A Novel, Hybrid Prominence-Coronal Rain Complex Near Magnetic Null Points

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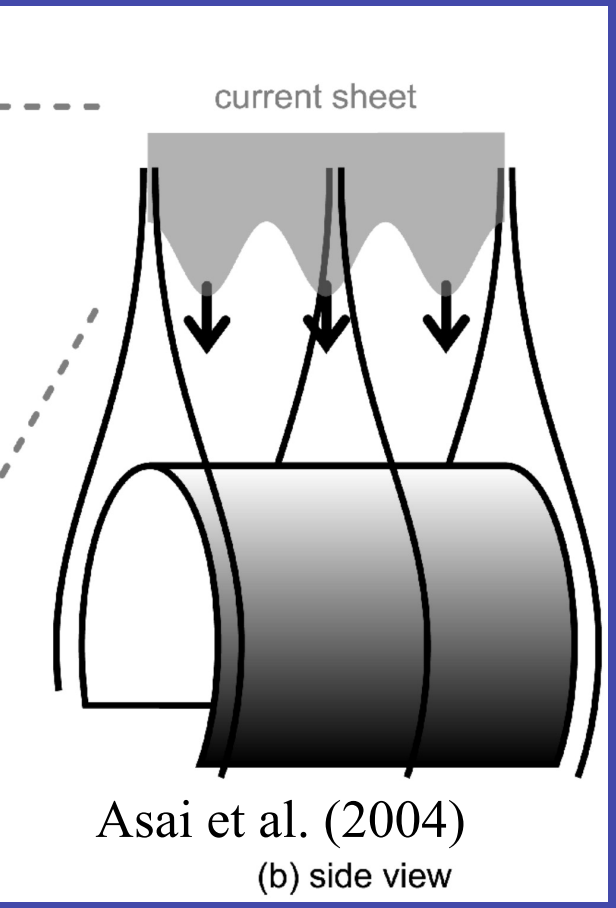
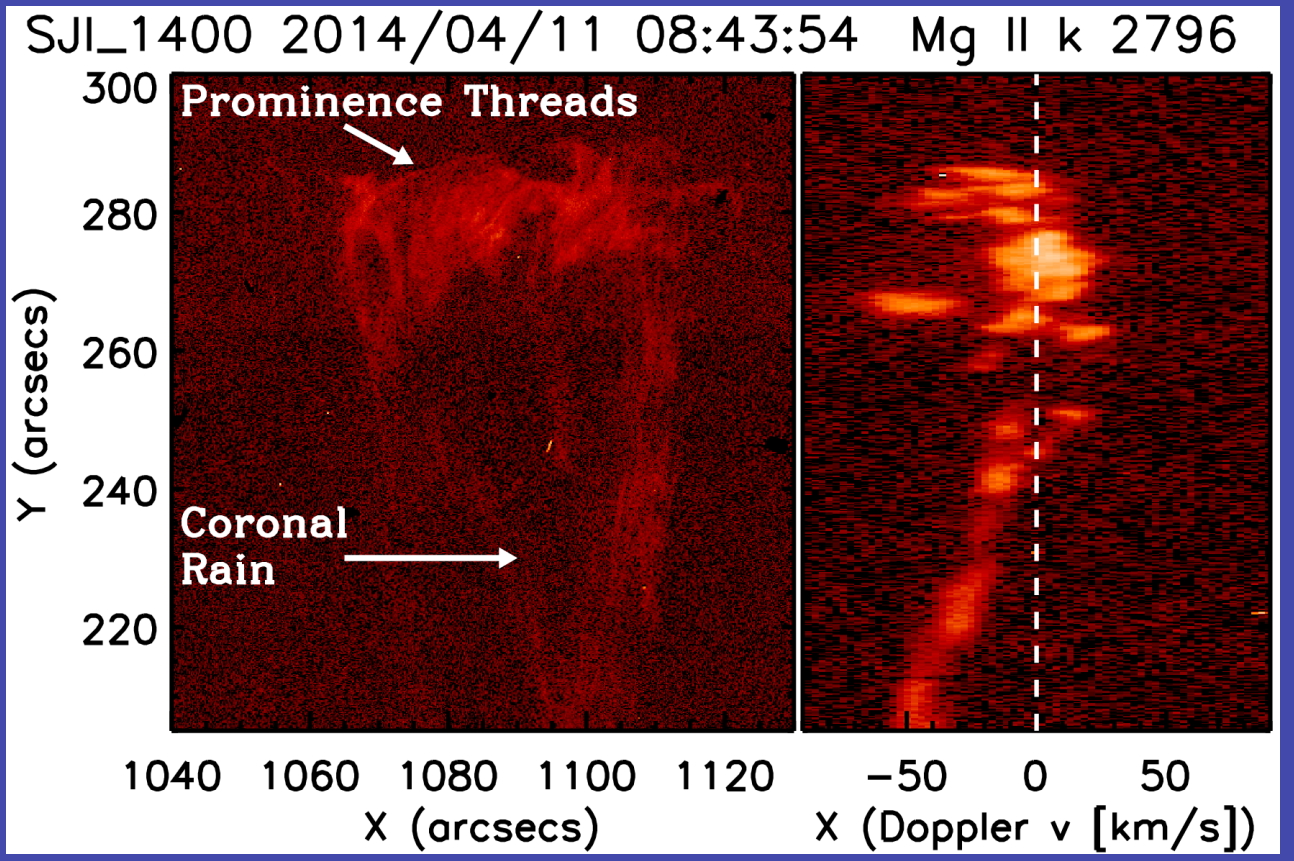




Outline

1. Introduction
   Chromosphere–corona mass cycle, two forms of return flows: coronal rain and prominences (similarities and differences).

2. IRIS observations of hybrid prominence – coronal rain near null points, 2014/04/11

3. Why condensation near nulls?
   More examples.

4. Summary

1. Introduction – Chromosphere–corona Mass Cycle (e.g., McIntosh+ 2012): prominence and coronal rain as return flows

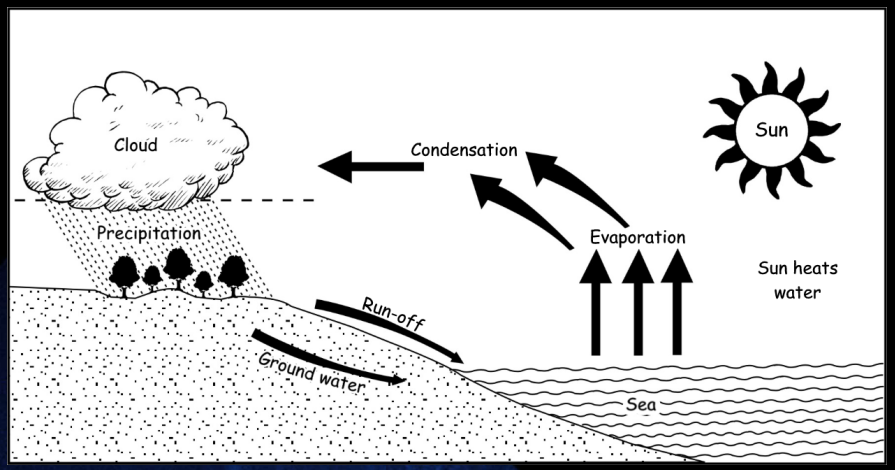
(1) Hot mass/Magnetic flux Up:

• Spicules, footpoint upflows, flux emergence (e.g., bubbles/plumes)

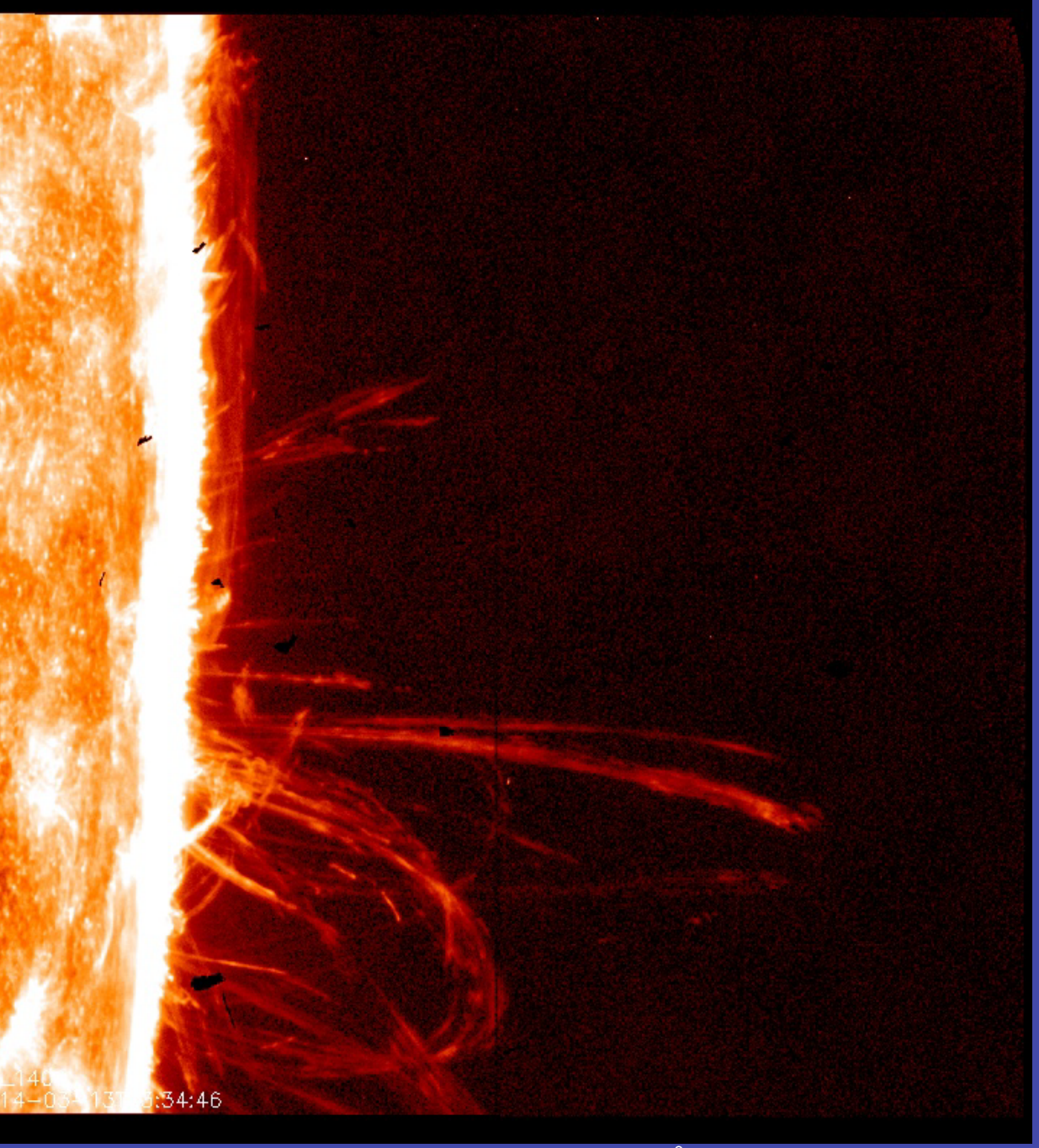
(2) Cool mass down:

