Hybrid Prominence-Coronal Rain Complex in a Supra-arcade Fan Geometry

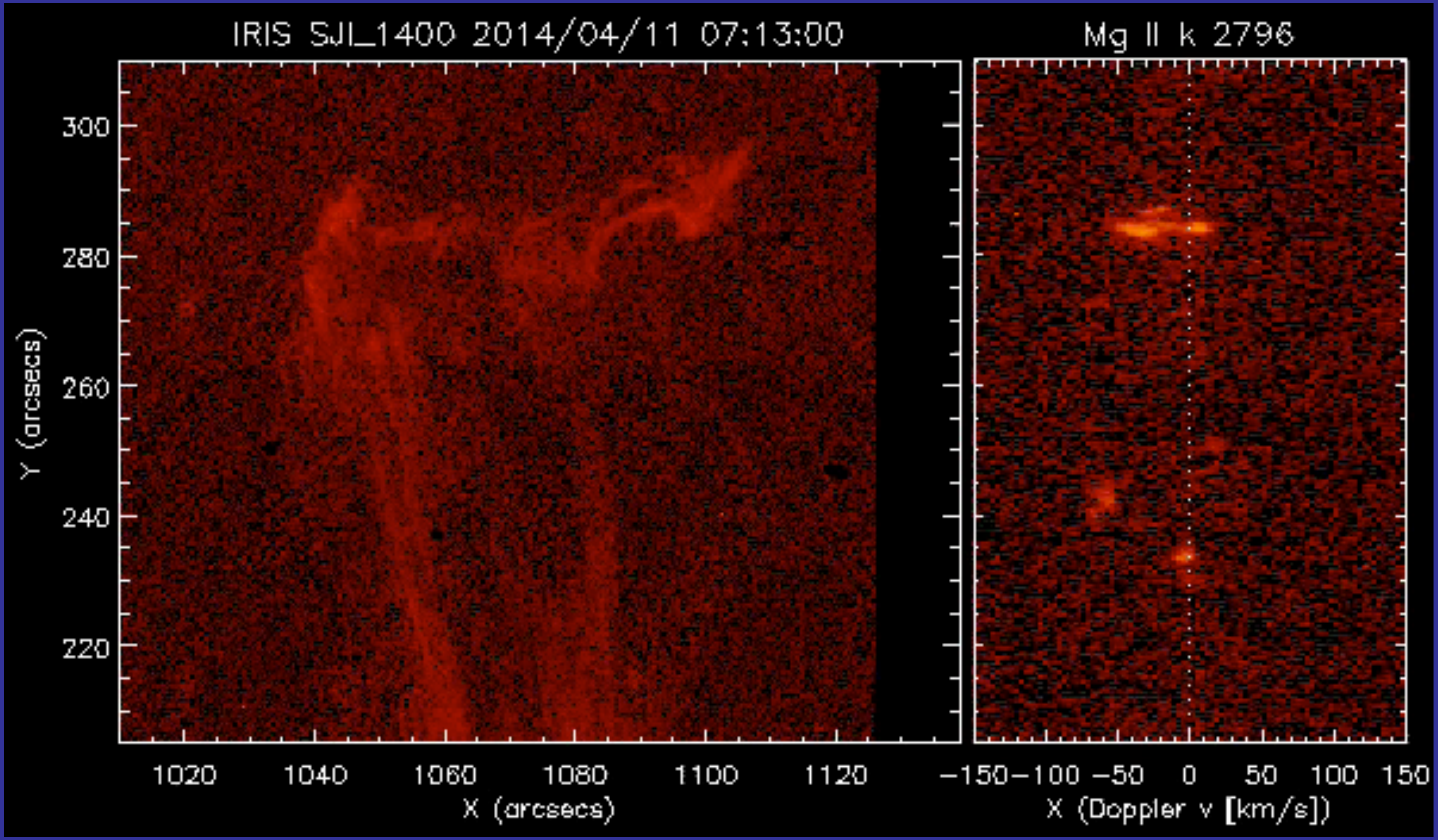
Wei Liu (LMSAL/Stanford, weiliu@lmsal.com), Patrick Antolin (NOAJ), Xudong Sun (Stanford), Tom Berger (NOAA), Takenori Okamoto (JAXA/ISAS)

1. New obs.: hybrid prominence + coronal rain

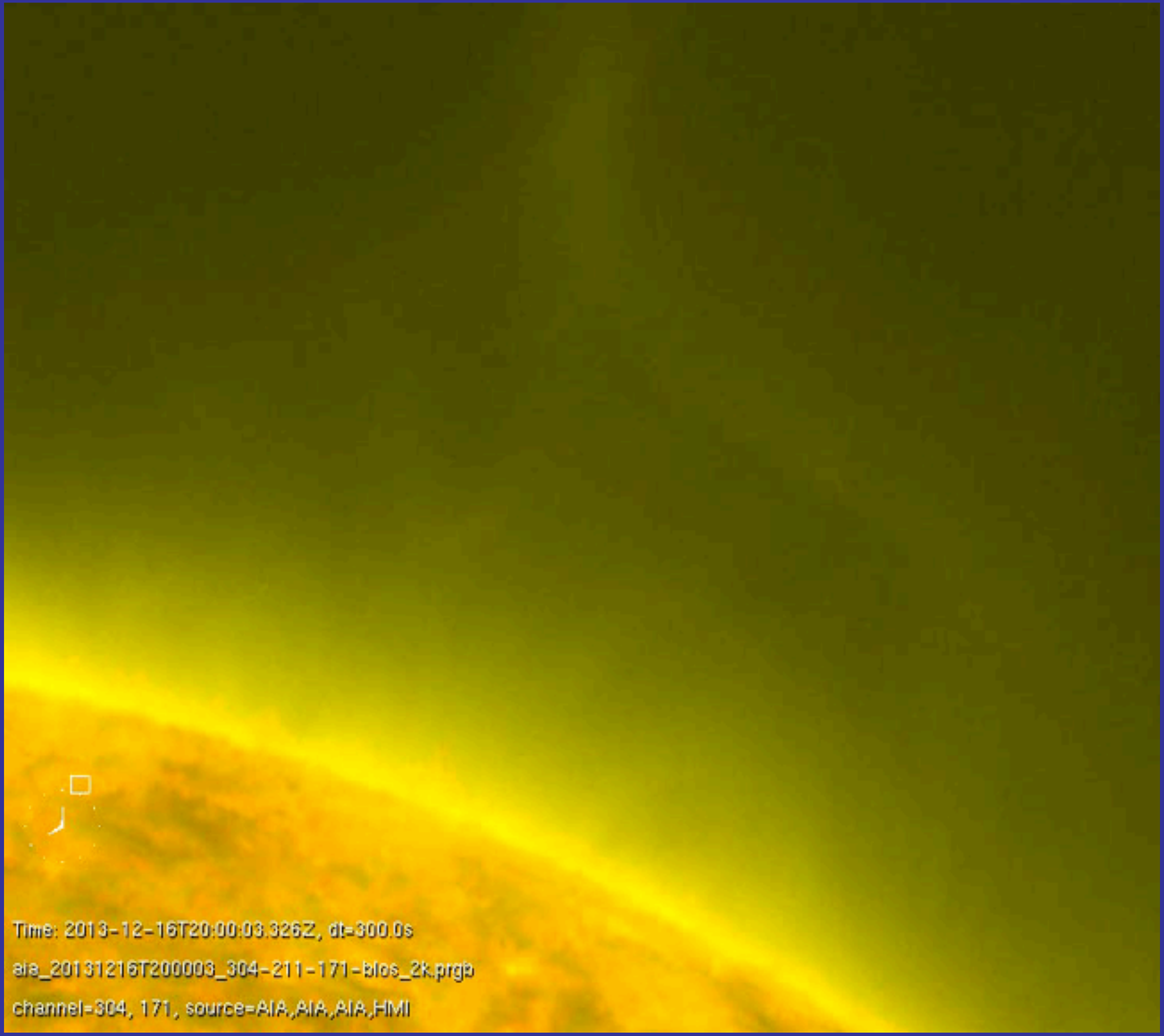
(cf., cloud prominences, coronal spiders; Lin, Martin, Engolvd 2006)

coronal rain originates from prominence-like, turbulent, possibly an open fan/ current sheet above an arcade/dome, cf., McKenzie supra-arcade fans, AIA 171 (Y)/304 (R)

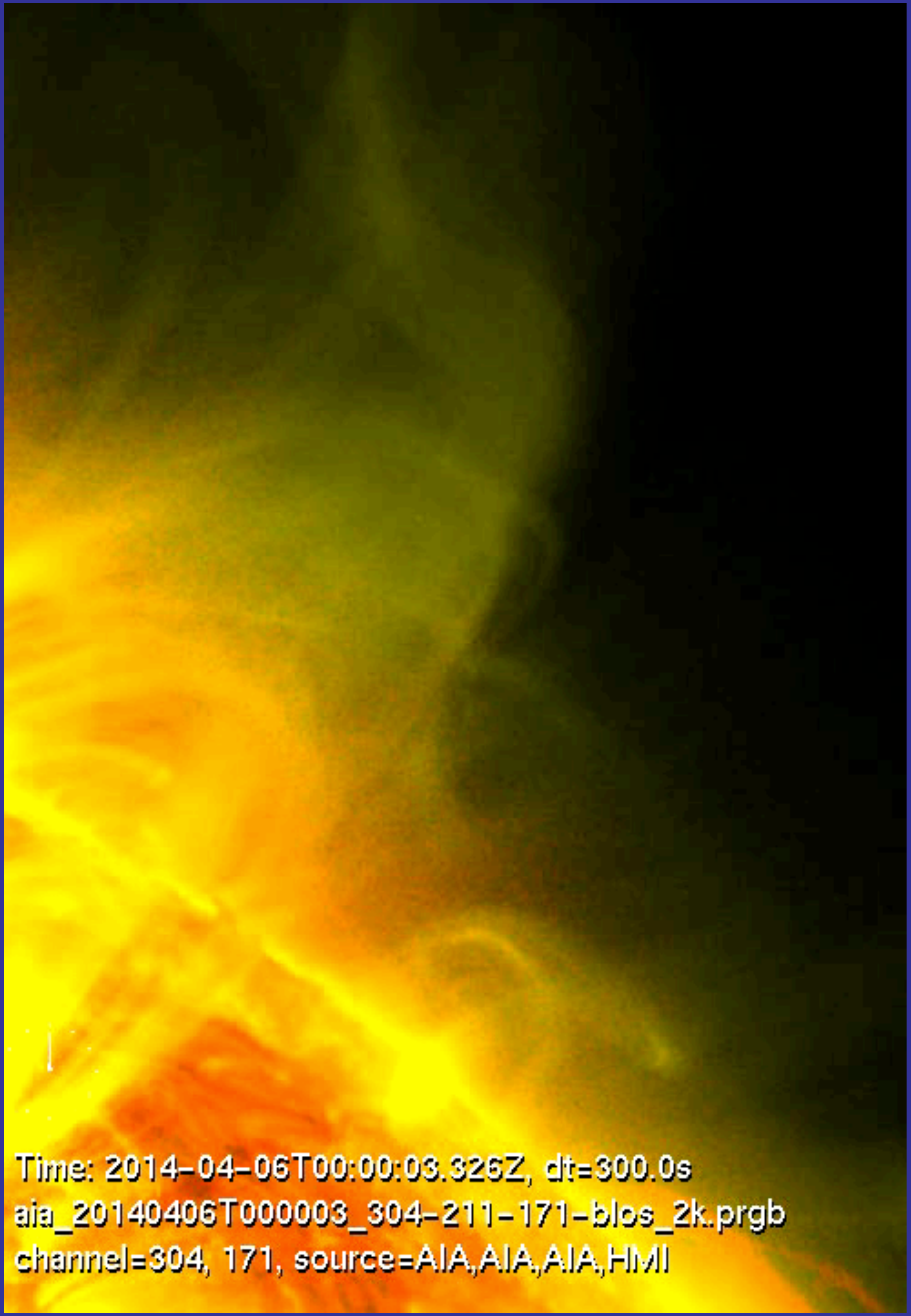
Hybrid prominence + coronal rain: IRIS
Top (open fan): prominence threads, turbulent flows, large line width
Bottom (closed loops): coronal rain, narrow line width



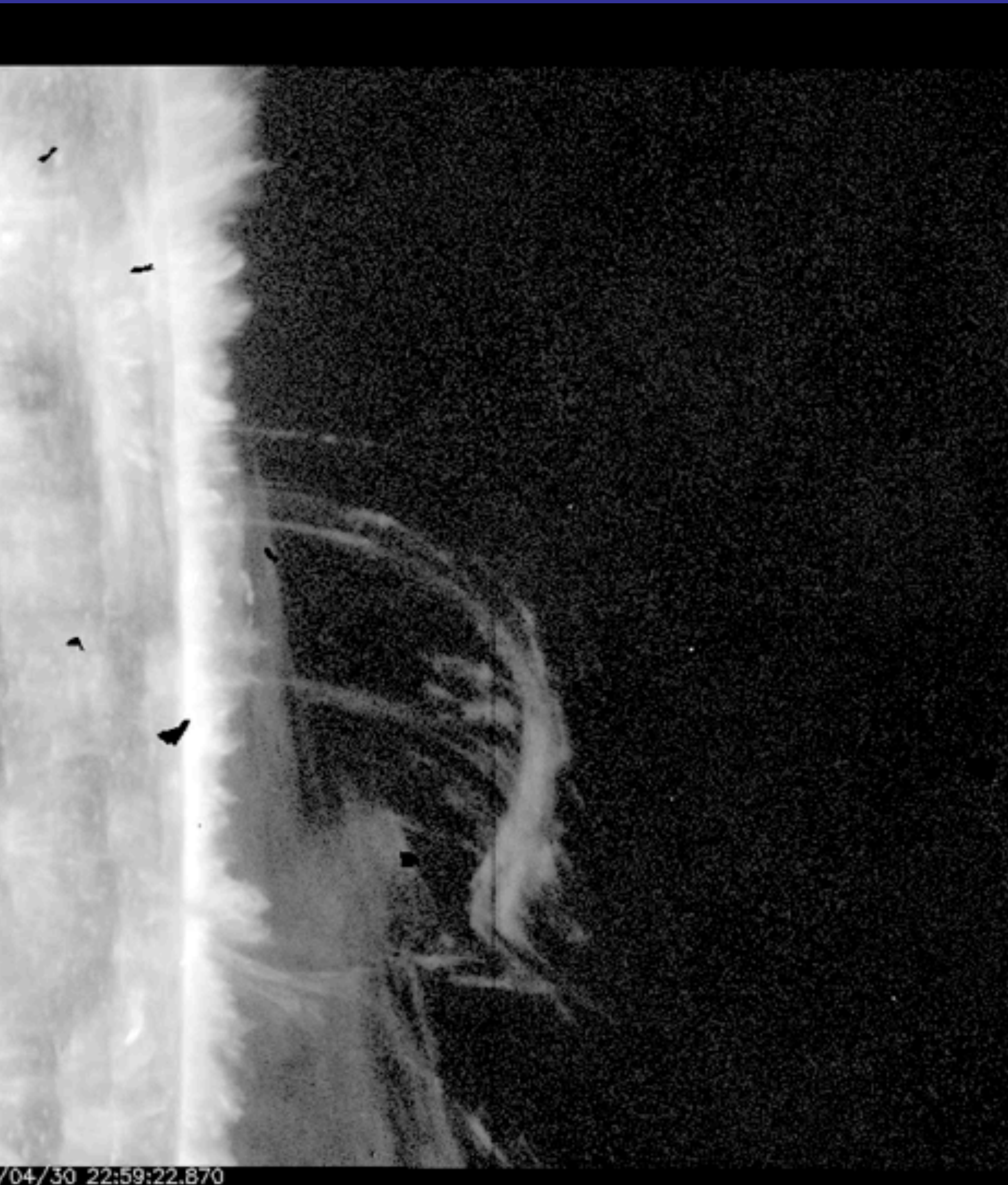
More examples: More examples: Turbulent prominence threads turning into underlying coronal rain

