Triggering of Solar Magnetic Eruptions on Various Size Scales

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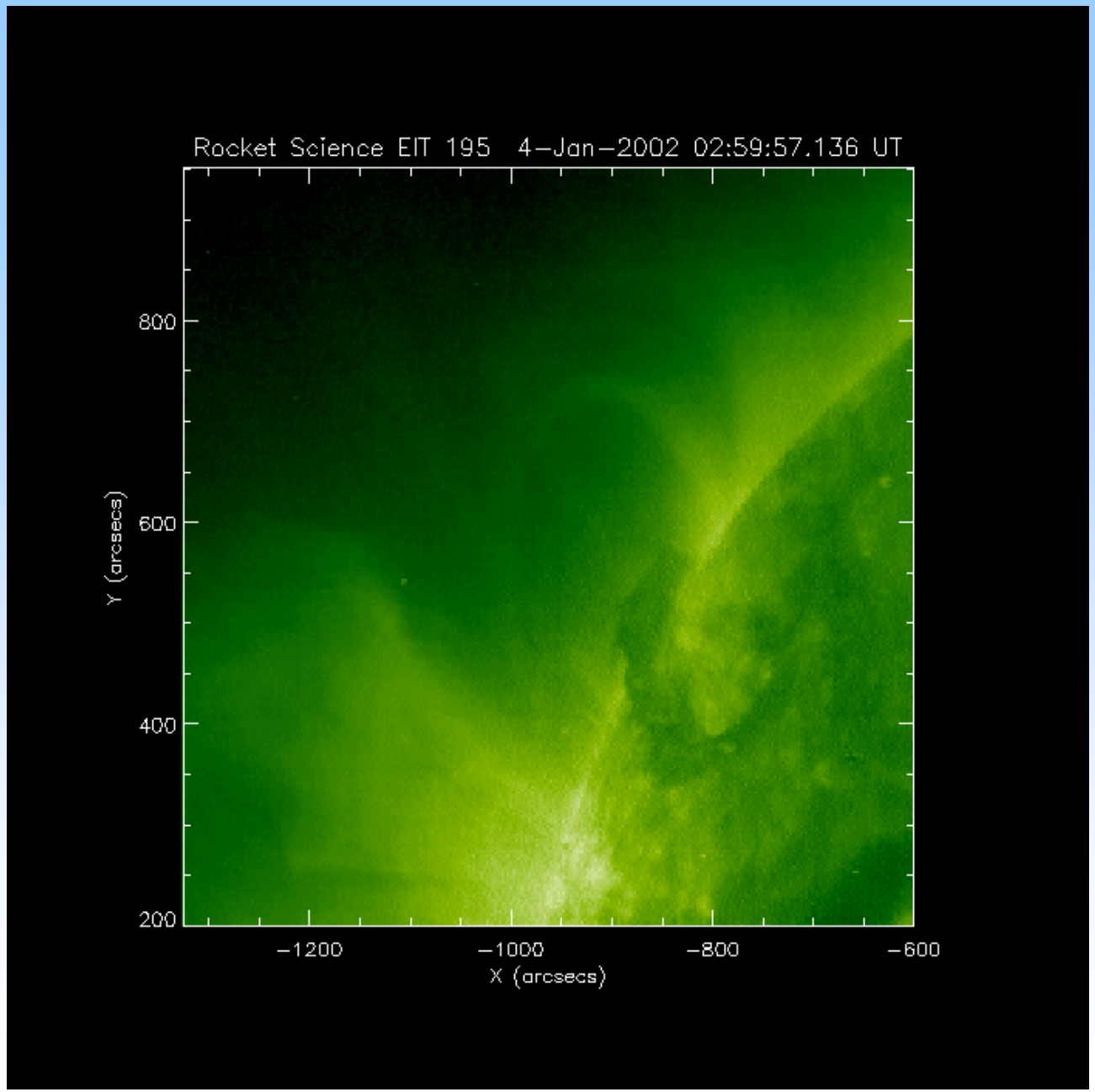
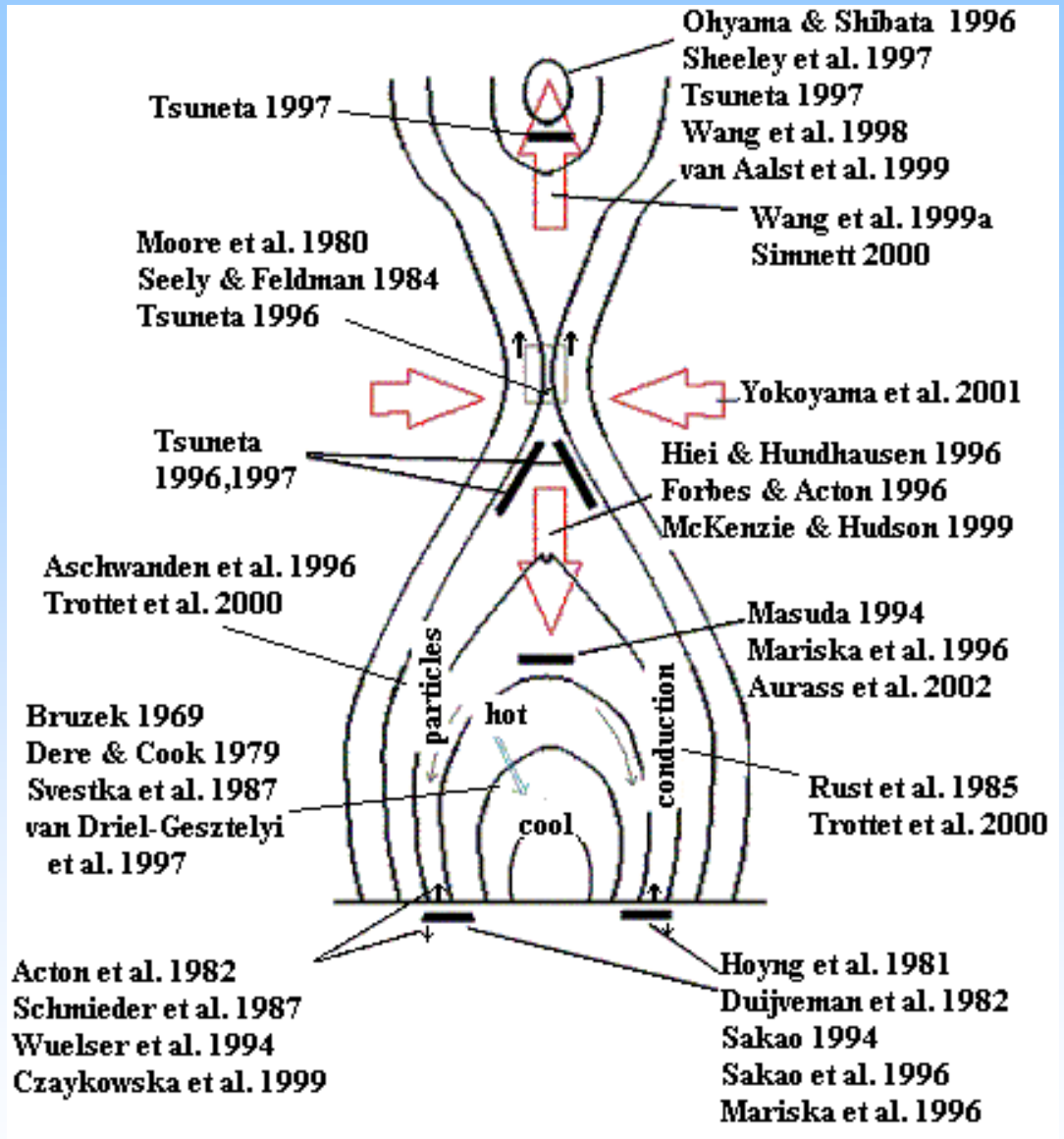
Introduction