• **Prominences** – filamentary, meandering downflow threads (reviews by, e.g., Labrosse+2010, Mackay+2010)

• **Coronal rain**



Berger et al. (2008, 2010, 2011)



IRIS 1400 Å (Courtesy of Hui Tian)

coronal rain –

intermittent in active region loops, more substantial in flares

Always follows well-defined, curved paths

– quite different from meandering prominence threads

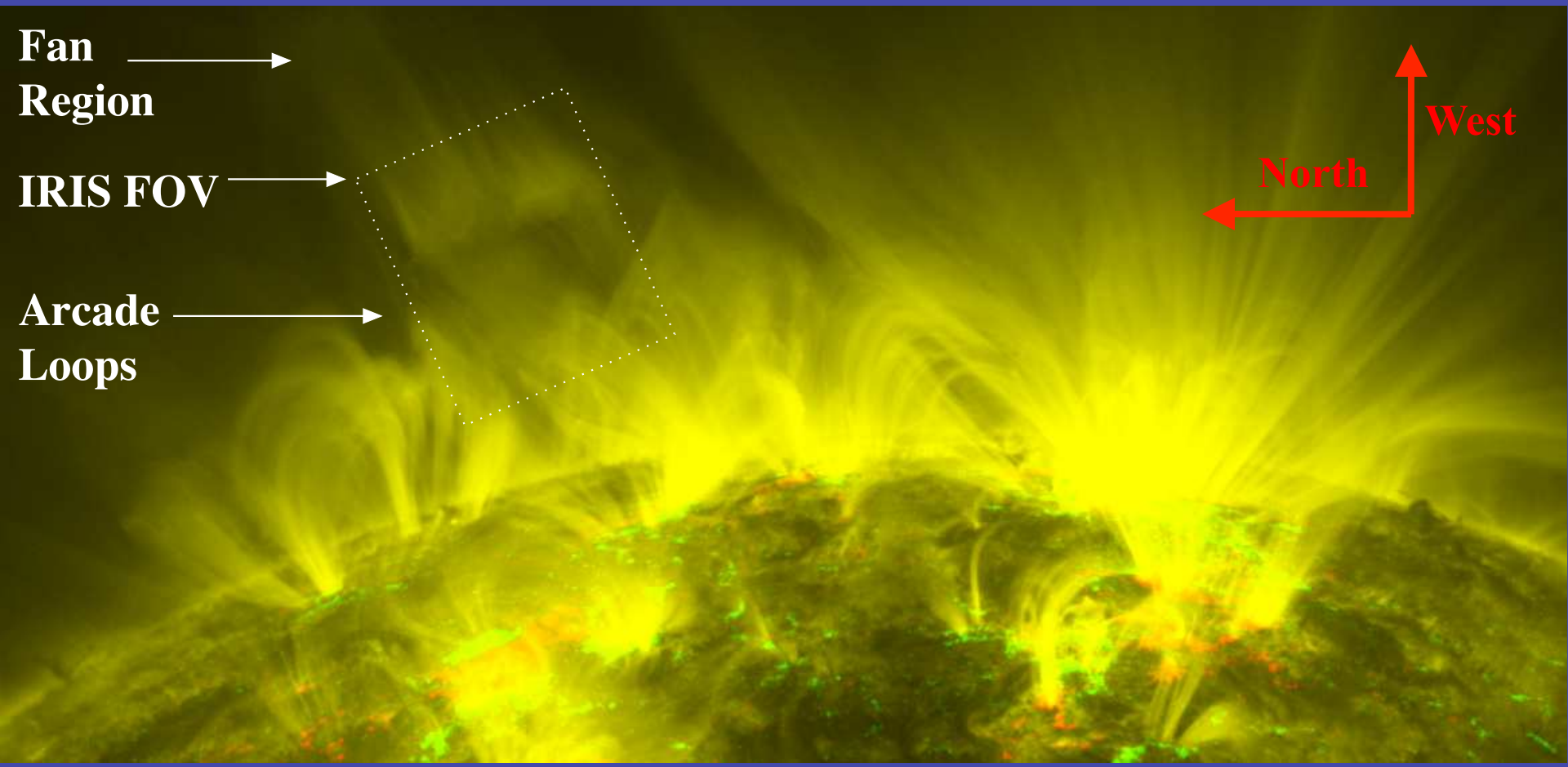
Why?

2. Hybrid prominence – coronal rain

2.1) SDO/AIA overview

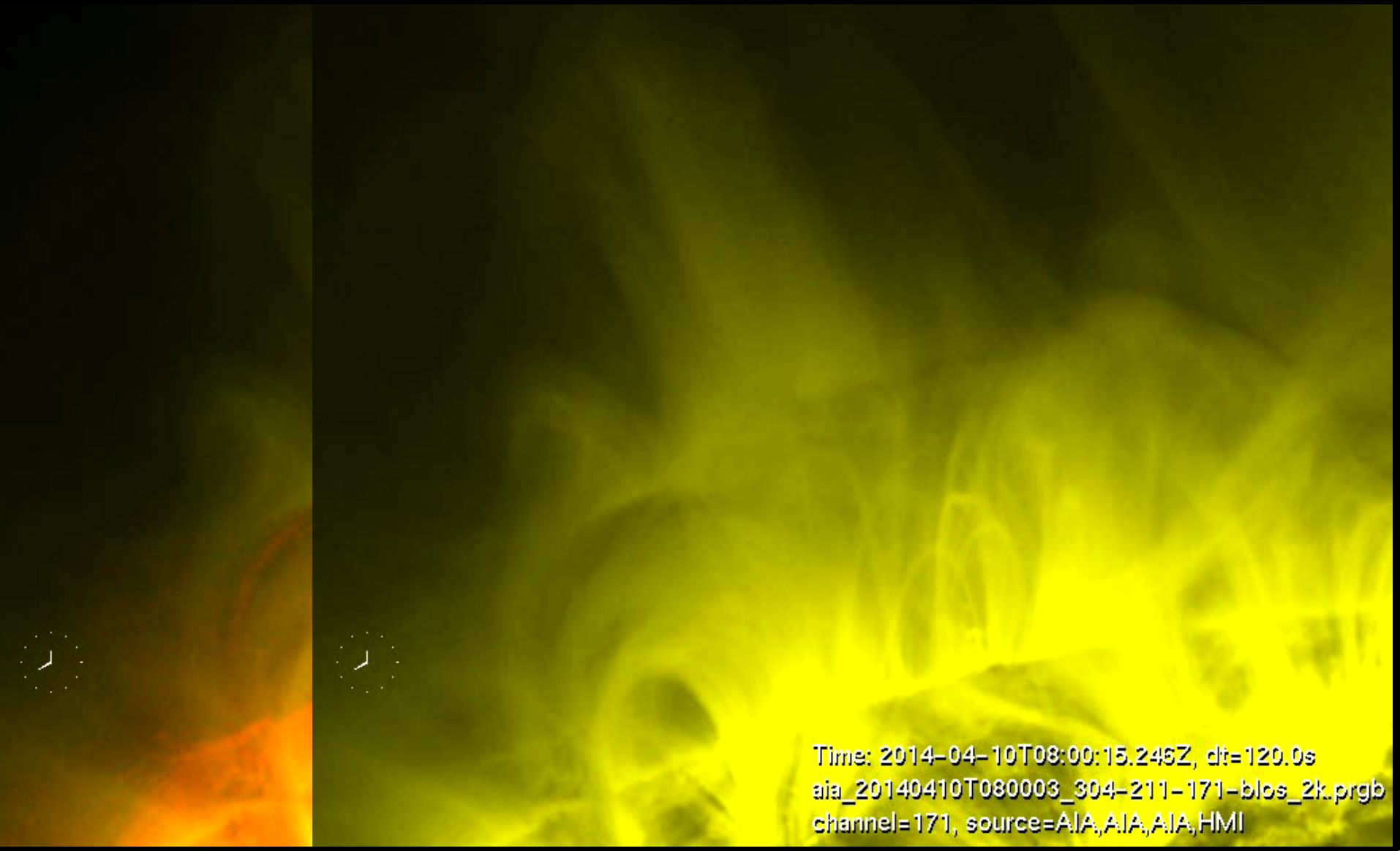
Top ("fan"-like): "prominence threads", irregular flows

Bottom (closed loops): coronal rain



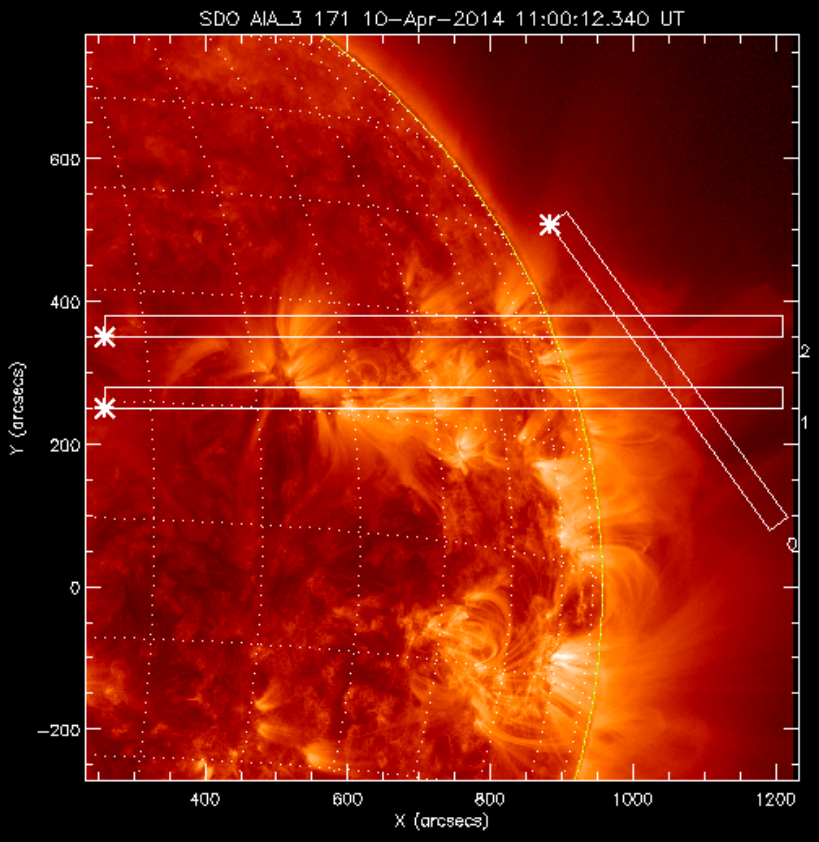
Hybrid prominence + coronal rain (cf., cloud prominences, coronal spiders; Lin, Martin, Engolvd 2006; Kleczek 1972);