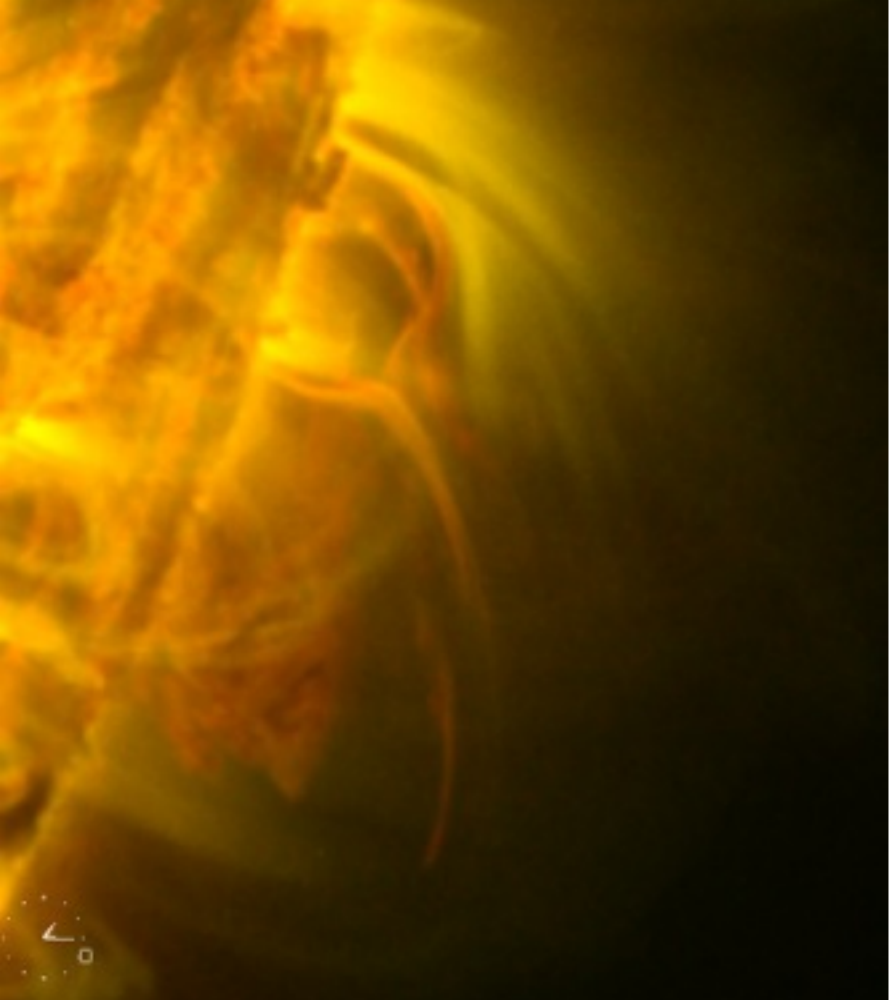


More examples:
Turbulent prominence threads turning into underlying coronal rain

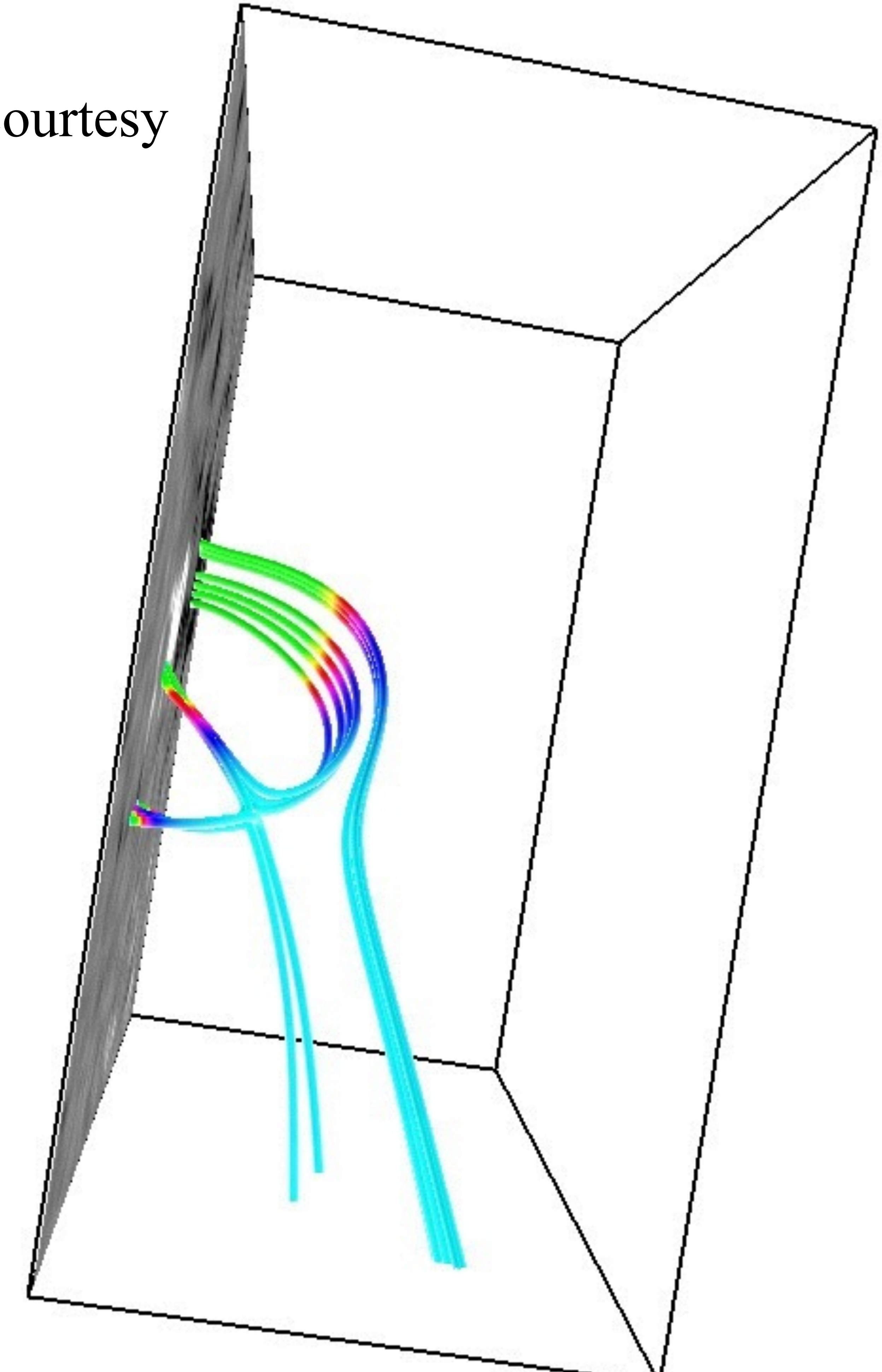


2. Fan-spine geometry and coronal rain (Reeves+, submitted)

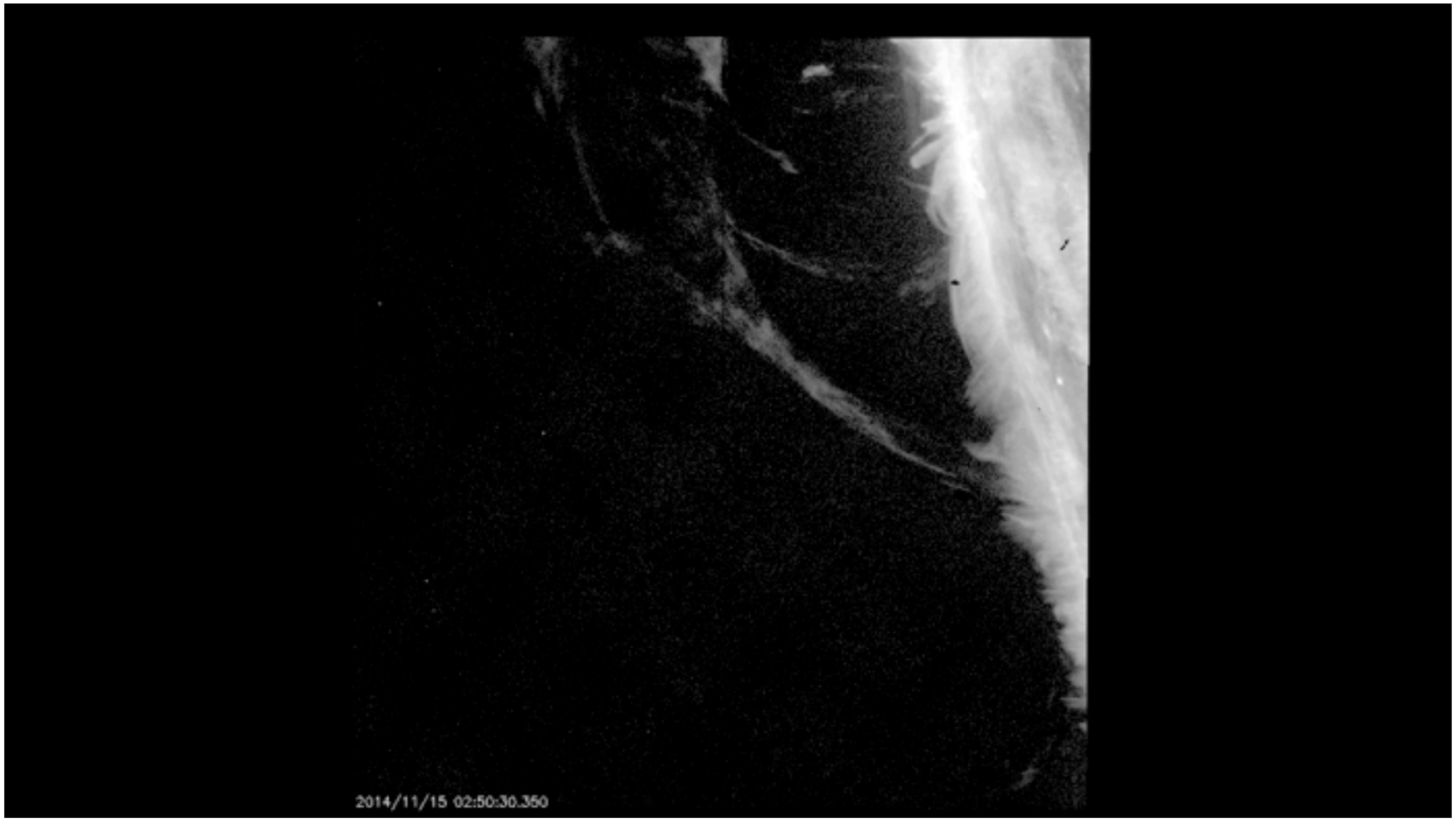




Potential field extrapolation (Courtesy of Xudong Sun)

