What Are the Outstanding Issues with Coronal Jets?

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Main Additional Contributions:
Ronald L. Moore
Navdeep Panesar
David Falconer
Mitzi Adams

Supported by NASA's HGI program, NASA NPP program, and the MSFC/Hinode project.

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Invited Talk

4. Eruptions in the solar atmosphere

What are the outstanding issues with coronal jets?

Alphonse C. Sterling[1]

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Solar coronal jets have been observed in X-rays since the early 1990s. Since then, high-cadence, high-resolution observations of them in the EUV with SDO/AIA, and similar advances in magnetic field information with SDO/HMI, resulted in a revolution in thinking about the mechanisms leading to and driving the jets. It now appears that at least many jets result when a small-scale filament (minifilament) erupts, and the field of that erupting minifilament undergoes magnetic reconnection with pre-existing surrounding field. Moreover, a primary - if not exclusive - mechanism for building the minifilaments and triggering them to erupt is cancelation of magnetic flux in the photosphere near the location from where the minifilament/fluxrope erupts. This presentation will discuss outstanding questions regarding coronal jets, such as the need to verify the above scenario with more data; confirming whether the same mechanism(s) drive jets in all solar regions, including active regions, quiet Sun, and coronal holes; and determining whether there is a threshold condition (or set of conditions) necessary for driven reconnection to result in explosive jets.

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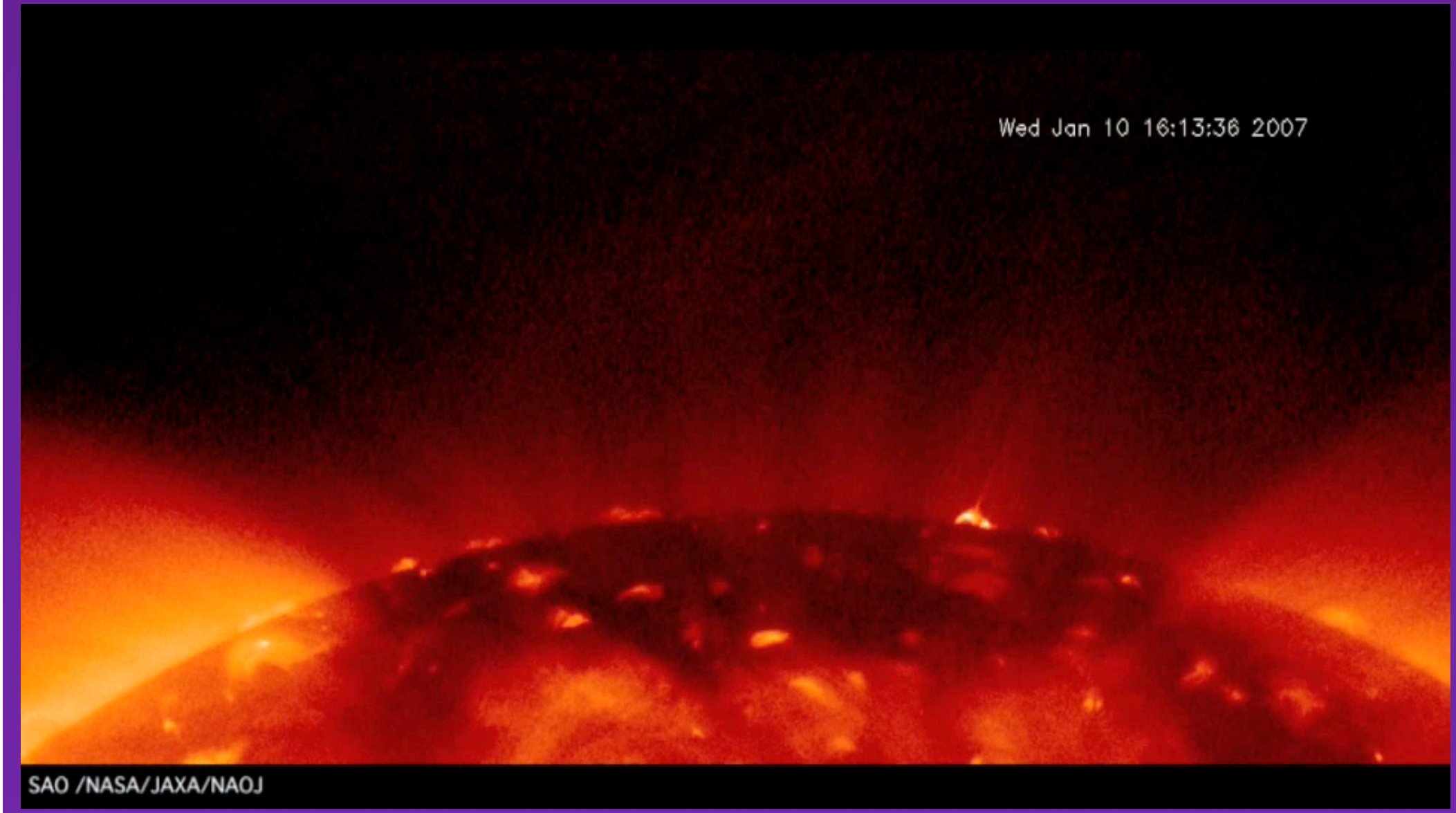
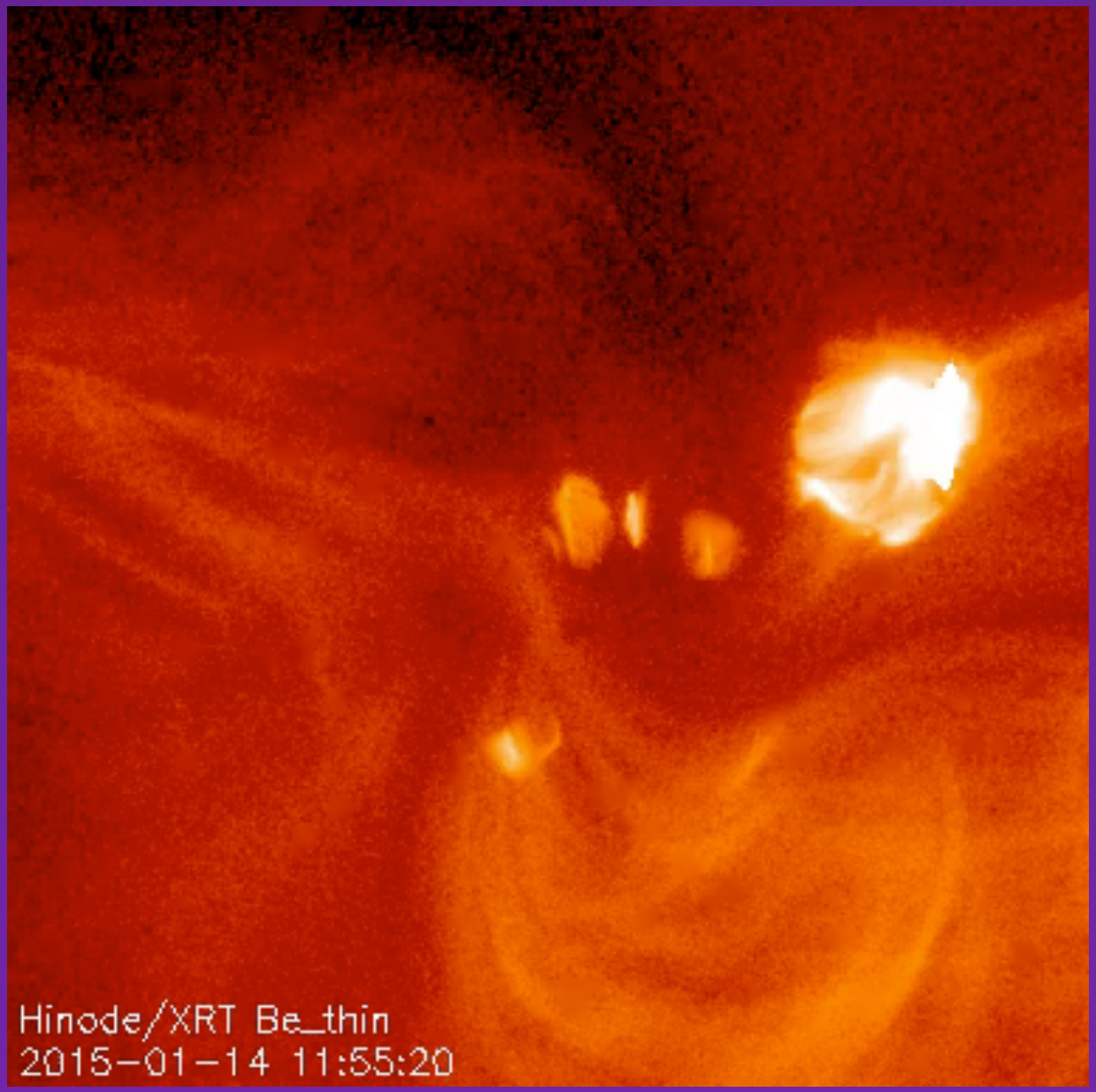


Cirtain et al. (2007)



Sterling et al. (2017)