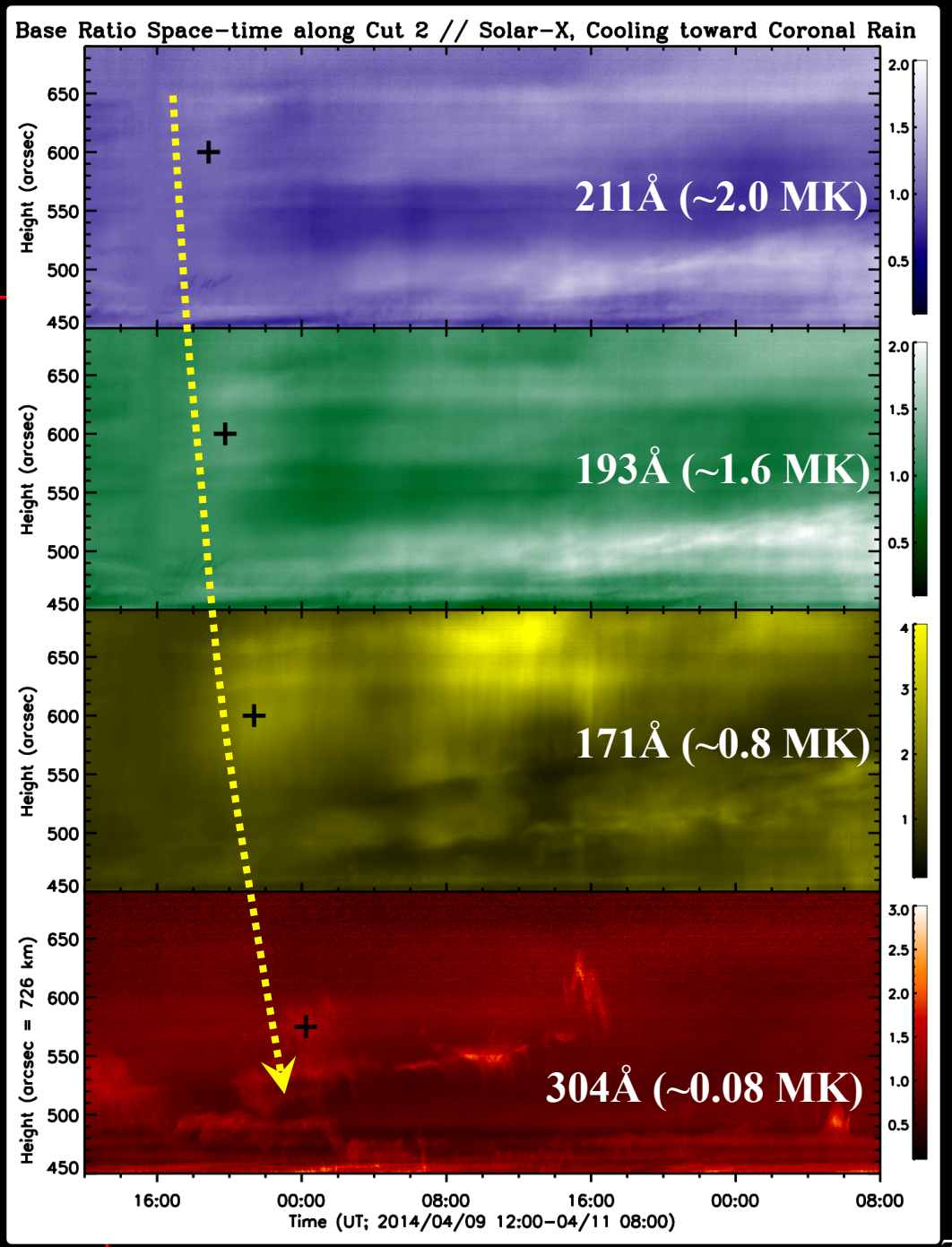
Coronal rain originates from prominence-like material AIA 171 Å (Y)/304 Å (R)



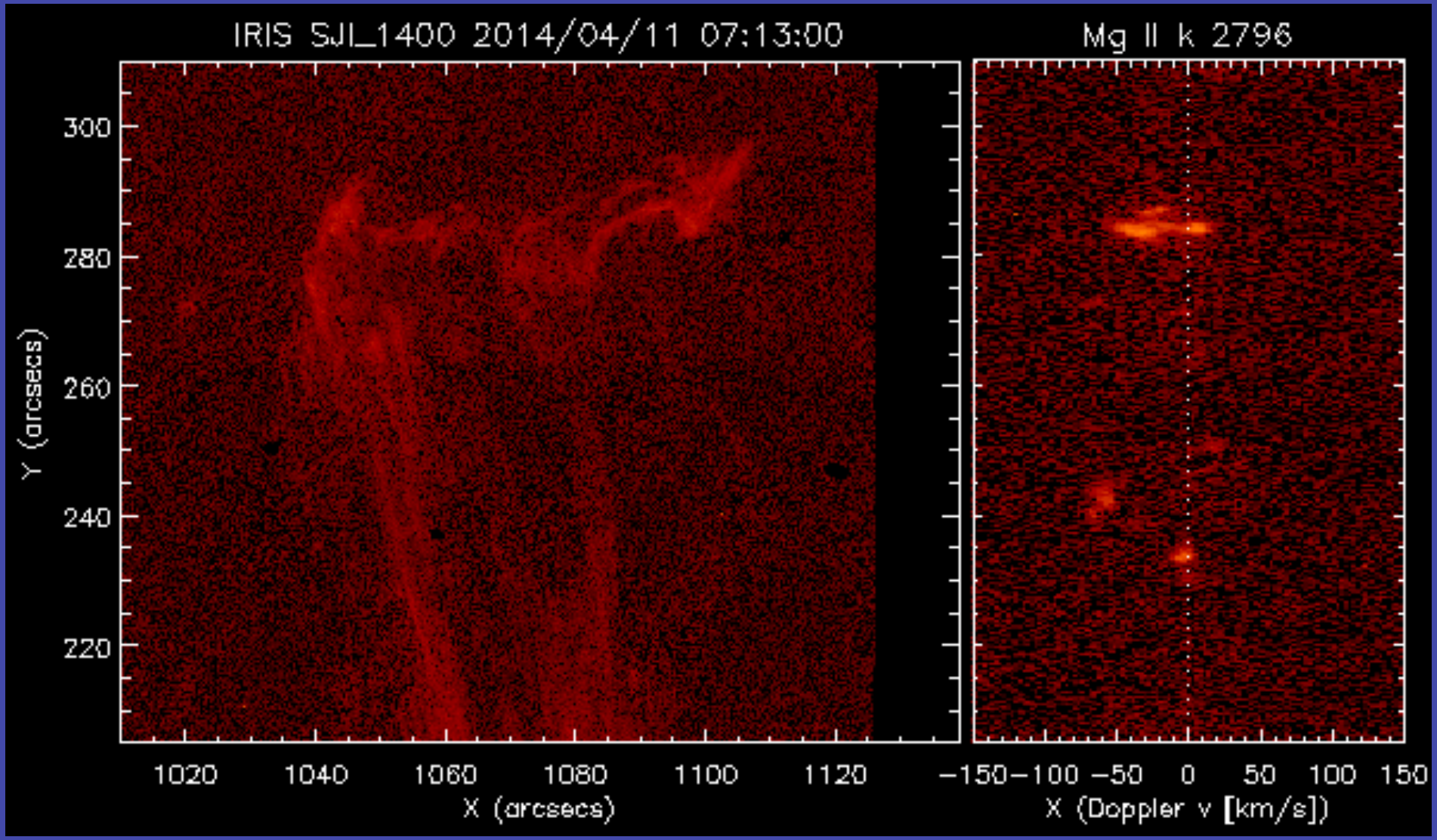
Cooling sequence toward condensation

Delayed emission in progressively cooler AIA channels





2.2) IRIS: SJI + Mg II k spectra
Top: prominence threads, irregular flows, large line width
Bottom (closed loops): coronal rain, narrow line width