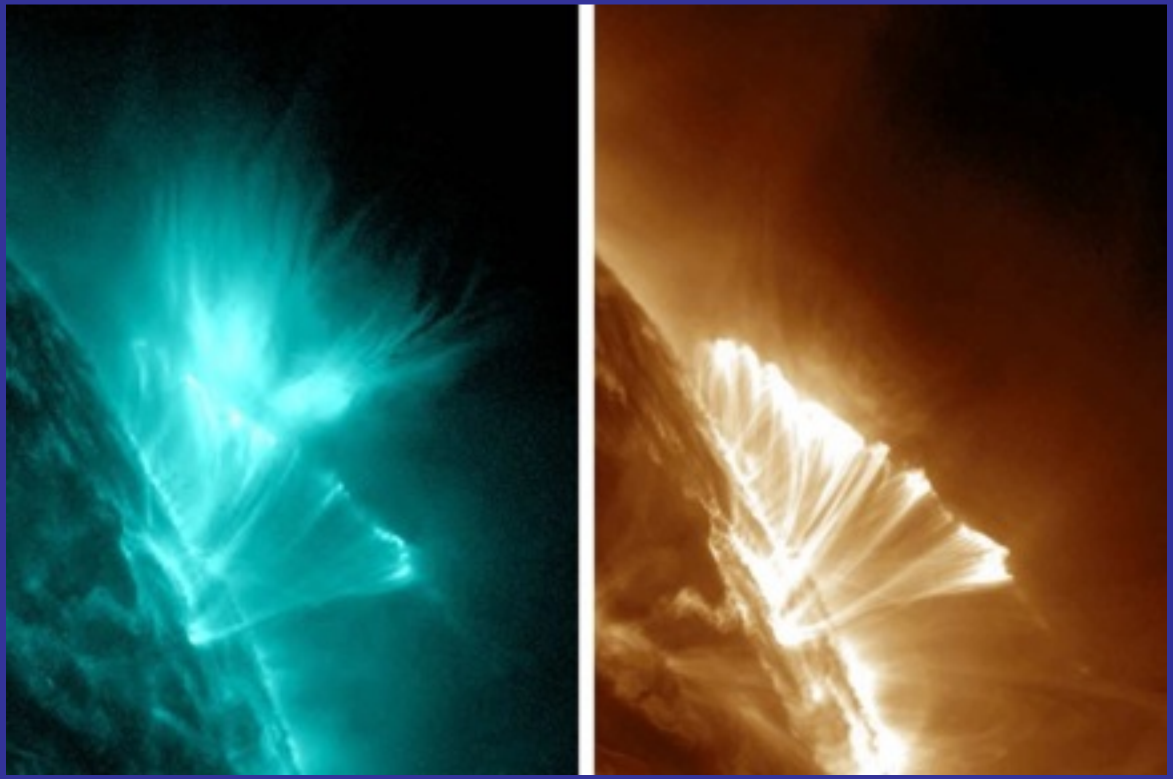


Another example with IRIS

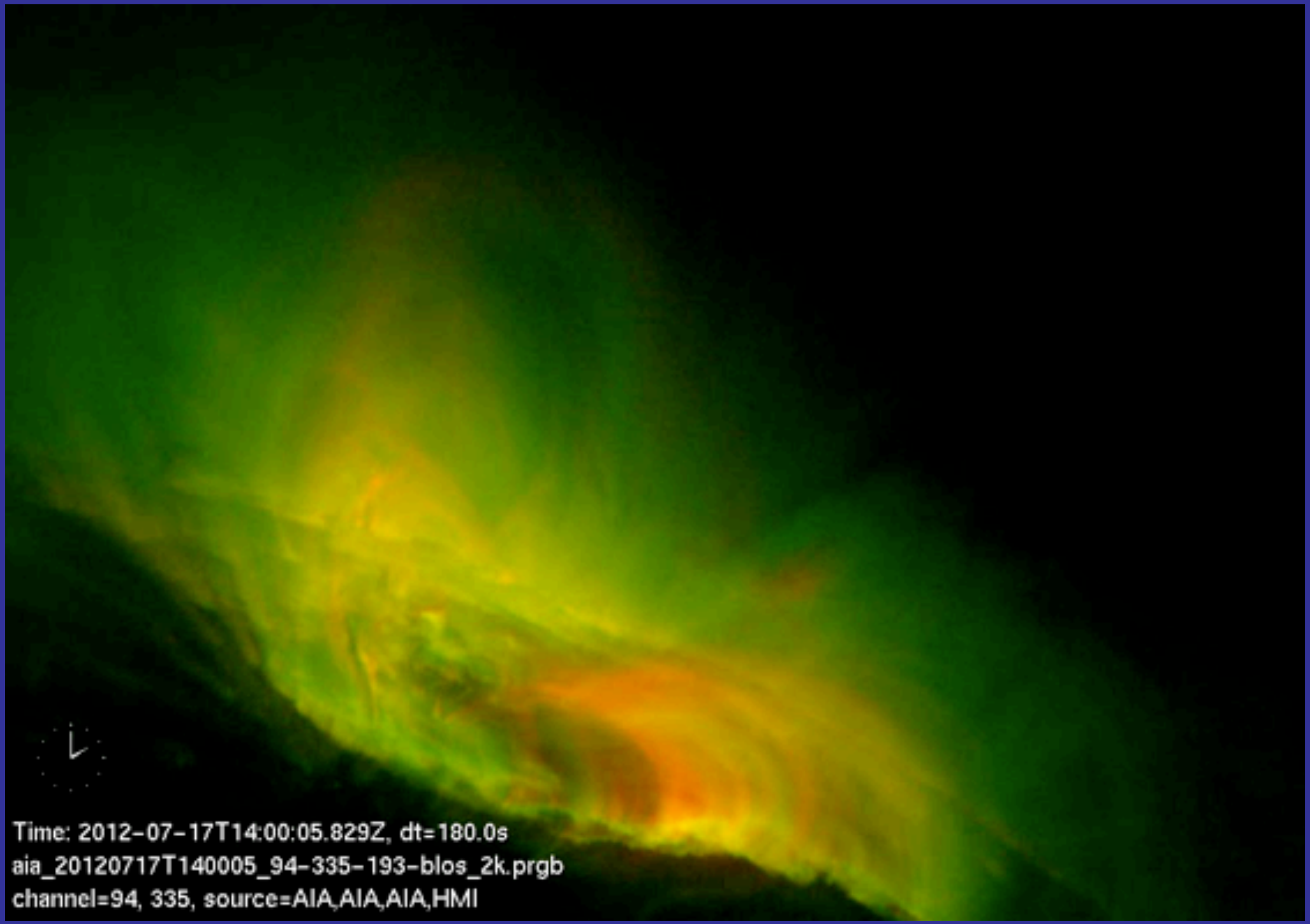


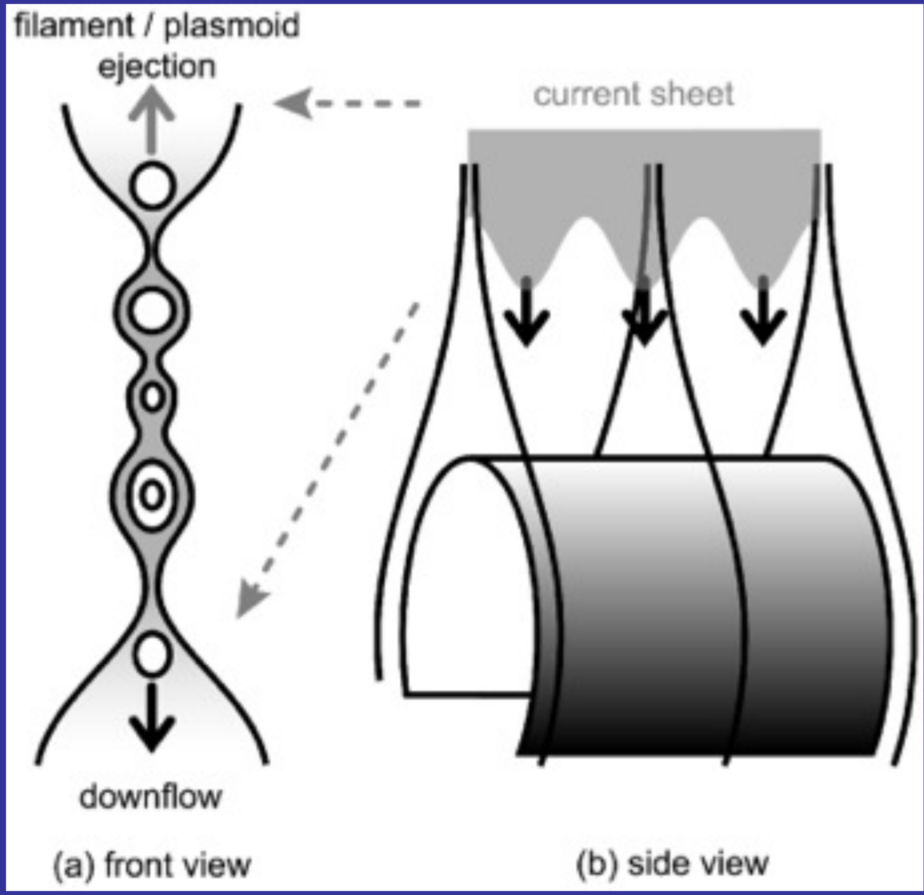
- High density regions above loop arcades, apparently high-β. Sometimes dips are visible
- Subsonic and supersonic fast flows away from high density regions
- Filamentary structure

Supra-arcade downflows,
McKenzie tadpoles



McKenzie 2014



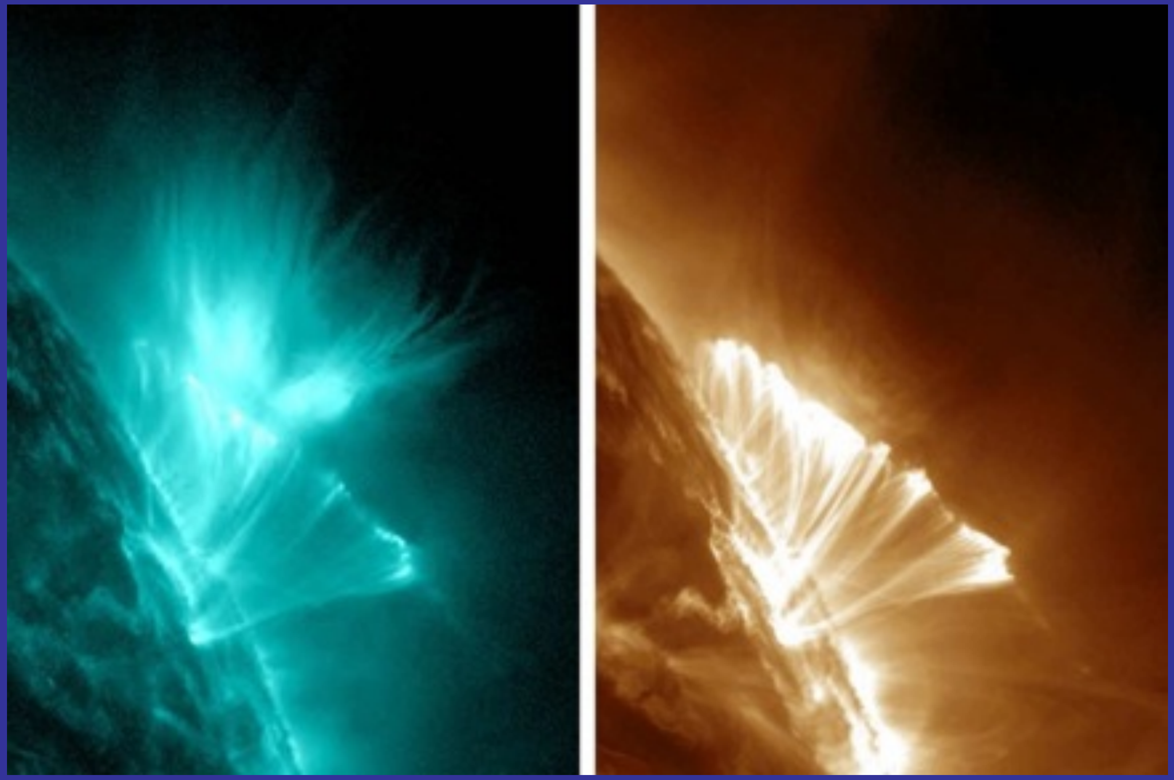


Asai et al. 2003

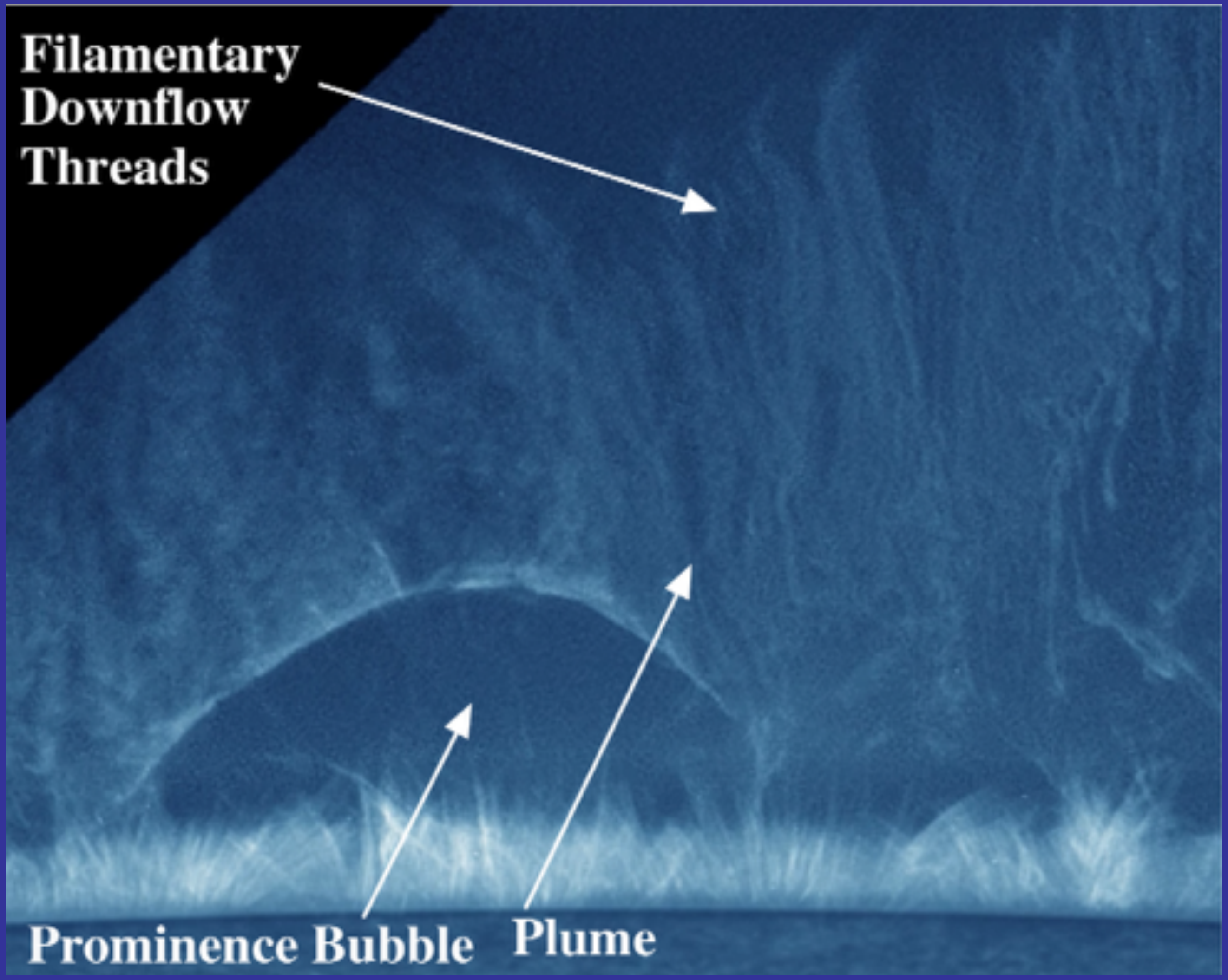
3. A Unifying Picture relating to apparently disparate phenomena

