Recent and Forthcoming Studies of Solar Coronal Jets

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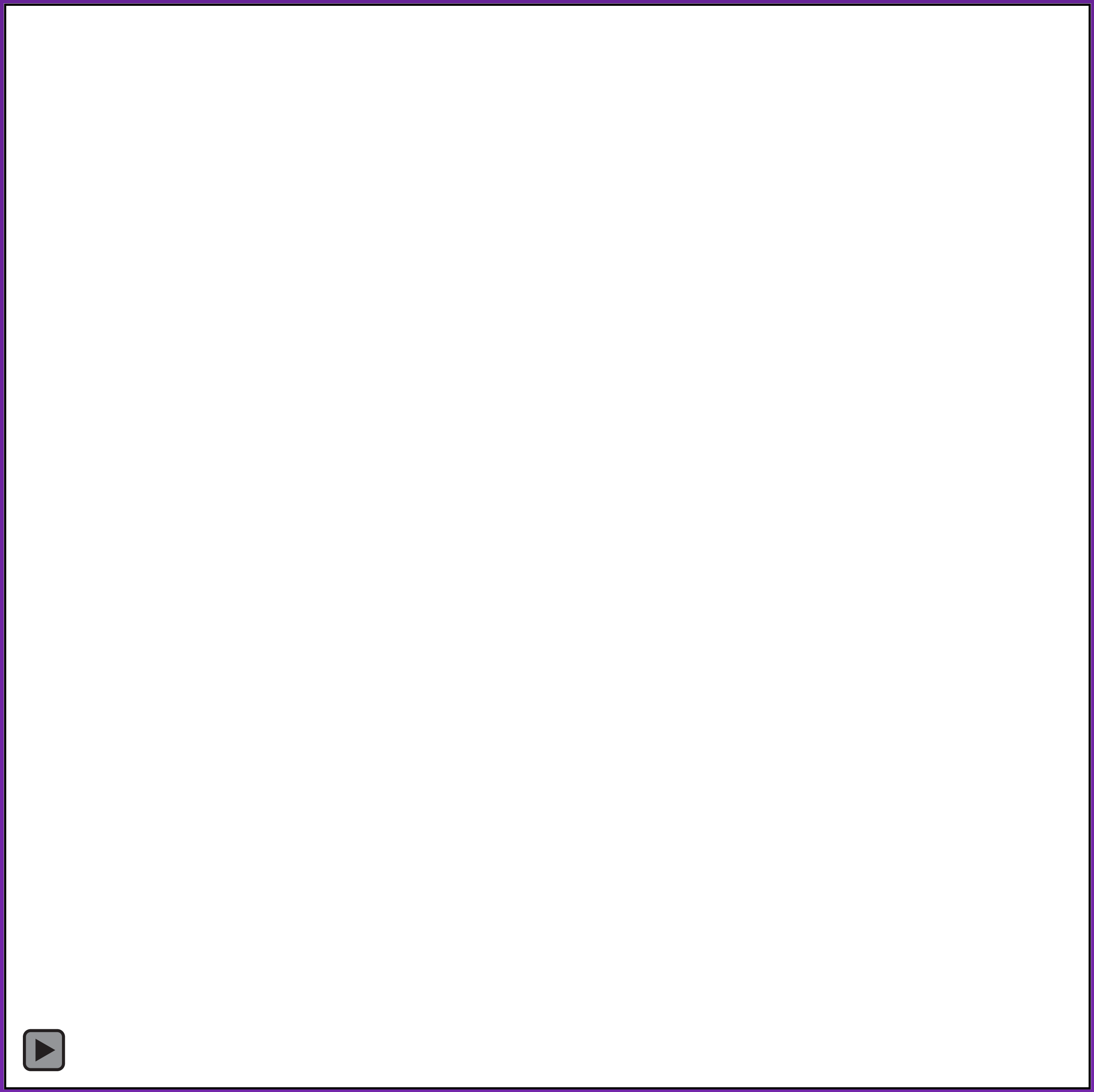
Cirtain et al. (2007)

Introduction: Solar X-Ray Jets

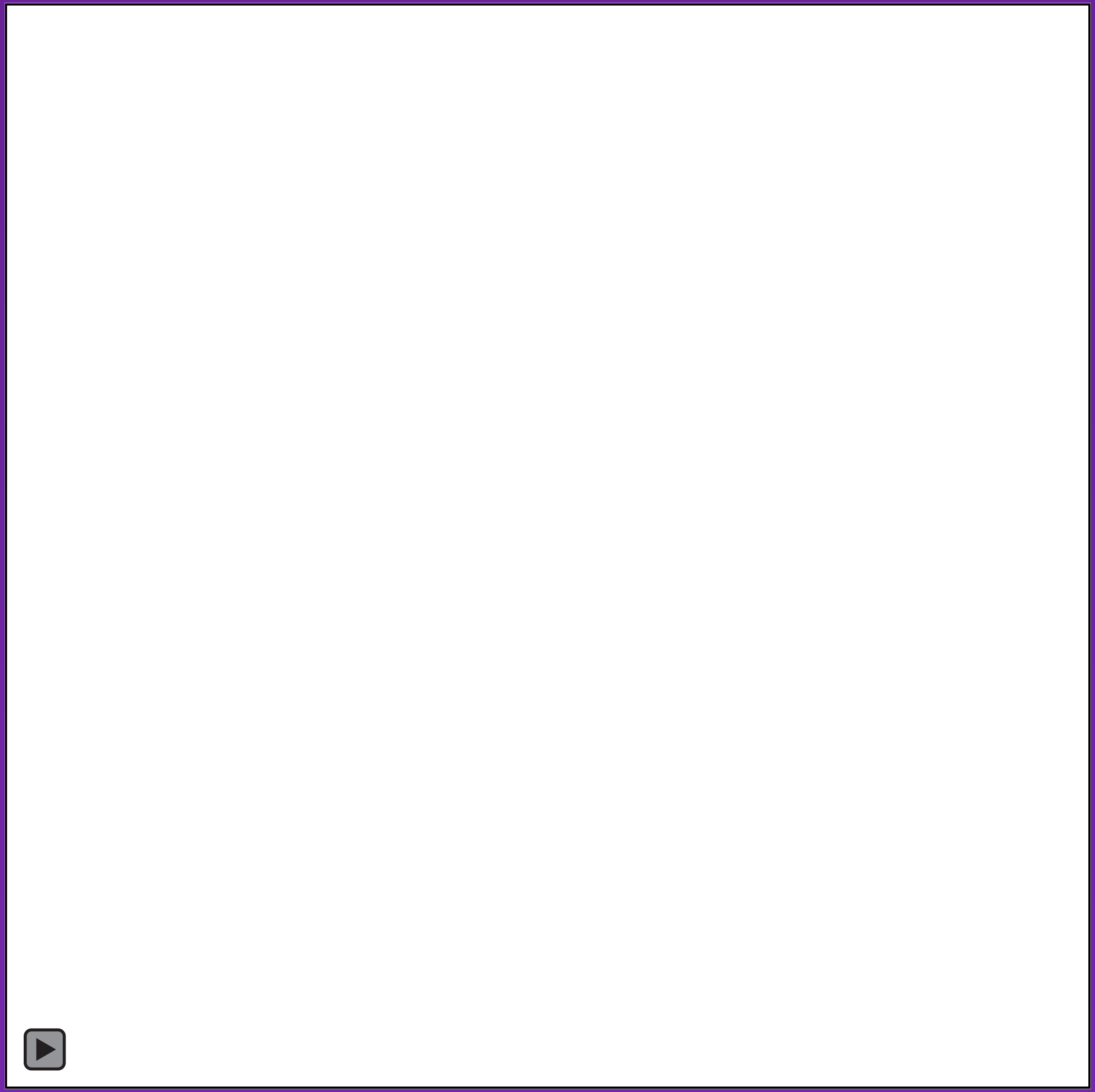
- Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc. Reviewed by Raouafi et al. 2016.)
- Yohkoh (SXT) saw them mainly in active regions.
- Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- In polar coronal 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; 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