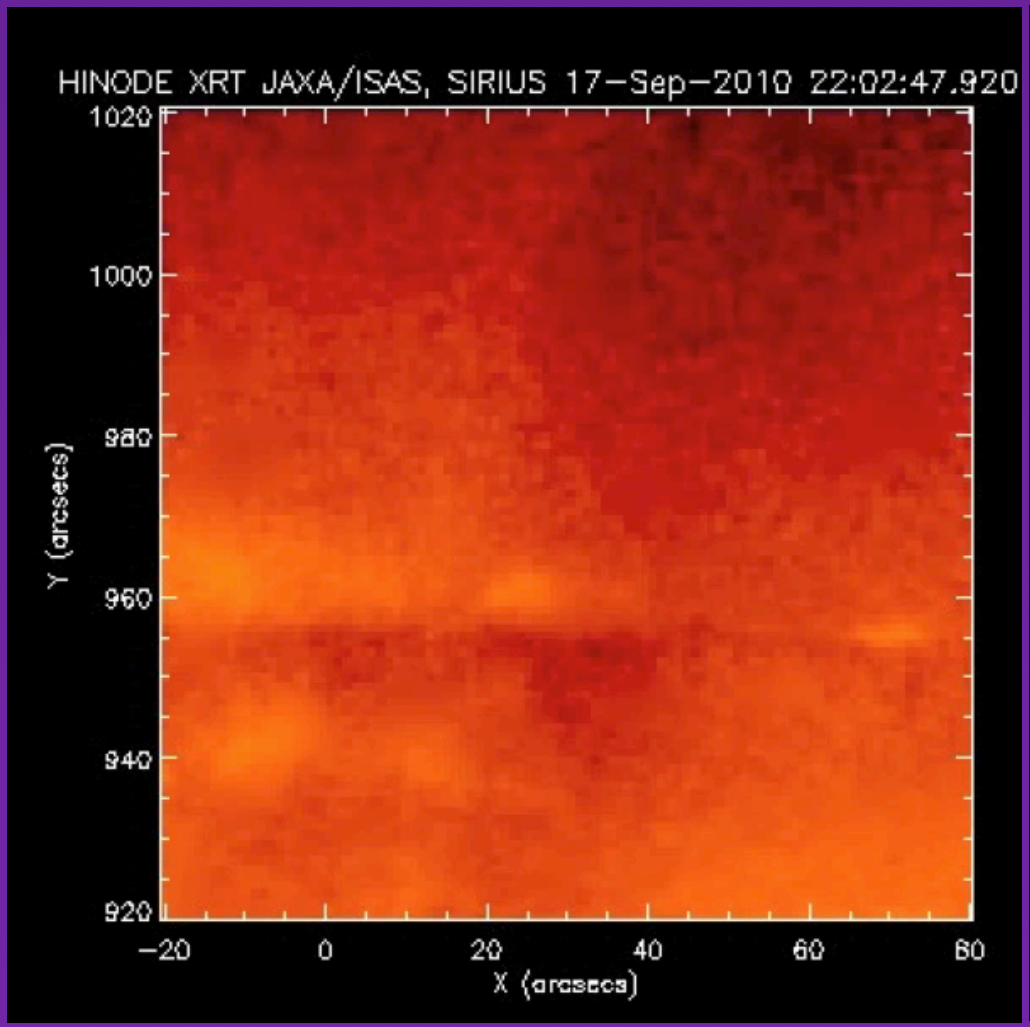
Introduction: Solar X-Ray Jets

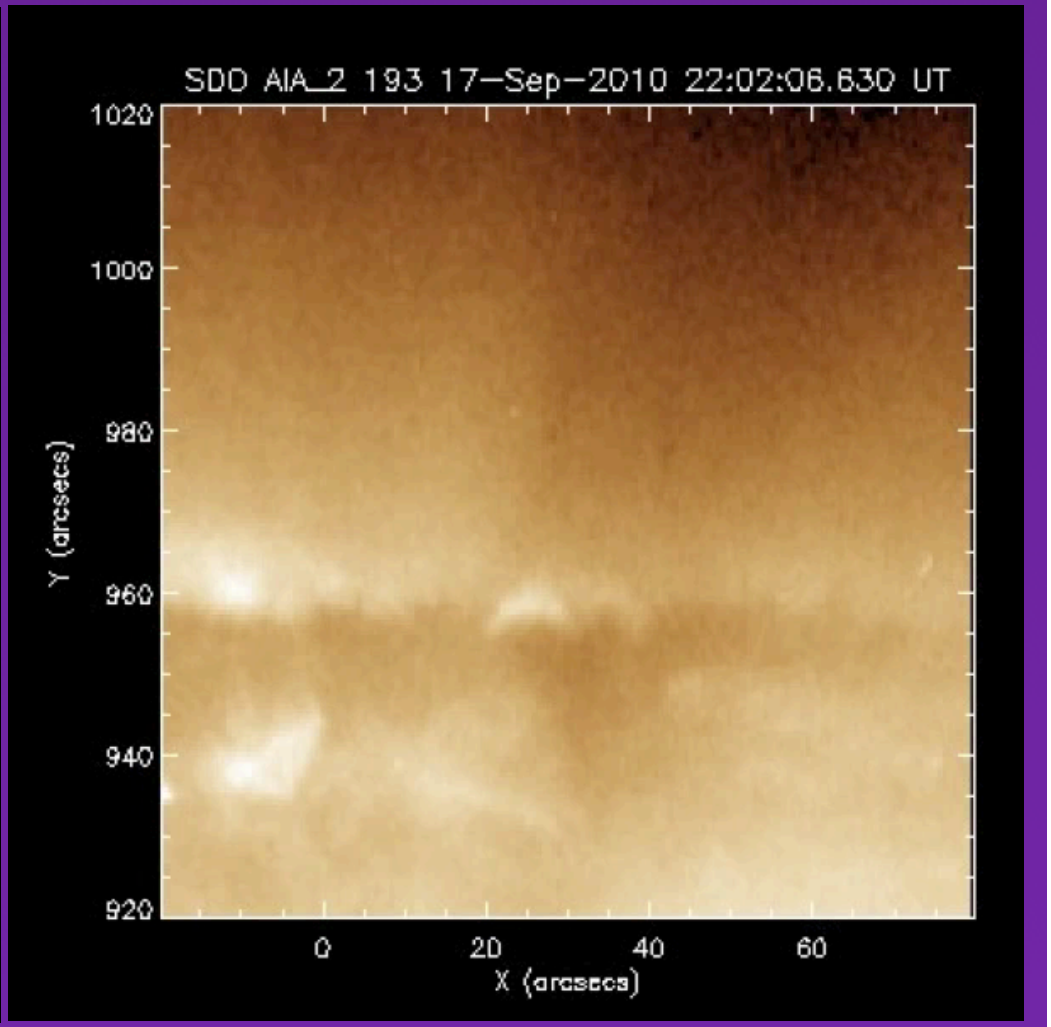
- Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc. Reviewed by Raouafi et al. 2016.)
- Yohkoh (SXT) saw them mainly in active regions.
- Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- Stereo EUVI+coronagraph (Nisticò et al. 2009, 2015).
- In polar coronal holes: size ~50,000 km x 8000 km; rate ~60/day (Savcheva et al. 2007).
- Often have a "hot loop" at the jet's base.