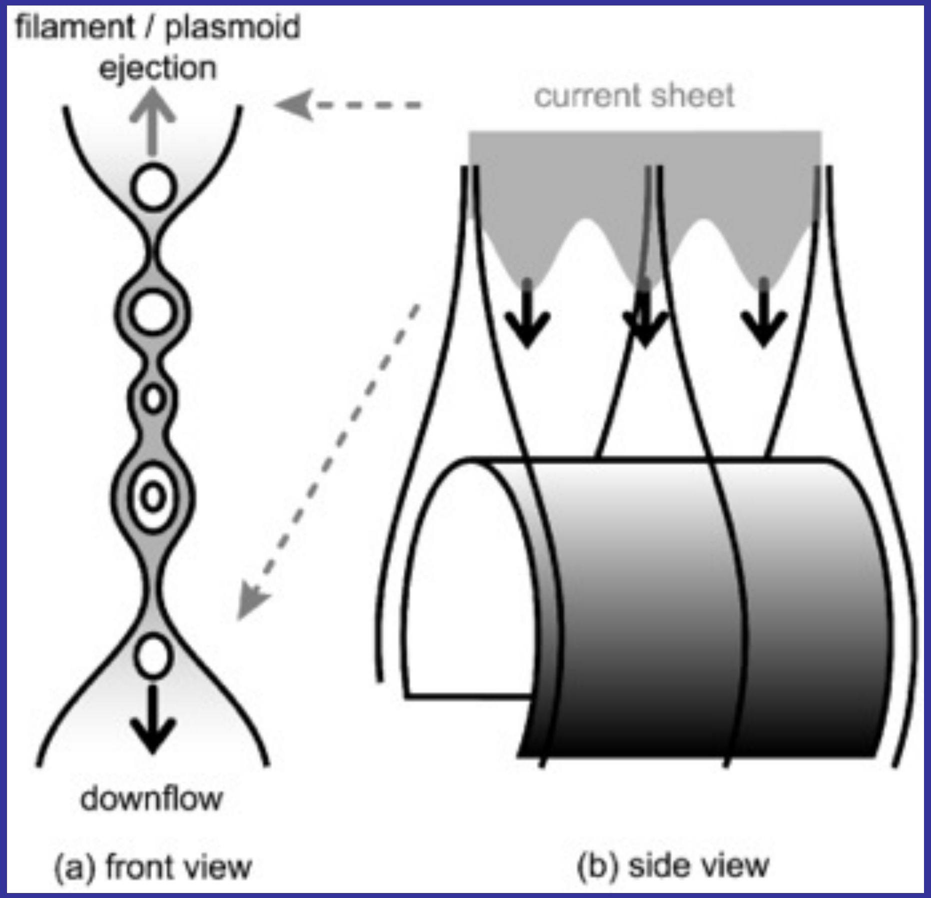
Common: current sheet above loops

1) Hedgerow Prominence
2) SADs
3) Coronal rain



McKenzie 2014





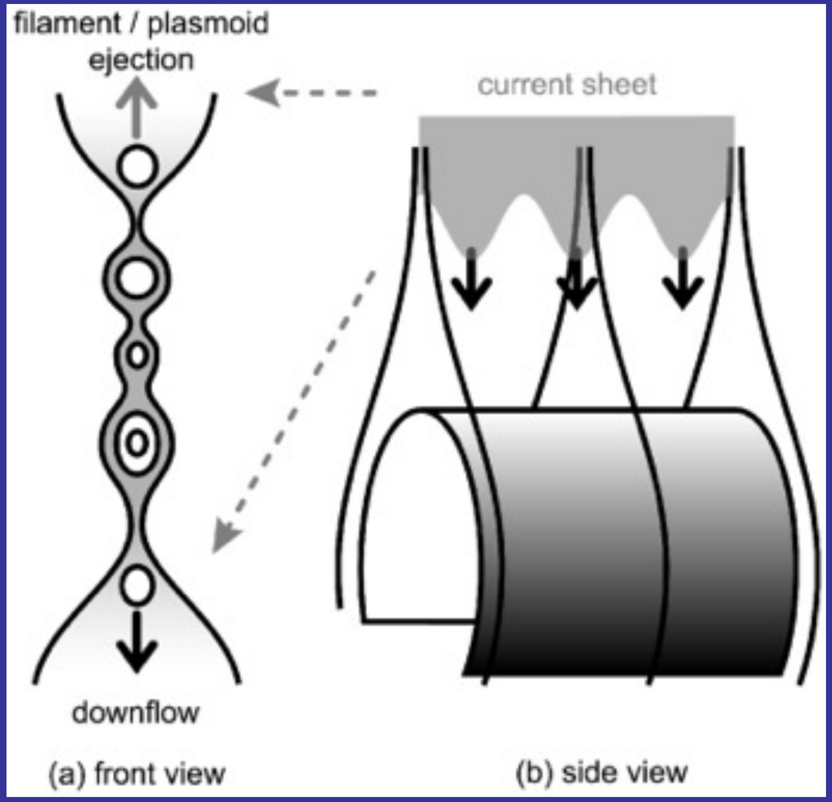
Asai et al. 2003

Summary

A new paradigm: Hybrid Prominence – Coronal Rain complex in supra-arcade turbulent fan regions

1) Open fan: Prominence, turbulent flow patterns; possibly related to high-beta condition – like flare SADs;

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

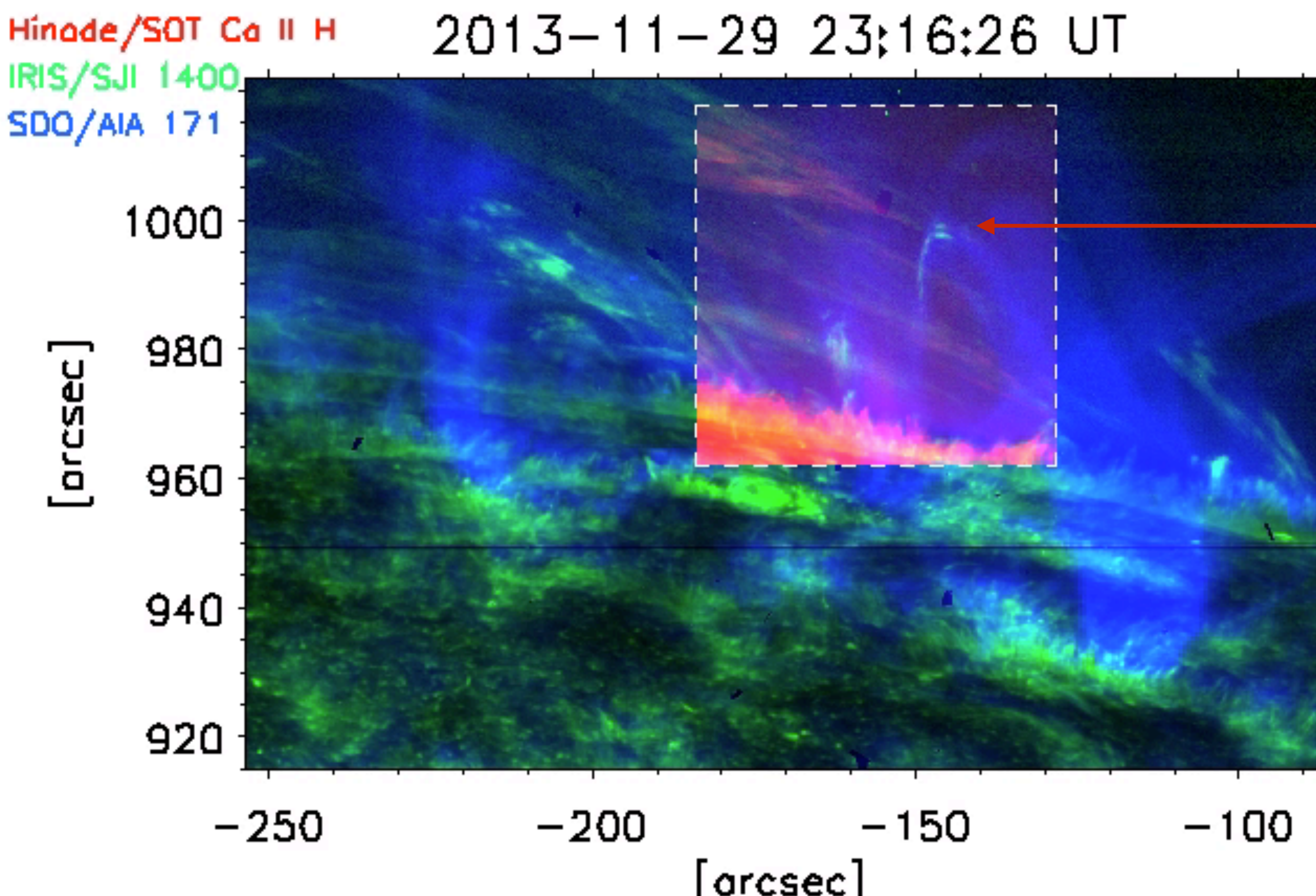


A new kind of rain?

Patrick Antolin[1] & Wei Liu[2]

[1]:NAOJ, [2]: LMSAL

Present study: Hinode - IRIS - SDO

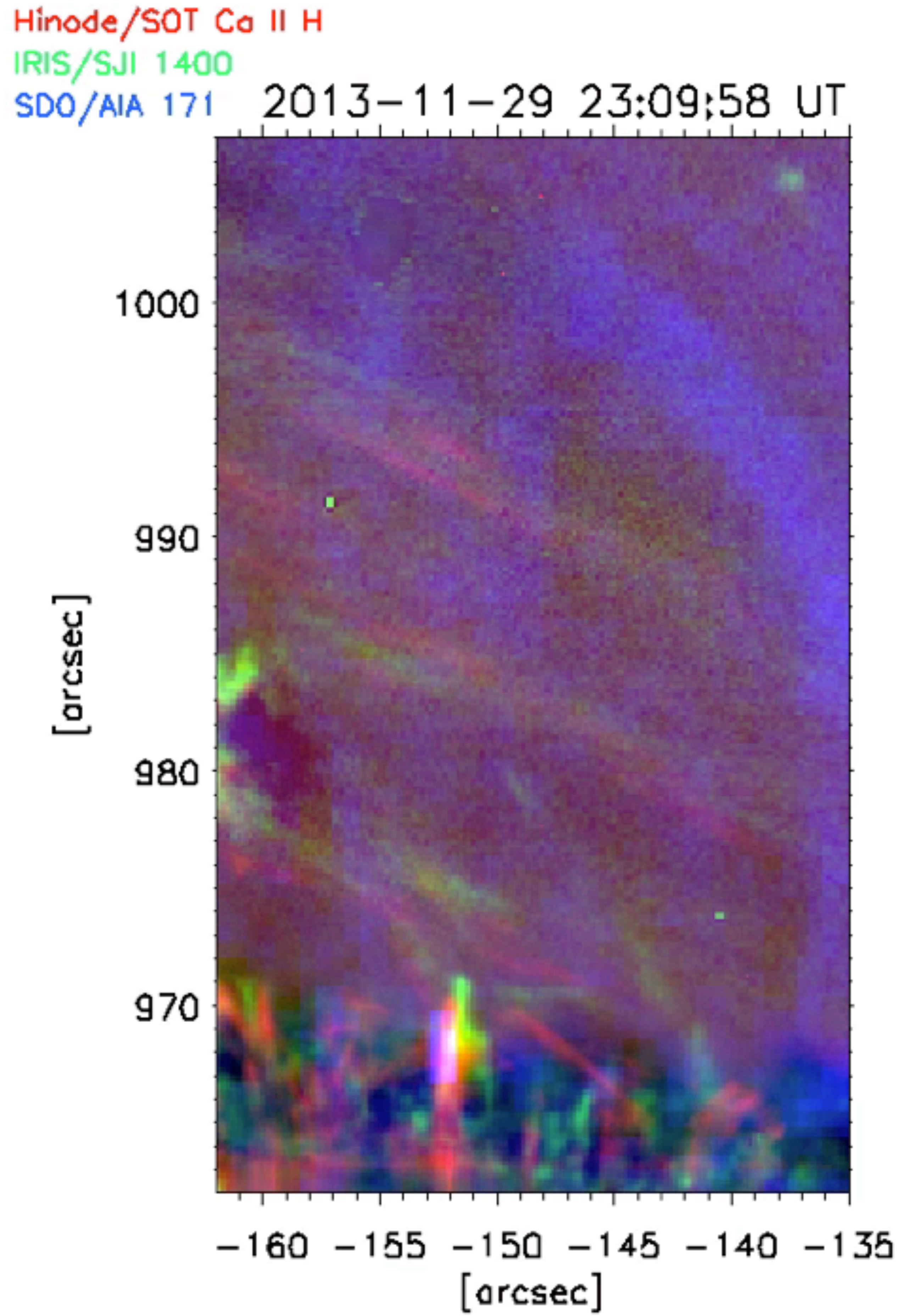


loop with rain (starting at 23:12 UT)