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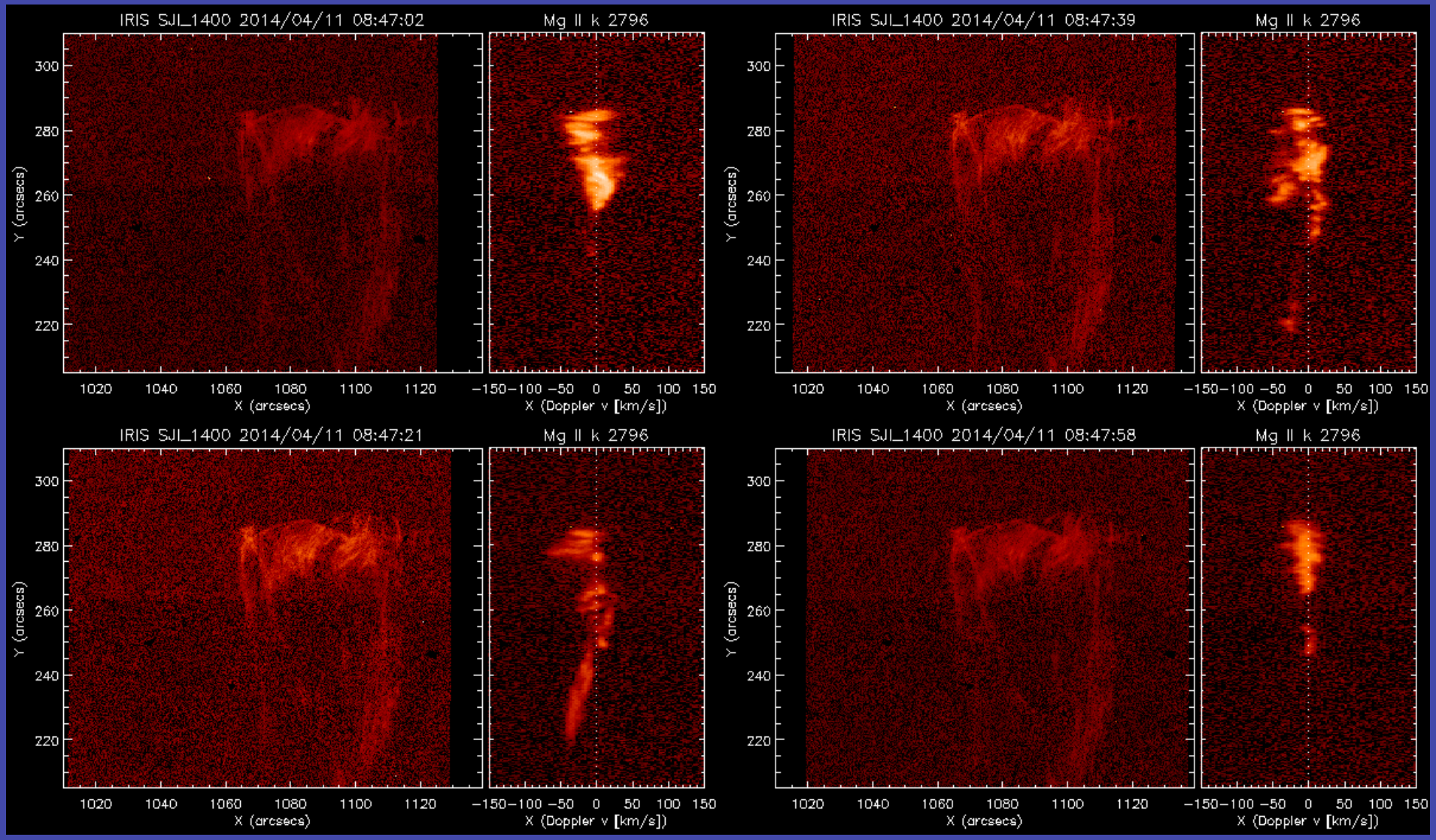
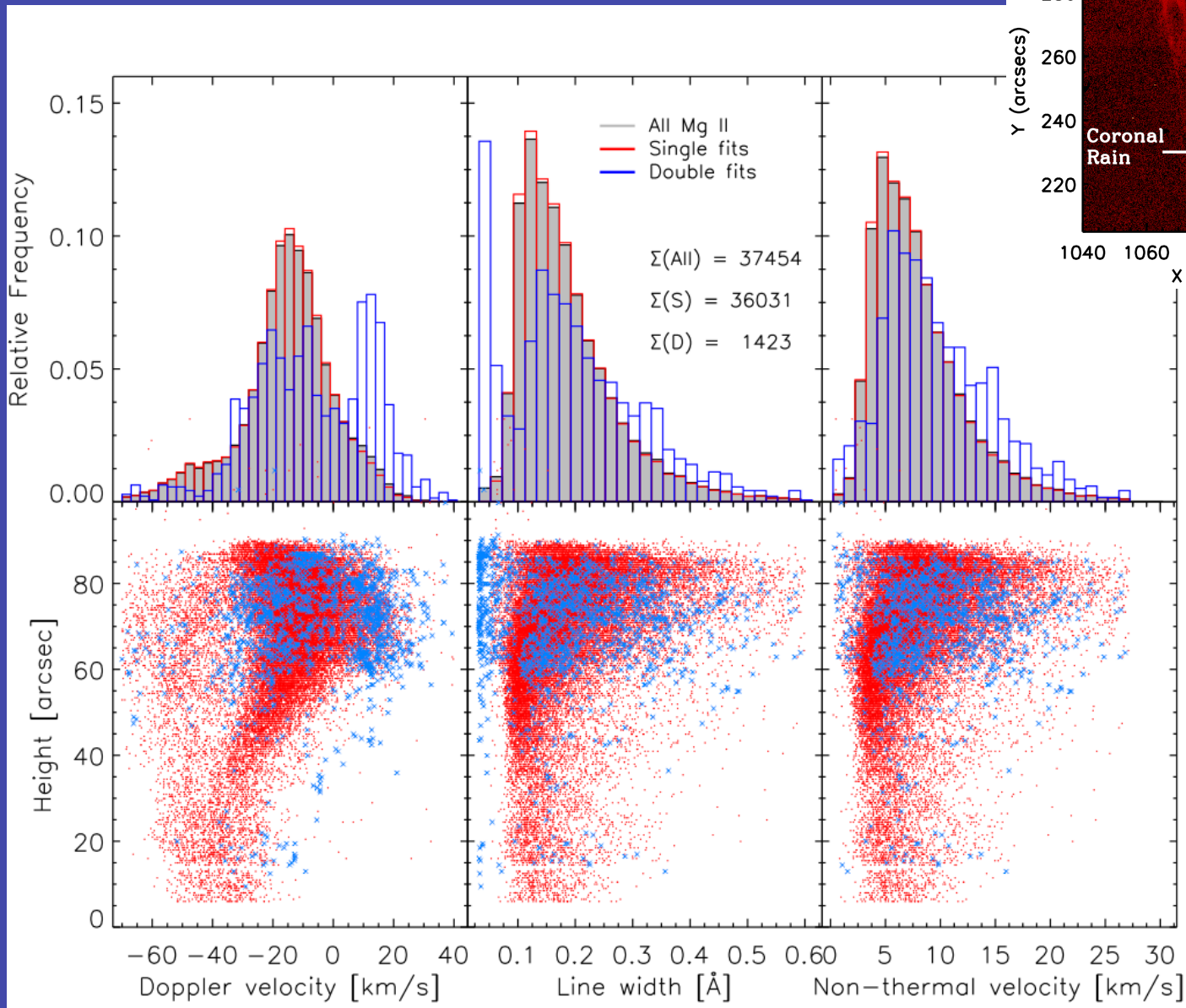
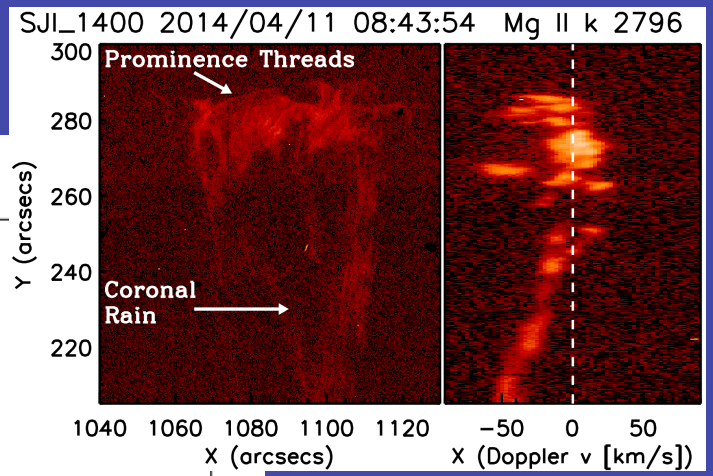
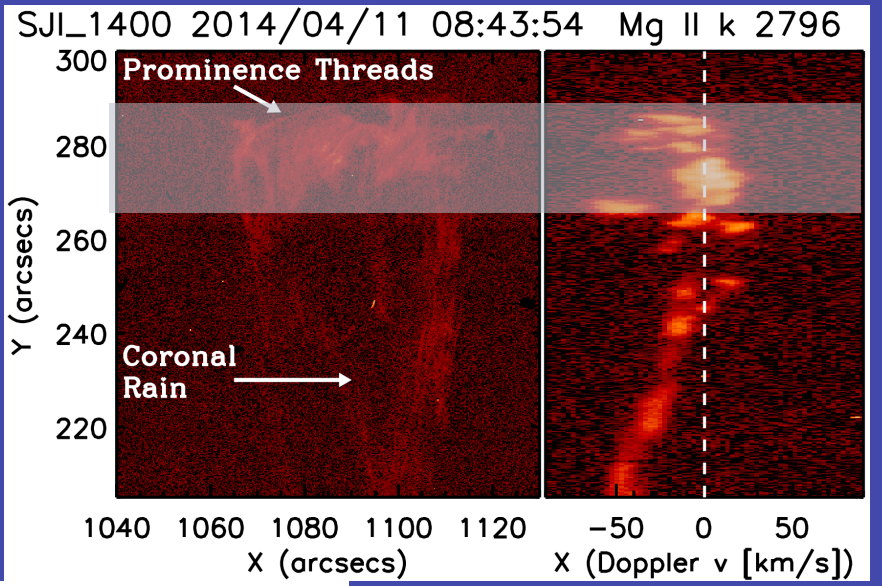


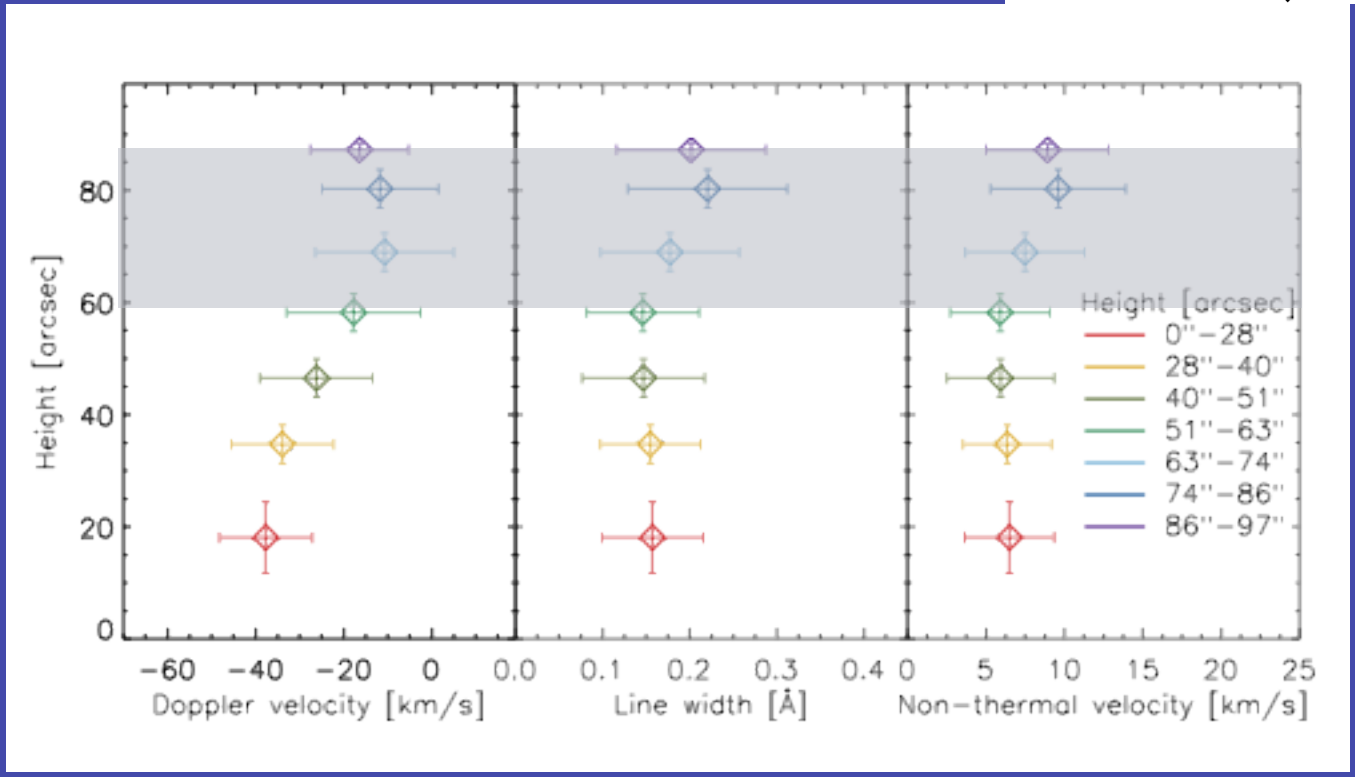
Spectral fits and height dependence (Patrick Antolin)