- Previously often-discussed mechanism is based on emerging flux ("emerging-flux model"). (Shibata et al. 1992; Yokohama & Shibata 1995, 1996; see also Moore et al. 2010.)
- Many of the above ideas deduced from SXRs, and pre-SDO AIA observations.

Coronal Hole Jets: "Minifilament eruptions"

XRT

AIA 193





Sterling et al. (Nature, 2015): 20 Polar CH jets.

XRT

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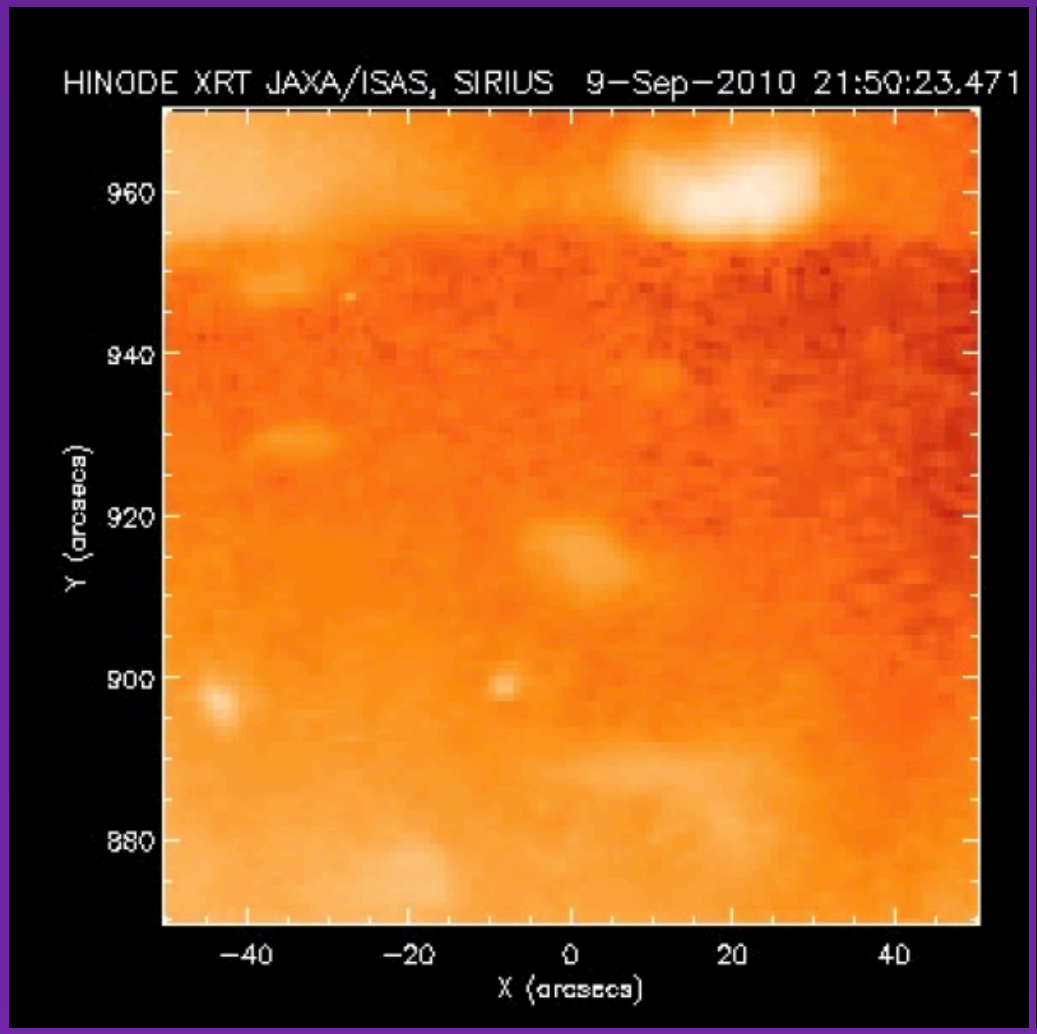
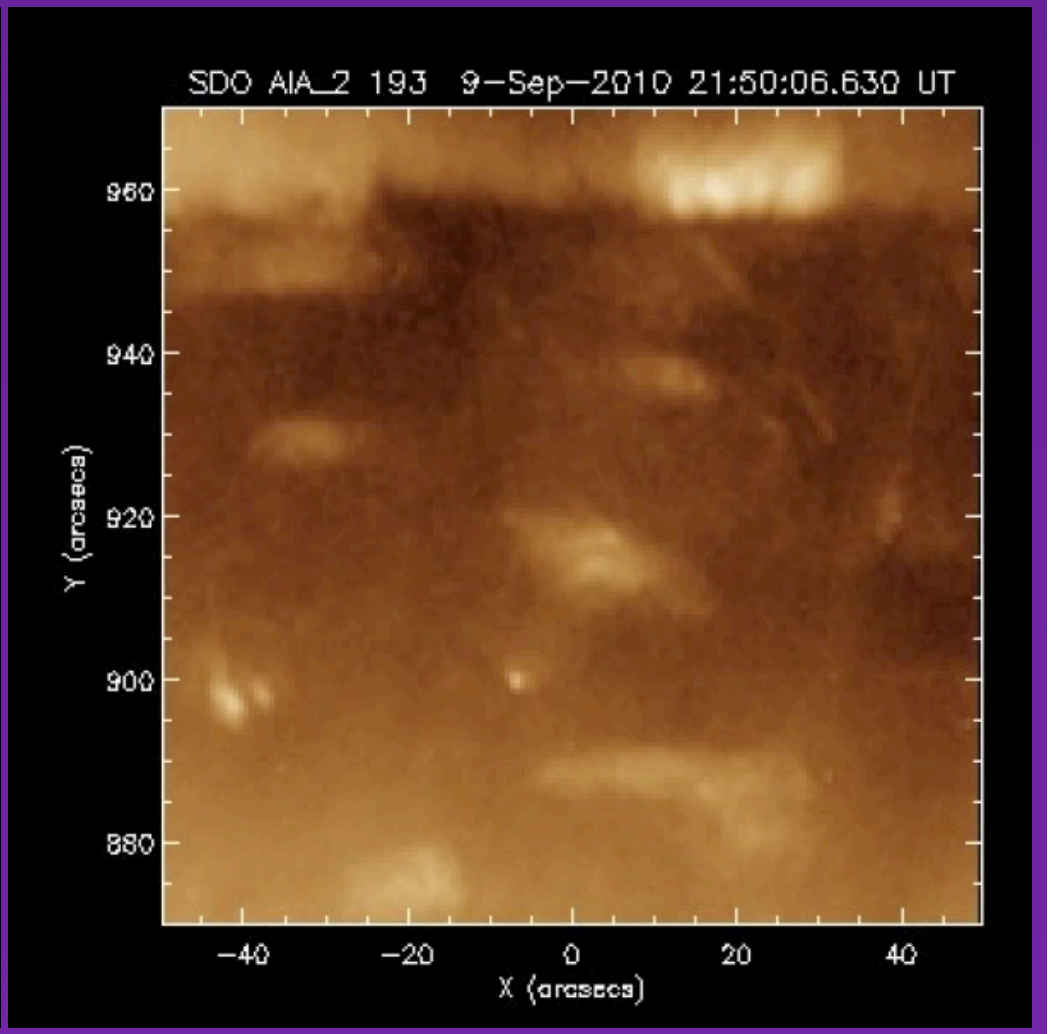
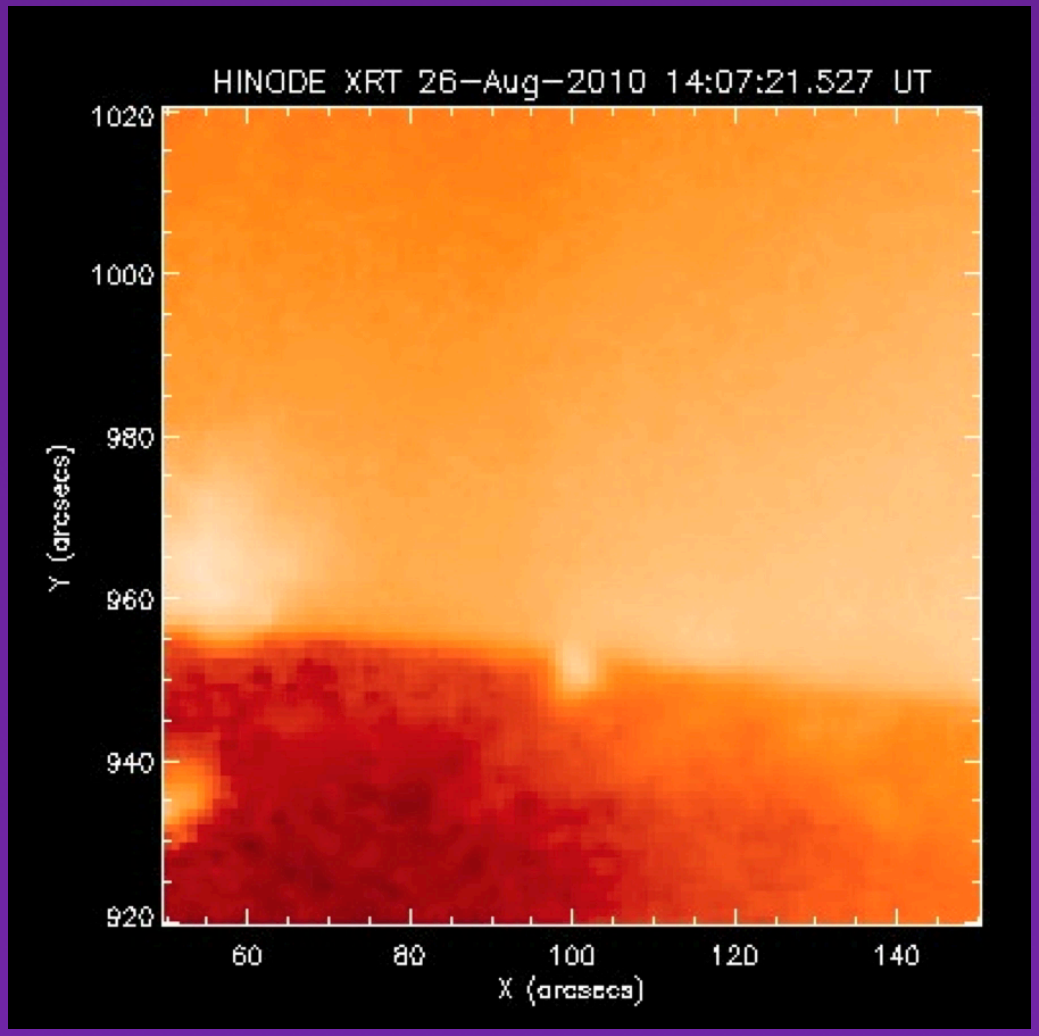