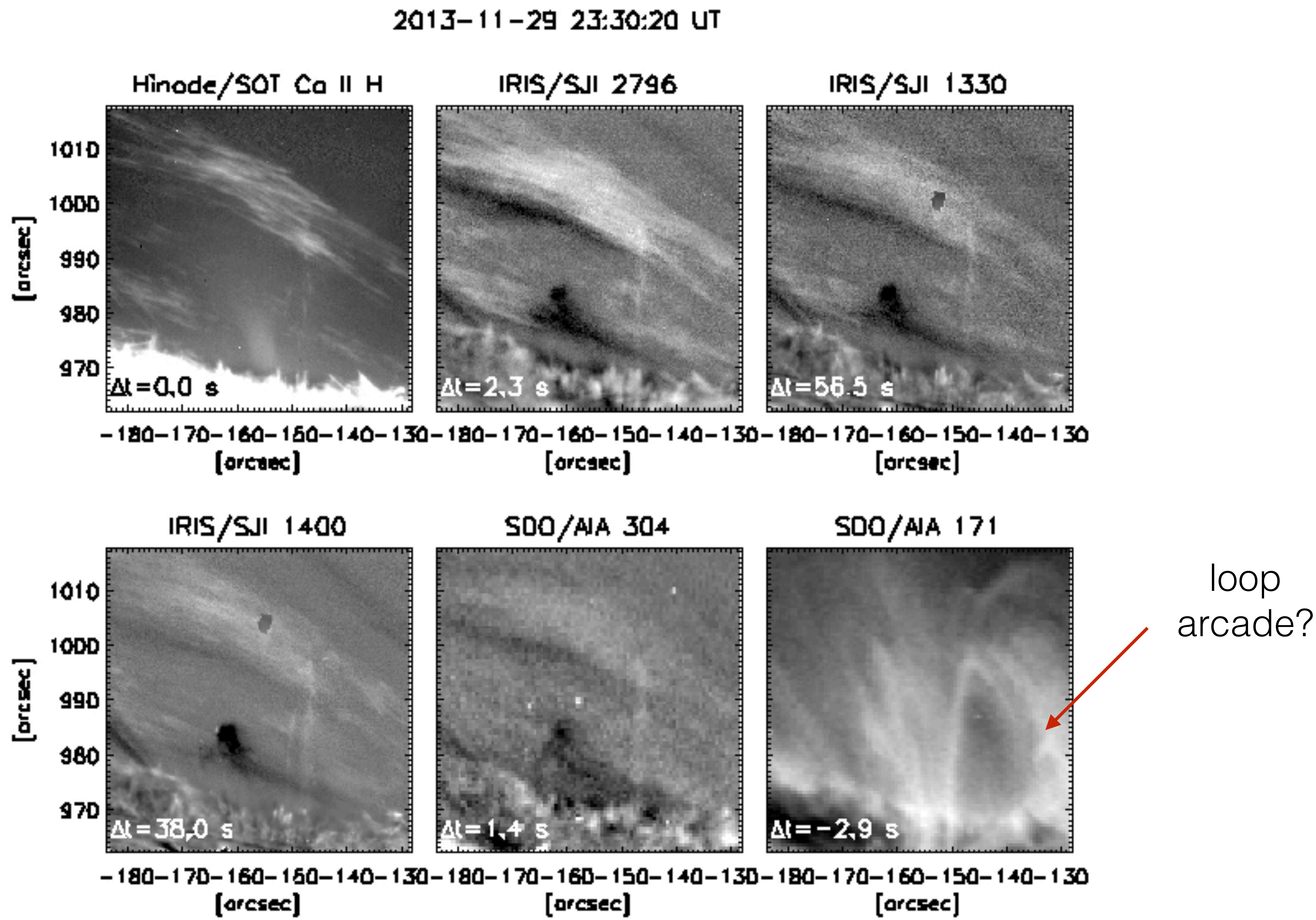
- Iris/SJI (no SG): 1400, 1330 & 2796 (36.5 s)
- SDO AIA: 304 & 171 (12 s)
- Hinode/SOT (4.8 s)

Observations: SOT - SJI - AIA

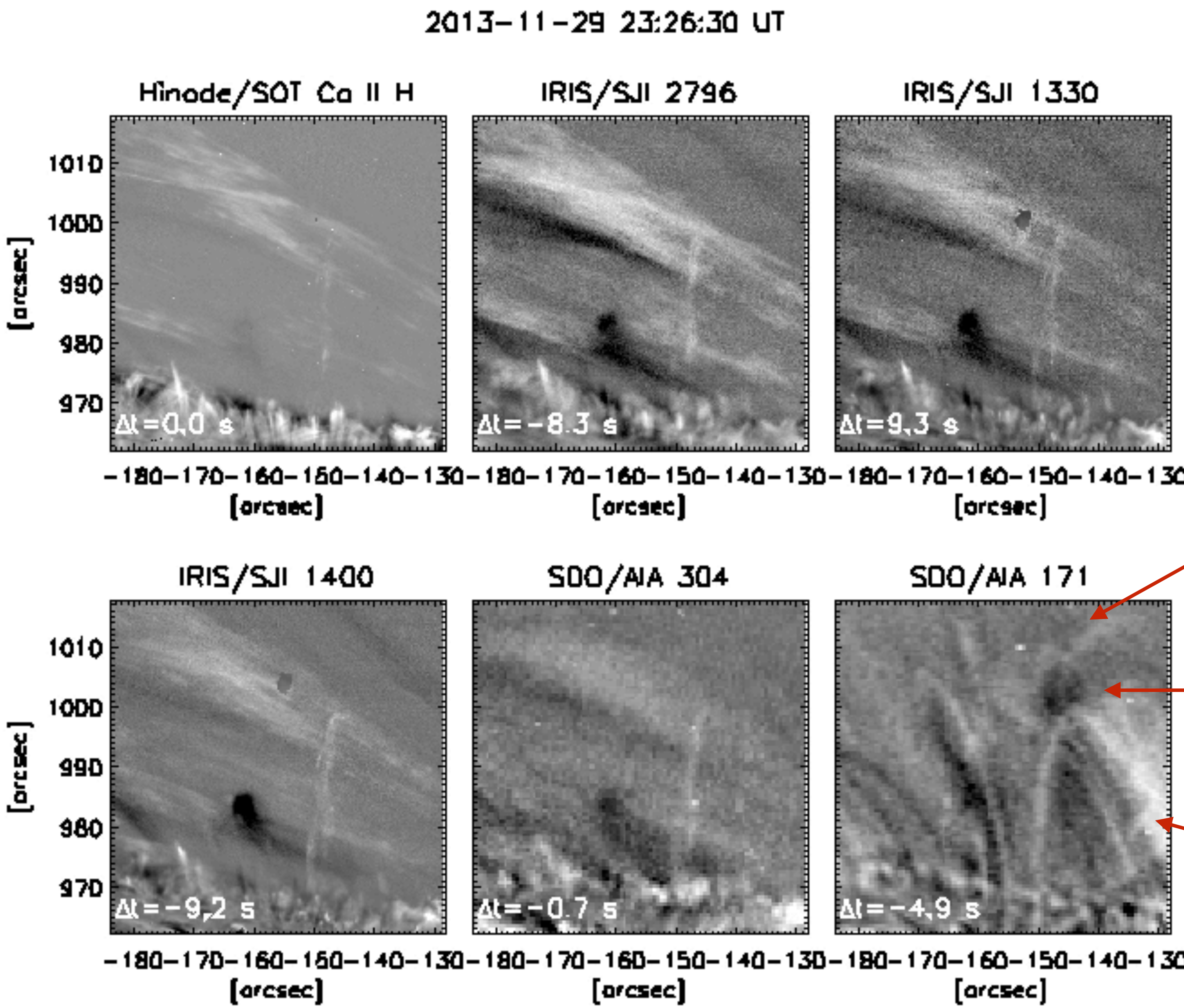
- Loop arcade?
- Loops stay bright in AIA (and even increases during rain event)
- Peculiar rain paths towards the end: rain in more than 1 loop?



Observations: SOT - SJI - AIA



Observations: SOT - SJI - AIA

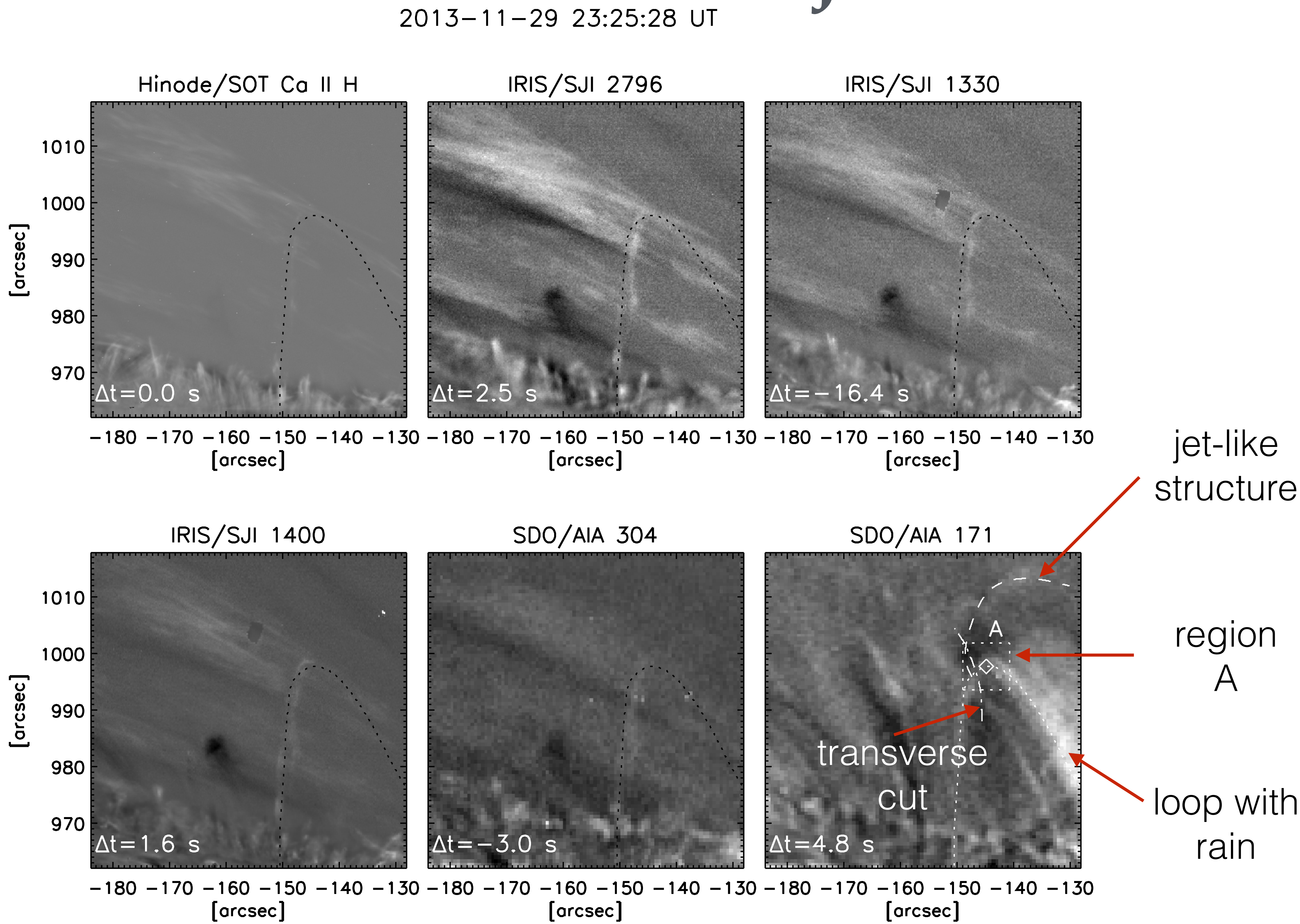


jet-like structure or LOS effect?

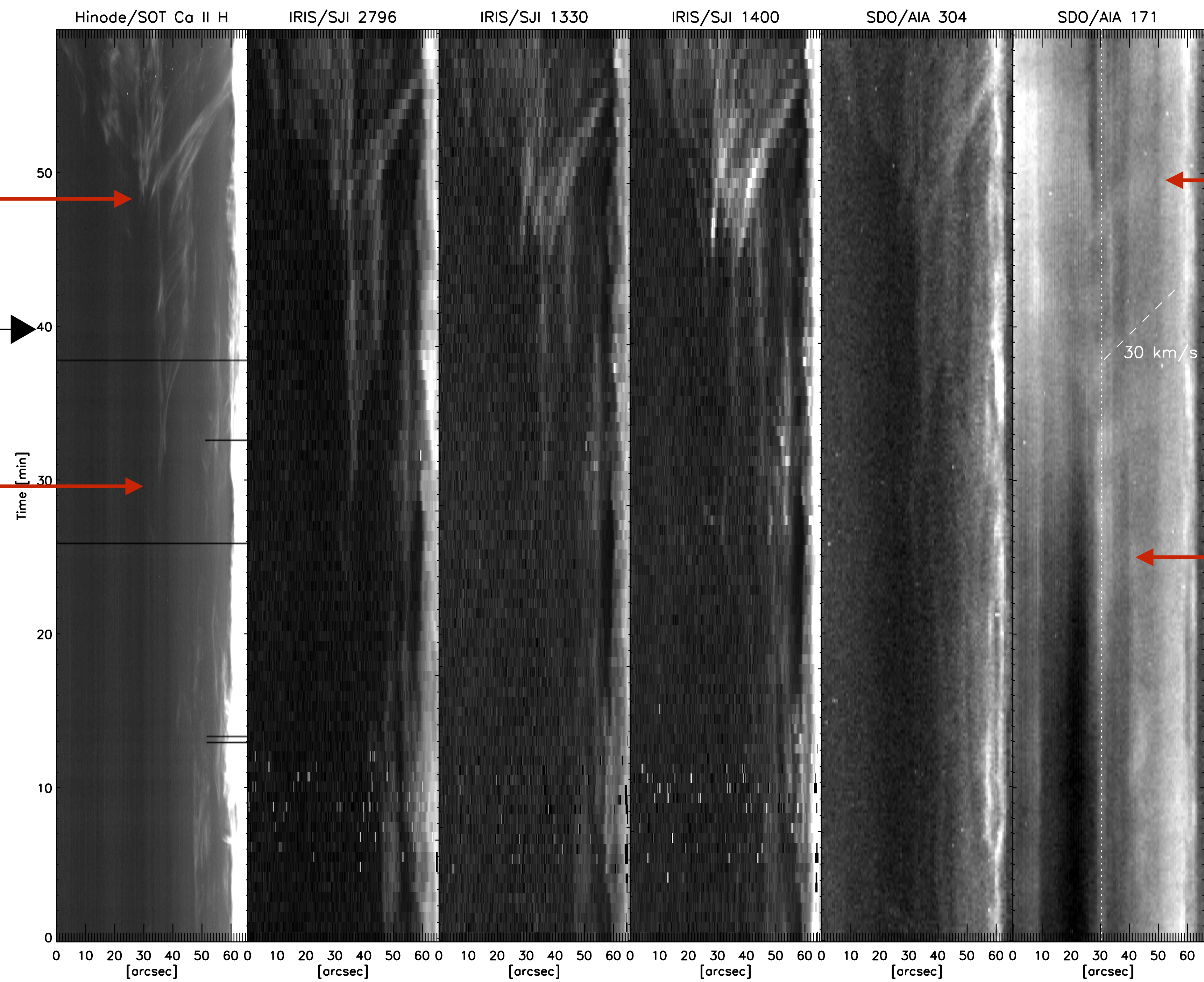
Intensity decrease, simultaneous with rain