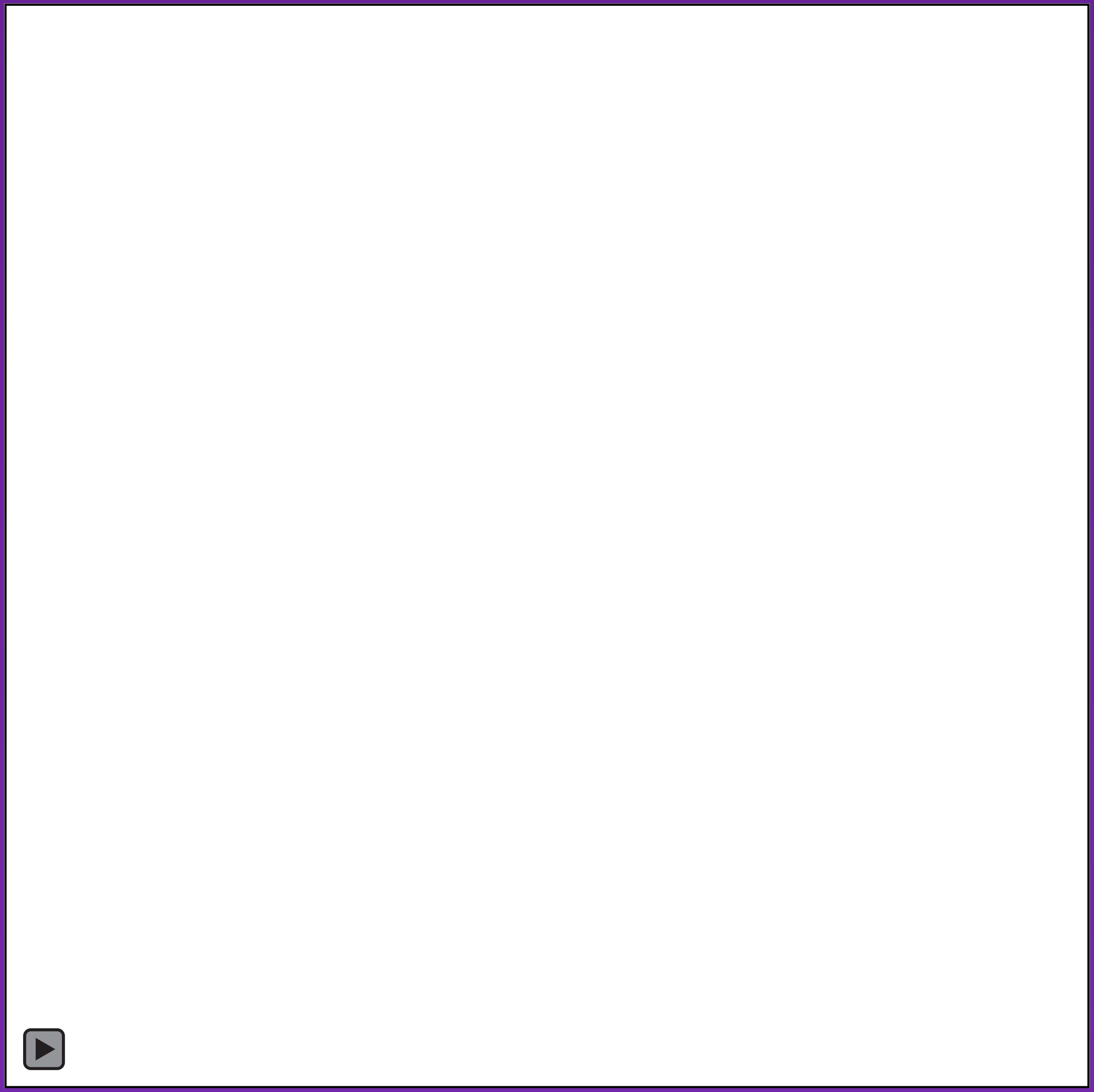
AIA 193



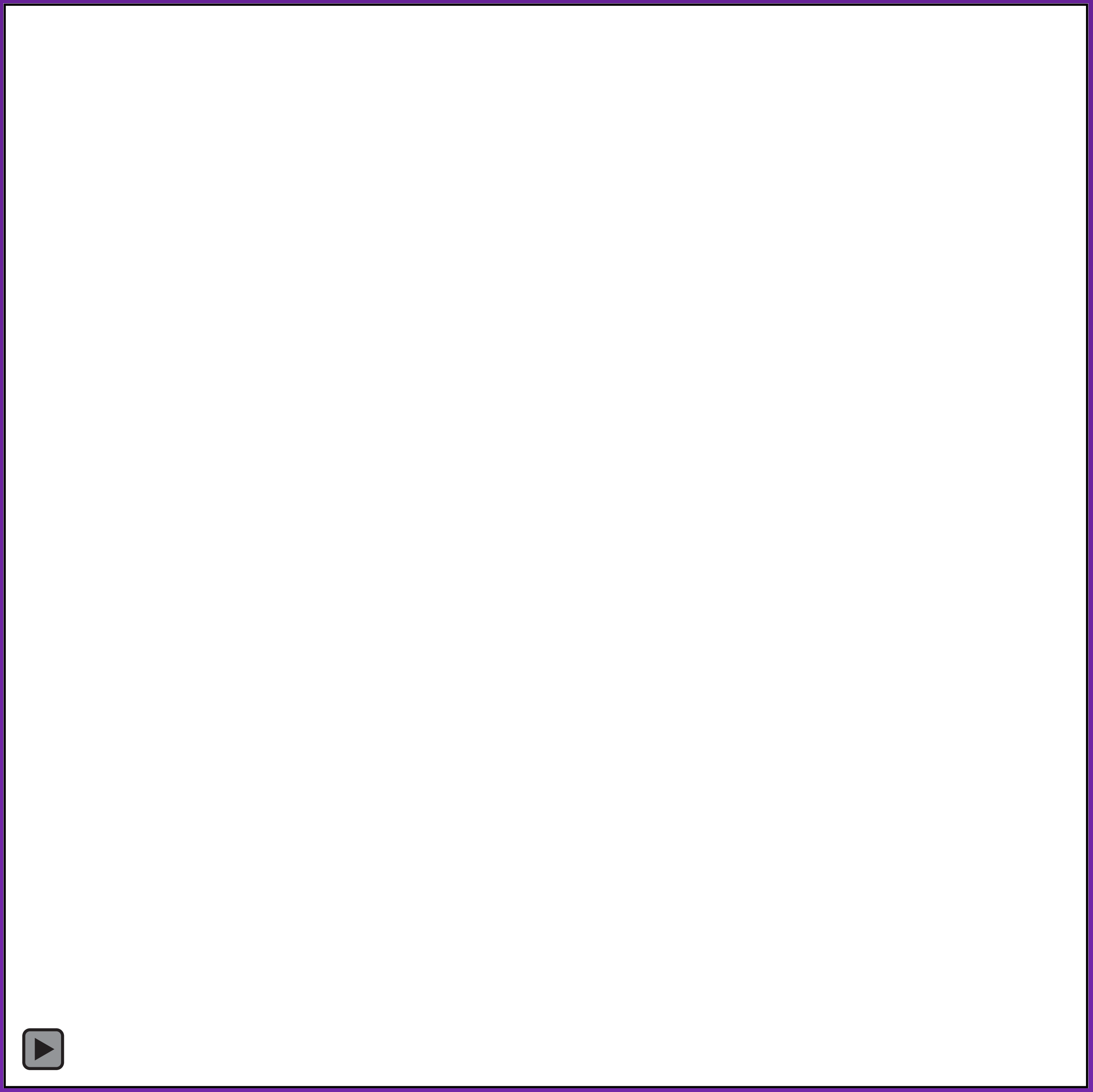
Sterling et al. (Nature, 2015): 20 Polar CH jets.