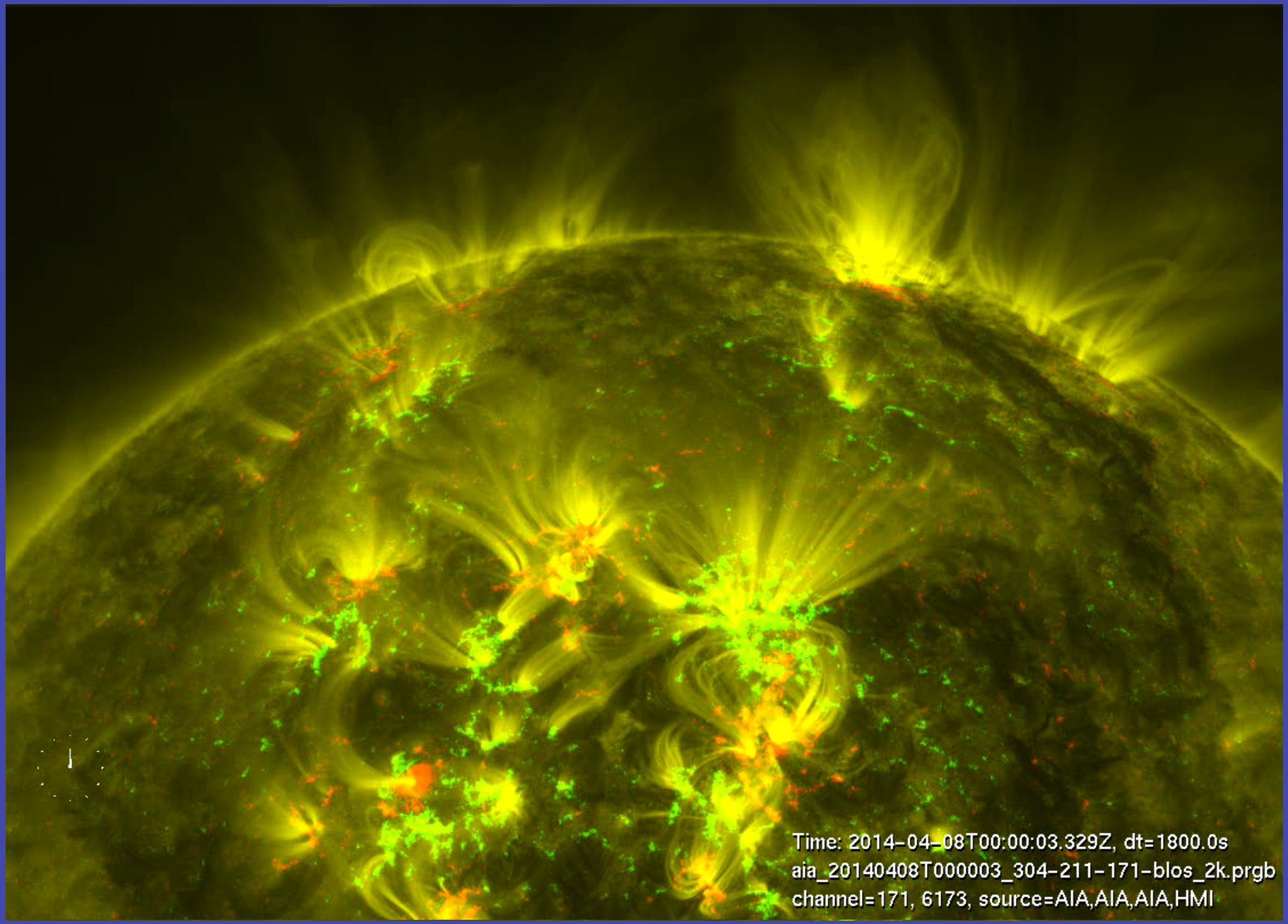


Line width height dependence
(Patrick Antolin)

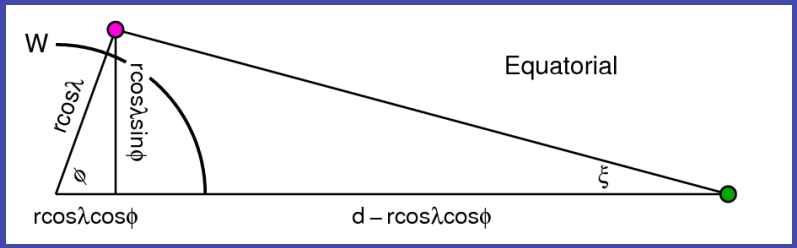




2.3) Magnetic geometry: AIA 171 Å (yellow) on HMI magnetogram

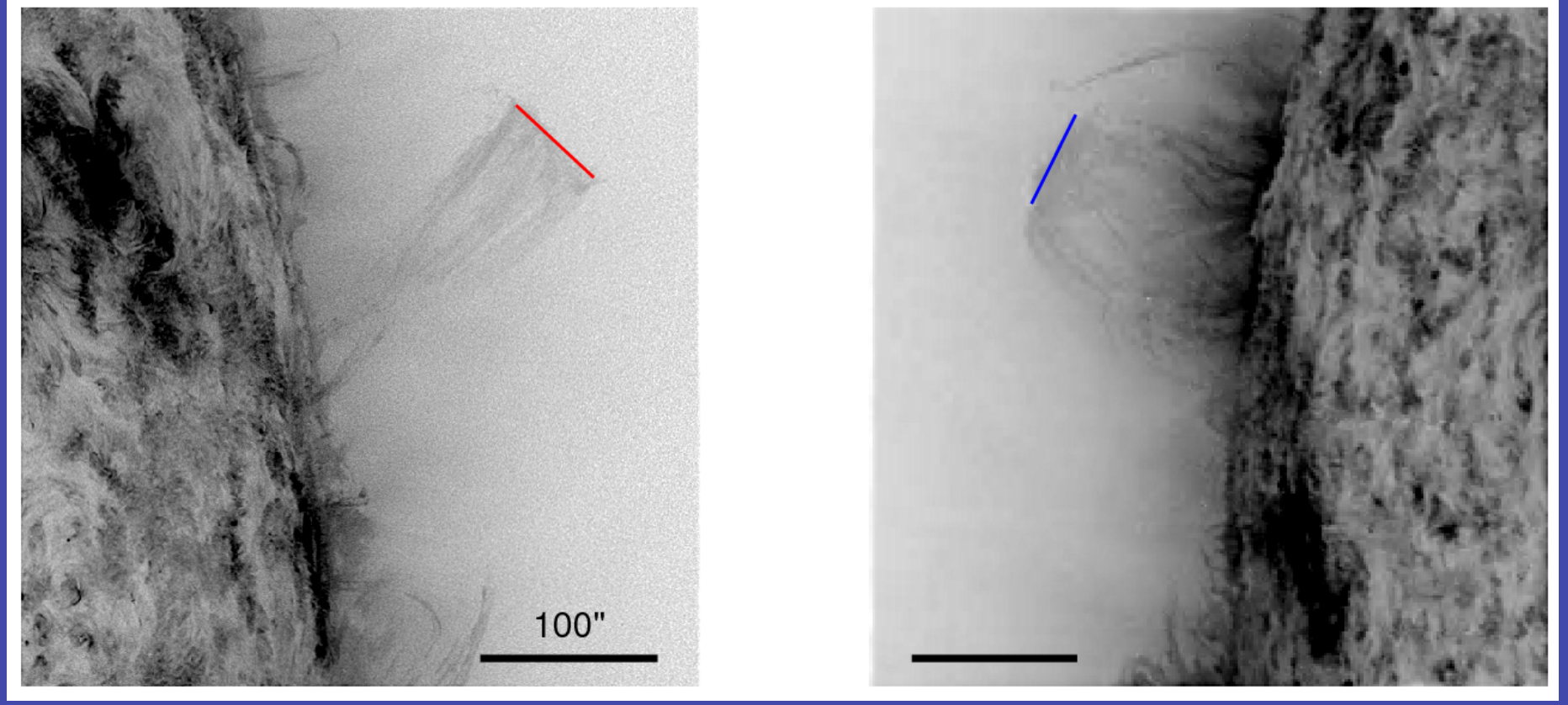


Localization by triangulation of 304 Å material (Xudong Sun)