loop with rain

Observations: SOT - SJI - AIA



x-t diagrams along loop



rain

start time of movies

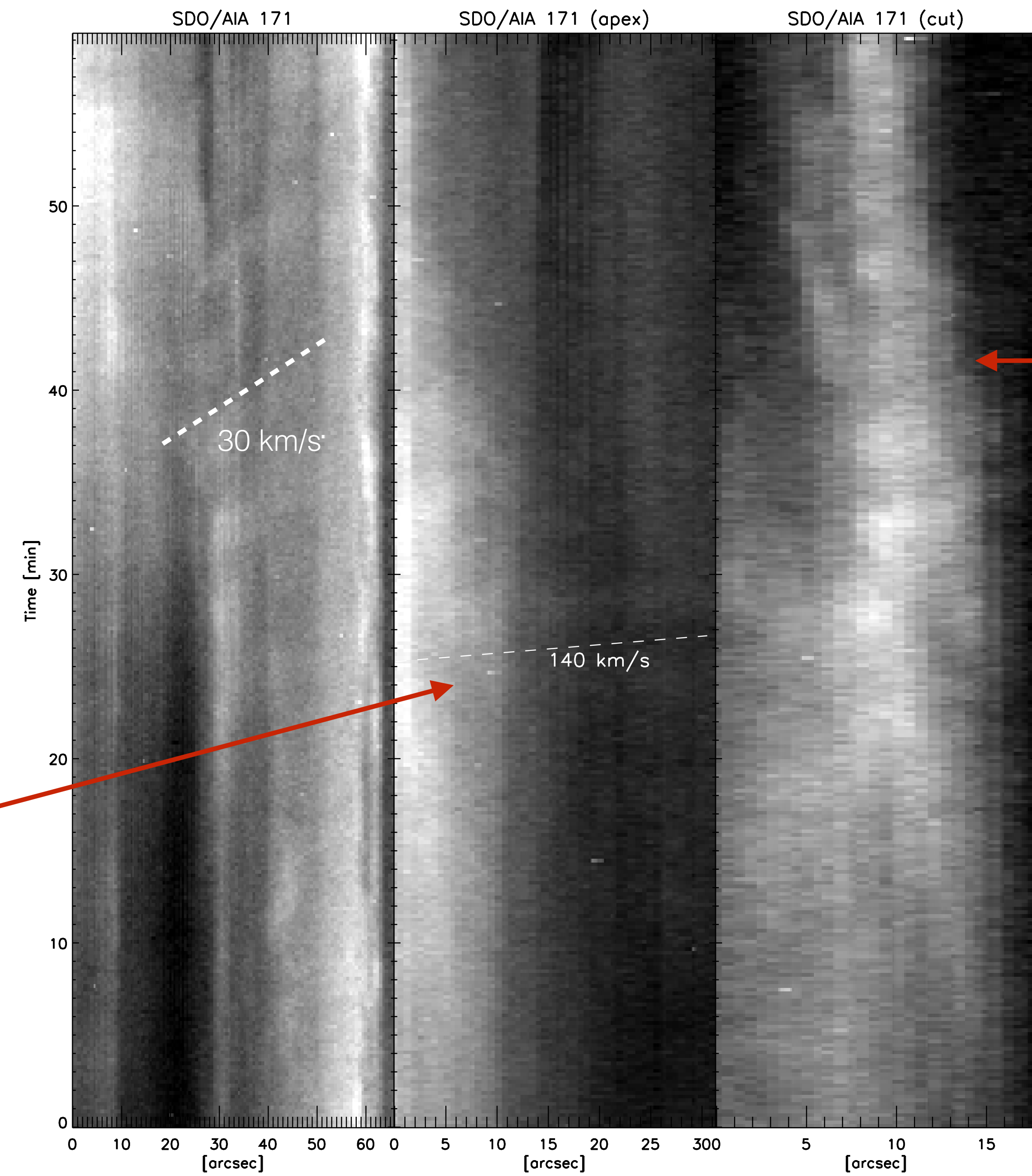
prominence material flowing into FOV

propagating intensity disturbances

periodic intensity variations at apex

length along loop

x-t diagrams along cuts



supersonic propagating intensity disturbances?

loop

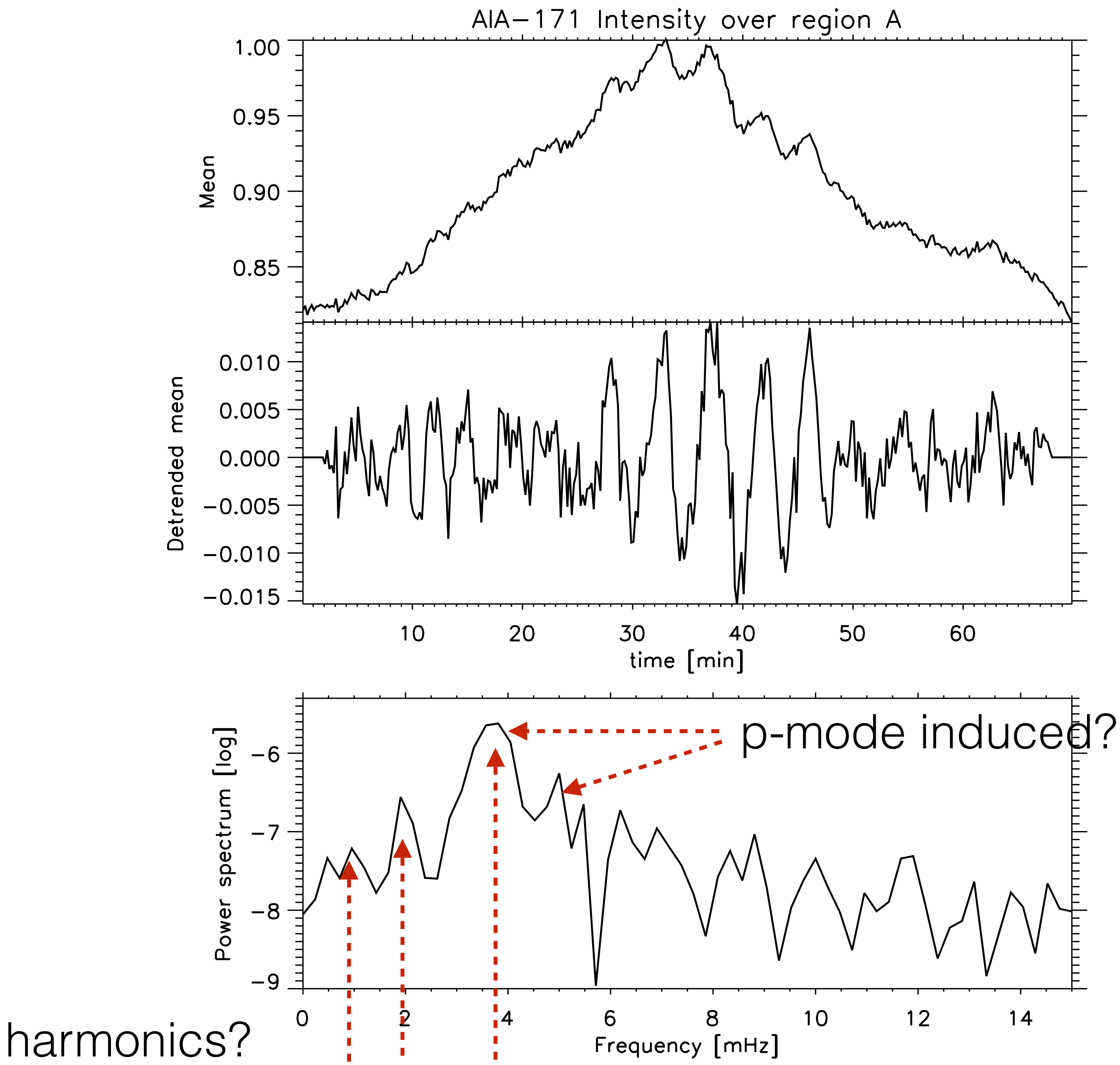
jet-like structure

transverse cut

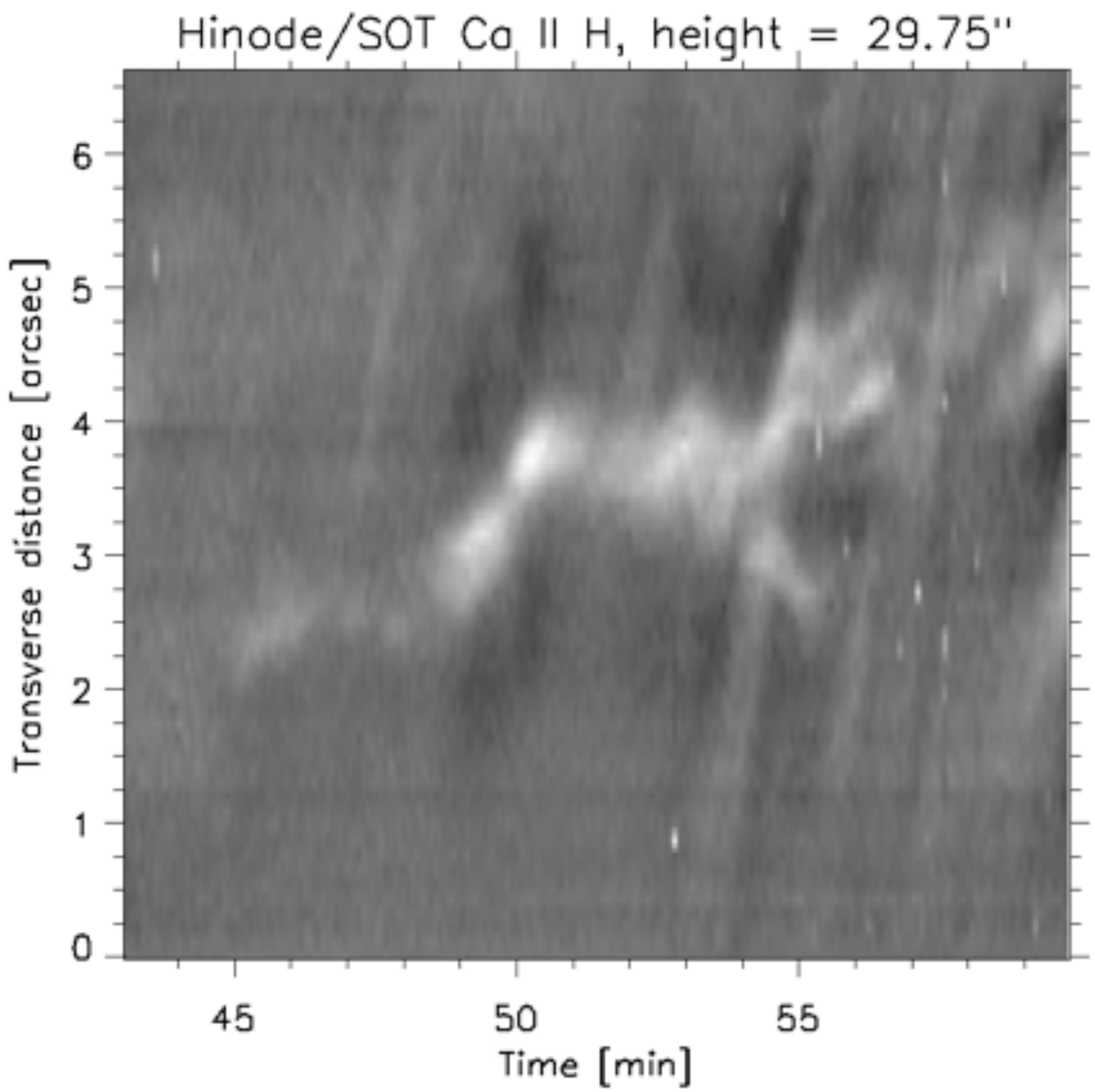
Transverse MHD waves in phase with intensity variation

- 4-5 min period
- signatures of damping
- slight drift downward

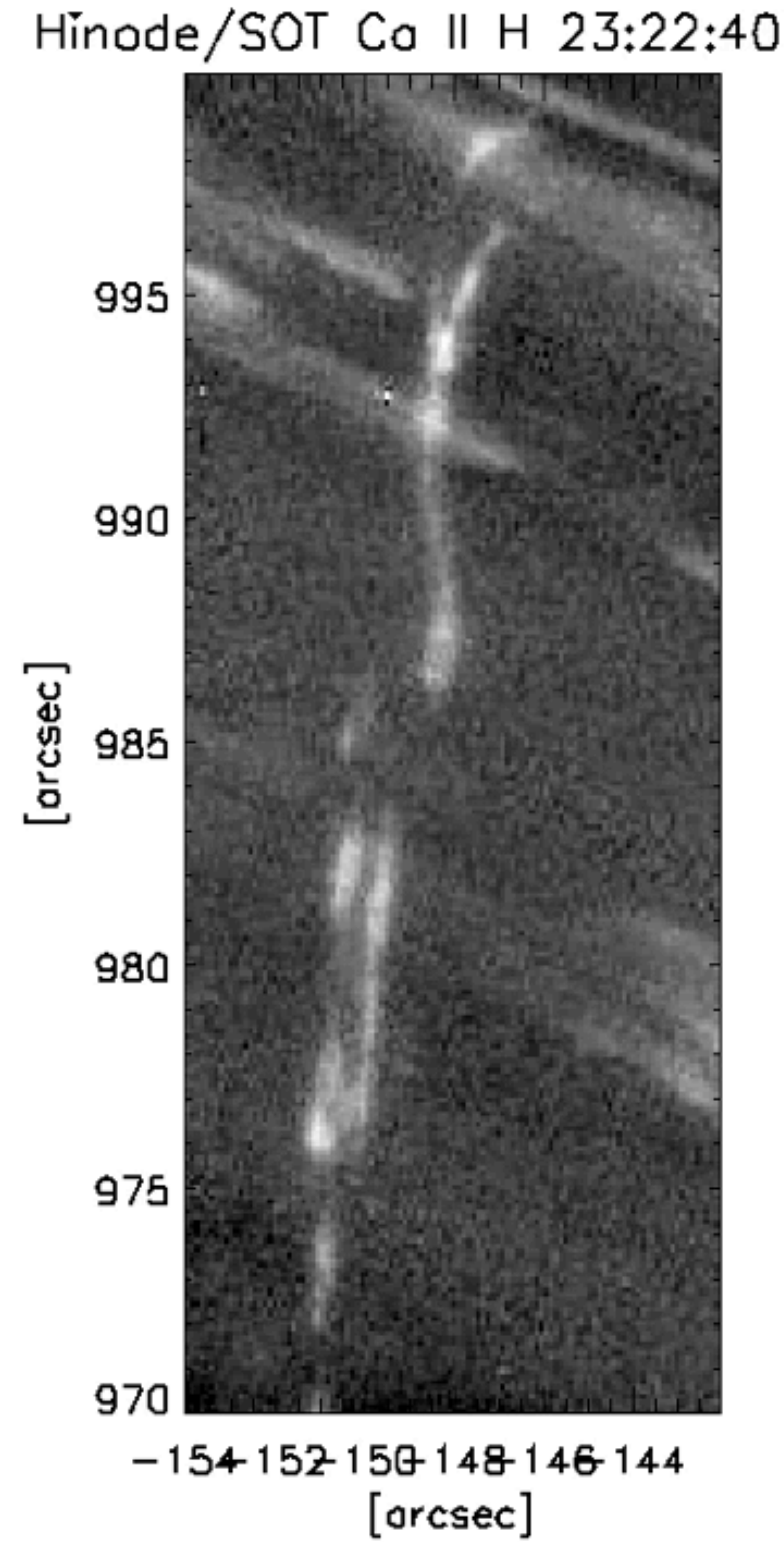
Power maps


AIA−171 Intensity over region A
Mean
1.00
0.95
0.90
0.85
Detrended mean
0.010
0.005
0.000
−0.005
−0.010
−0.015
10
20
30
40
50
60
time [min]
Power spectrum [log]
−6
−7
−8
−9
0
2
4
6
8
10
12
14
Frequency [mHz]
p-mode induced?
harmonics?