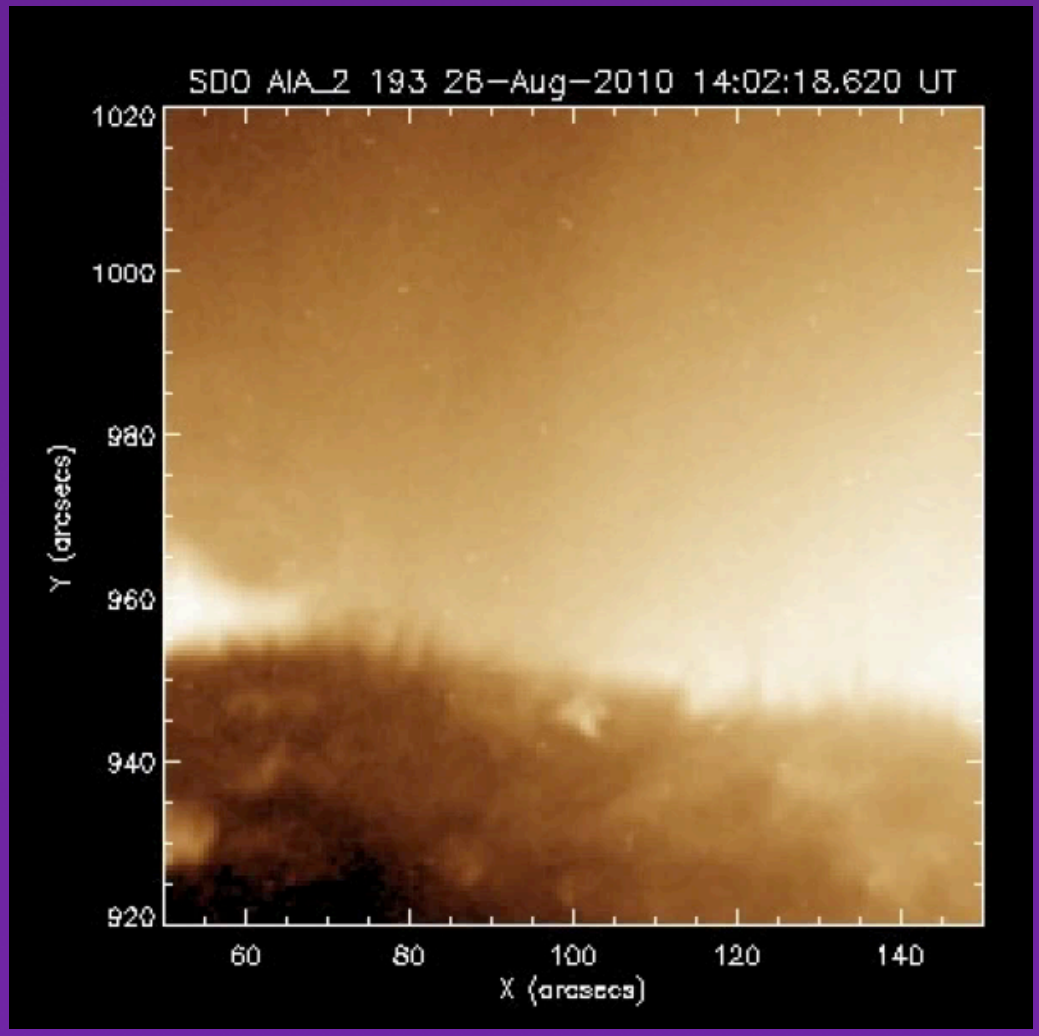


Event 12

XRT

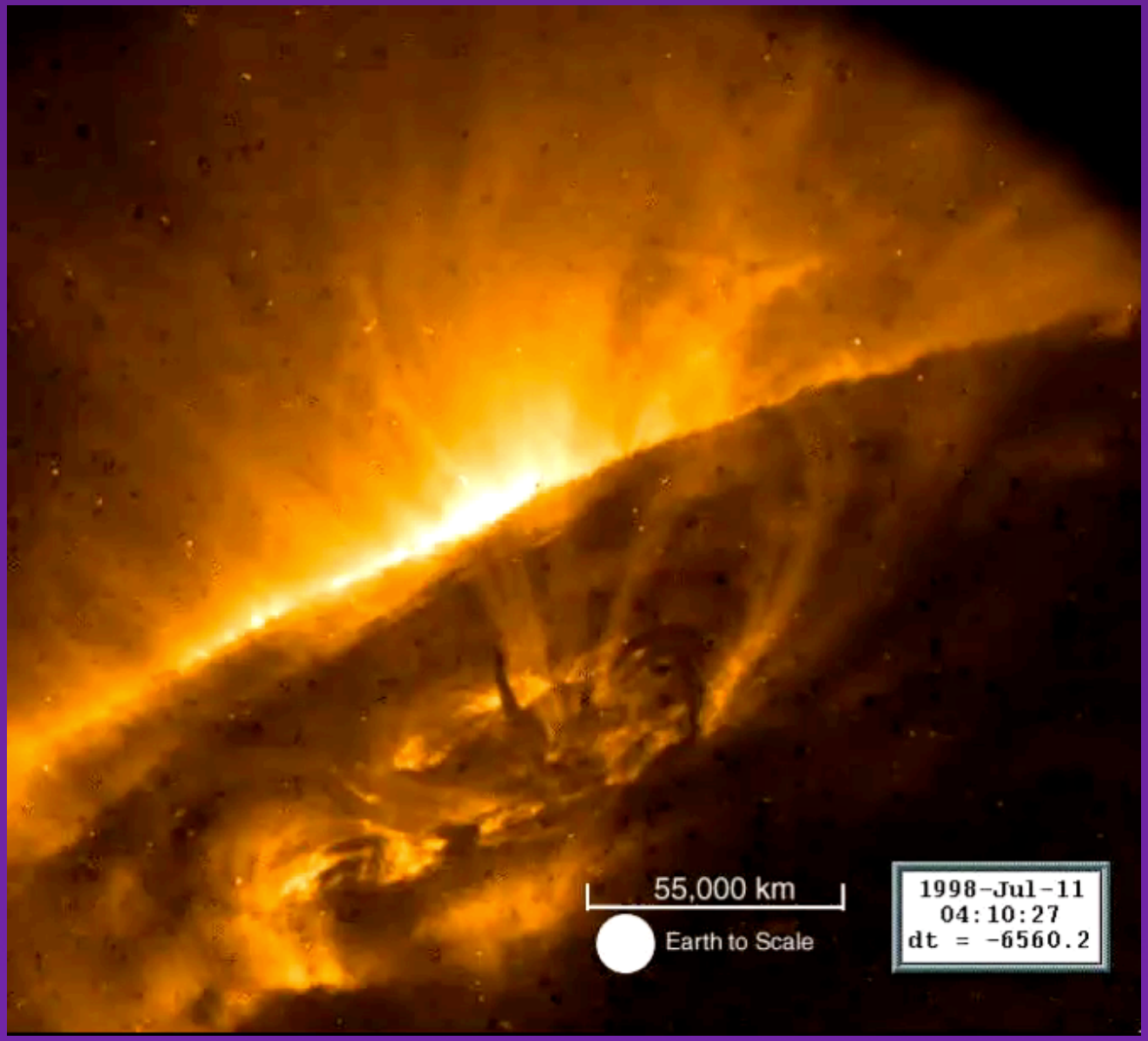
AIA 193





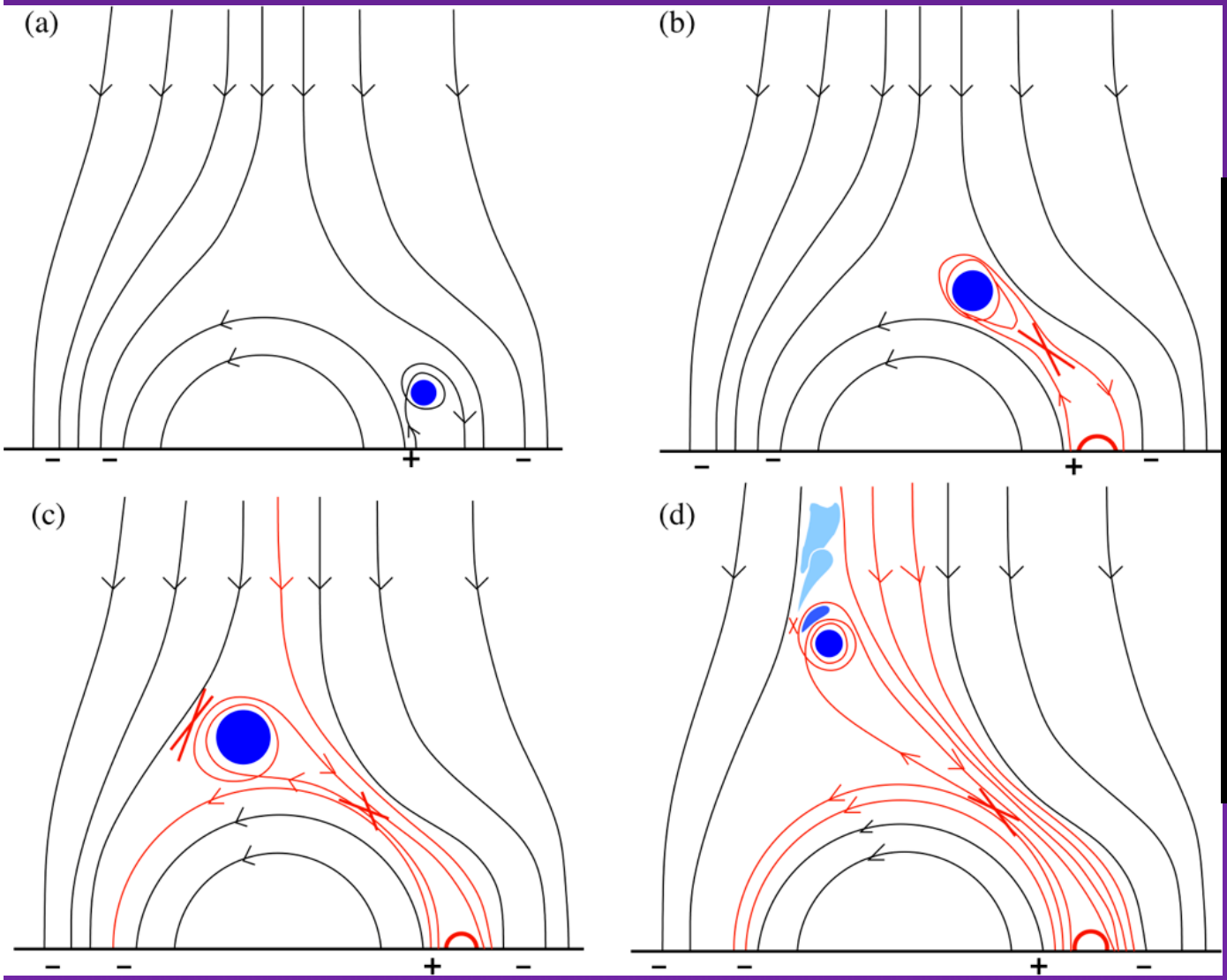
Event 3

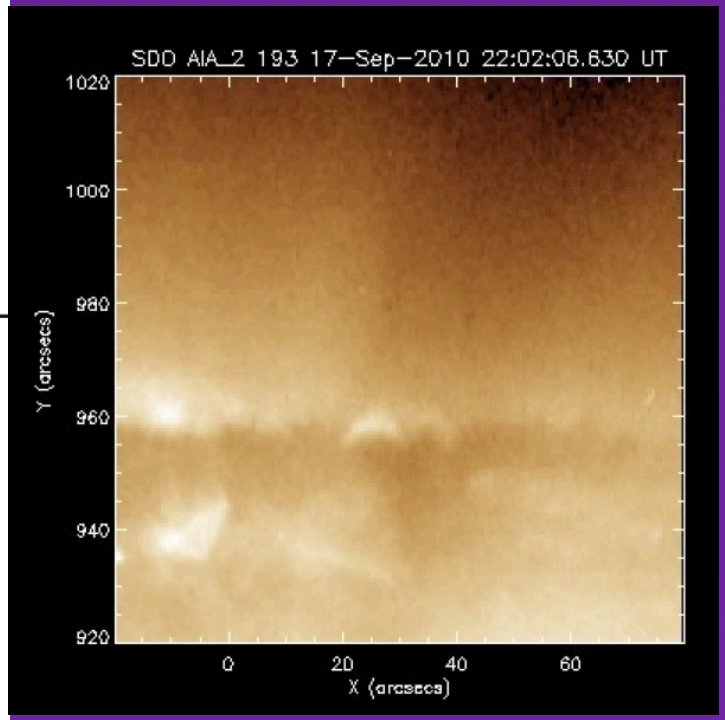
“Normal” Filament Eruption (TRACE)



A. Sterling

Minifilament-Eruption Model for (X-Ray) Jets





Sterling et al. (2015, 2016, 2017)

Quiet Sun jets work the same way (Panesar et al. 2016b)

Recently modeled by Wyper et al. 2017, 2018)

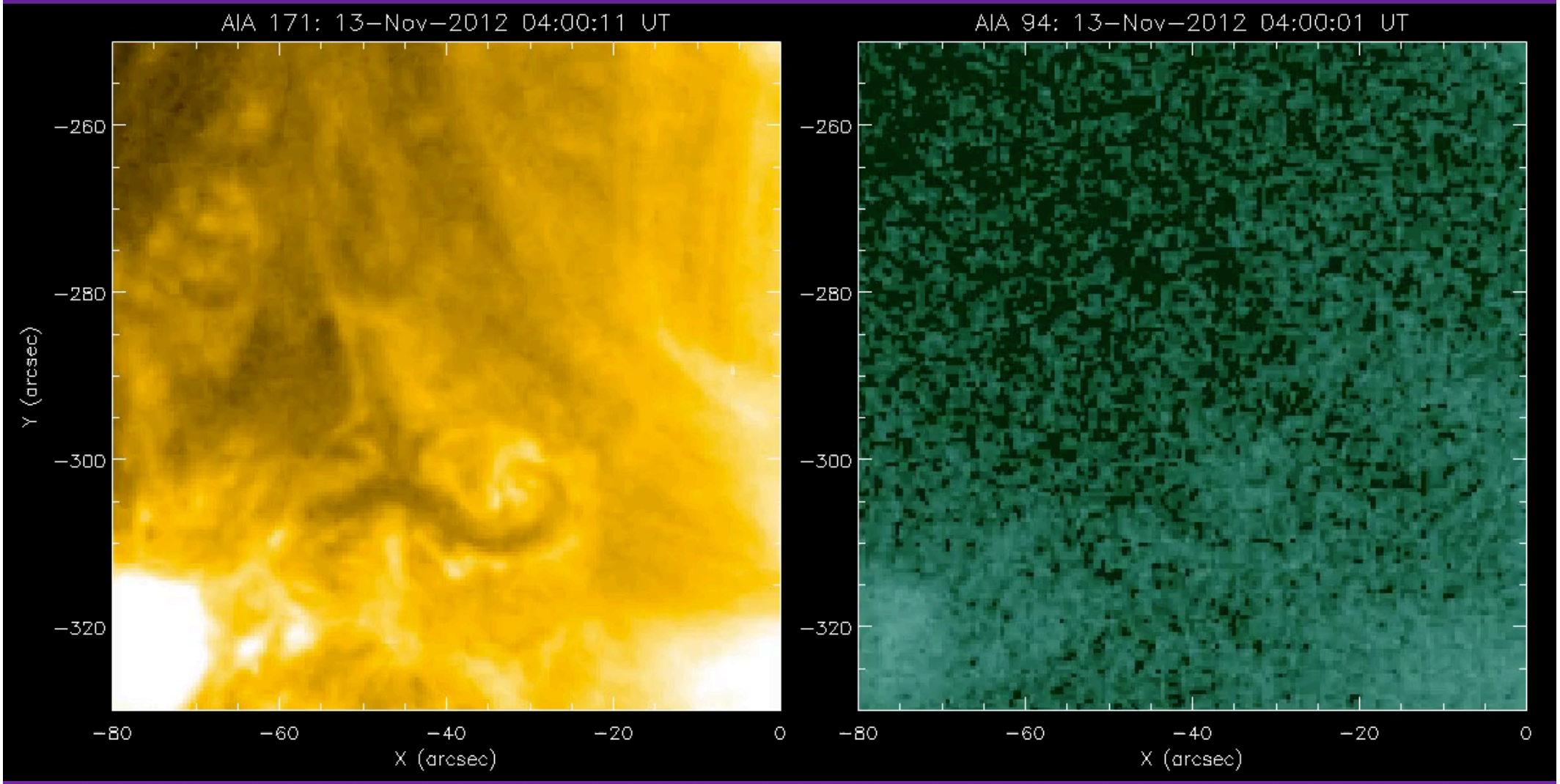
What Causes Miniature-Filament Eruptions?