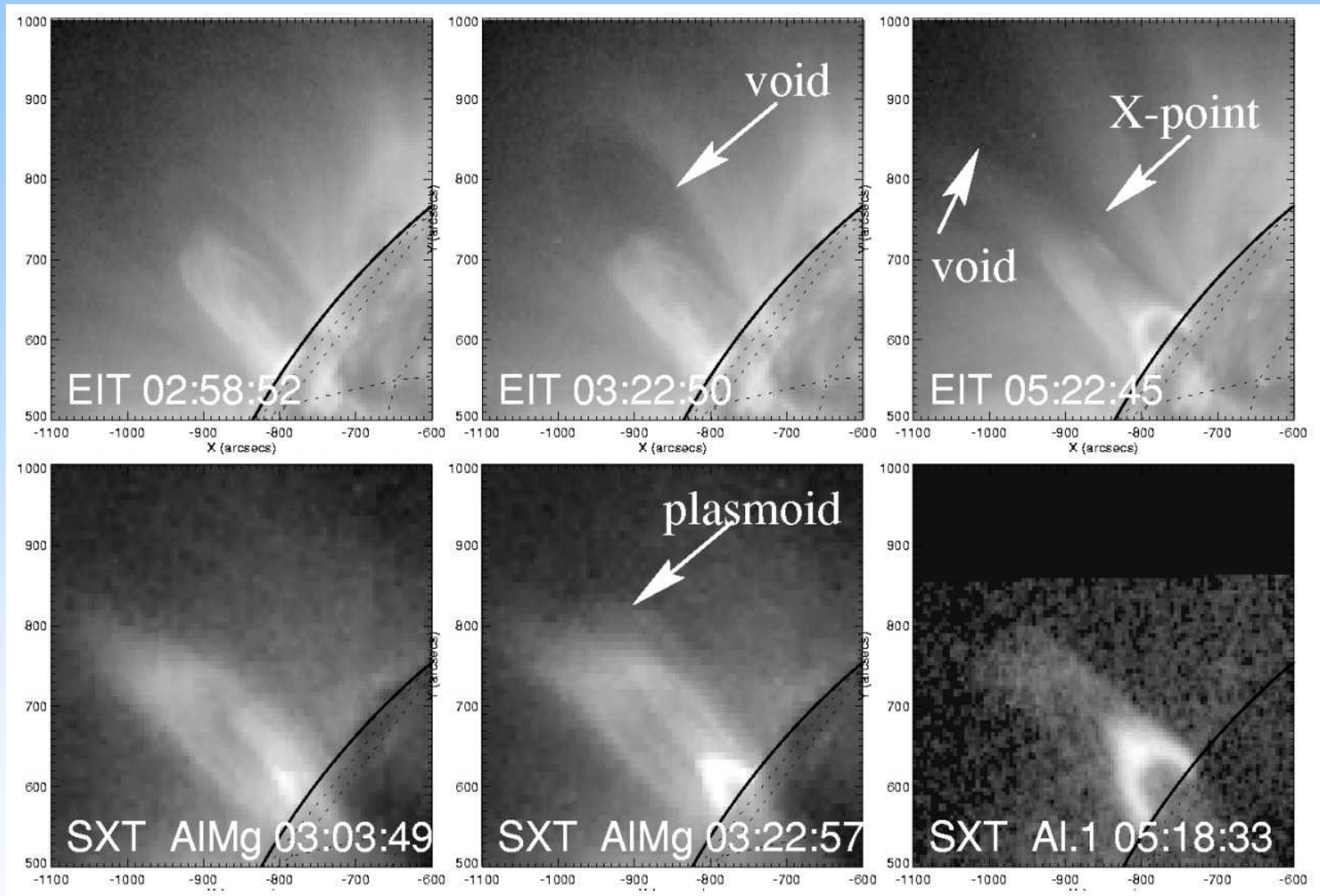
- Solar eruptions occur on various size scales
  - Flares and CMEs (AR L~60’’; E_{flare}~10^{29} -- 10^{32}; E_{CME}~10*E_{flare})
  - Intermediate-scale (small CMEs, Puffs, etc.) (base L~40’’?, E~Goes B- or C-class flare).
  - X-ray jets (base L ~ 30’’, E~10^{25} - 10^{28} erg)
- Will present examples of eruptions on the different scales.
- What triggers the eruptions? No certain answer, but many of the pieces are likely there!



Yurchyshyn (2002), Sterling & Moore (2004), Gibson et al. (2006),…



McKenzie (2002)

