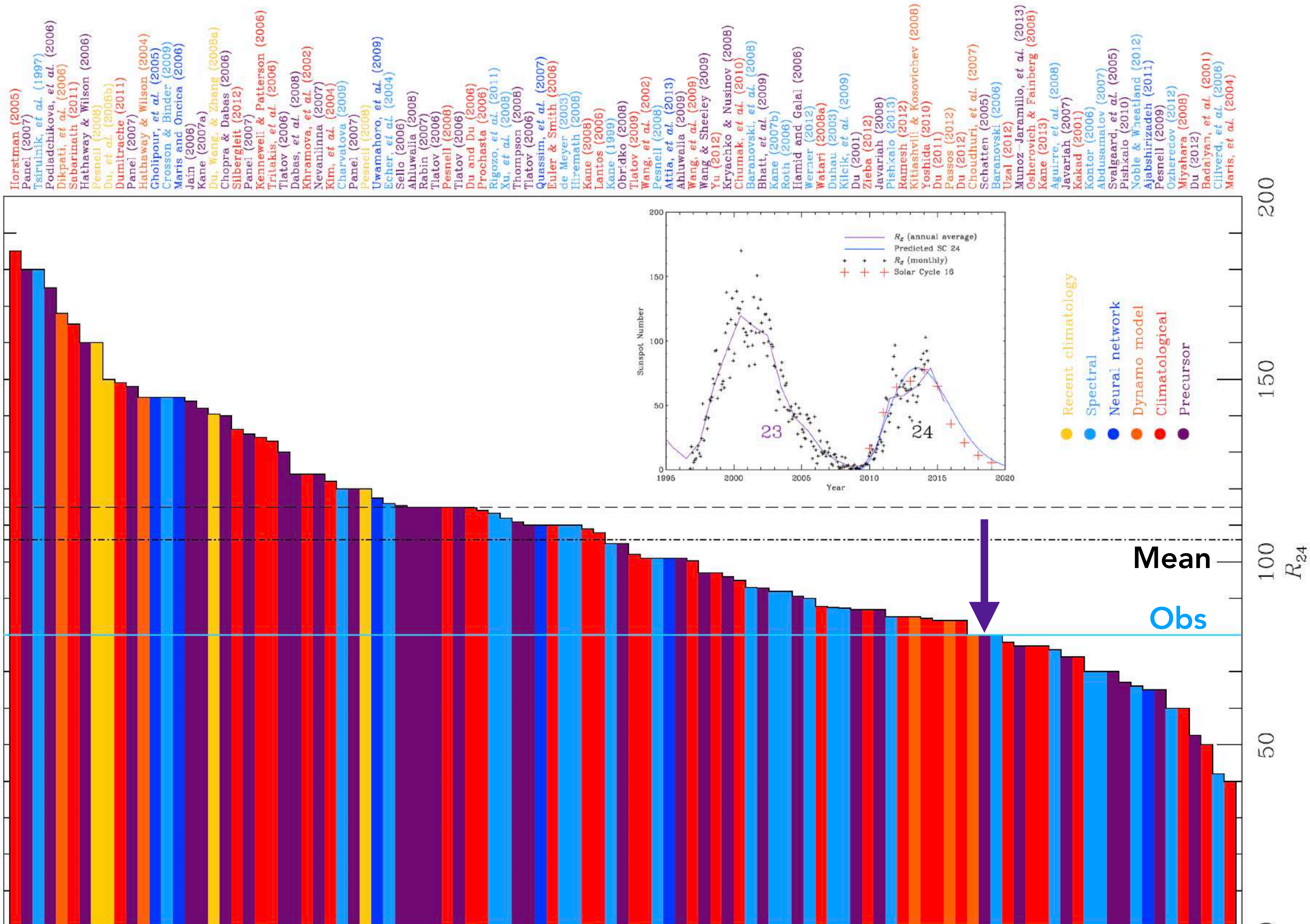
Downs et al. (2013)