Transverse MHD waves in Ca II H

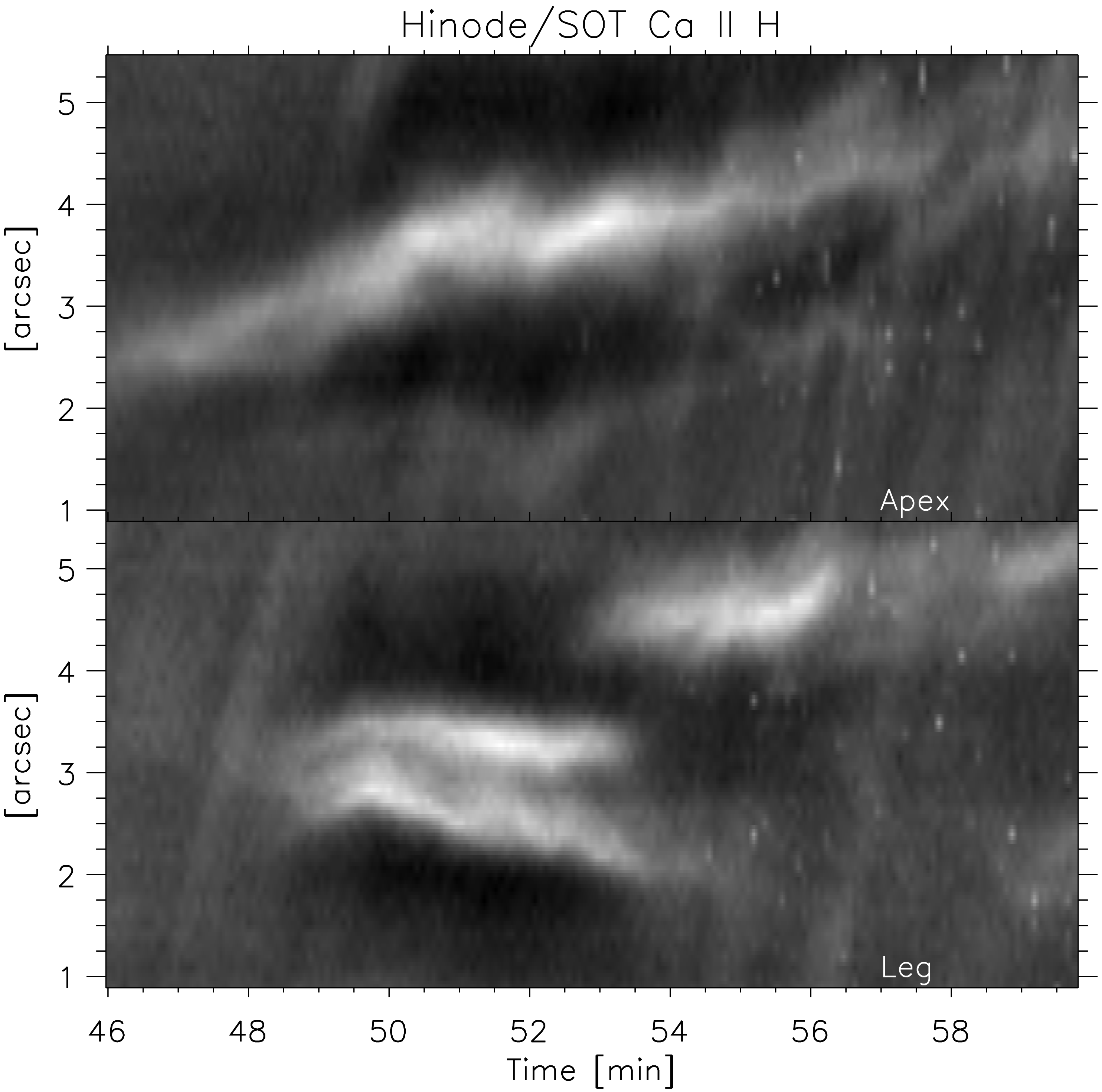


Movie of xt transverse cuts with height



Transverse MHD waves in Ca II H

Image of maxima for xt transverse cuts with height



- Rain occurs after damping of transverse MHD waves detected by AIA
- Transverse MHD waves in Ca II H
- Smaller periods
- More complex pattern, multiple period?

Discussion - Peculiar rain event

- Loop stays warm, especially upstream of rain
- Coronal intensity decrease, mostly above loops: cooling seems to occur only above apex. No usual progressive cooling from coronal temperatures is observed (only TR to chromospheric)
- Very low downward velocities (~30-40 km/s)
- Dark intensity region above loop arcade
- Periodic EUV intensity variations at apex in phase with damped oscillations in POS of loop (harmonics with fundamental mode at ~5 min + other freqs.)
- Small amplitude oscillations in POS in Ca II H with multiple periodicity (differ from EUV)
- Fast jet-like structures from region? Apparently in-phase with intensity variations
- Divergence of rain paths towards the end: multiple rain loops?

What is happening?

Discussion - Possible scenarios

Transverse MHD waves

- Transverse MHD waves generated somehow (leaky p-modes…)
- Ponderomotive force from standing waves may generate intensity variation and high density region at apex, from which catastrophic cooling follows (rain). Force may decelerate the rain
- Damping of waves goes into heating and maintains parts of the loop at coronal temperatures (for instance, where resonant absorption takes place)
- Resonant absorption and KHI may result, leading to multiple current sheets (heating), turbulent spectra (multiple periodicities) and reconnection (jet)

Potential issues:

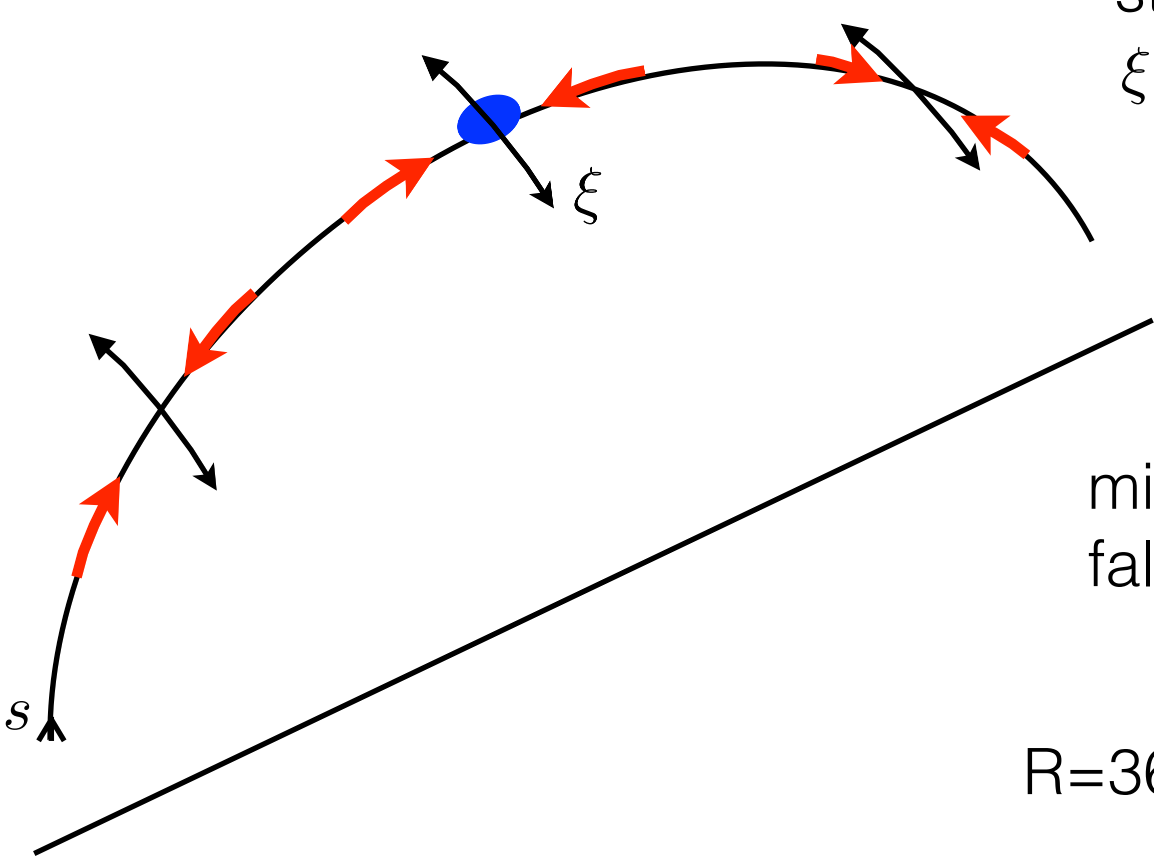
- Darkening observed mostly above loop arcade, simultaneous with rain (not at time of large amplitude waves)
- Slow propagating EUV disturbances
- Enough amplitude and energy? v_{ph}~400 km/s, v_t~15 km/s (A~2 Mm), $\langle n \rangle \sim 3\times10^9$ cm^{-3} -> $F = 2\times10^5$ erg cm^{-2} s^{-1} .

Discussion - Possible scenarios

Transverse MHD waves

- Kinematic effects on rain: Clumps modelled as beads on a string:
- → dynamical system (Verwichte+, in prep.)

$$\mathcal{L} = \int_0^{\pi R} \left[\frac{\rho}{2} \left(\frac{\partial \xi}{\partial t} \right)^2 - \frac{B^2}{2\mu_0} \left(\frac{\partial \xi}{\partial s} \right)^2 \right] S \mathrm{d}s + \frac{m}{2} \left[\left(\frac{\mathrm{d}s_\mathrm{p}}{\mathrm{d}t} \right)^2 + \left(\frac{\mathrm{d}x_\mathrm{p}}{\mathrm{d}t} \right)^2 \right] - m \int_0^{s_\mathrm{p}} g(s') ds'$$



string:

$$\xi(s,t) = \frac{a}{k} \sin(ks) \cos(\omega t), \qquad k = n/R, \ \omega = v_\mathrm{A} k$$

blob:

$$\frac{\mathrm{d}^2 s_\mathrm{p}}{\mathrm{d}t^2} = a_0 \frac{\omega^2}{k} + a_1 \omega \frac{\mathrm{d}s_\mathrm{p}}{\mathrm{d}t} + a_2 k \left(\frac{\mathrm{d}s_\mathrm{p}}{\mathrm{d}t} \right)^2$$

minimum amplitude required to prevent blob from falling:

$$a_\mathrm{min} = \frac{\sqrt{2 g_\odot R}}{v_\mathrm{A} n}$$

R=36 Mm, v_A = 400 km/s → a_min = 12.5 Mm

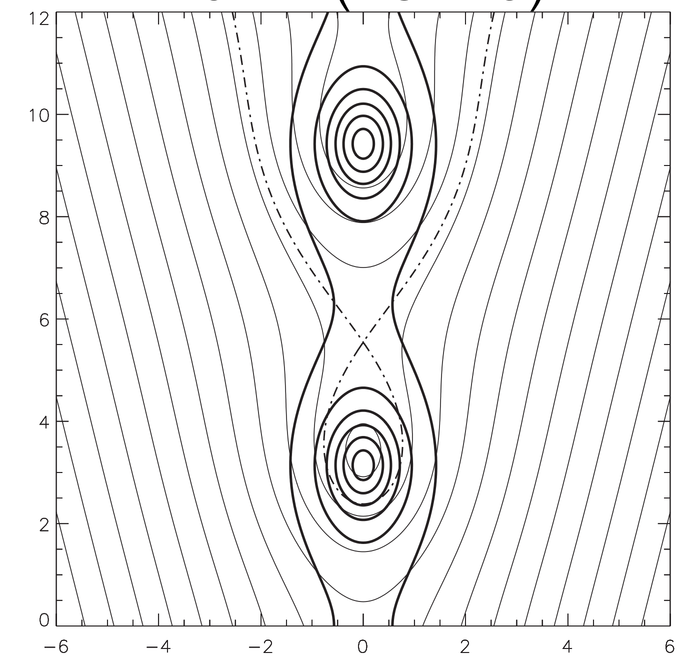
→ may not explain low speeds

Discussion - Possible scenarios

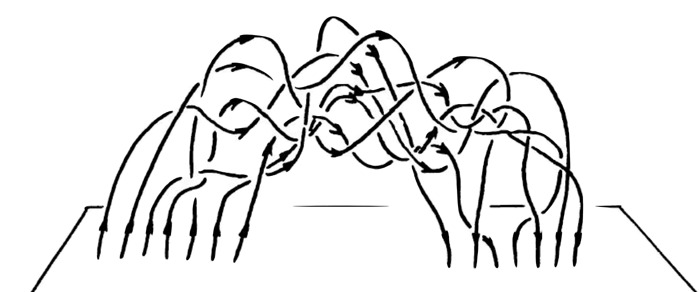
current sheets

- Complex interaction between plasmas and fields in low-β: 0 thickness current sheets (tangential discontinuities) can form where material can collapse (Low+ 2012a,b; Low 2014)
- Spontaneous formation and resistive dissipation of discrete currents
- Parker’s view: tangential discontinuities must exist in the corona to allow the field to release energy and reach the observed magnetic field topologies
- Null points in the field are preferential sites for thermal instabilities (Murawski+ 2011): MHD thermal mode (entropy mode)

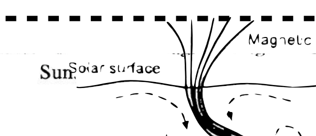
Low+ (2012b)