A. Sterling

XRT

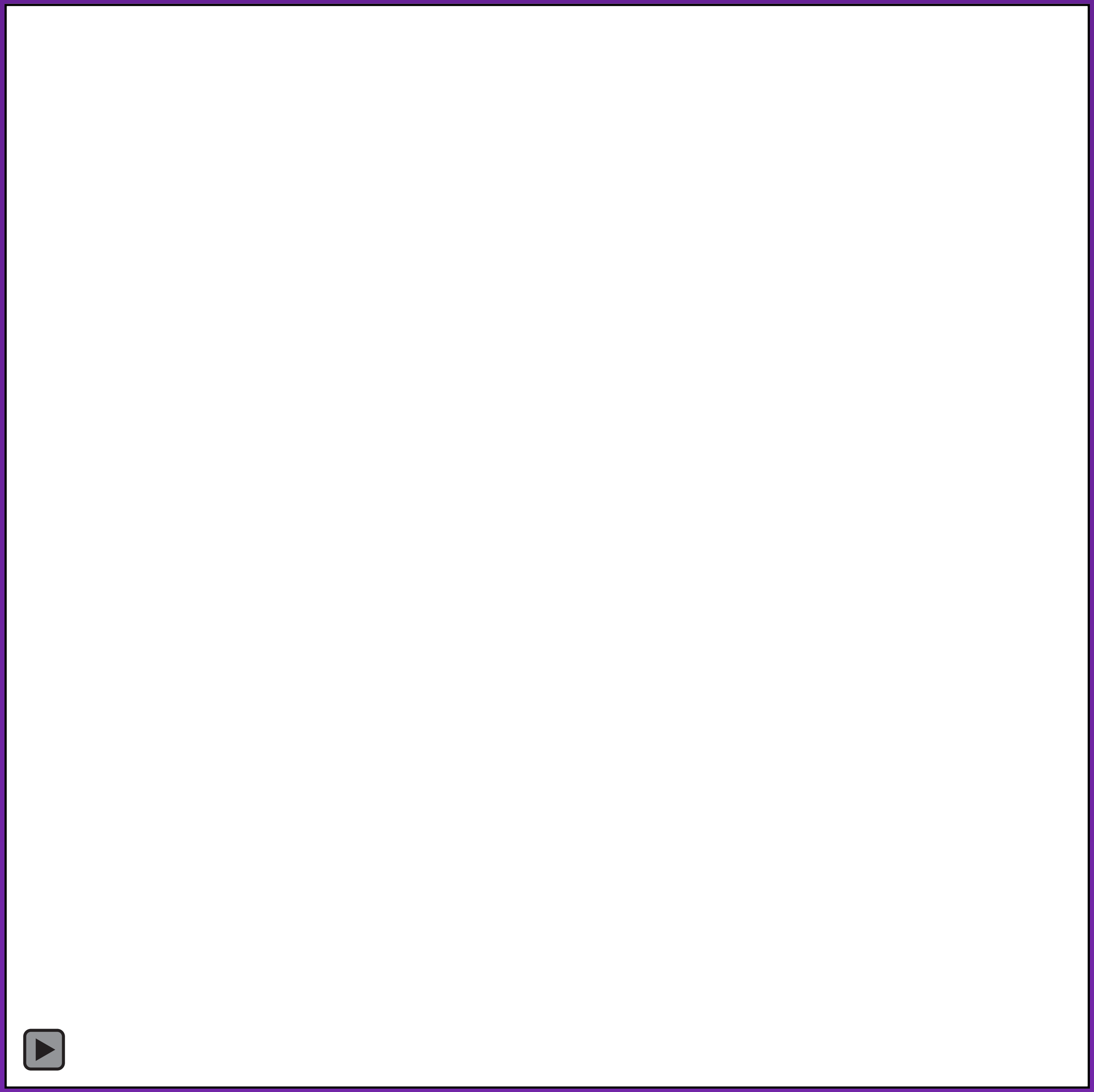


AIA 193

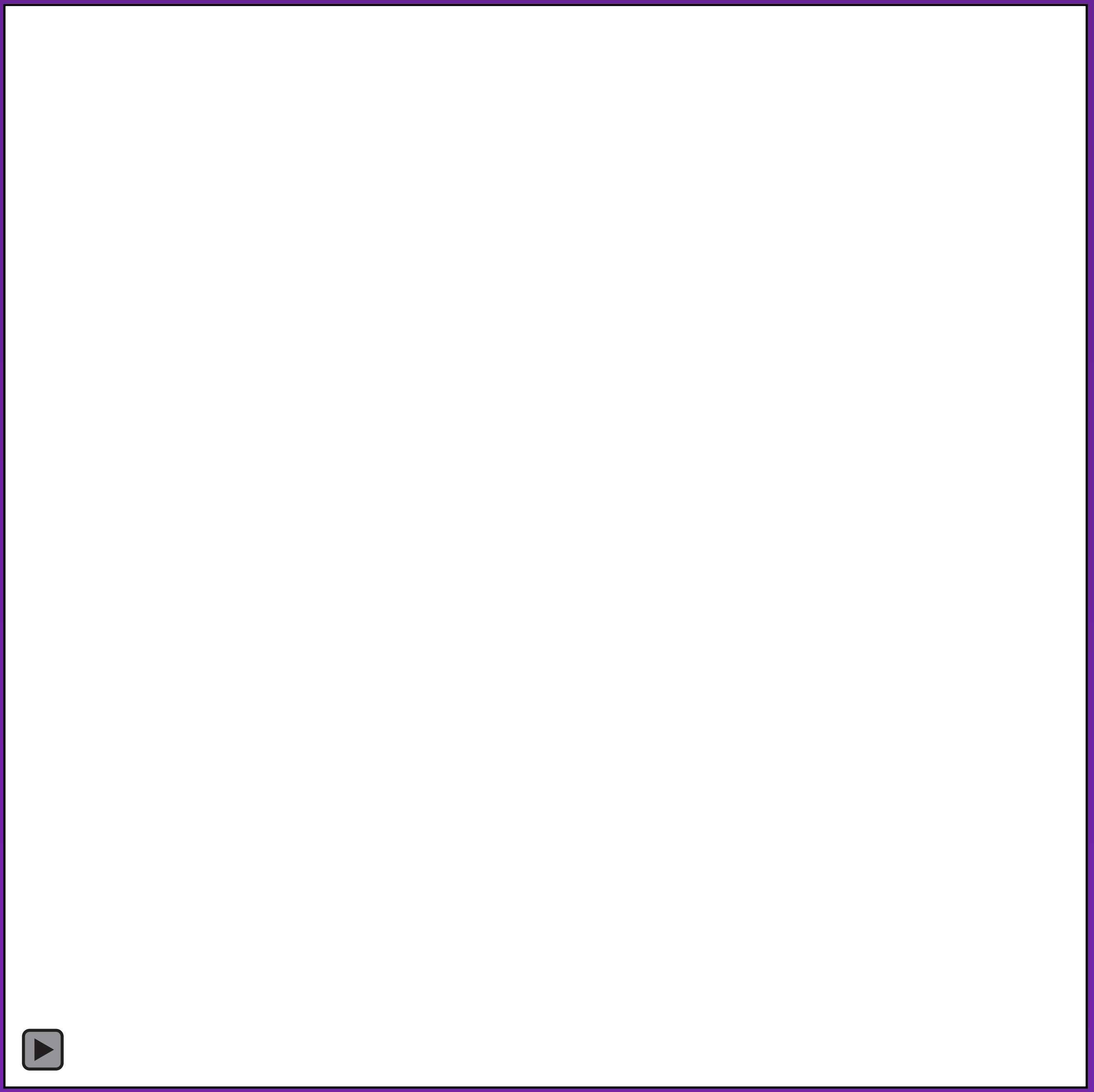


Event 12

XRT



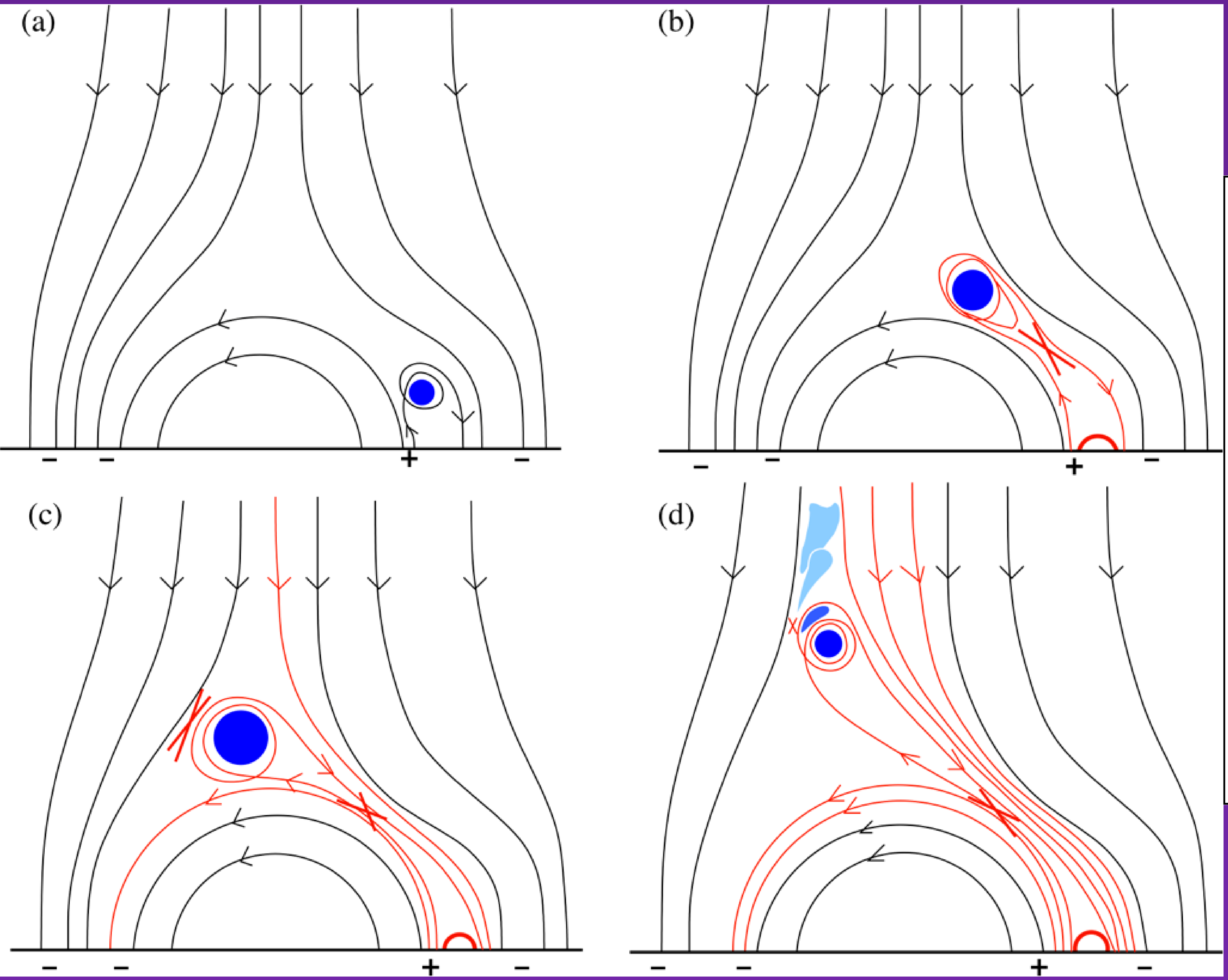
AIA 193

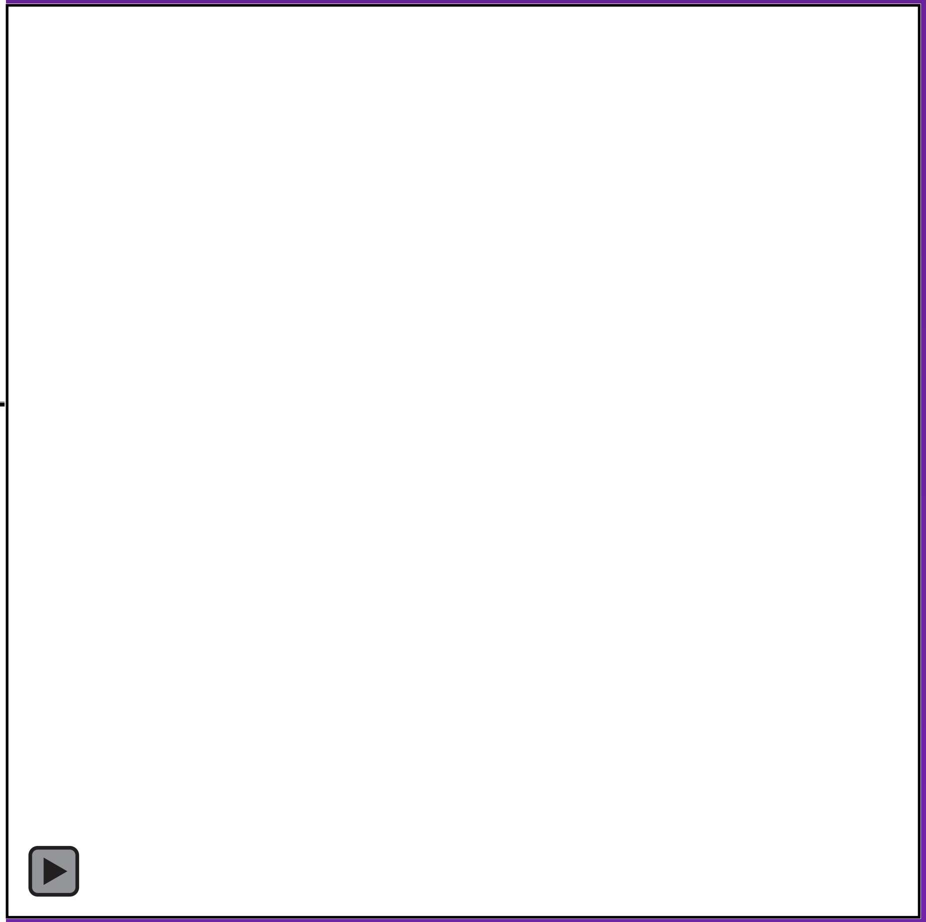


Event 3

“Normal” Filament Eruption (TRACE)

Minifilament-Eruption Model for (X-Ray) Jets