- Did not look on-disk in this study, due to polar view. But….
- Adams et al. (2014) found no emerging flux in the jet region. Filament erupted from location where flux canceled. (Also, Hong et al. 2014.)
- Several other found cancelation leading to jets (e.g., Hong et al. 2011; Huang et al. 2012; Young & Muglach 2014a,b).
- Some others found jets from location of emerging flux+flux cancelation (e.g., Liu et al. 2011; Shen et al. 2012, 2017; Hong et al. 2012; Li et al. 2015).

Quiet Sun Jets — Similar to PCH jets

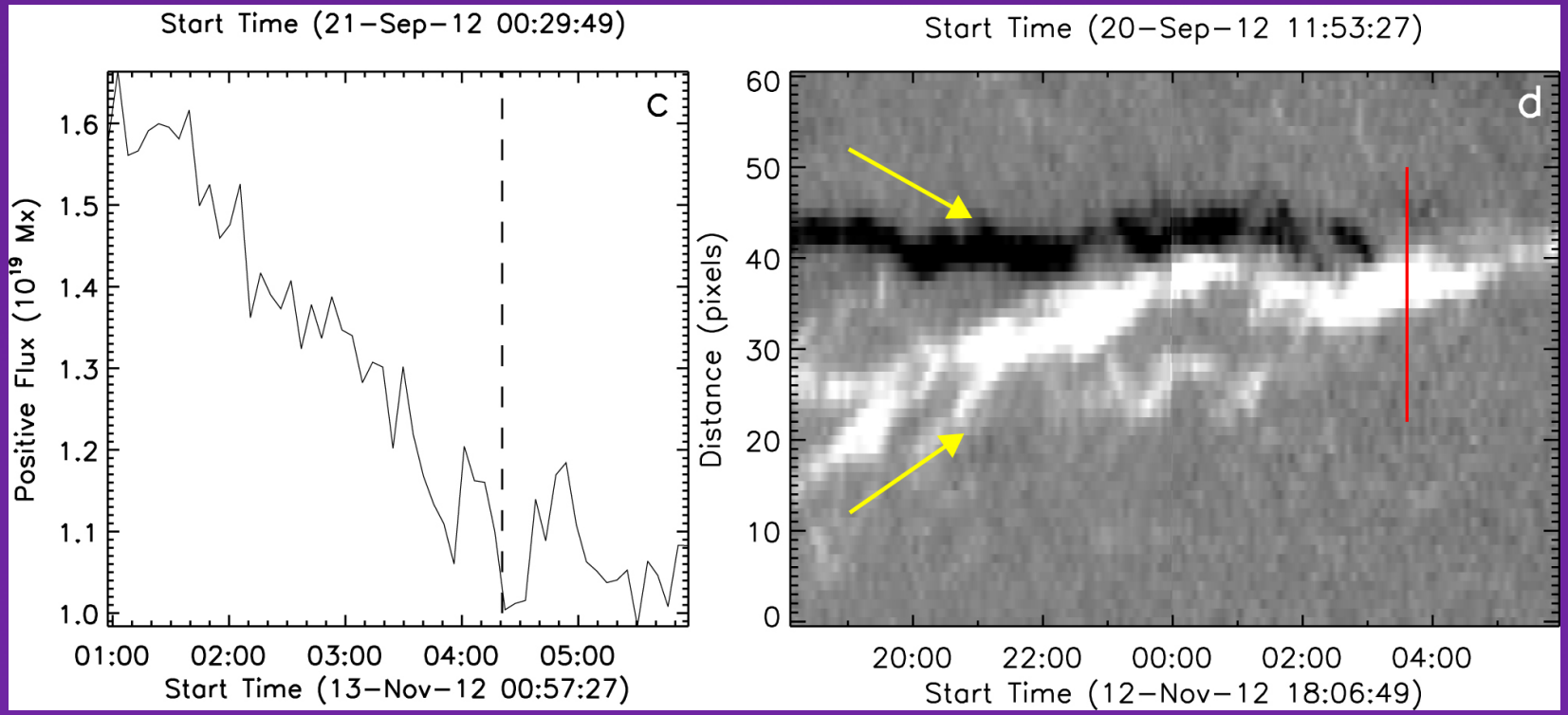
AIA 171

AIA 94



(Panesar et al. 2016b)

Same for QS jets: Occur at cancelation sites.



(Ave. Cancelation rate: ~10^{18} Mx/hr.)

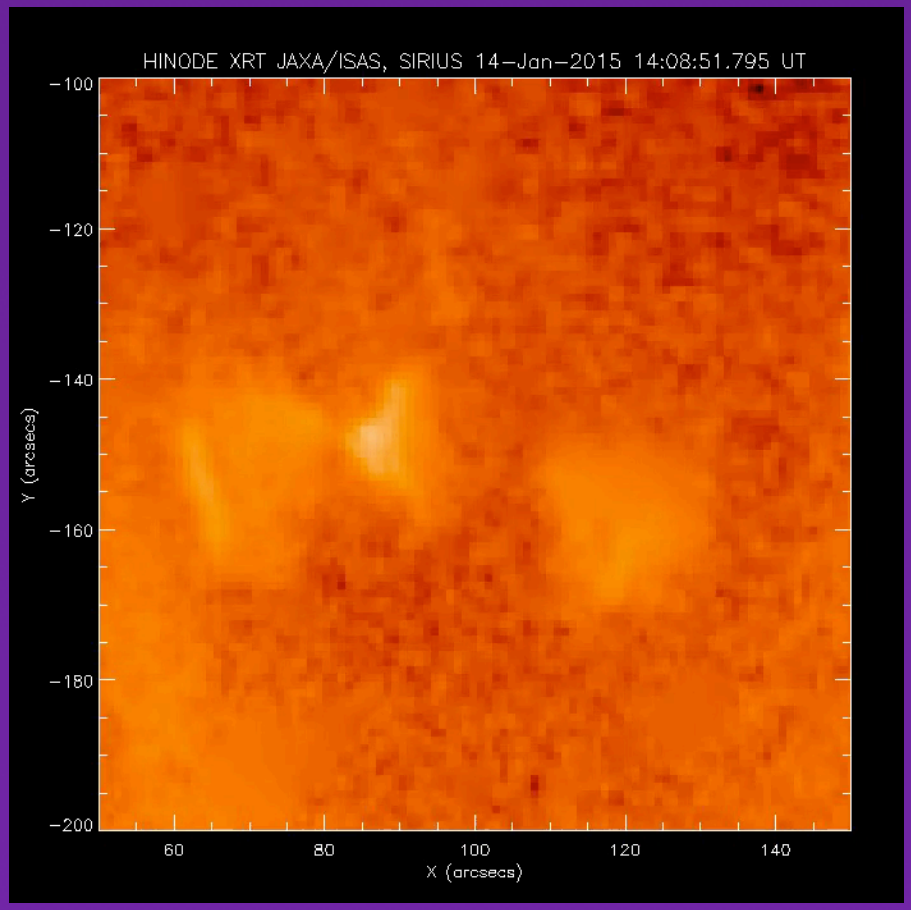
Panesar, Sterling, & Moore (2016b) — 10 jets.

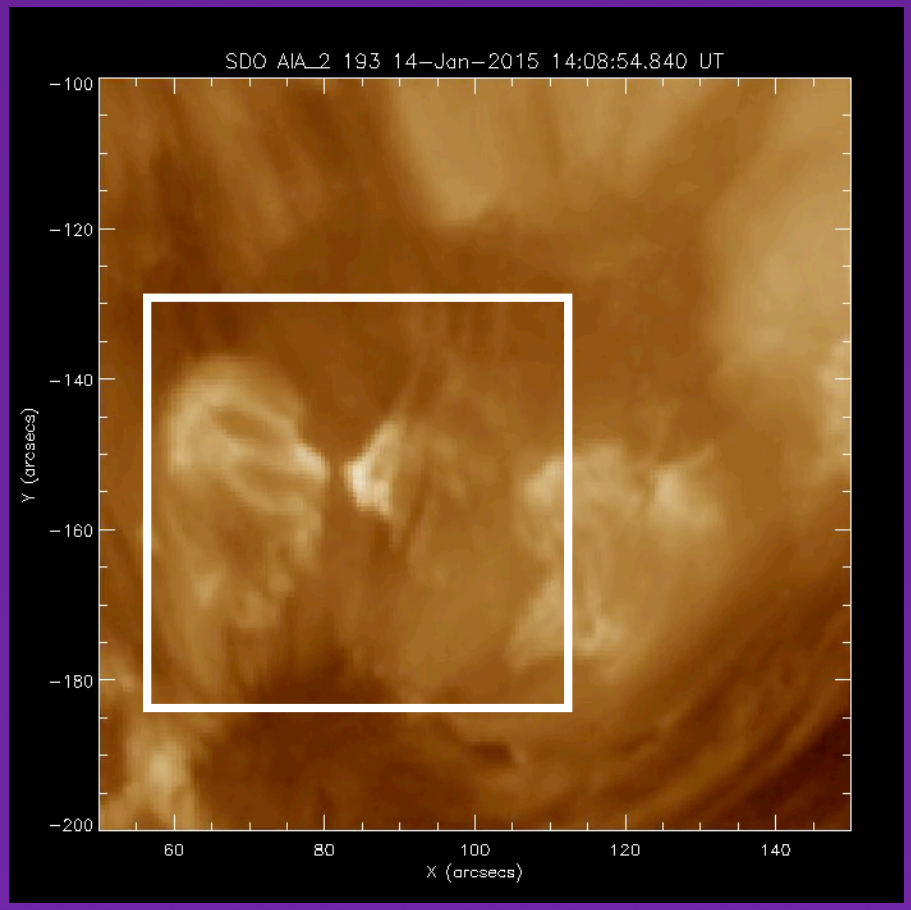
Active Region Coronal Jets

- Yohkoh studies (Shibata et al., Shimojo et al., many others).
- Raouafi et al. (2016).
- Mulay et al. (2017a, b) - AR-jet temps/emissions.
- Hong et al. (2017) — Minifil. eruption —> AR jet & Type III burst (also Shen et al. 2017, Moroccan et al. 2017).
- Panesar et al. (2016a); Sterling et al. (2016, 2017).