C/2011 W3 (Comet Lovejoy)



Downs et al. (2013)

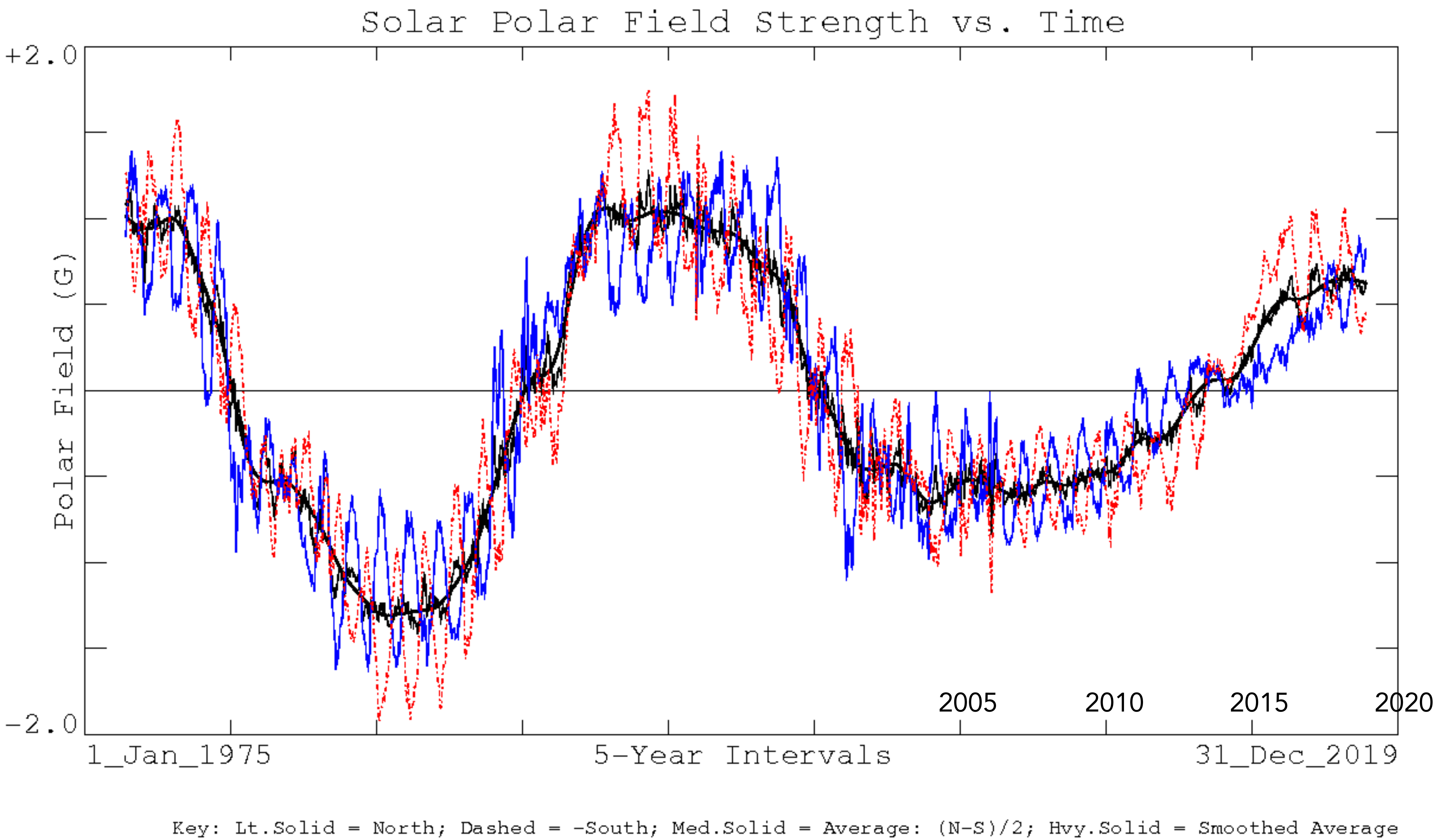
Cycle 24 Prediction 😬



Pesnell (2016)

Can We Do Better for Cycle 25?