Sterling et al. (2015, 2016, 2017)

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

Recently modeled by Wyper, Antiochos, & Devore (Nature, 2017)

Quiet Sun Jets — Similar to PCH jets

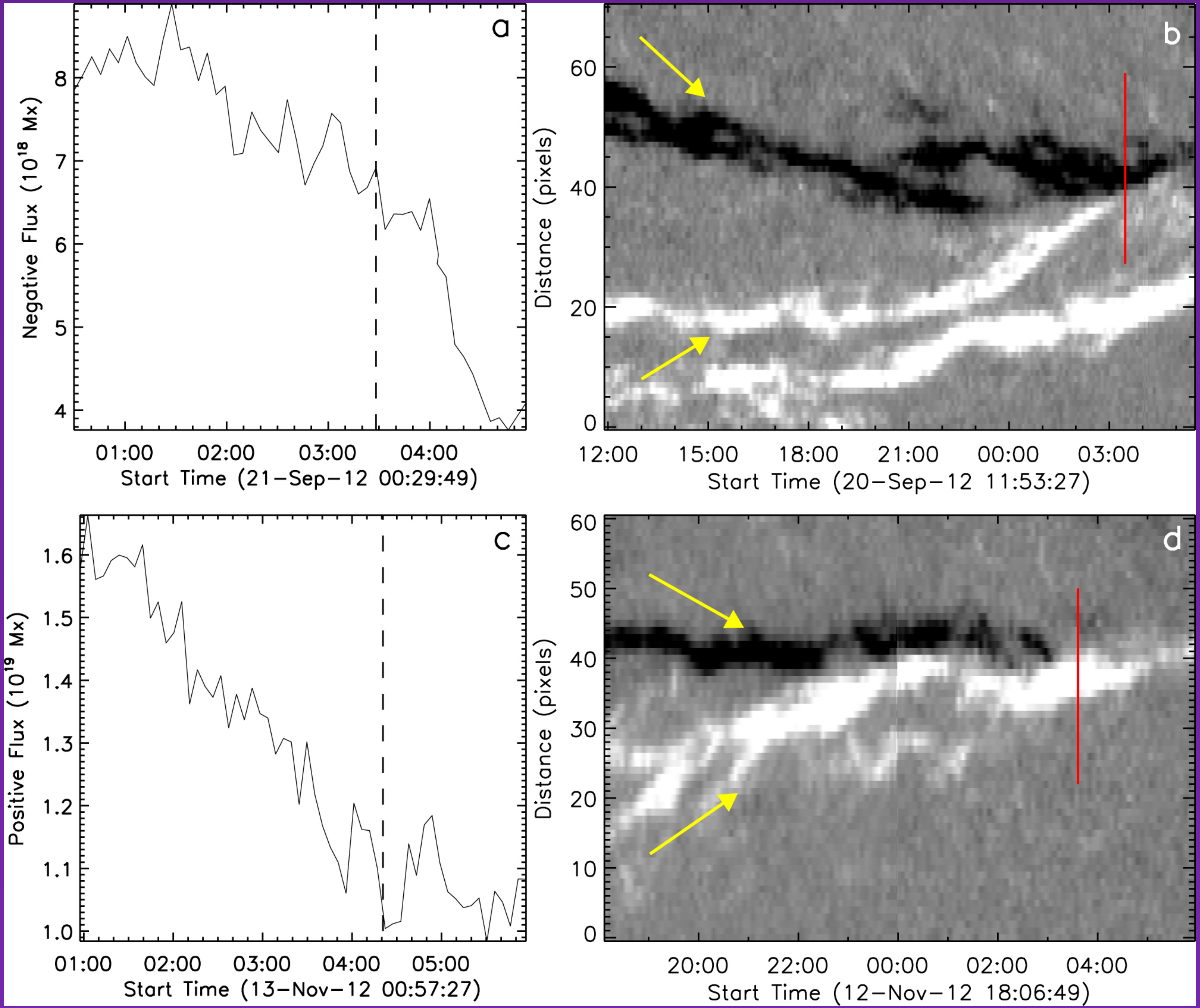
AIA 171

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.