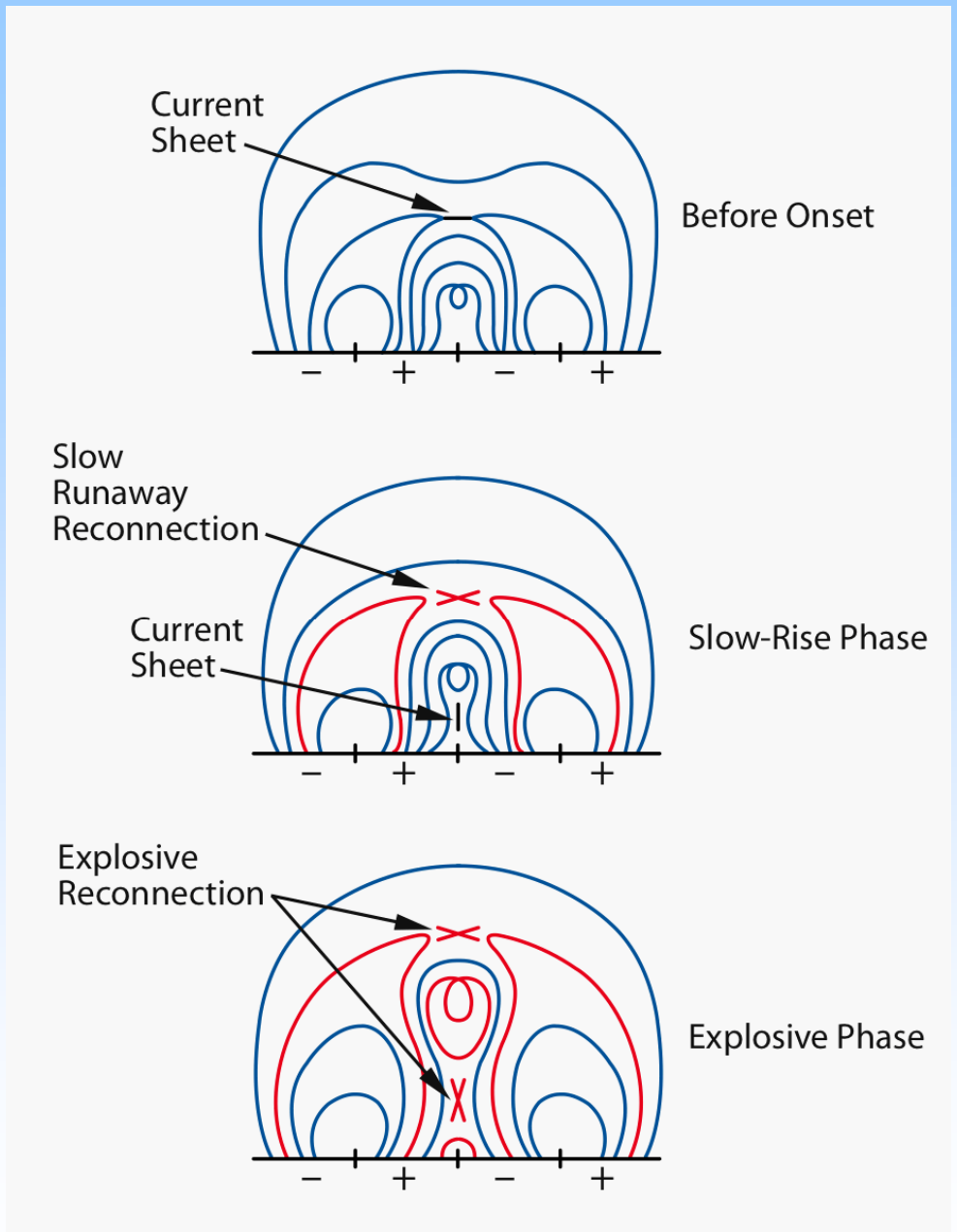


Yokoyama et al. (2001)

Large eruptions are well-seen; what triggers them?

Basic problem: Magnetic balance must be disrupted in favor of the upward-directed pressure force.

- Tether cutting (Moore et al. 1980, 1992, 2001)
- Breakout (Antiochos 1998; Antiochos et al. 1999)
- Ideal MHD instability (e.g., Isenberg et al. 1993; Linker & Mikic 1995; Titov & Demoulin 1999; Kliem & Torok 2006; Fan & Gibson 2007….)
- Flux Cancelation (e.g., Martin et al. 1985; van Ballegooijen & Martens, 1989; Wang & Shi 1993,….)
- Flux emergence (e.g., Chen & Shibata, 2000)
- Current increase (e.g., Leka et al. 1996, Okamoto et al. 2009; Amari et al. 2004)
- "No signature" eruptions (Hudson et al. 1998, Robbrecht et al. 2009)