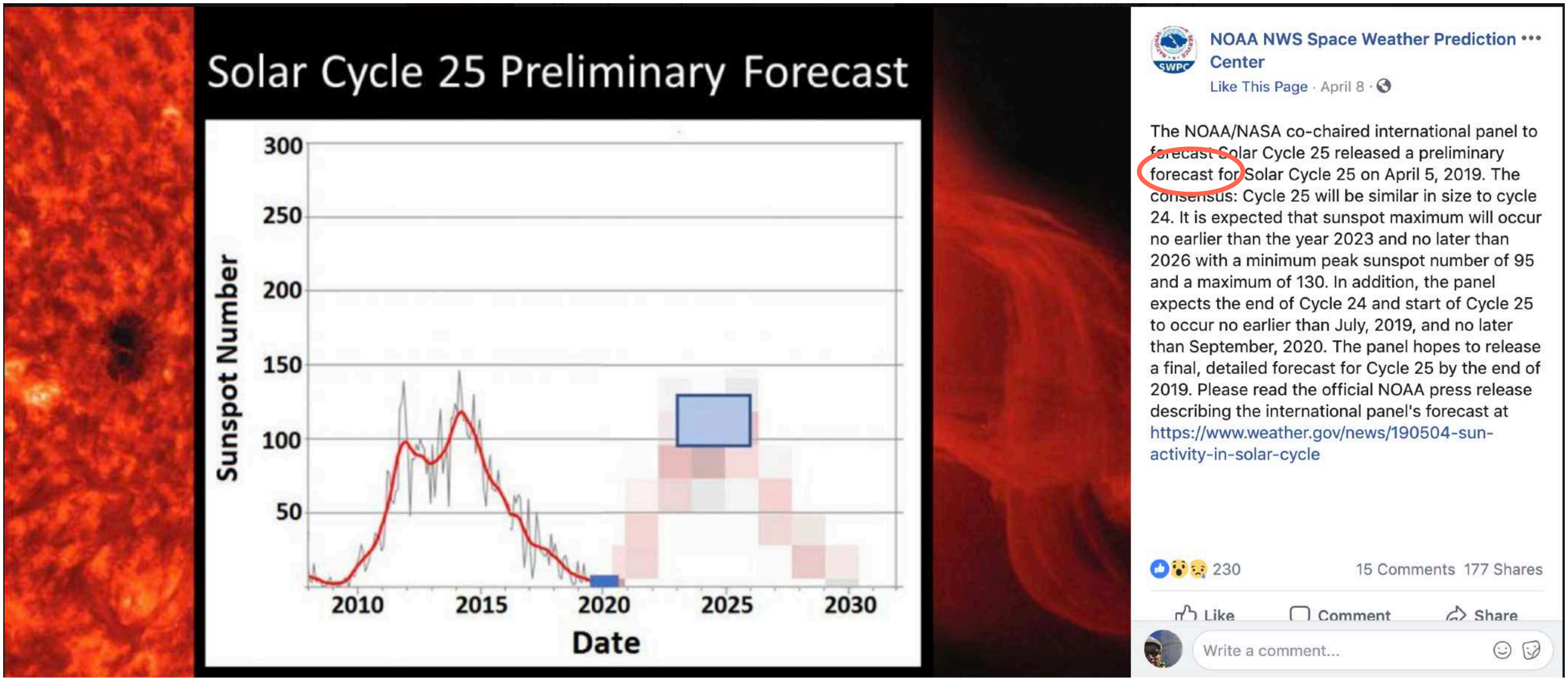
Q: Make an educated bet?



http://wso.stanford.edu/gifs/Polar.gif

Cycle 25 Prediction!

Apparently solar physicists *DO* learn from their mistakes.



Next: *DKIST* Science (Dr. Tom Schad)