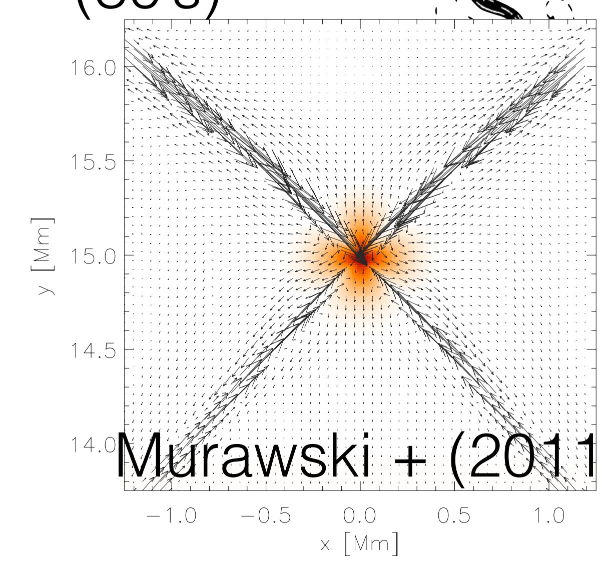


A solution for a Kippenhahn-Schlütter slab



Parker (80’s)





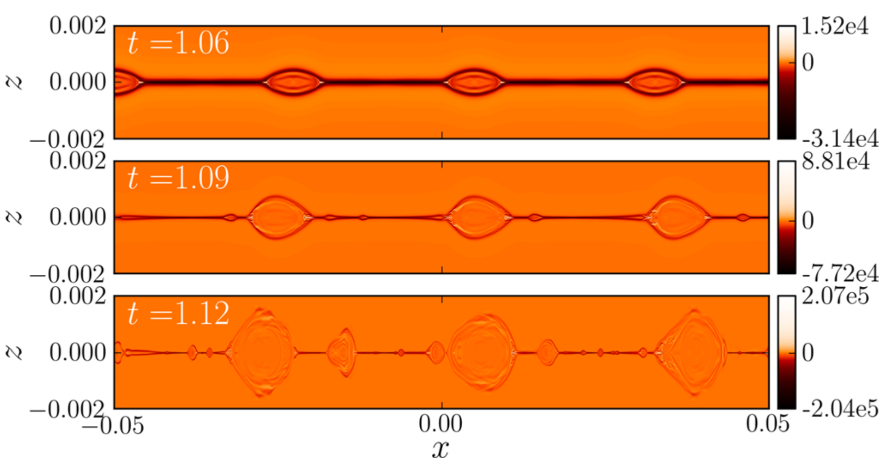
Murawski + (2011)

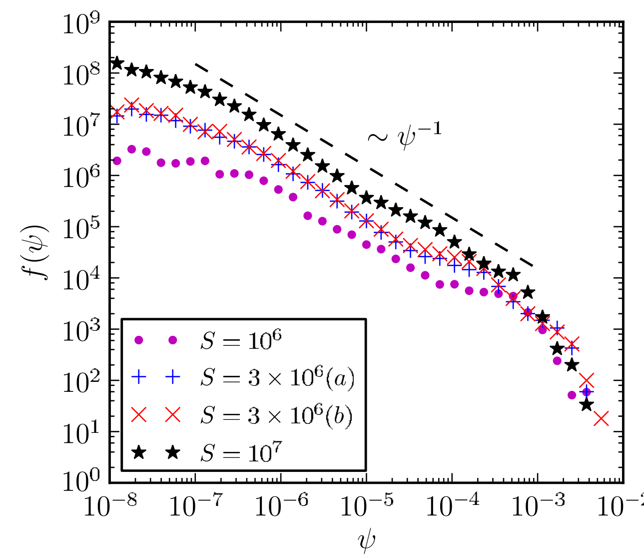
Discussion - Possible scenarios

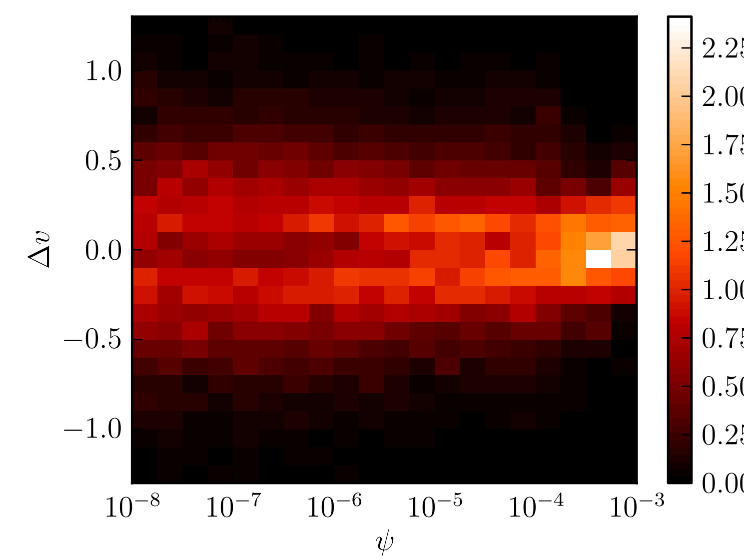
current sheets

- Reconnection sites: 2nd tearing mode instability -> plasmoid generation. Major role in energy release (Biskamp 2007, Lapenta 2008, Drake+ 2006, Daughton+ 2006)

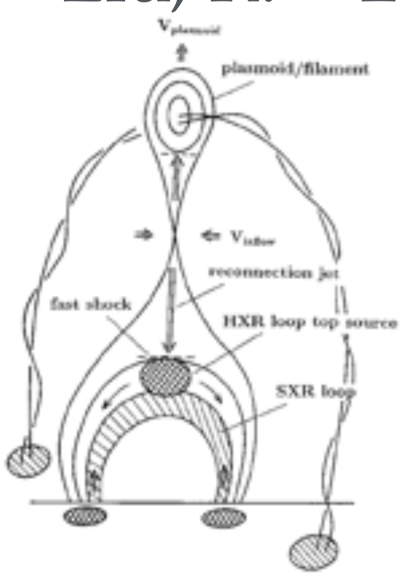
Huang & Bhattacharjee (2012, 2013)

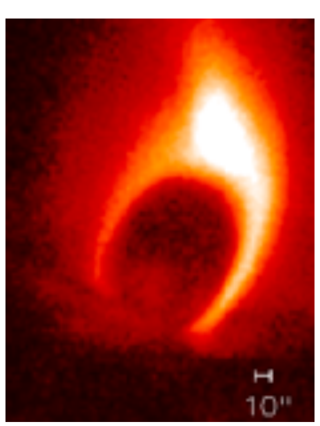


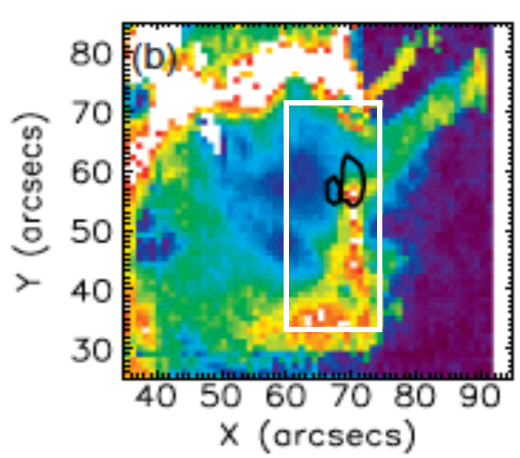


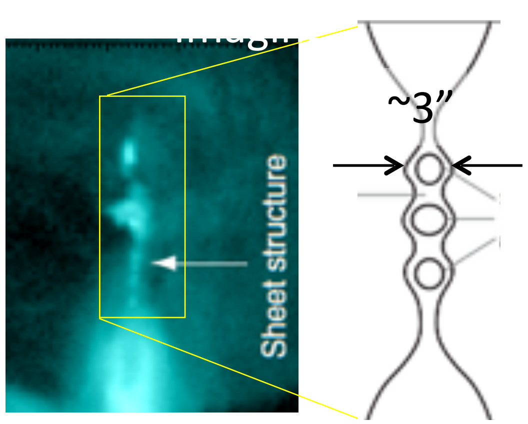


- Large plasmoids are those who live longer. Exponential increase in number at small scales (observed in magneto-tail & corona: Lin, J.+2008; Liu, R. + 2013; Nishizuka+ 2010, Takasao+ 2012)









Takasao et al. (2012)

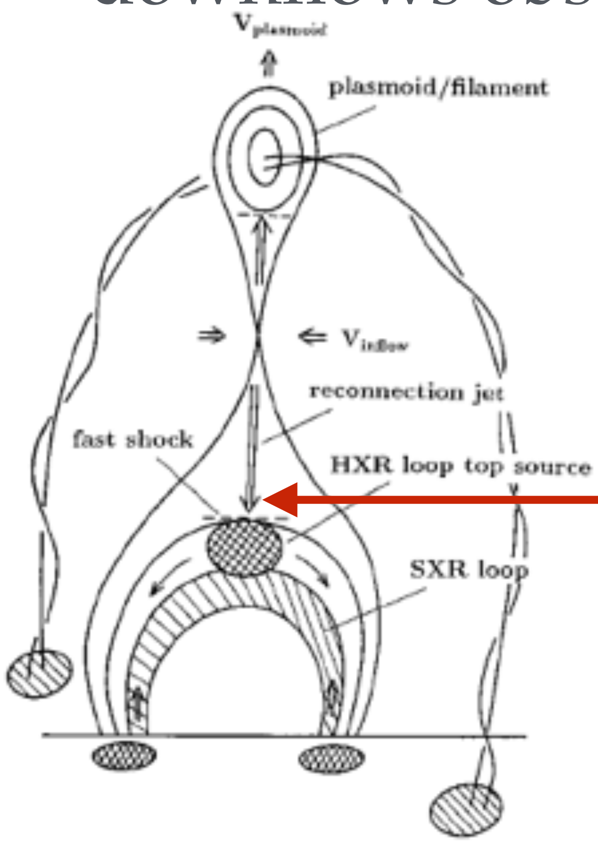
Plasmoids: partly magnetically insulated

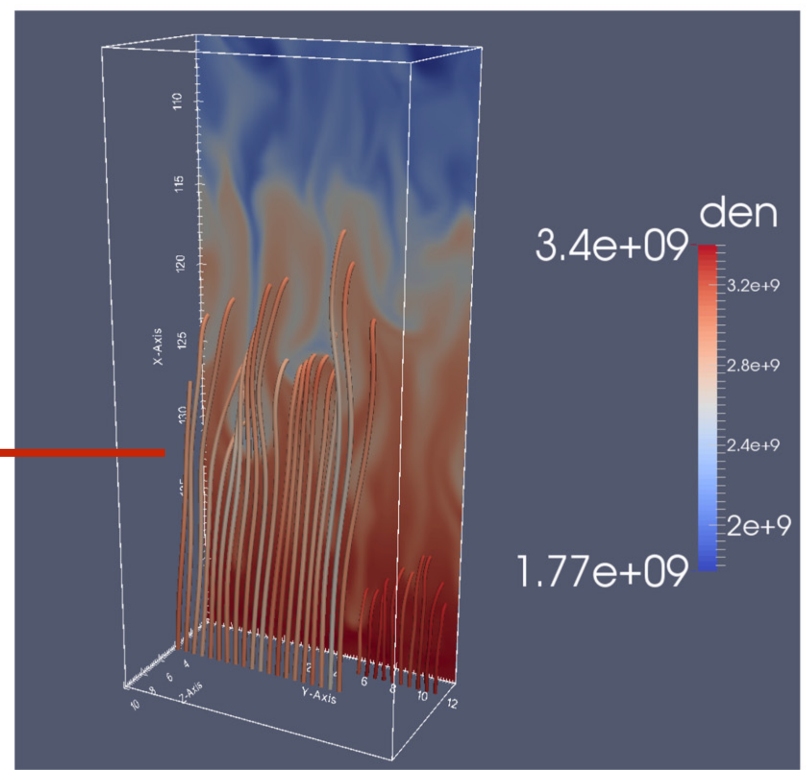
Prone to thermal instability?

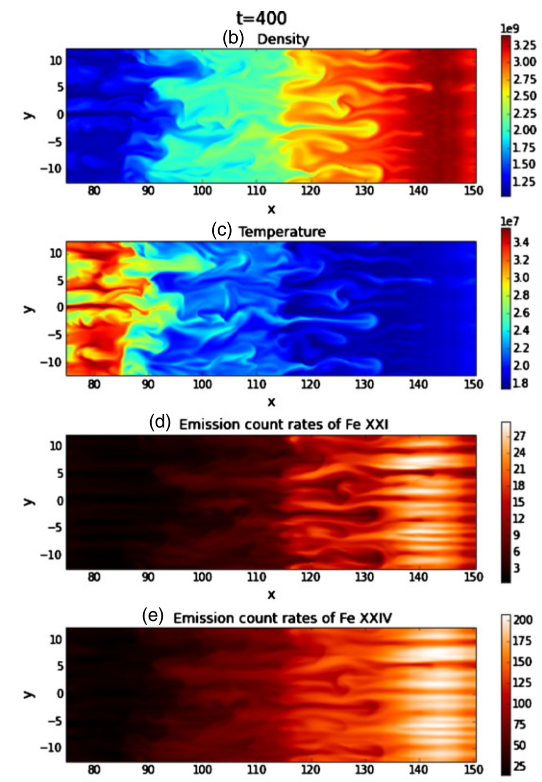
Discussion - Possible scenarios

current sheets

- Downward reconnection outflow can generate high density region (high-β?) above loop arcades: may explain dark supra-arcade downflows observed by McKenzie et al. (Guo + 2014)







continuous downflows hit high density region leading to RT instabilities

Two possible scenarios for rain:

1. High density region can catastrophically cool down, leading to condensations. Due to reconnection the material becomes trapped in the loops leading to rain
2. Large plasmoids may themselves become rain

Discussion - Possible scenarios

current sheets

Application to observations:

- Rain (1&2)
- Darkening observed mostly above loop arcade, simultaneous with rain
- Downward reconnection outflow impinges on loop generating transverse MHD waves (1&2)
- Upward reconnection outflow may correspond to the observed jet. Similar speeds observed for "tadpoles" (1&2)
- Shocks from reconnection outflow may partially warm-up the loop (1&2)
- Clumpy morphology and evolution could be explained by continuous dissipation of resistive currents in plasmoids (2)

Potential issues:

- Slow rain speeds
- Periodicities?
- Slow propagating EUV disturbances (plasmoids?)
- Hot counterpart higher up in the corona? (to do)

Thank you!