Jets frequently occur at sights where magnetic flux cancels (flux cancelation).

- Flux cancelation found in these cases:
  - ☐Panesar et al. (2016b): 10 QS jets.
  - ☐Sterling et al. (2017): Series of AR jets.
  - ☐Panesar et al. (2018): 13 CH jets.

- McGlasson et al. (2019): 60 QS and CH jets, at least 85% of jets results from monofilament eruptions triggered by flux cancelation.
- In a small percentage of cases, mechanism not determinable or triggered by something else (e.g. Kumar et al. 2018).

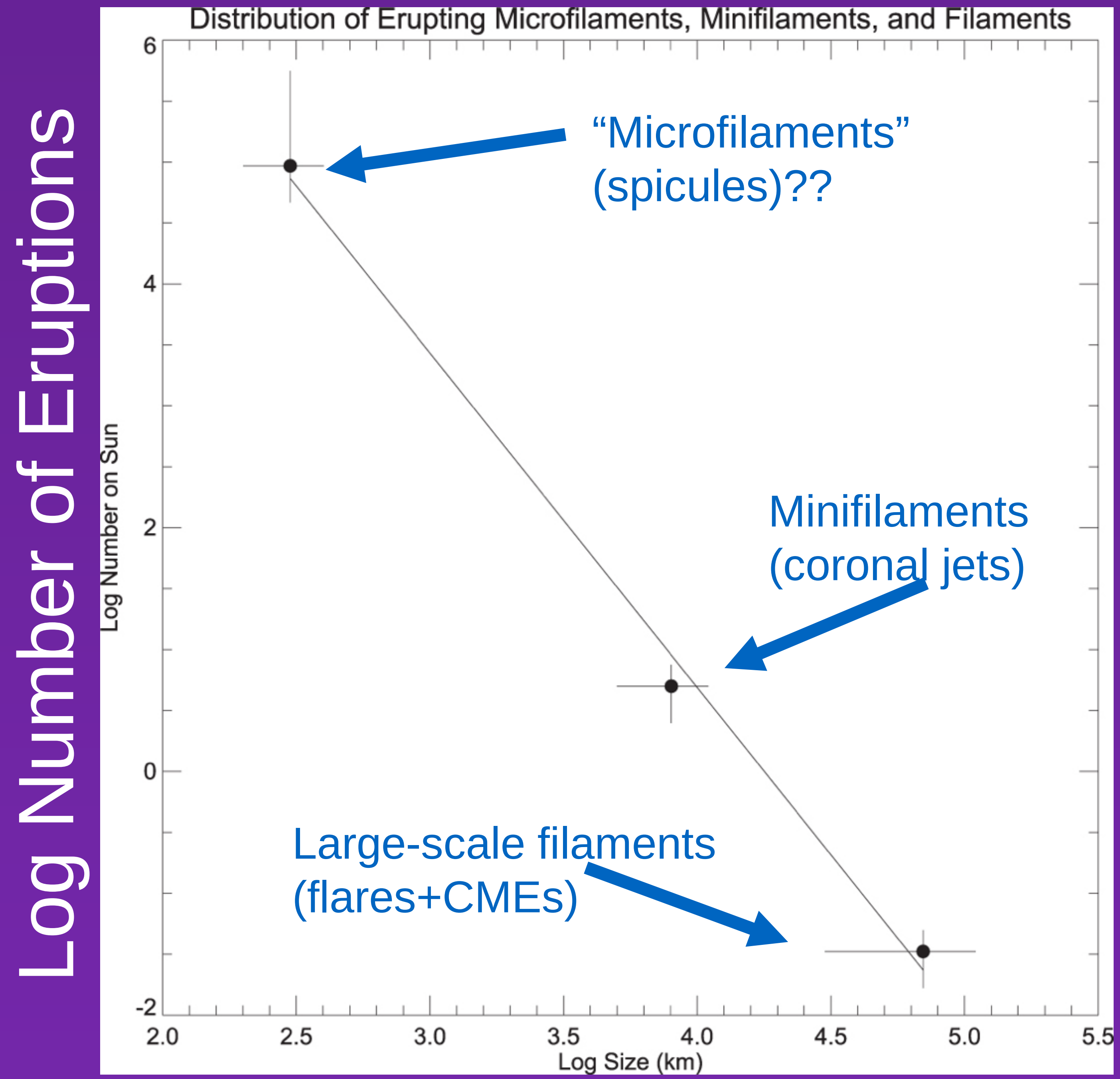
- Several earlier studies found flux cancelation in single/few-event studies (e.g., Hong et al. 2011; Huang et al. 2012; Young & Muglach 2014a,b; Adams et al. 2014).
- Some others found jets from location of emerging flux+flux cancelation (e.g., Liu et al. 2011, Shen et al. 2012, Hong et al. 2012, Li et al. 2015).

Jets and Other Solar Features

- “Normal” coronal jets, and smaller-scale jets:
  - “Jetlets” with IRIS (Panesar et al. 2018)
  - Jetlets with Hi-C (Panesar et al. 2019)
  - AR plage small-scale jet-like features (Hi-C)
  - Possible extension down to spicules (Sterling & Moore 2016).

- Jets and larger-scale features
  - CMEs and white-light jets (Sterling et al. 2016, Panesar et al. 2016)
  - AR eruptions. ...

Filament-Like Feature Eruptions on Smaller Scales??



Log "Filament" Size

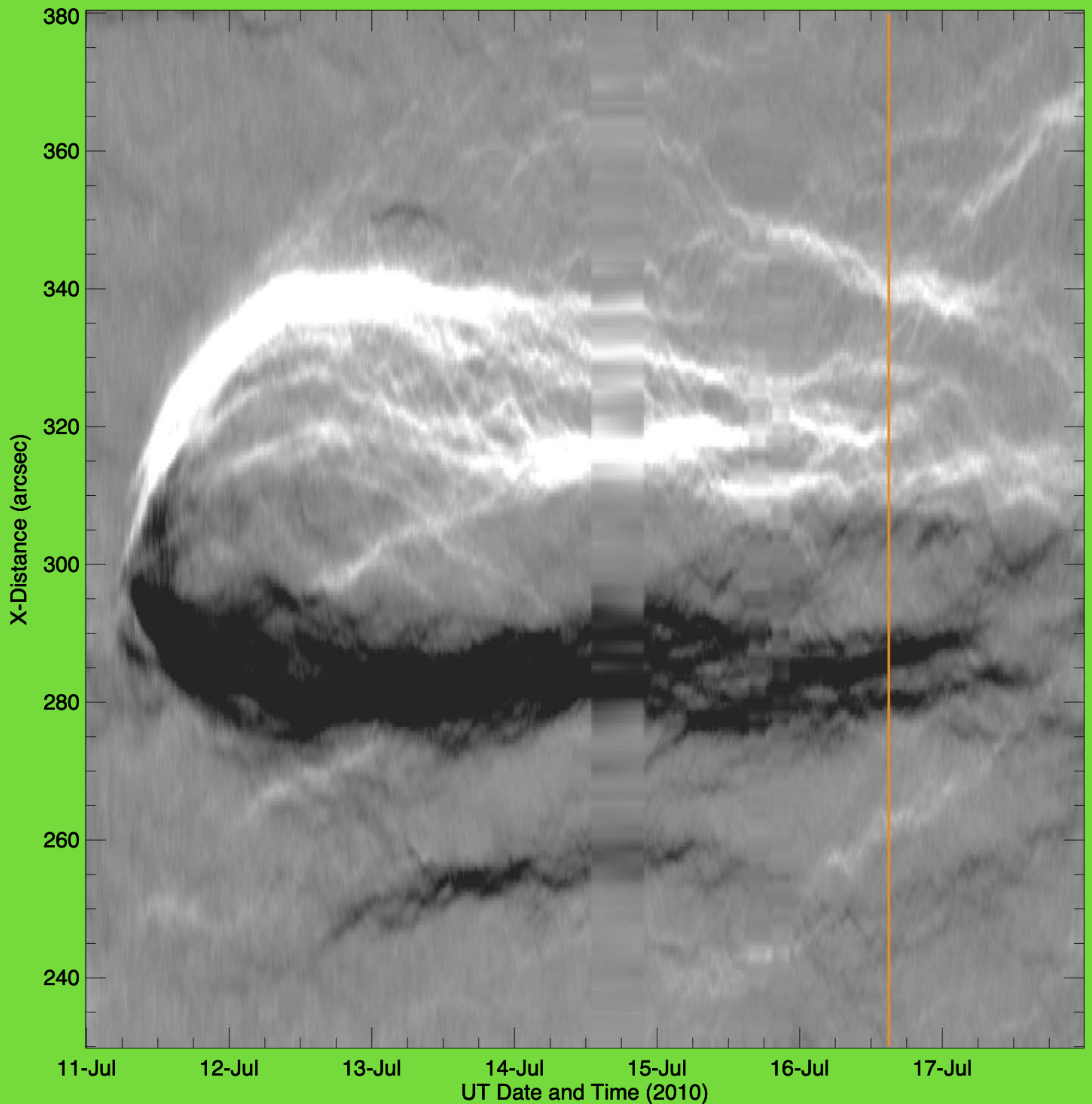
Sterling & Moore (2016)