An Example: AR Jets

- 14 Jan 2015 (NOAA AR 12259), AIA, HMI, Hinode, IRIS.
- Sterling et al. (2017)



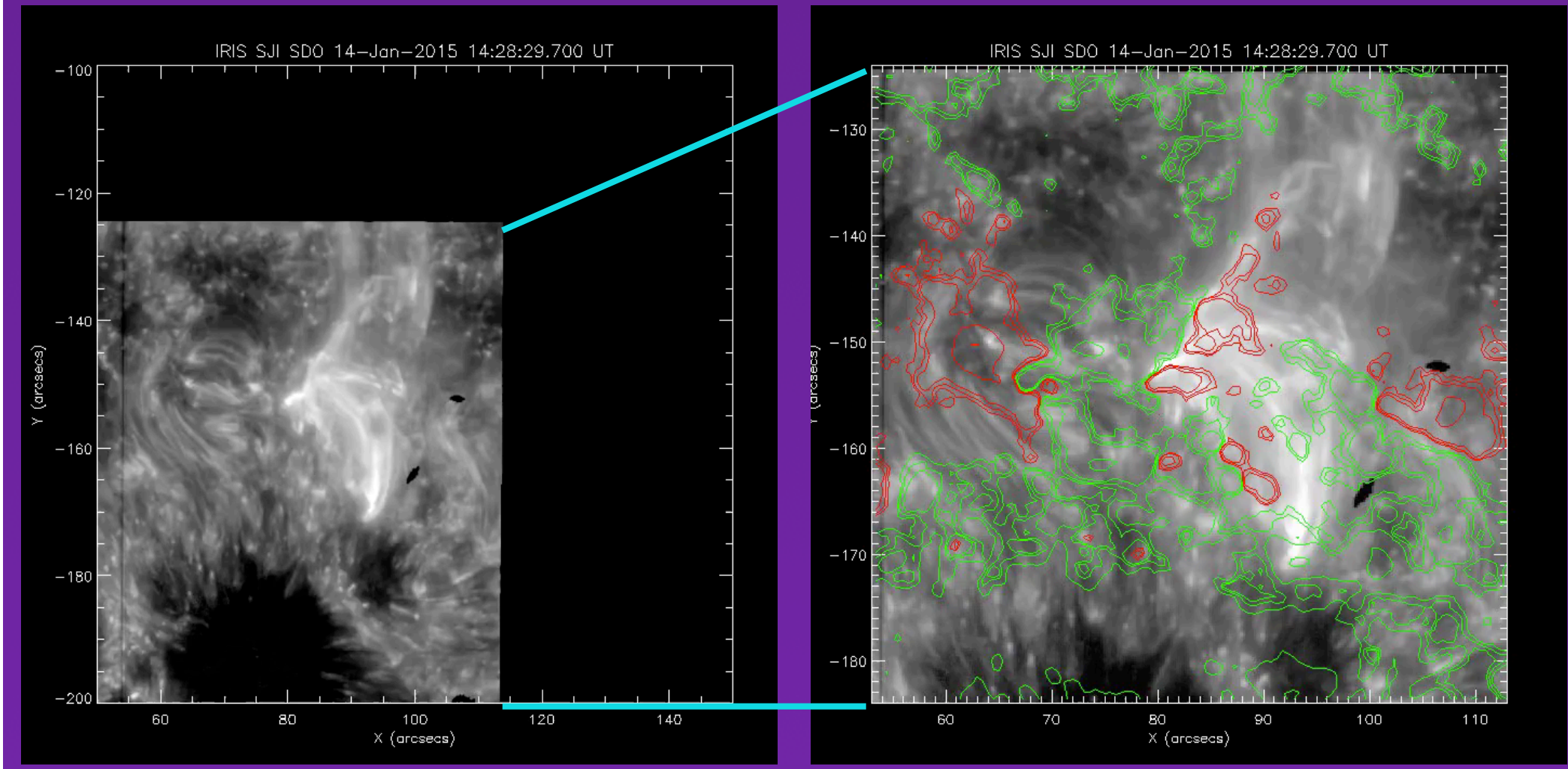


Hinode/XRT

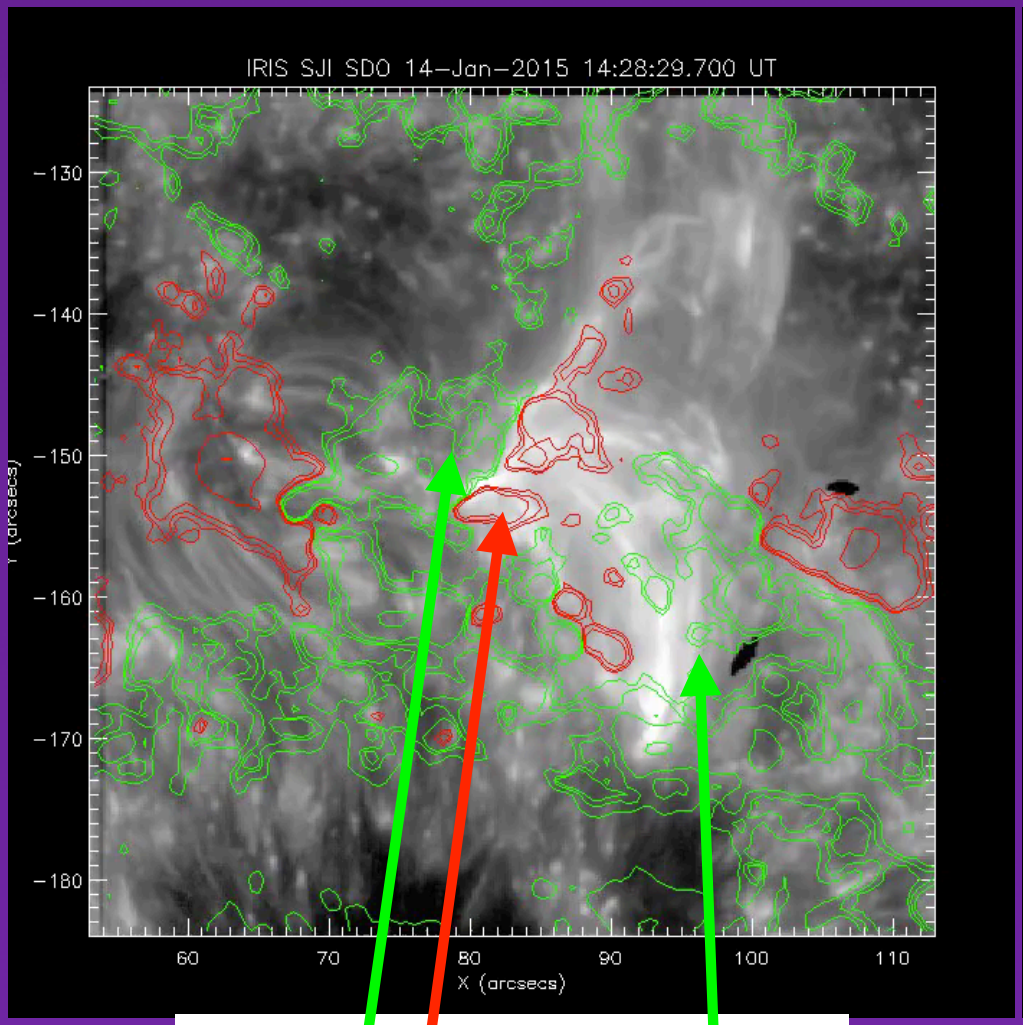
AIA 193

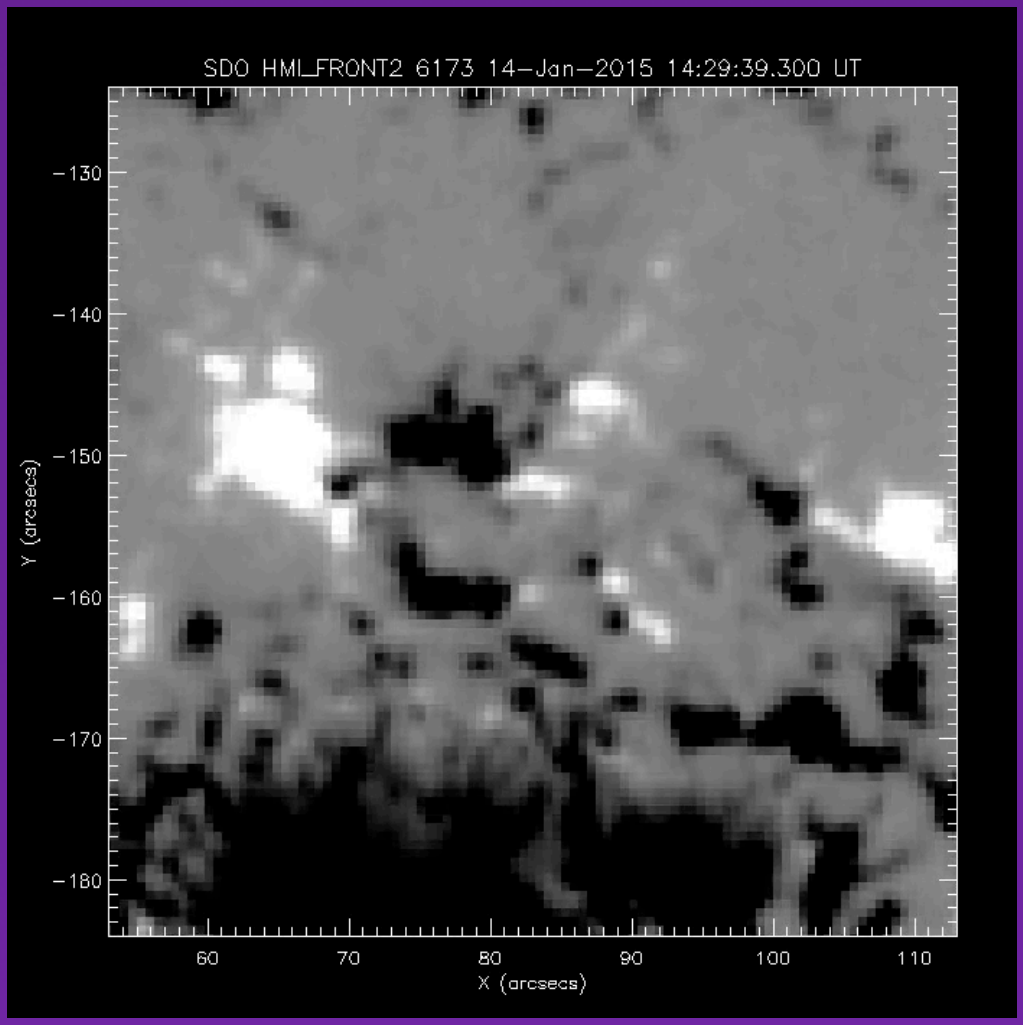
Minifilament hard to see (absent?). Work the same way??