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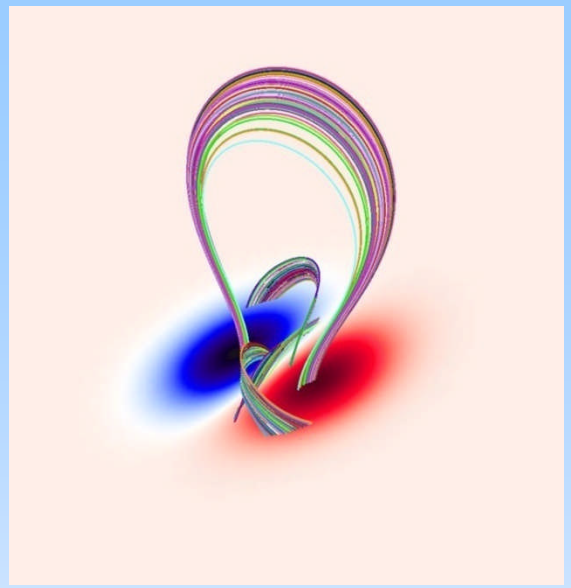
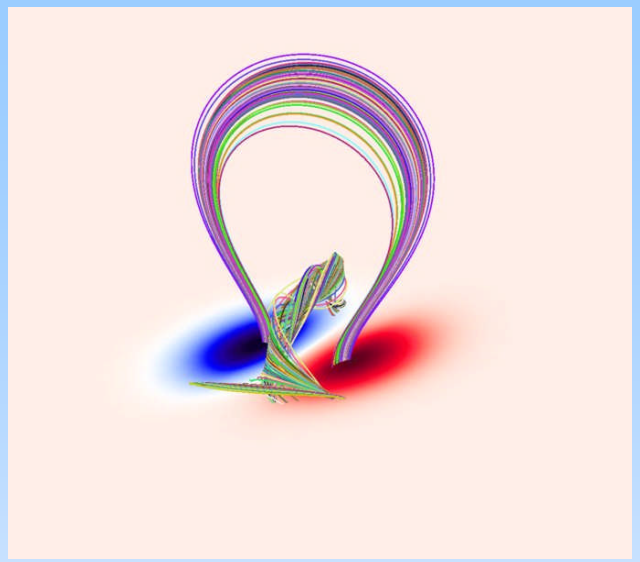
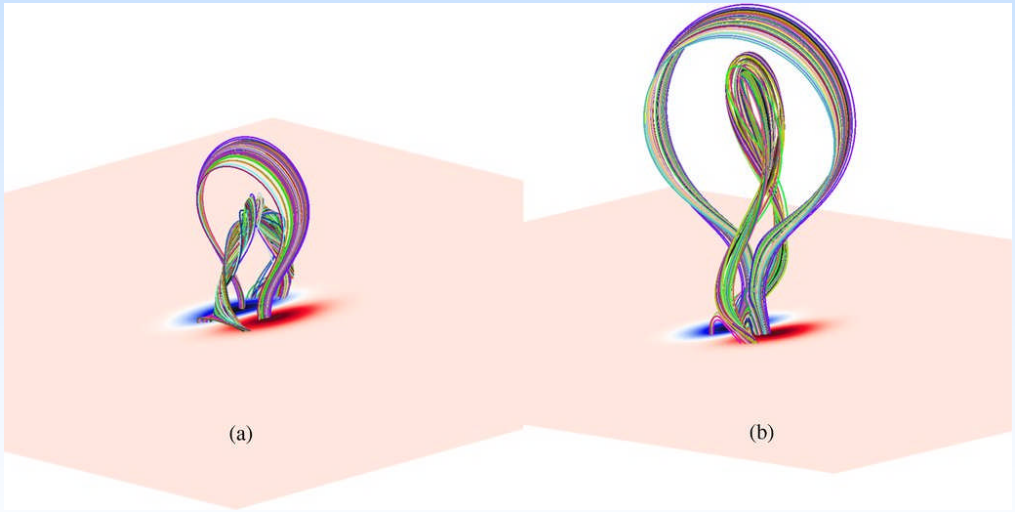
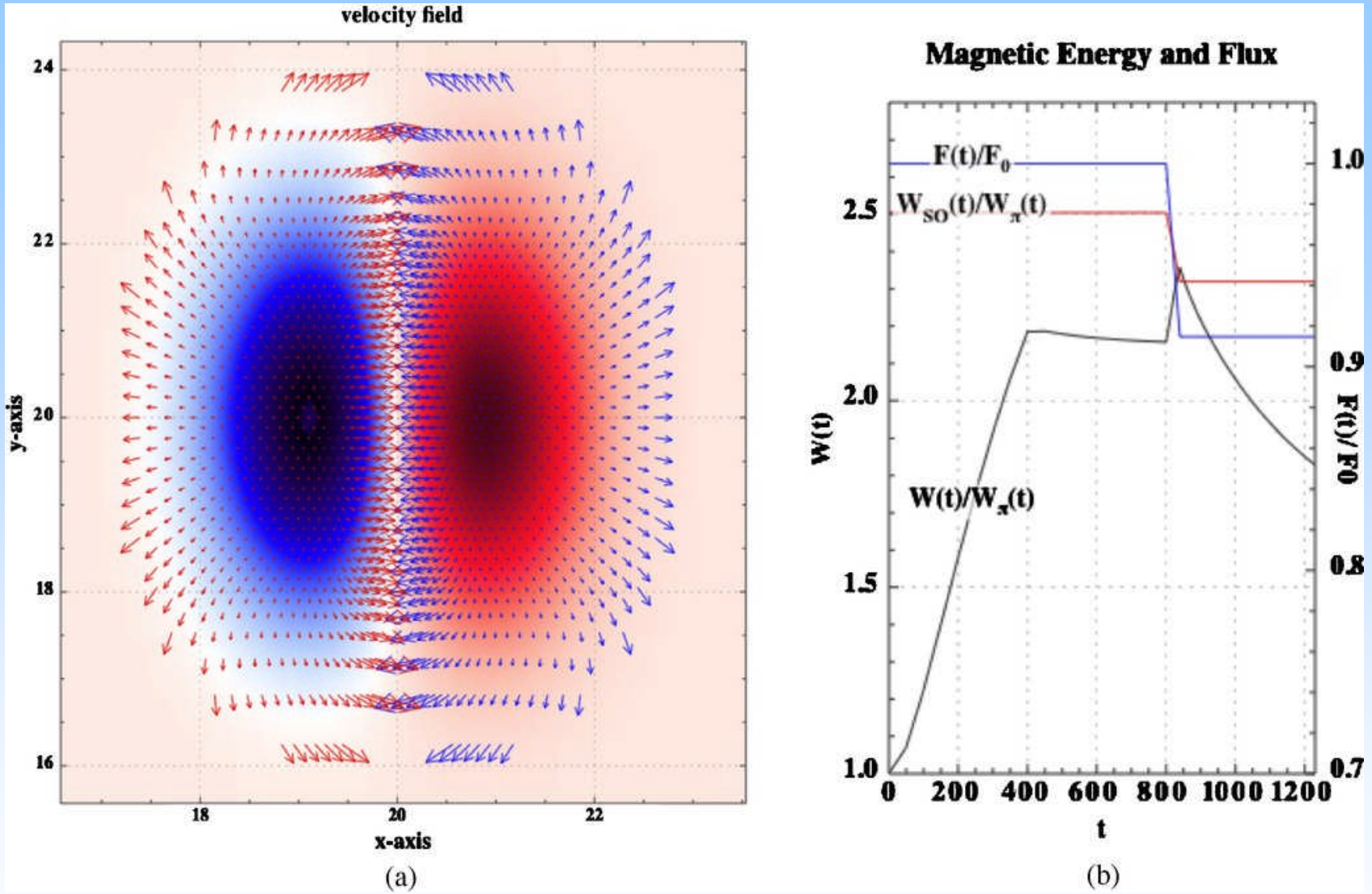
Moore & Sterling (2006)