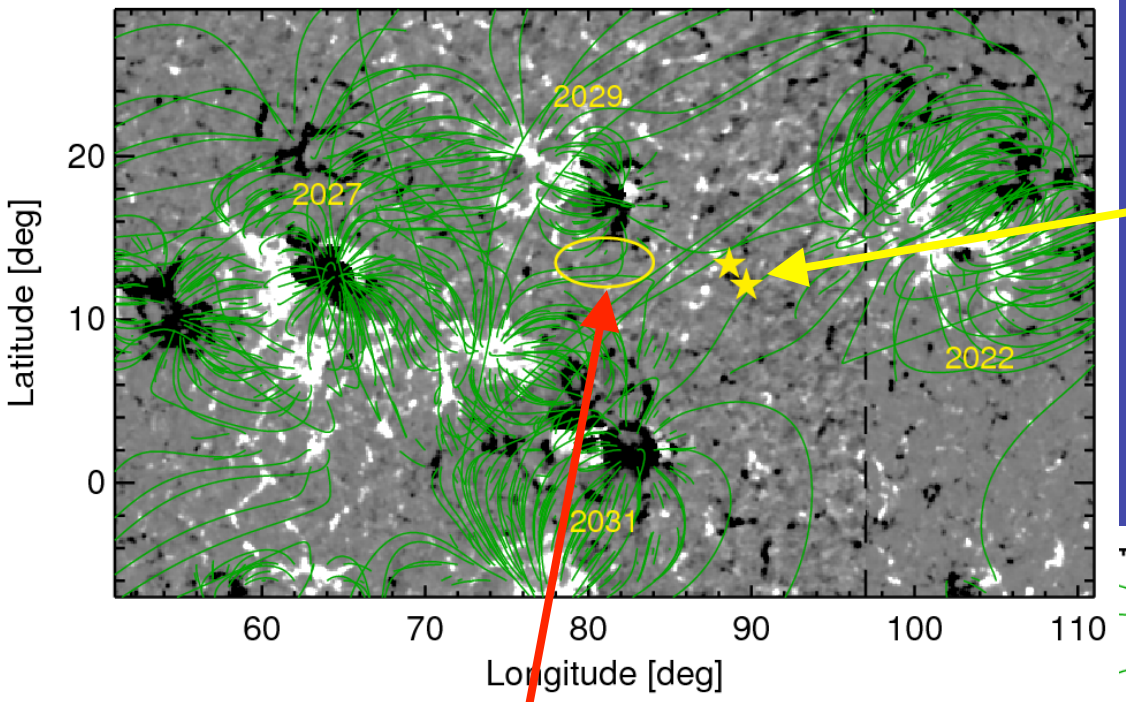


SDO/AIA

STEREO-A/EUVI

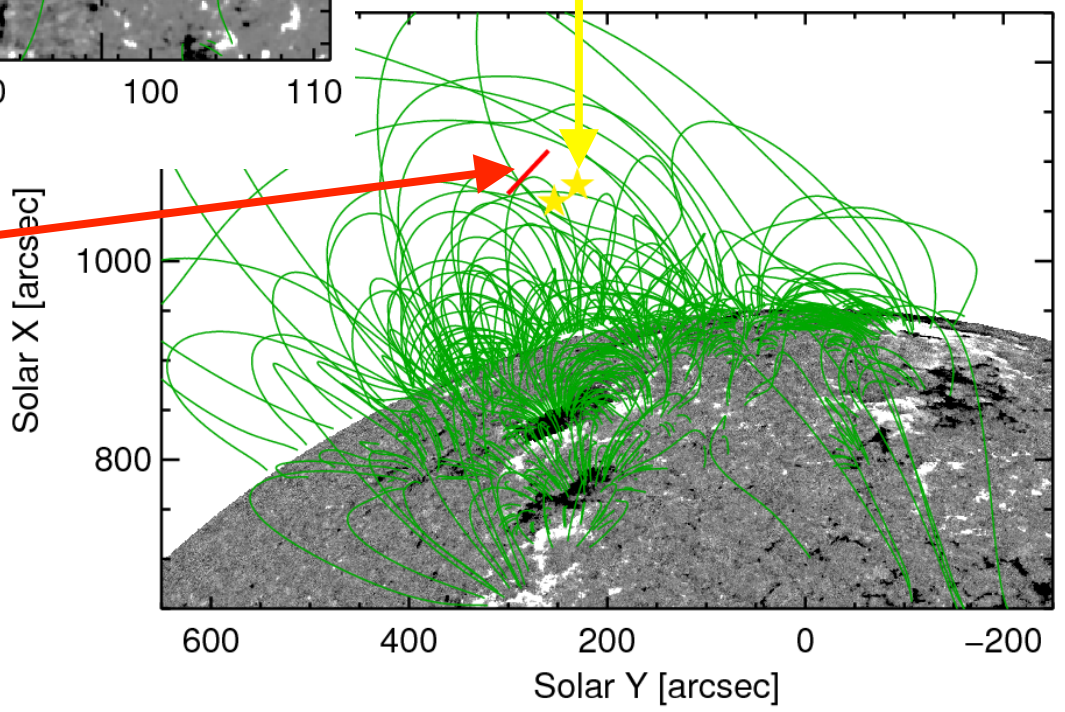


Magnetic geometry: Potential field (PFSS) model from HMI magnetogram (Xudong Sun)

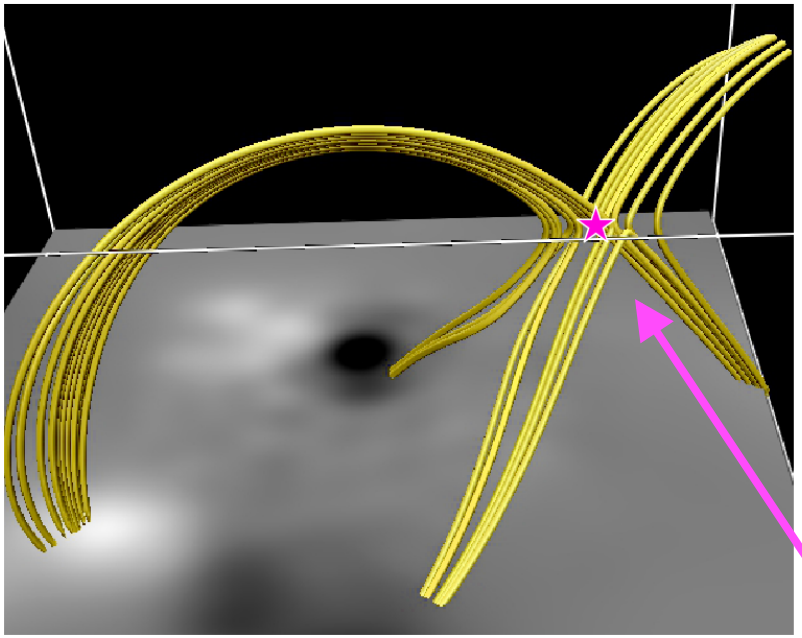


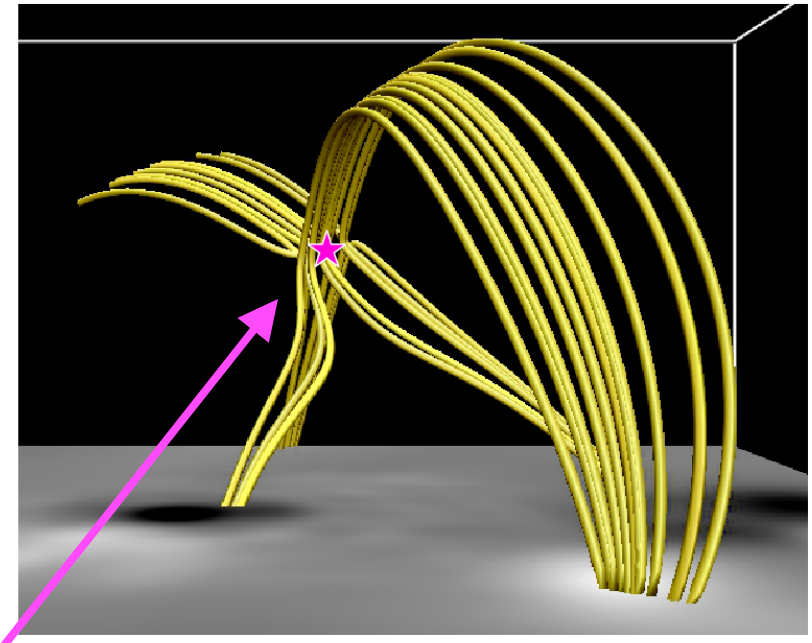
Null points

Prominence – coronal rain



Magnetic geometry: detailed view near null (Xudong Sun)



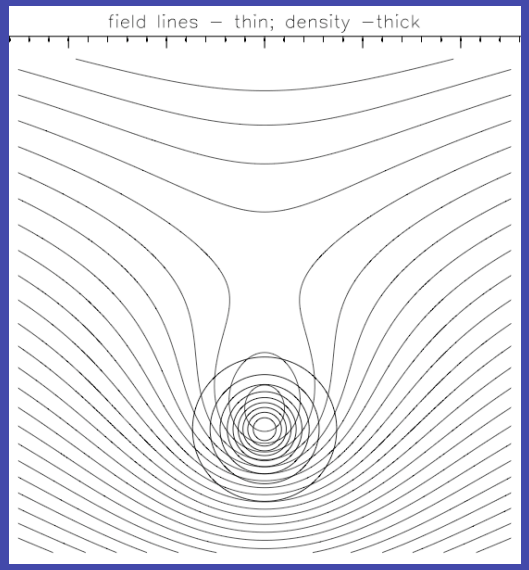


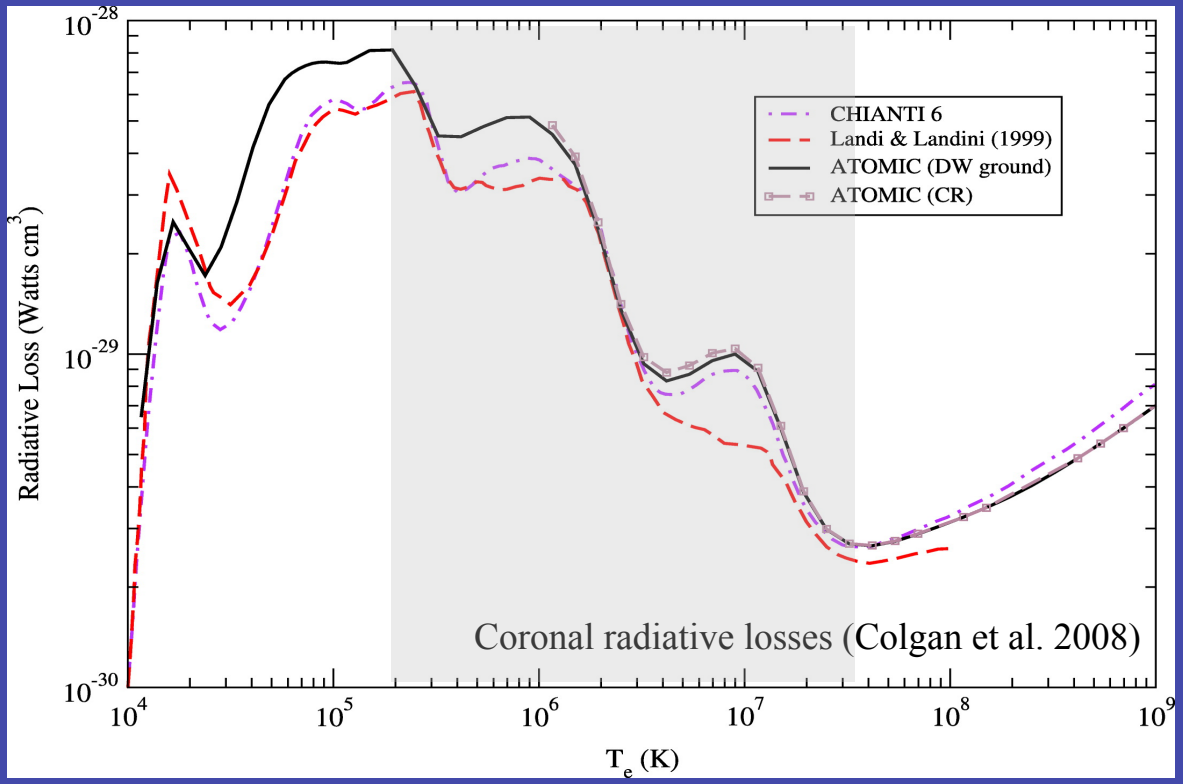
Null point

3. Why null points – (1) Coronal Condensation (thermal non-equilibrium, e.g., Karpen, Xia, Keppens, et al.; magnetic fields are crucial, e.g., Low+2012a,b)