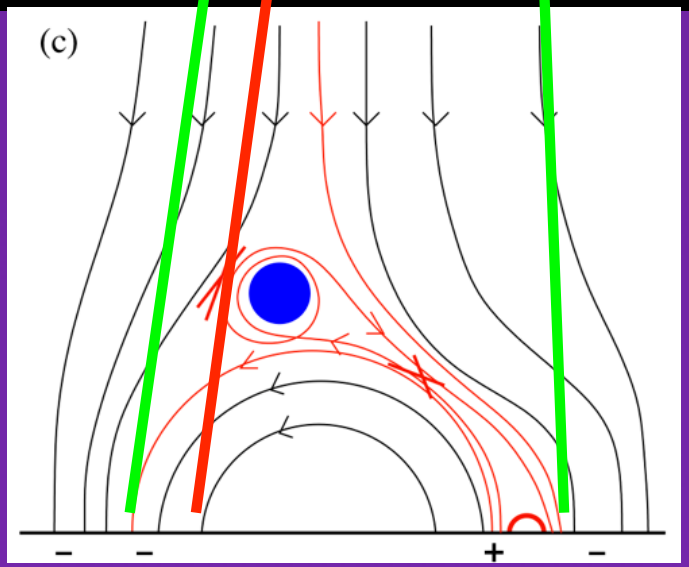
Coronal Jets in Active Regions



Sterling et al. (2017)

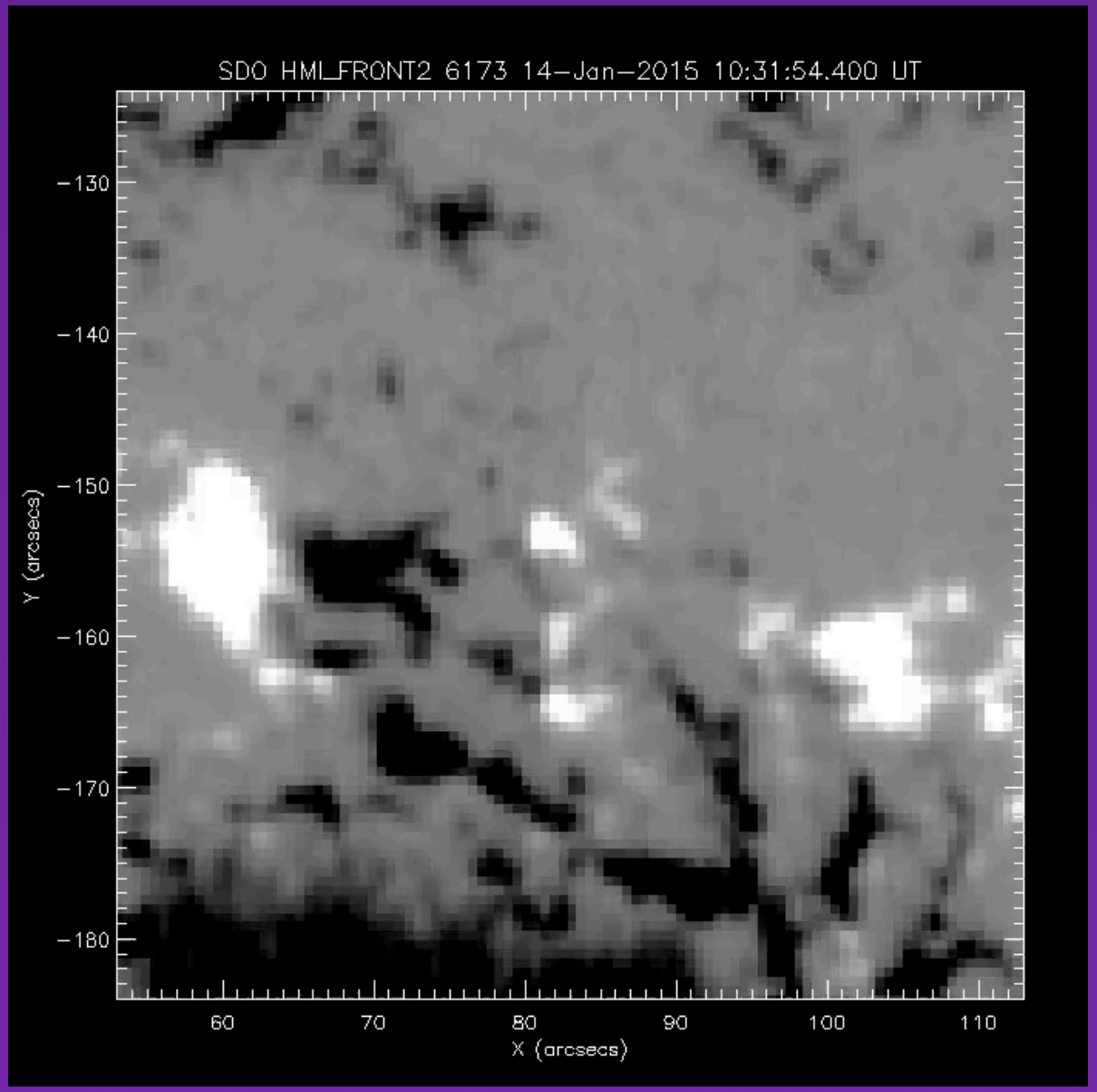






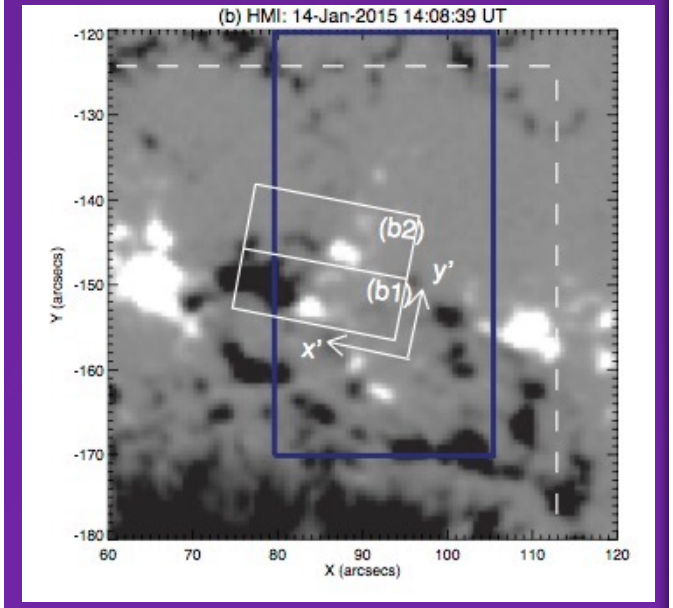
Sterling et al. (2017)