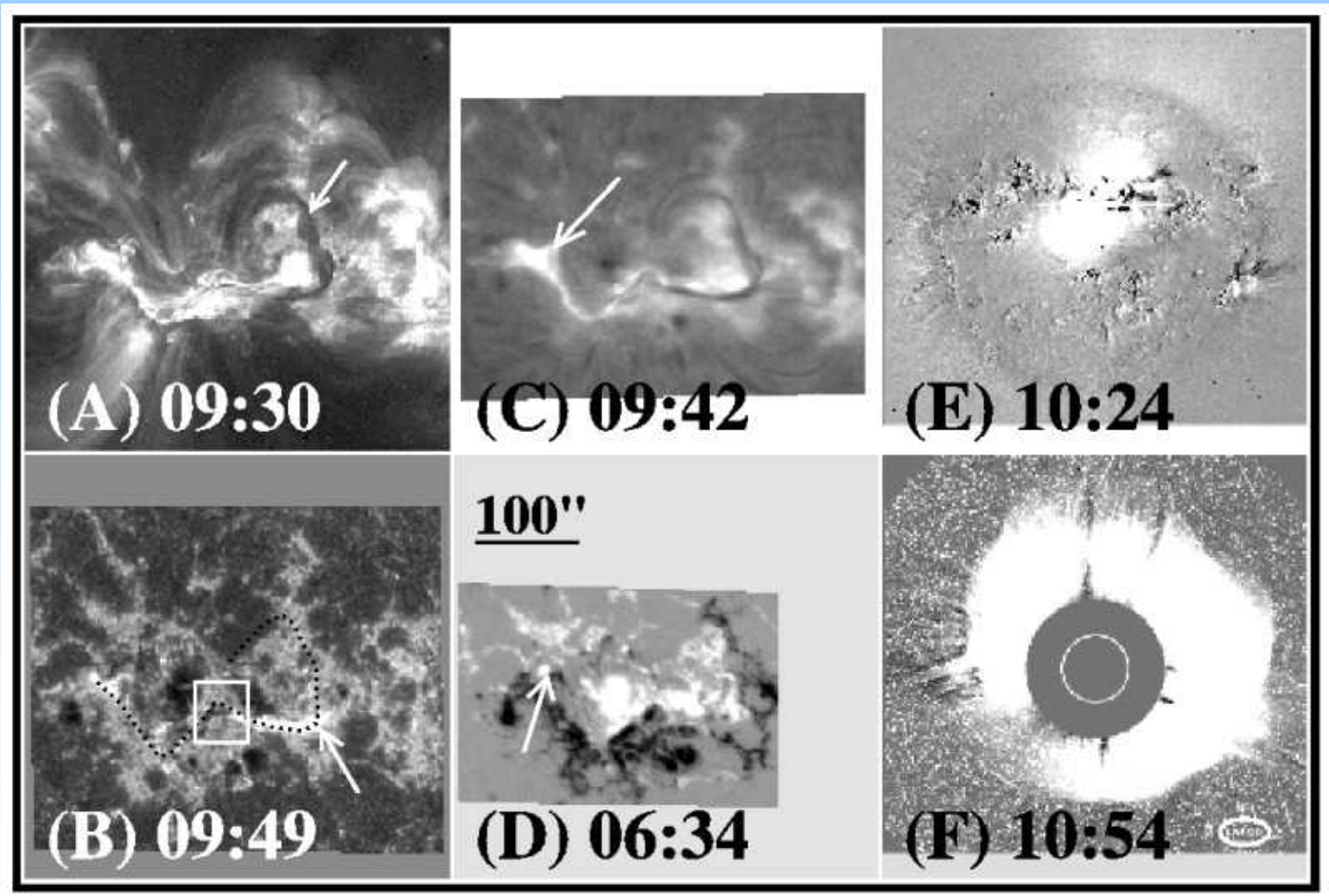


Amari et al. (2010) -- Flux Cancelation

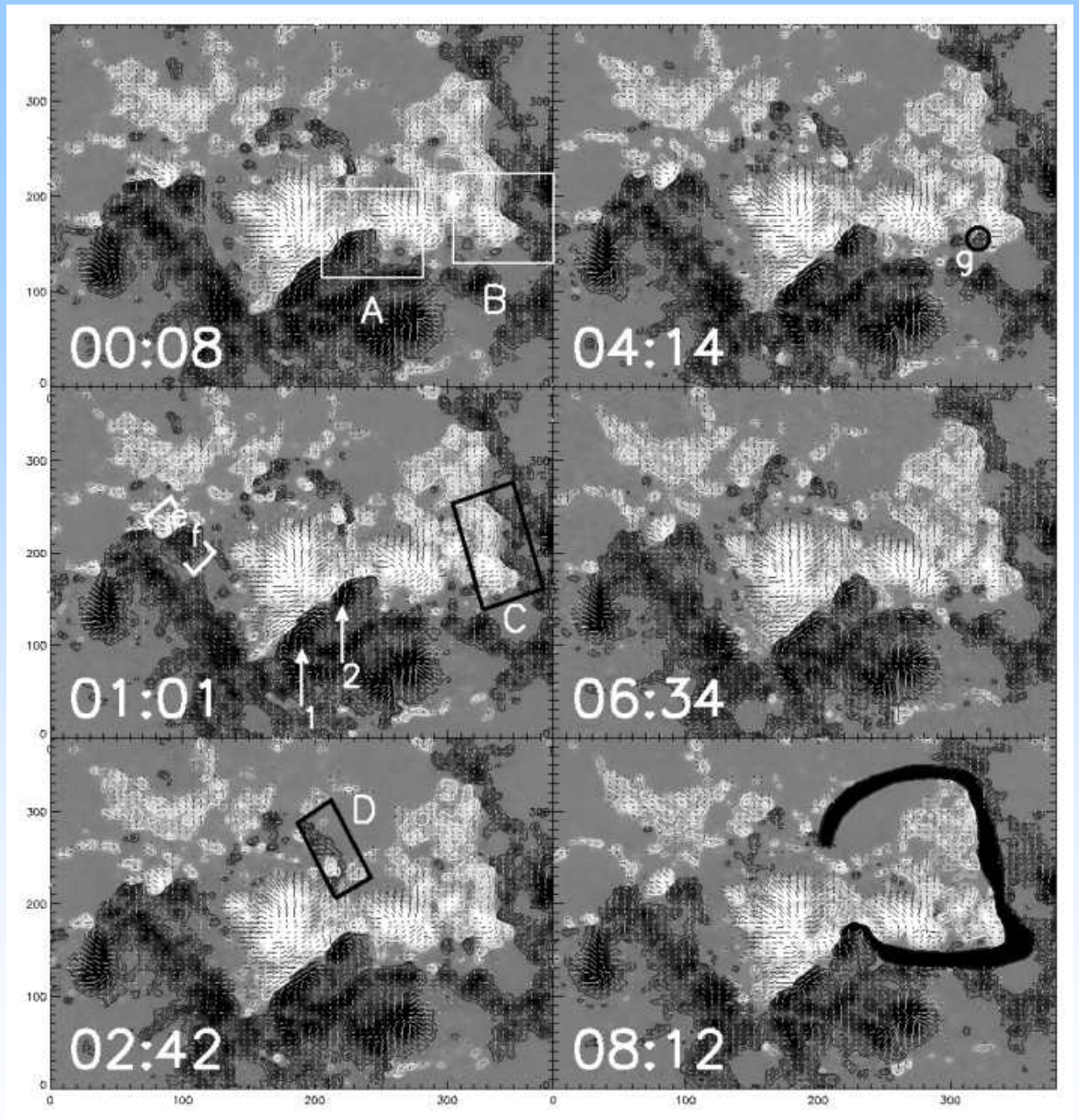


Amari et al. (2010) -- Flux cancelation

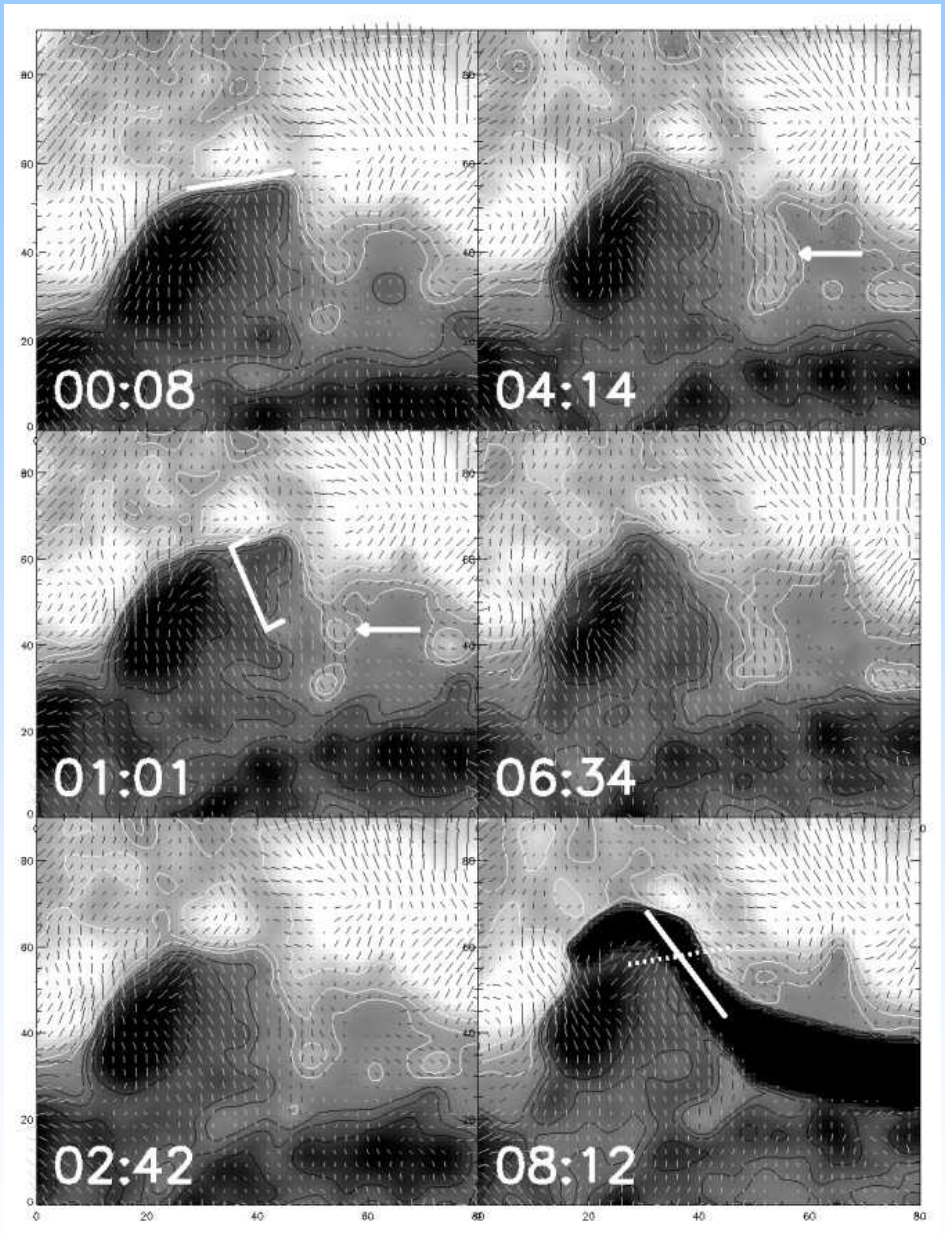
Flux cancelation observation example



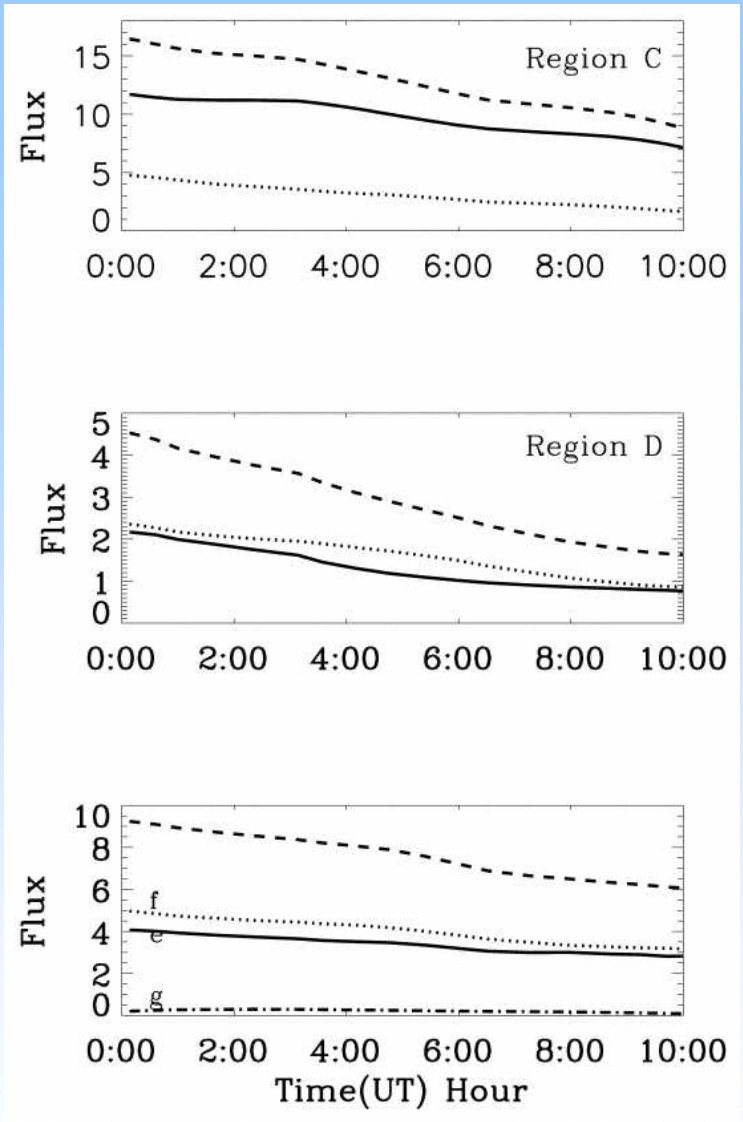
Jun Zhang et al. (2001)



Jun Zhang et al. (2001)



Jun Zhang et al. (2001)



Jun Zhang et al. (2001)

How much flux must cancel for eruption?

- Theory: ~6% from Amari et al. (2010) simulations.

- Observation: Sterling et al. (2007, 2010) found eruption to observe in two different events with 5% - 10% of total Flux canceled.

More observations (and theory?) needed.