A. Sterling

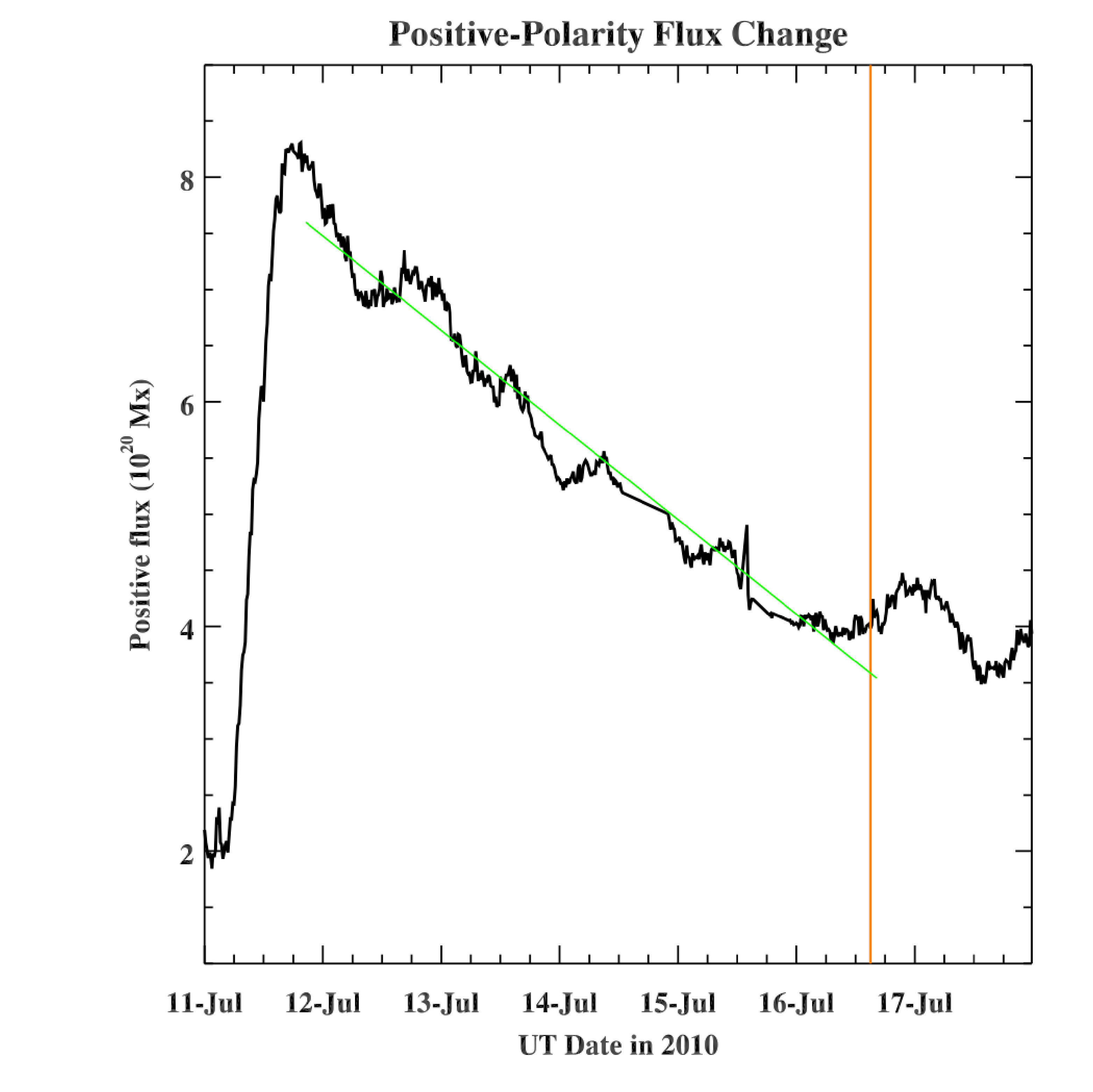
Does the same thing really happen for larger eruptions? Check it by looking at evolution of magnetically-isolated ARs

- Study CME-producing ARs (Sterling et al. 2018).
- Use SDO/AIA and SDO/HMI (+STEREO COR).
- Follow the AR development from emergence to eruption.
  - Regions must be (largely) magnetically isolated;
  - Birth-to-eruption lifetime less than one-disk passage.

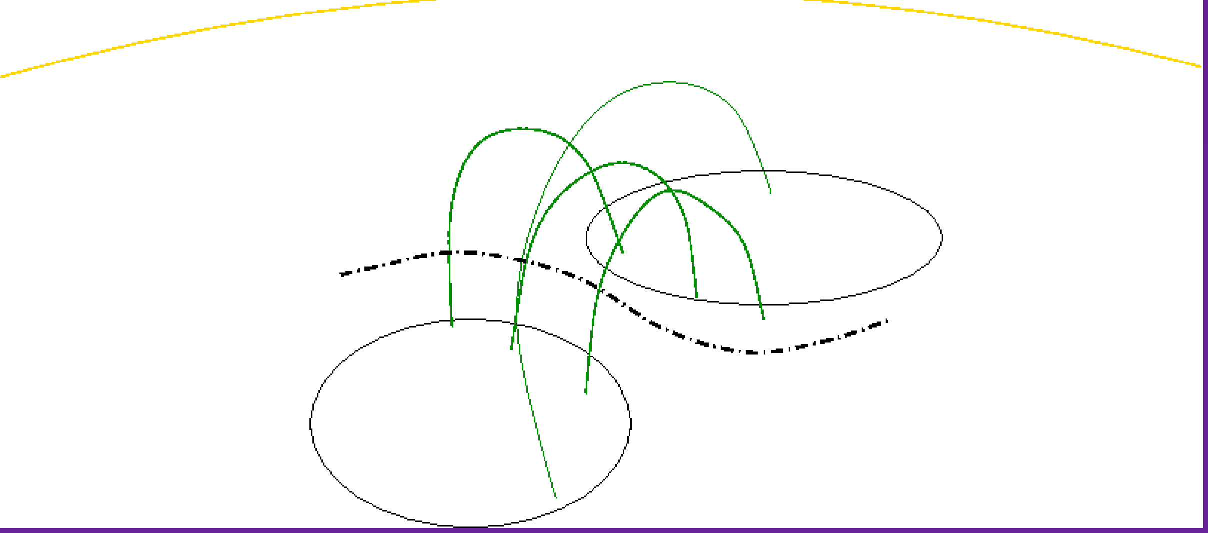
- Two small ARs: ~10^{21} Mx; lifetime ~5 days.