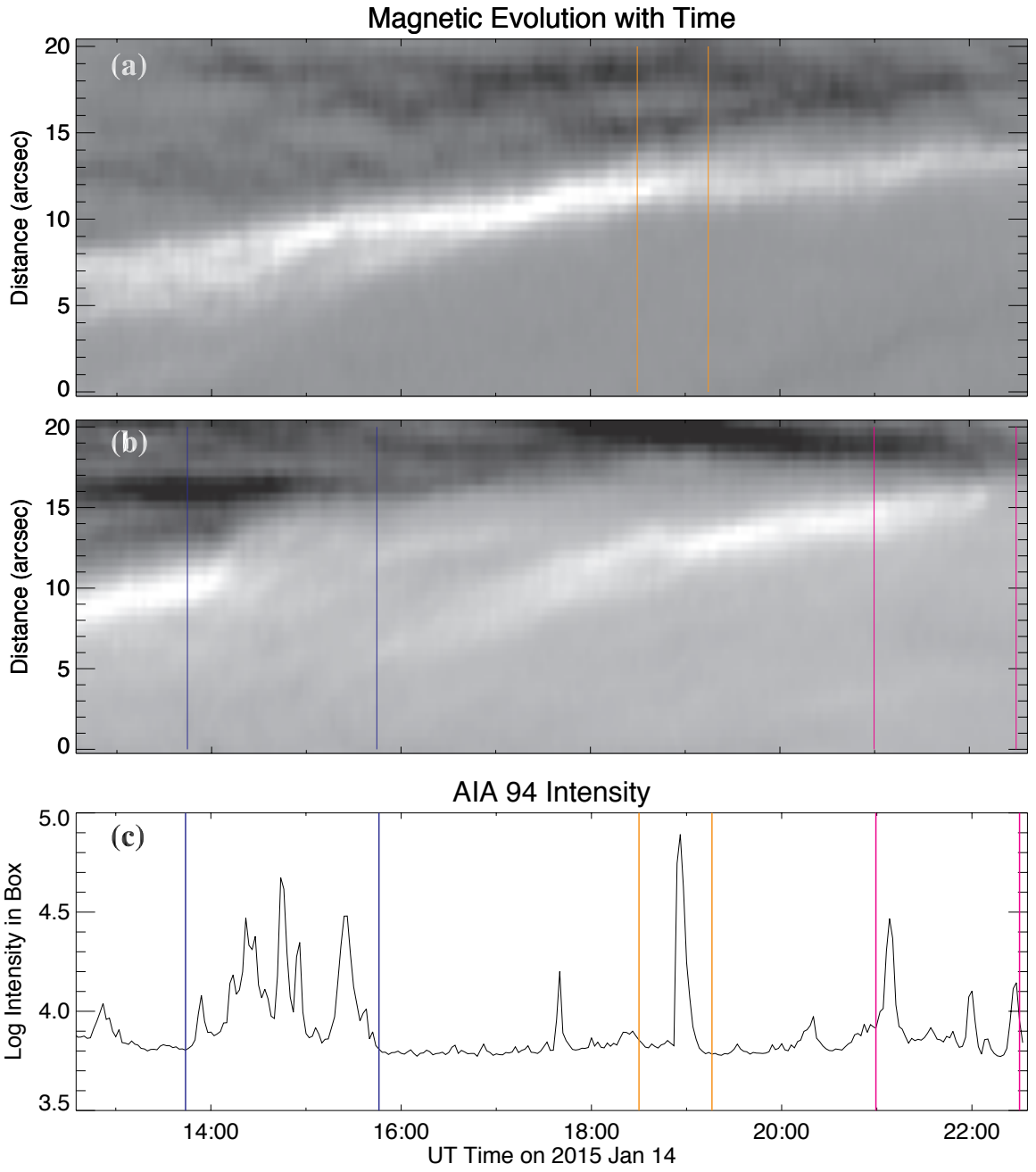
HMI of jetting region



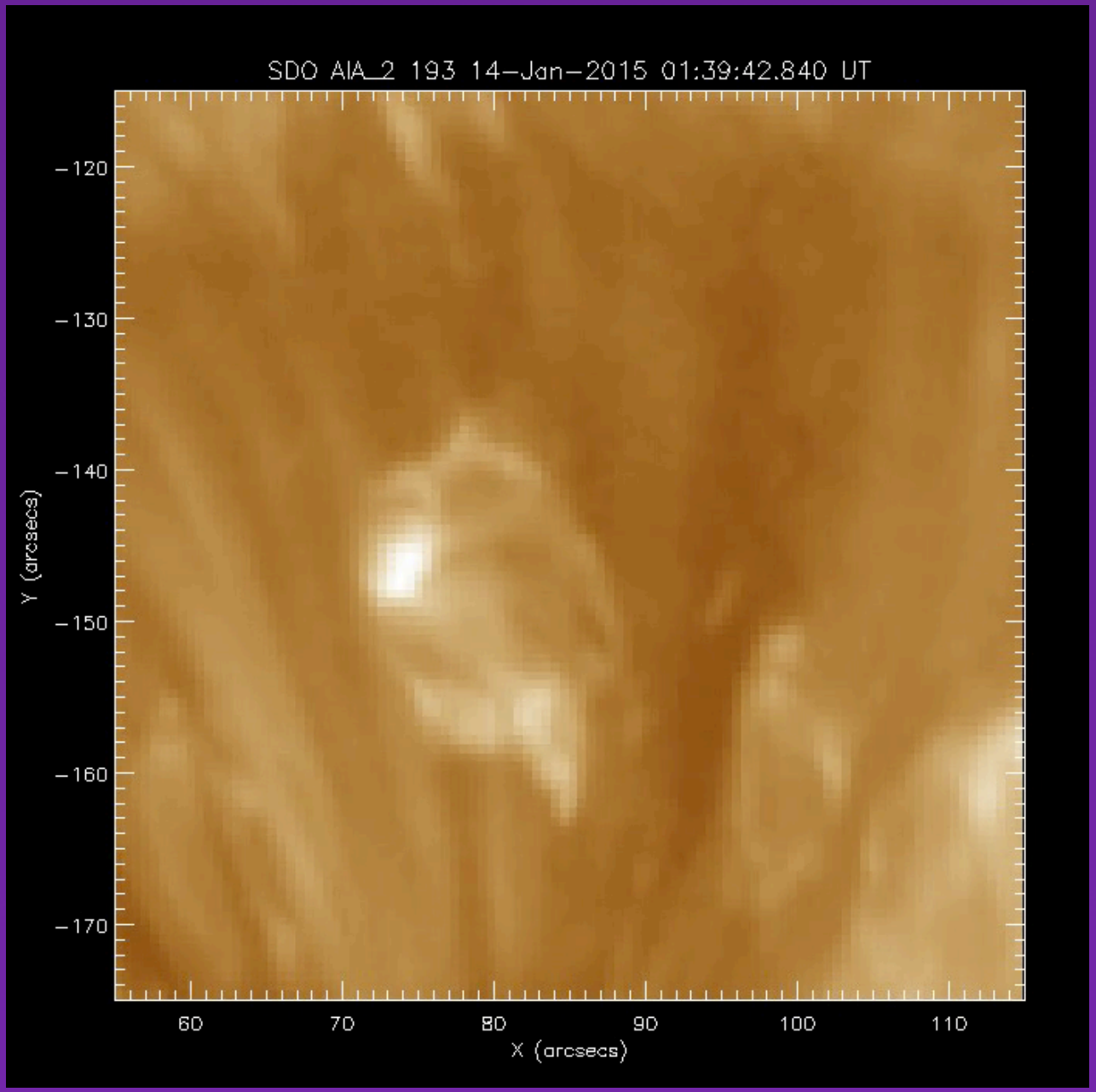
Jets occur at *flux cancelation* locations!

AR jets (Sterling et al. 2017)





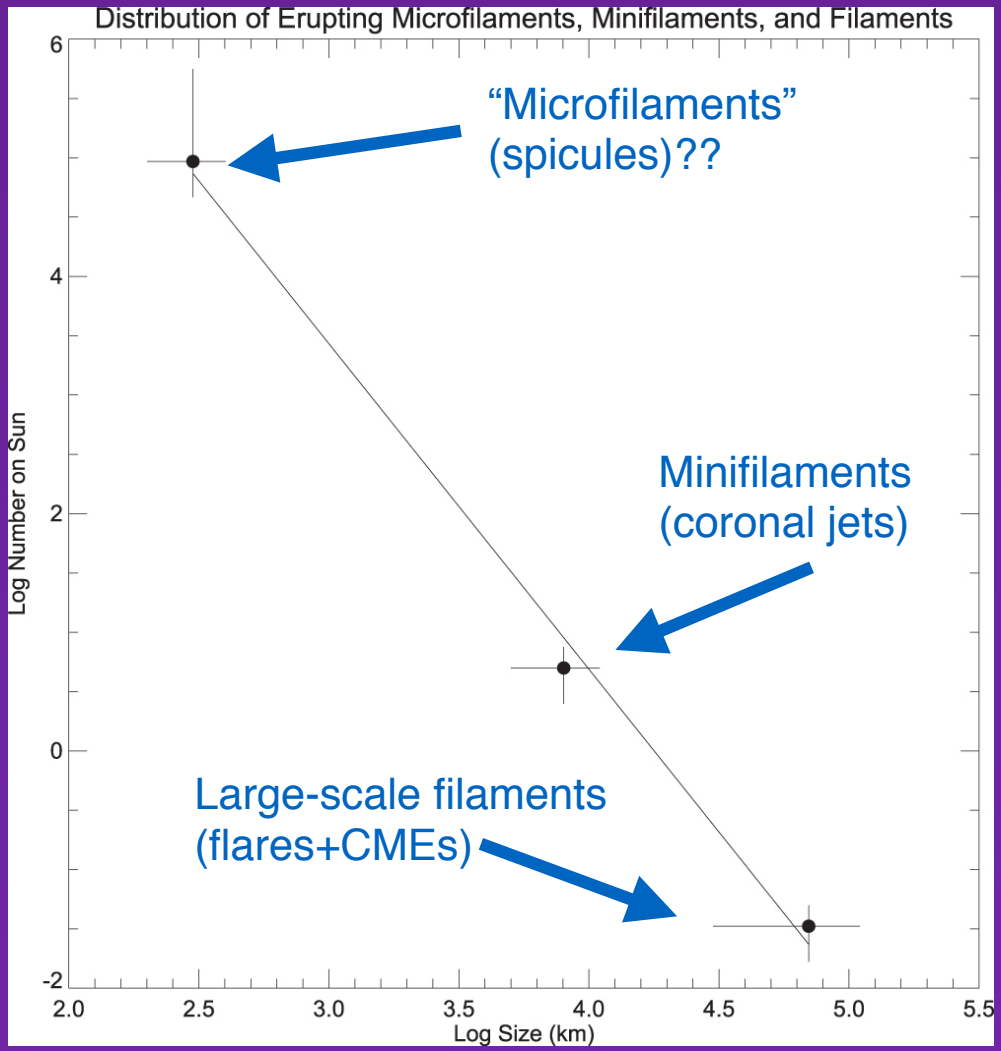
Minifilament “strand” visible from neighboring region, slightly different time.



AIA 193

Do Jets Exist on Smaller Size Scales?

Filament-Like Feature Eruptions on Smaller Scales??



Log Number of Eruptions

Log "Filament" Size

Sterling & Moore (2016)

"Jetlets" in plumes (Raouafi & Stenborg 2014)?

("Jetlets" in more general network?? Panesar talk).

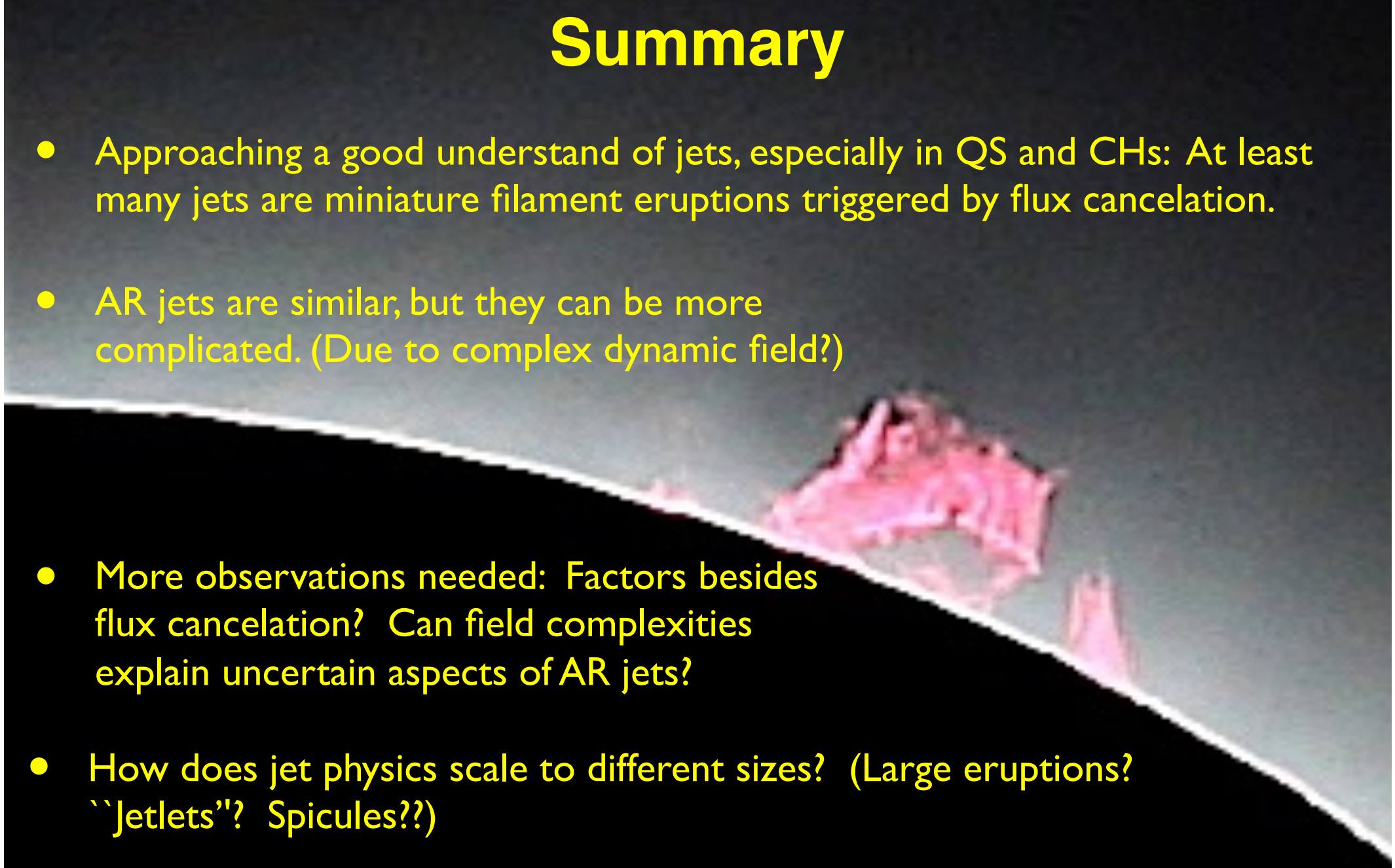
Some Outstanding Questions

- What causes jets? Strong evidence that it is flux cancelation in quiet Sun and CHs (20+ events; Panesar talk). Still must study more! (Shear only?? Kumar et al. 2018.)
- AR jets: Minifilaments sometimes less obvious (absent?). Also, ``brightest'' bright points sometimes in unexpected locations. (Result of complex field, multiple eruptions? Sterling et al. 2016, 2017.) Frequently see cancelation+emergence.
- How do jets scale to smaller structures (contribute to coronal heating? (Moore et al. 2015)).
- If most jets result from flux cancelation, what about larger eruptions? (Field complexities might disguise the key processes; Sterling et al. 2018.)
- Role of twist in powering jets, and "narrow CMEs."

Summary

- Approaching a good understand of jets, especially in QS and CHs: At least many jets are miniature filament eruptions triggered by flux cancelation.

- AR jets are similar, but they can be more complicated. (Due to complex dynamic field?)



- More observations needed: Factors besides flux cancelation? Can field complexities explain uncertain aspects of AR jets?

- How does jet physics scale to different sizes? (Large eruptions? ``Jetlets''? Spicules??)

- Needed: Jet simulations based on minifilament eruptions (e.g. Wyper et al), and *flux cancelation*!

Image:
Alphonse Sterling
21 August 2017,
Lewisville, Idaho