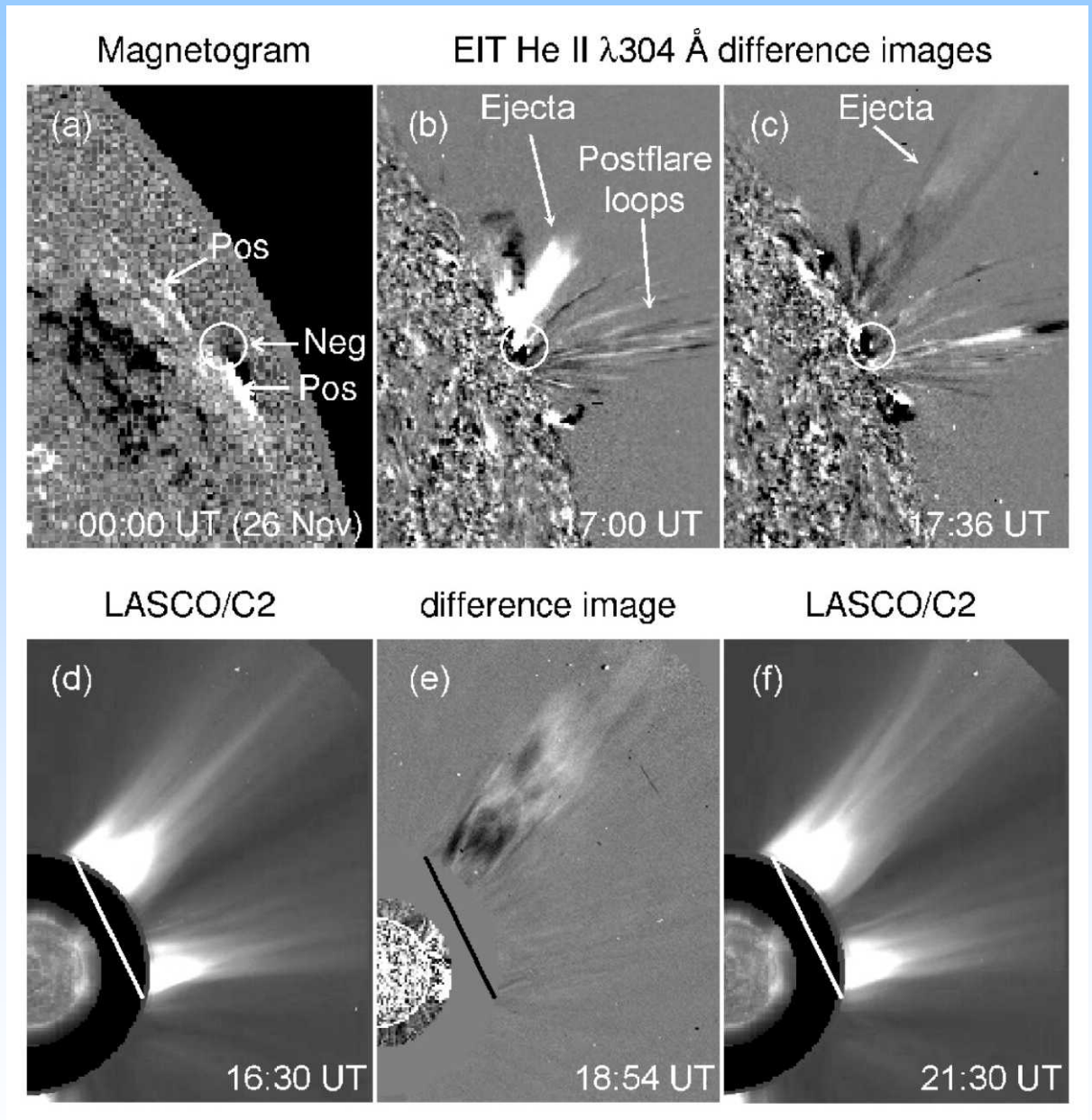
Which mechanism "responsible" for eruption? Hard to say!

- Moore & Sterling: Can't easily say whether TC, breakout, or ideal MHD is key trigger.
- Aulanier et al. (2010): Model based on flux cancelation, but eruption only occurred when torus instability (Kliem & Torok 2006; Isenberg & Forbes 2007) ensues.
- Observerations of flux emergence --> eruption (many, e.g. statistical study by Feynman & Martin 1995), but also observations of cancelation w/o emergence (H. Chen et al. 2009).

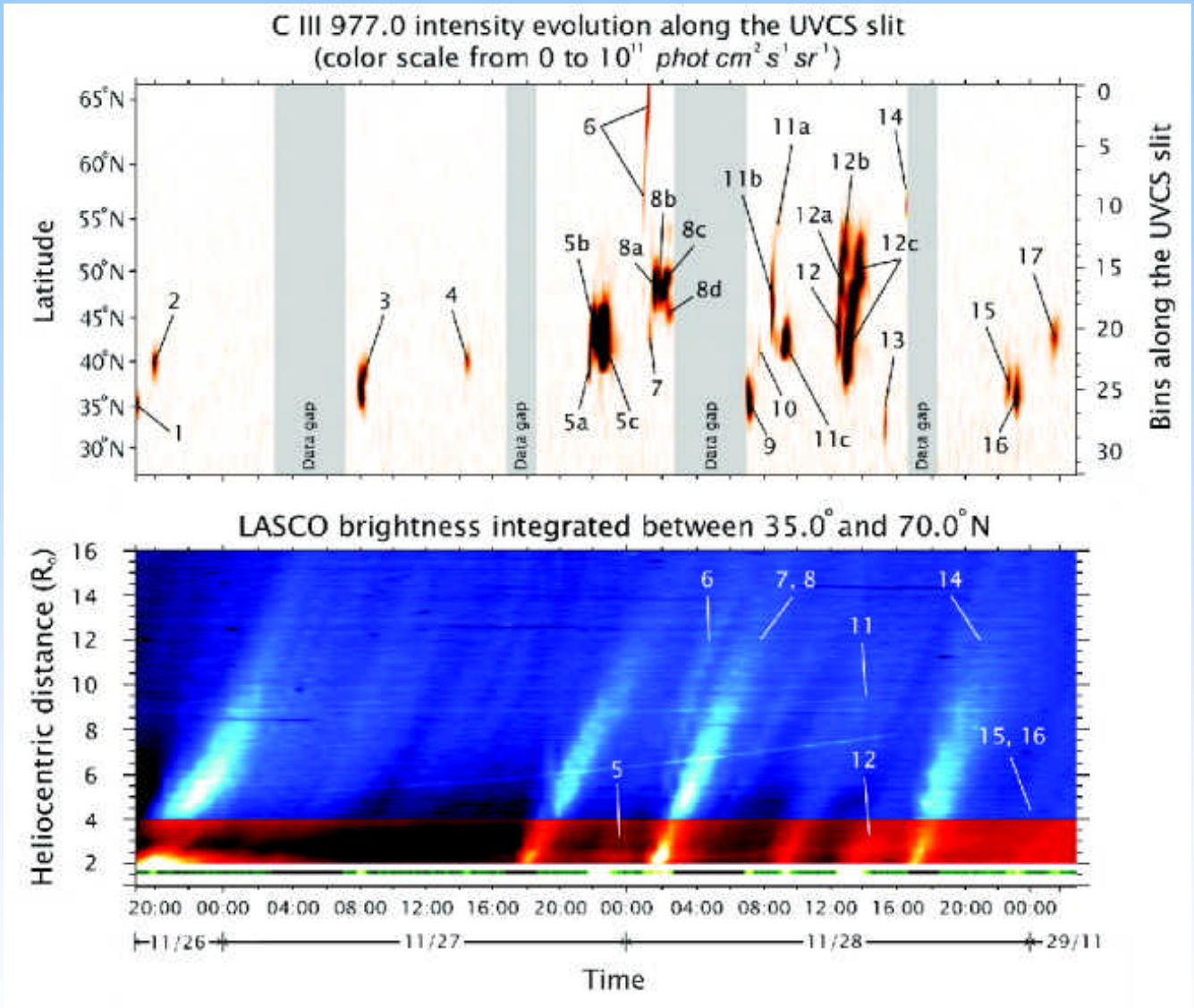
Maybe any of several mechanisms can drive system "over the edge," leading to eruption.