X-Distance (arcsec)
380
360
340
320
300
280
260
240
11-Jul
12-Jul
13-Jul
14-Jul
15-Jul
16-Jul
17-Jul
UT Date and Time (2010)

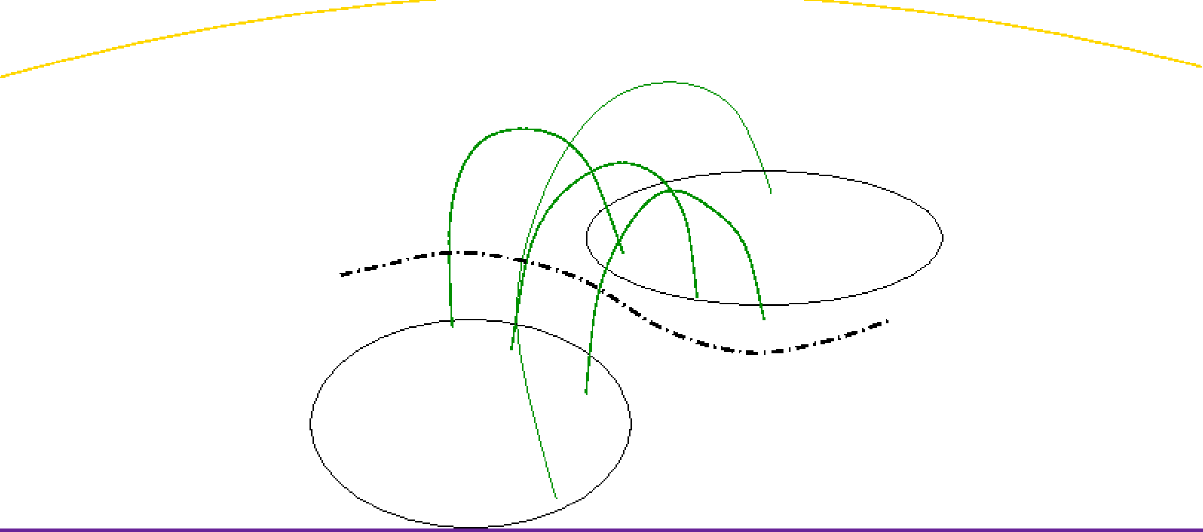
Positive-Polarity Flux Change



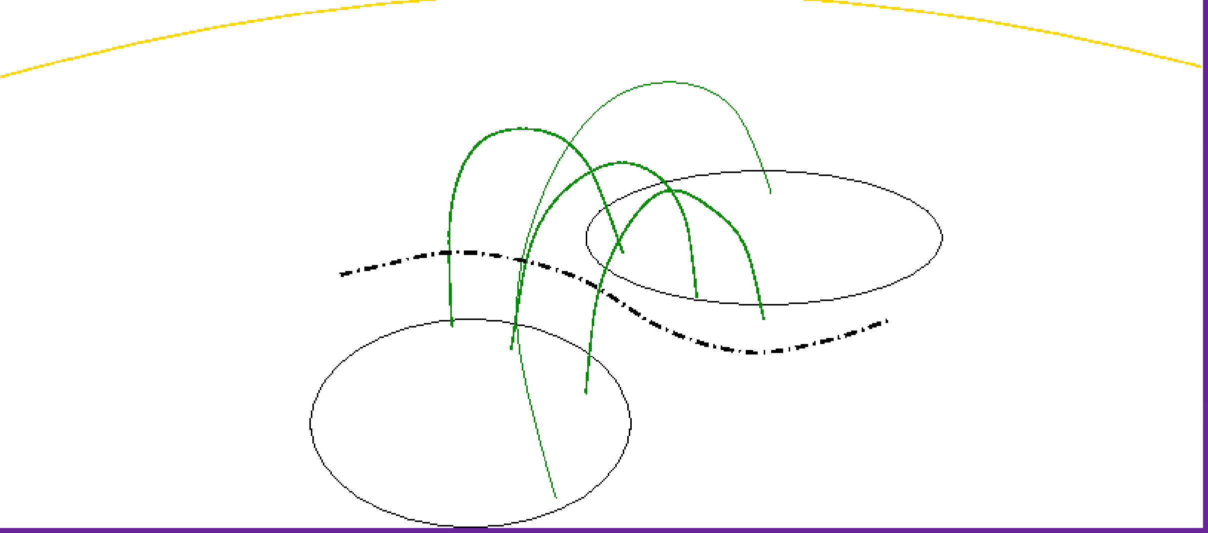
~51% of max flux removed



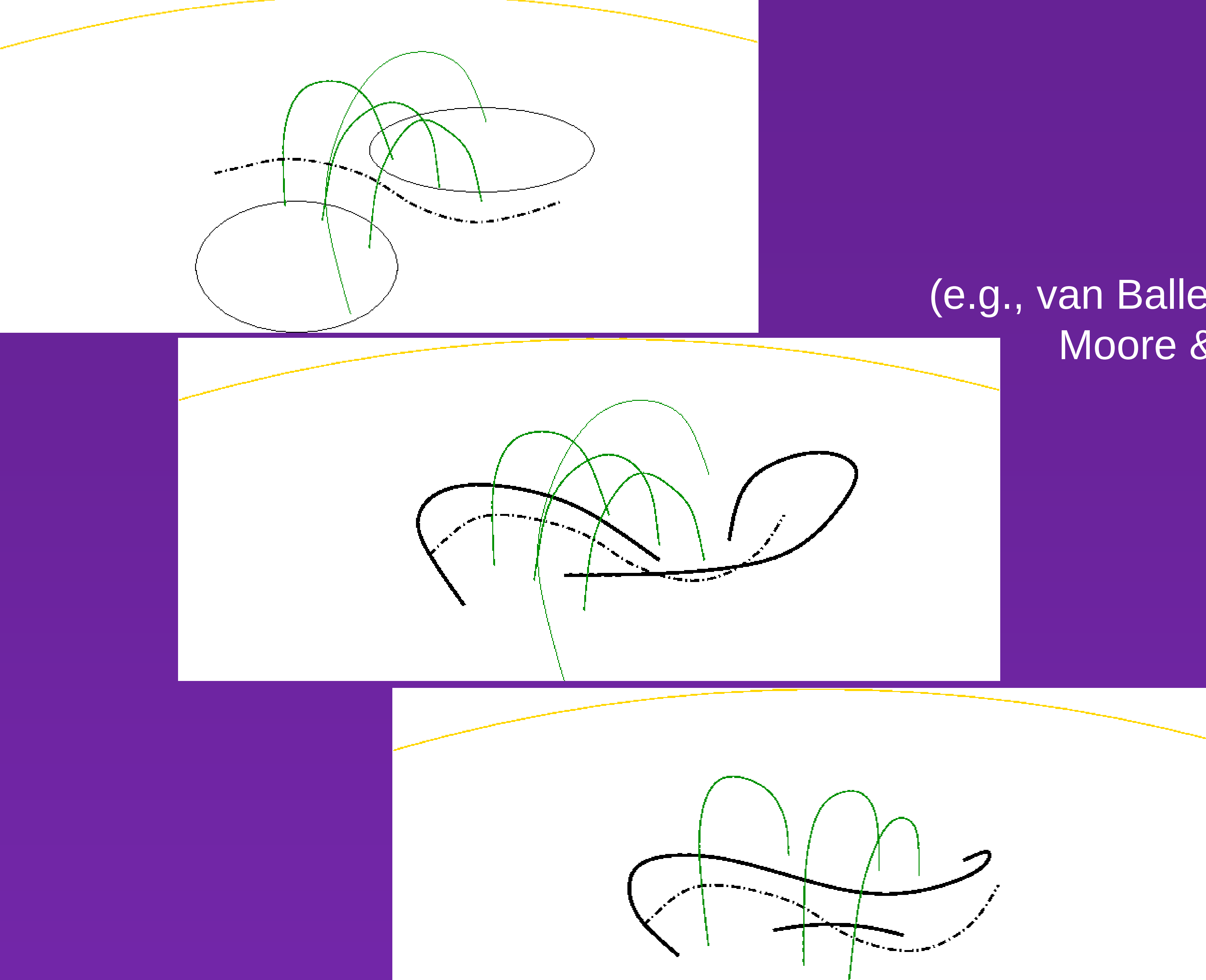
(e.g., van Balleggoijen & Martens 1989,
Moore & Roumeliotis 1992)



(e.g., van Balleggoijen & Martens 1989, Moore & Roumeliotis 1992)