(1) Radiative loss instability

$L = n_e^2 \Phi(T)$ increases with n^2, decrease with T (10^5 – 10^7 K)





(2) Magnetic fields (insulators): reduced cross-field thermal conduction

$$\kappa_{\parallel}(T) = 2 \times 10^{-6}\, T^{5/2}\ erg\ cm^{-1}\ s^{-1}\ K^{-1}$$

$$\kappa_{\perp} = \kappa_{\parallel}/(\omega_e \tau_e)^2 \qquad \omega_e \tau_e >> 1$$

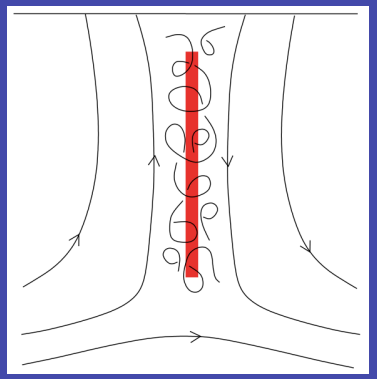
ω_e: electron gyro frequency;

τ_e: Coulomb collision time;

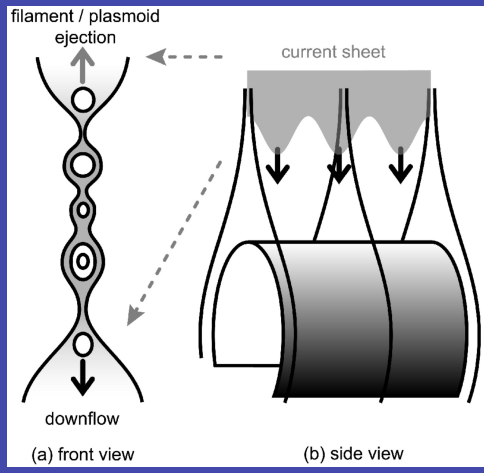
$(\omega_e \tau_e)^2 = \mathbf{10^{10}}$ for solar corona

Why null points – (2) plasma dynamics

1) Tangled magnetic fields in current sheets (van Ballegooijen & Cranmer 2010) – suppress thermal conduction (Chandran & Cowley 1998), meandering flows

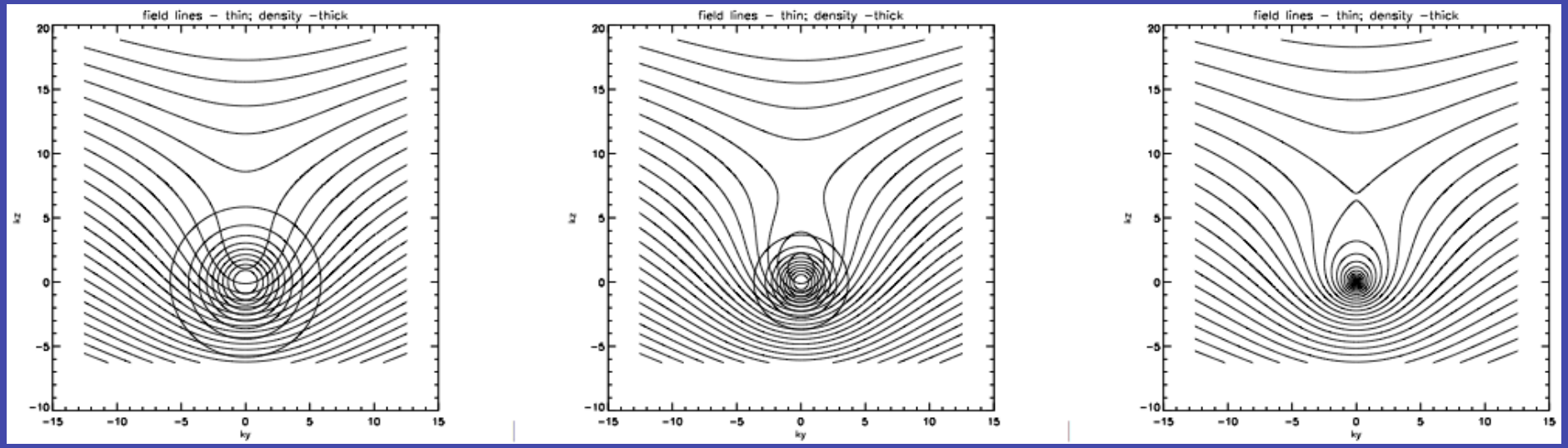


2) Current sheets: weak B-field, high-beta? Thus fluid/turbulent-like flow pattern (cf. SADs, McKenzie, Savage et al.).



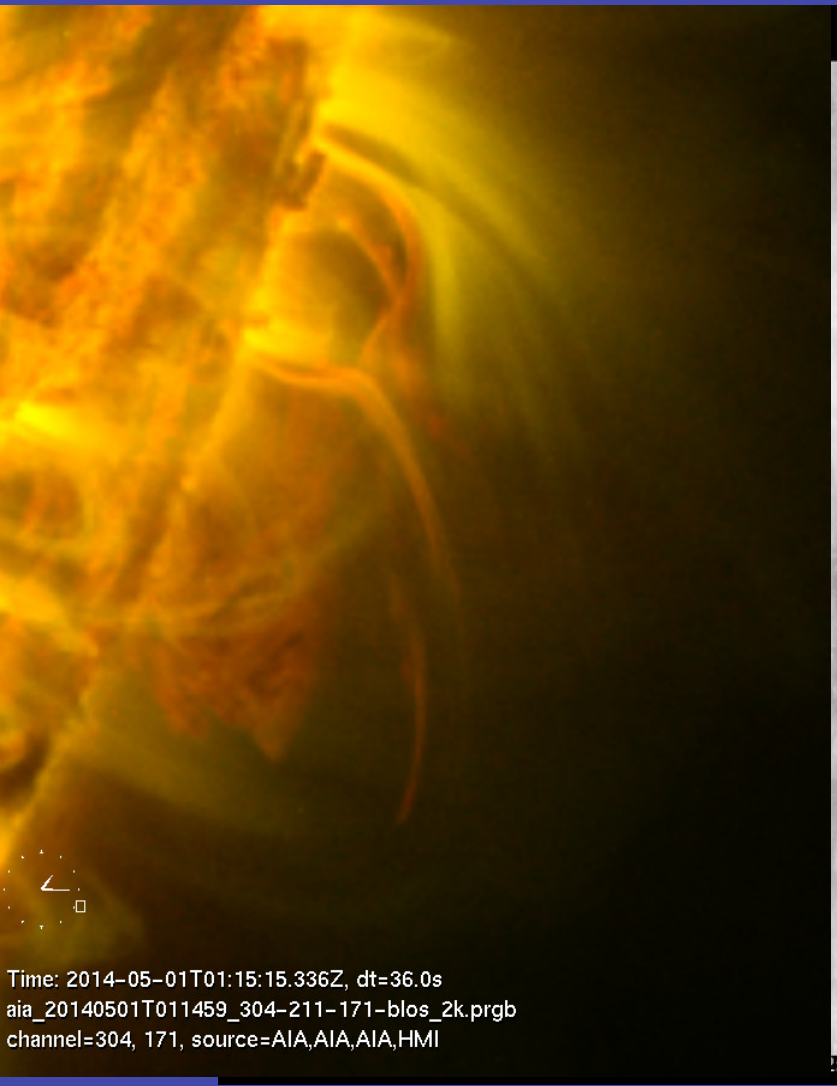
Asai et al. 2003

3) Null points result from condensation/reconnection (Low, B.C.+2012a,b); neutrals; plasmoids (Guo, Bhattacharjee, Huang 2013) by reconnection as seed condensation; pileup at "Y" (Guo+2014); entropy mode (Murawski+2011)…

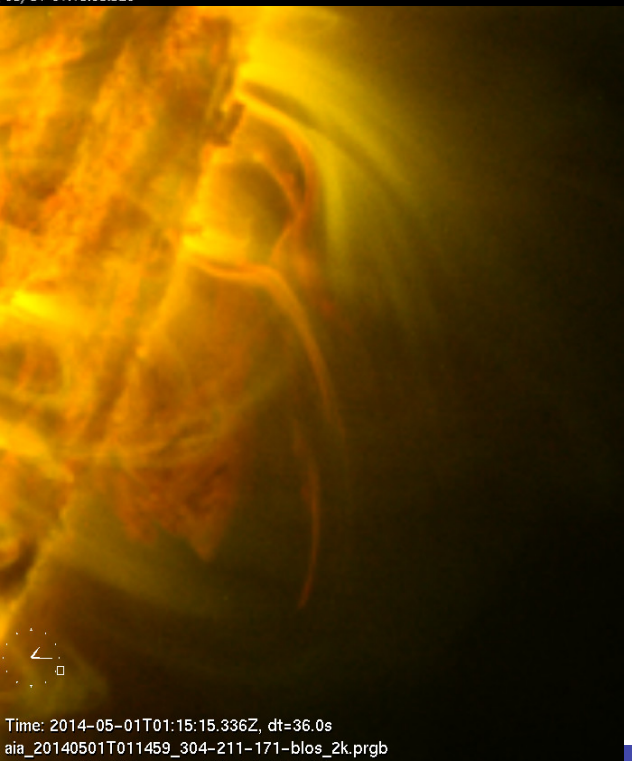


Another example: Fan-spine geometry and coronal rain
(eruption analyzed by Kathy Reeves et al. 2015 ApJ)

AIA171 Å (Yellow)/304 Å (Red)