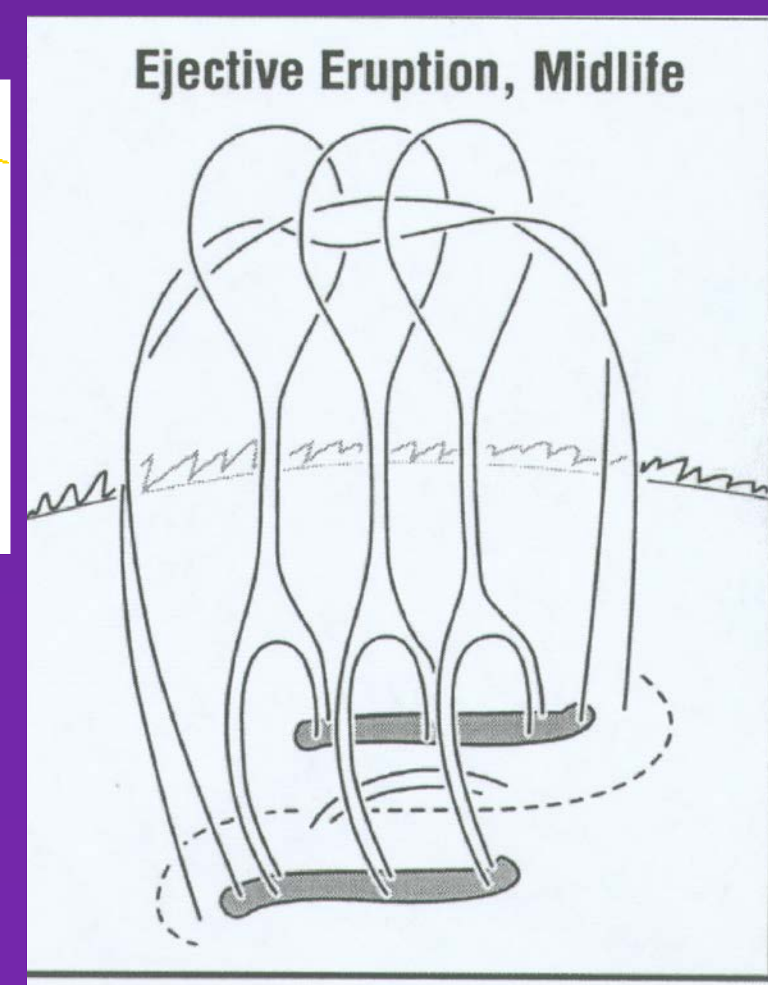


(e.g., van Balleggoijen & Martens 1989, Moore & Roumeliotis 1992)



(e.g., van Balleggoijen & Martens 1989, Moore & Roumeliotis 1992)

(Moore et al. 2001)



(Cf. Chintzoglou et al. 2019)

Flux Cancelation Rates and Percentages:

(Panesar et al. 2016b, 2018; Sterling et al., 2018):

	(% flux canceled)
For CH jets (~10 events):	45
For QS jets (~10 events):	37
Small AR Event 1:	51
Small AR Event 2:	29

Details in Sterling et al. (2018)

Jets are Small-Scale AR Eruptions!

- Many/most coronal jets are like miniature CME-producing eruptions, resulting from minifilament eruptions, accompanied by a bright point/flare.
- Usually flux cancelation triggers eruption of the mini filaments causing the jets.
- When ARs are isolated and small enough to be followed, parts of the emerged flux will converge and cancel on the main neural line, and form a filament that erupts — this is similar to jets.
- There may be a threshold for amount of flux required to be canceled for eruption to occur.

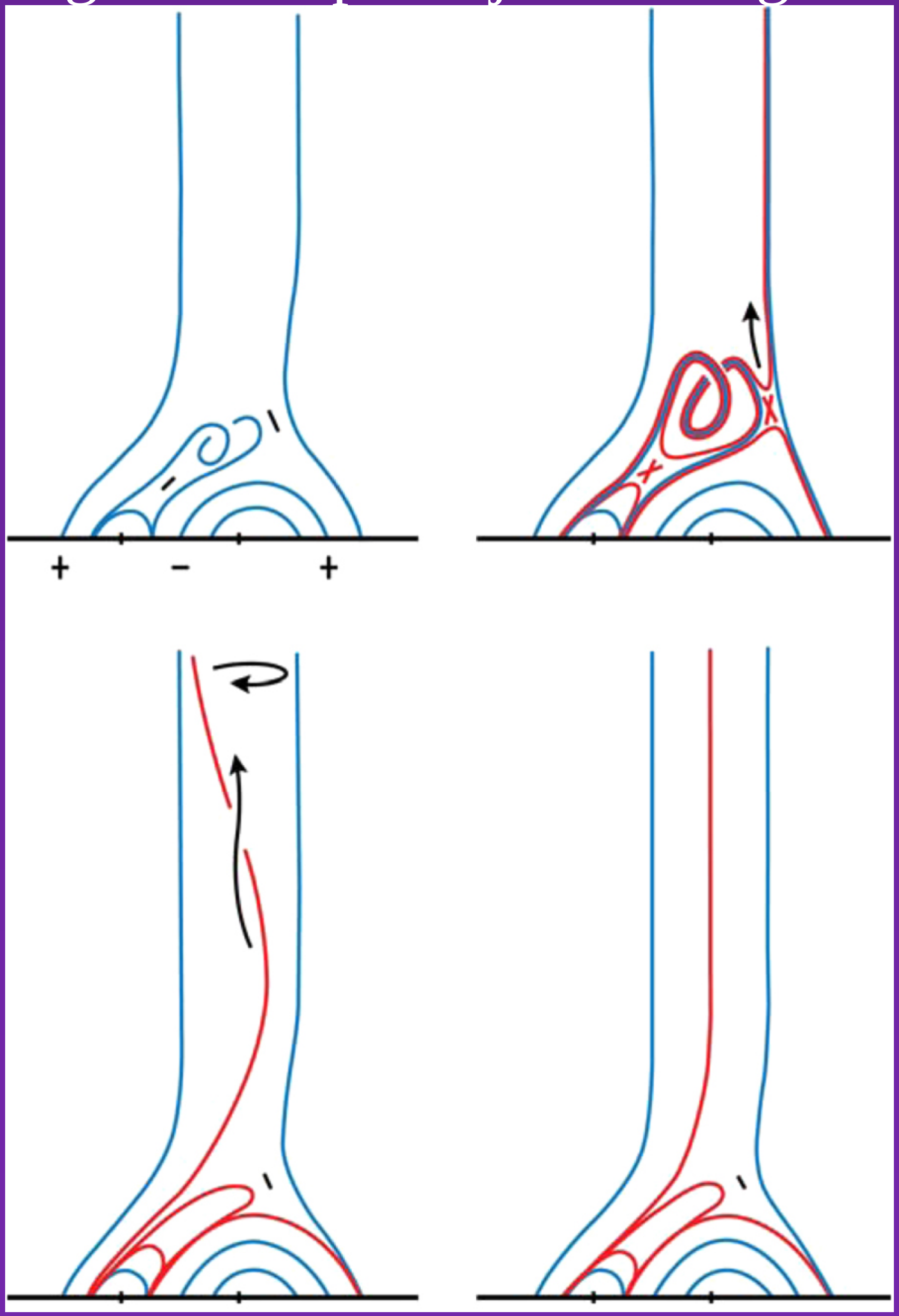
Jets and PSP “Switchbacks”?

AIA 171

Sterling et al. (2016, ApJ)

Sterling et al. (2016, ApJ)

This suggests that: “polar jets having more axial rotation usually extend to greater heights than polar jets having less axial rotation.”



Moore et al. (2015). (Shibata & Uchida 1986-type mechanism; Patsouraos et al. 2008; Pike & Mason 1998.)

Jets and PSP "Switchbacks"?

- Erupting minifilaments make coronal jets.
- If the erupting-minifilament field has twist, it can impart the twist to the coronal field via external (interchange) reconnection.
- These jets+twist can reach the outer corona.
- If they make it to PSP, they might be detected as switchbacks.

The Future of Jets: A Preview!

- High-resolution studies with DKIST:
  - Confirm/refute flux-cancelation as jet source.
  - Confirm/refute spicule/coronal-jet connection.
- PSP: Determine whether jets make switchbacks.
- Solar Orbiter: Jets from different vantage points. High(er)-resolution magentograms, to see the bases of spicules and jets (jet-spicule connection) [PHI]; spicule/coronal-heating connection [EUI, SPICE].
- If they make it to PSP, they might be detected as switchbacks.

Summary

- Jets are common, and occur all over the Sun (CHs, QS, and ARs)
- At least many, if not all, jets result from minifilament eruptions; smaller-scale version of large eruptions.
- At least many, if not all, minifilament eruptions triggered by flux cancelation.
- Large-scale eruptions might be the same.
- Jets make narrow CMEs (white-light jets) —> Switchbacks?
- Exciting prospects for PSP, Orbiter, and DKIST!

Image:
Alphonse Sterling
21 August 2017,
Lewisville, Idaho