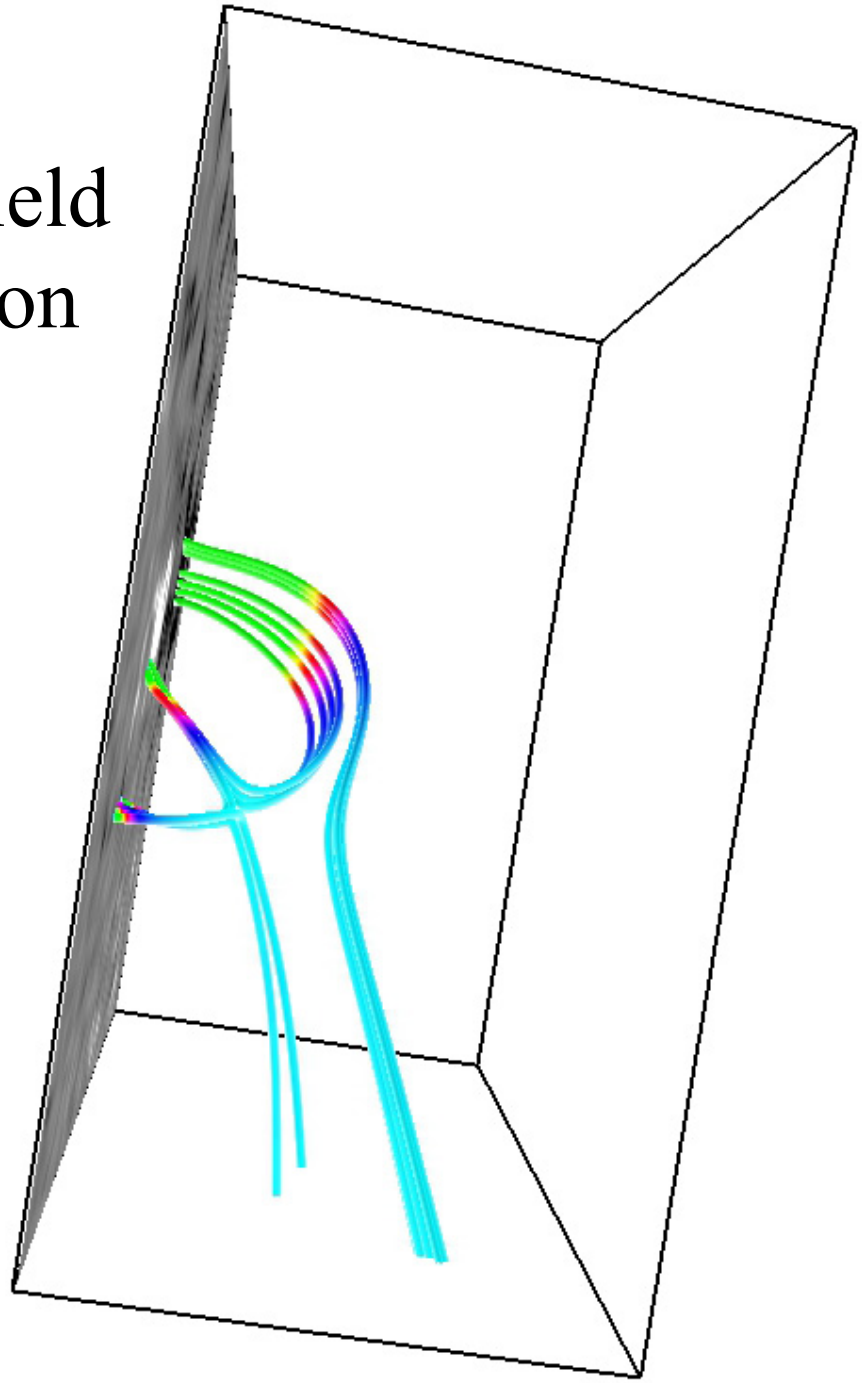


IRIS 1330 Å SJI

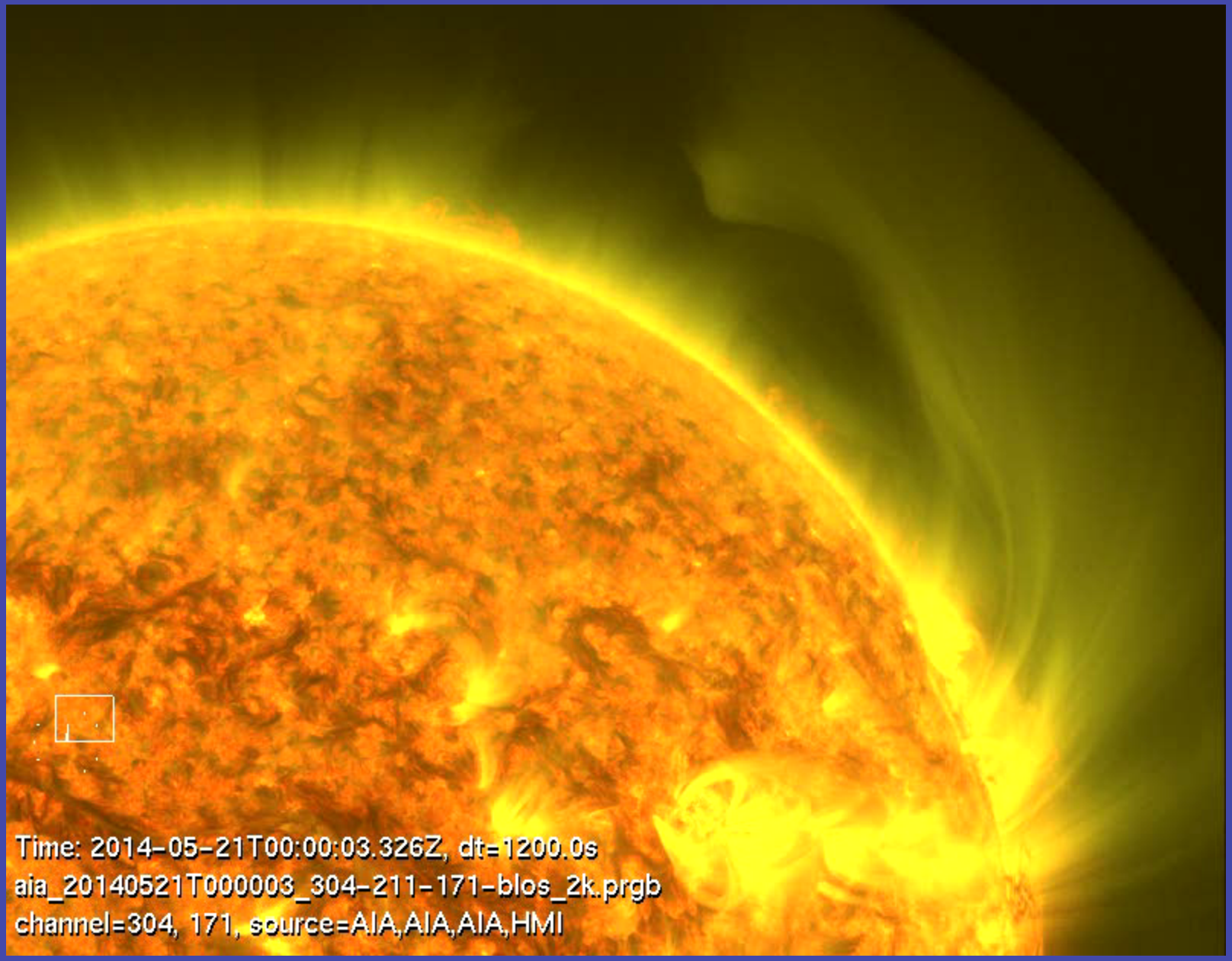


Potential field extrapolation

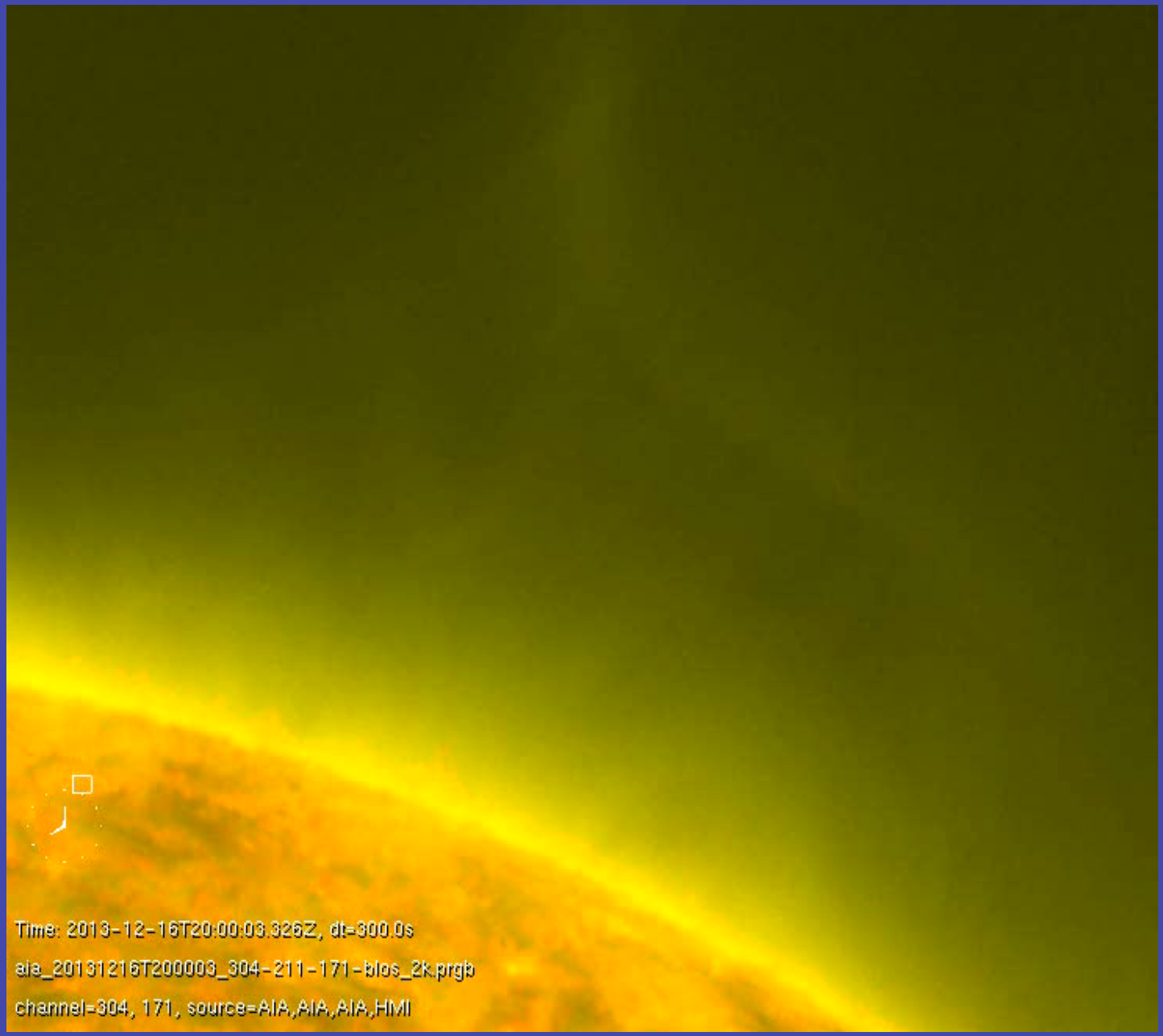
(Xudong Sun)



Another example: Preferential occurrence of coronal rain at dips/cusps



More examples: prominence threads turning into underlying coronal rain



4. Summary

A new paradigm: Hybrid Prominence – Coronal Rain complex (coronal spider?)

1) Prominence, irregular flow patterns near null points/current sheets: tangled field, enhanced cooling condensation, high-beta?

2) Underlying loops in arcade: coronal rain sliding down loops, stronger magnetic field, low-beta.

3) Future outlook:
DKIST/VBI, VTF, and ViSP for POS/Doppler velocity, DL-/Cryo-NIRSP for magnetic field.
ALMA for prominence (chromospheric) material – (see Nicolas Labrosse's talk this afternoon)