Smaller-Scale Eruptive Events

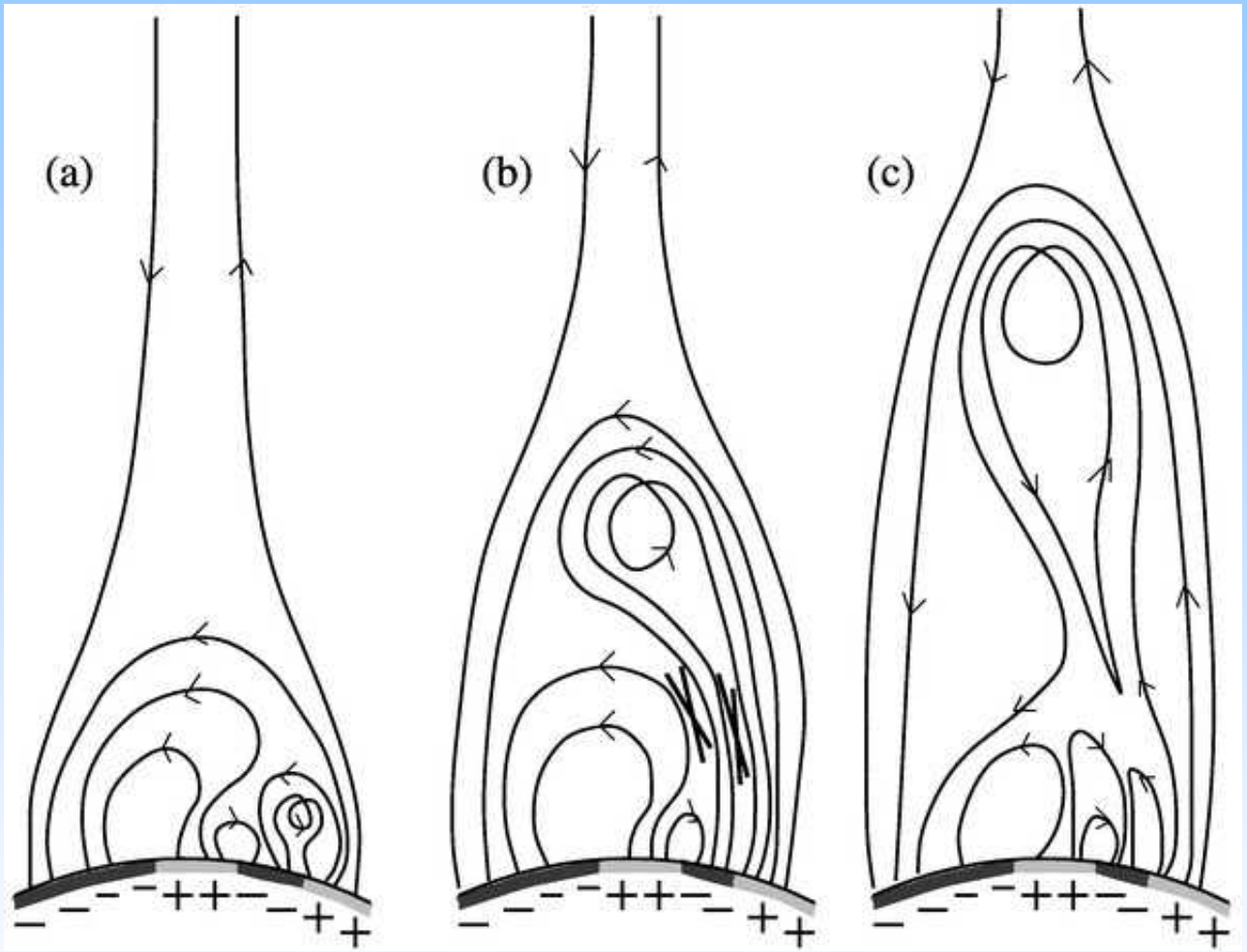
- Stremer Puff CMEs: Bemporad et al. (2005), Yunchun Jiang et al. (2009)
- Quiet Sun Mini-CMEs (Innes et al. 2009)
- Explosive Events Associated with Surges (Madjarska et al. 2009)
- ….



Bemporad et al. (2005)



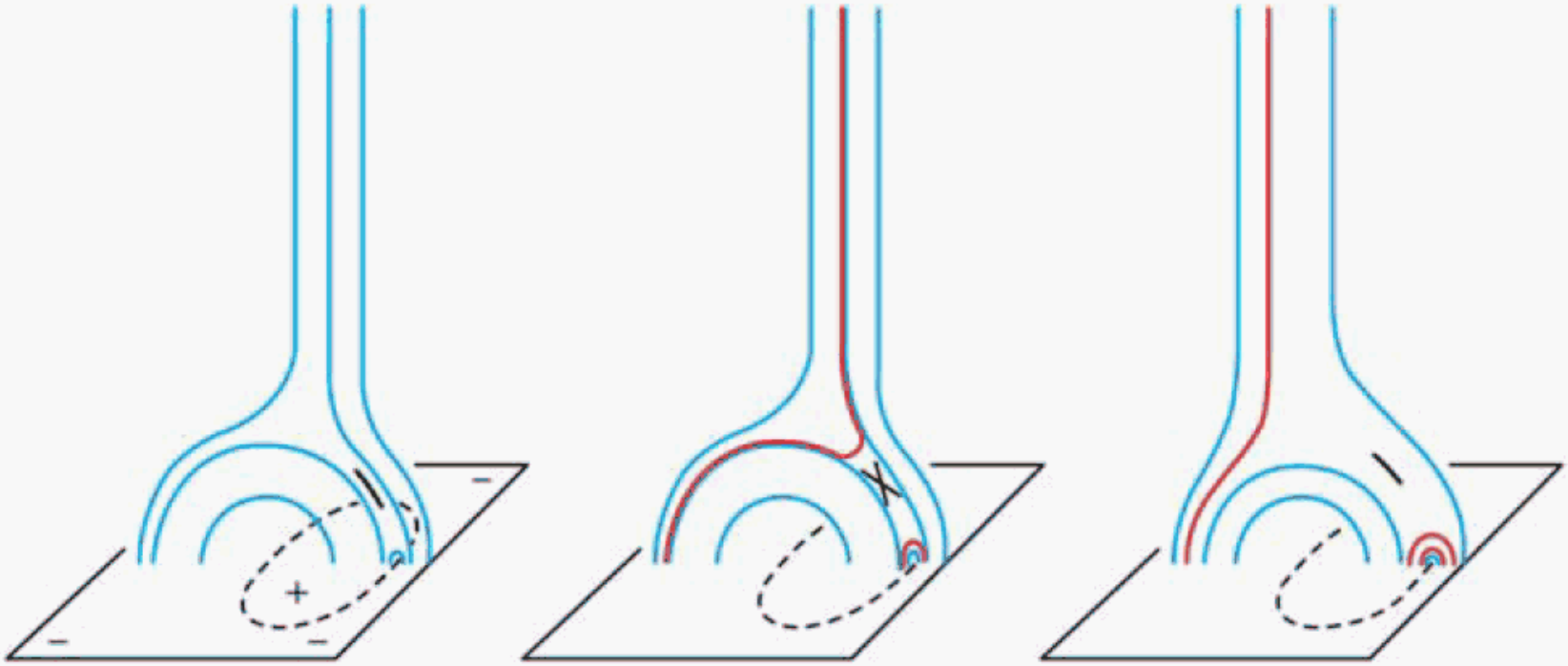
Bemporad et al. (2005)



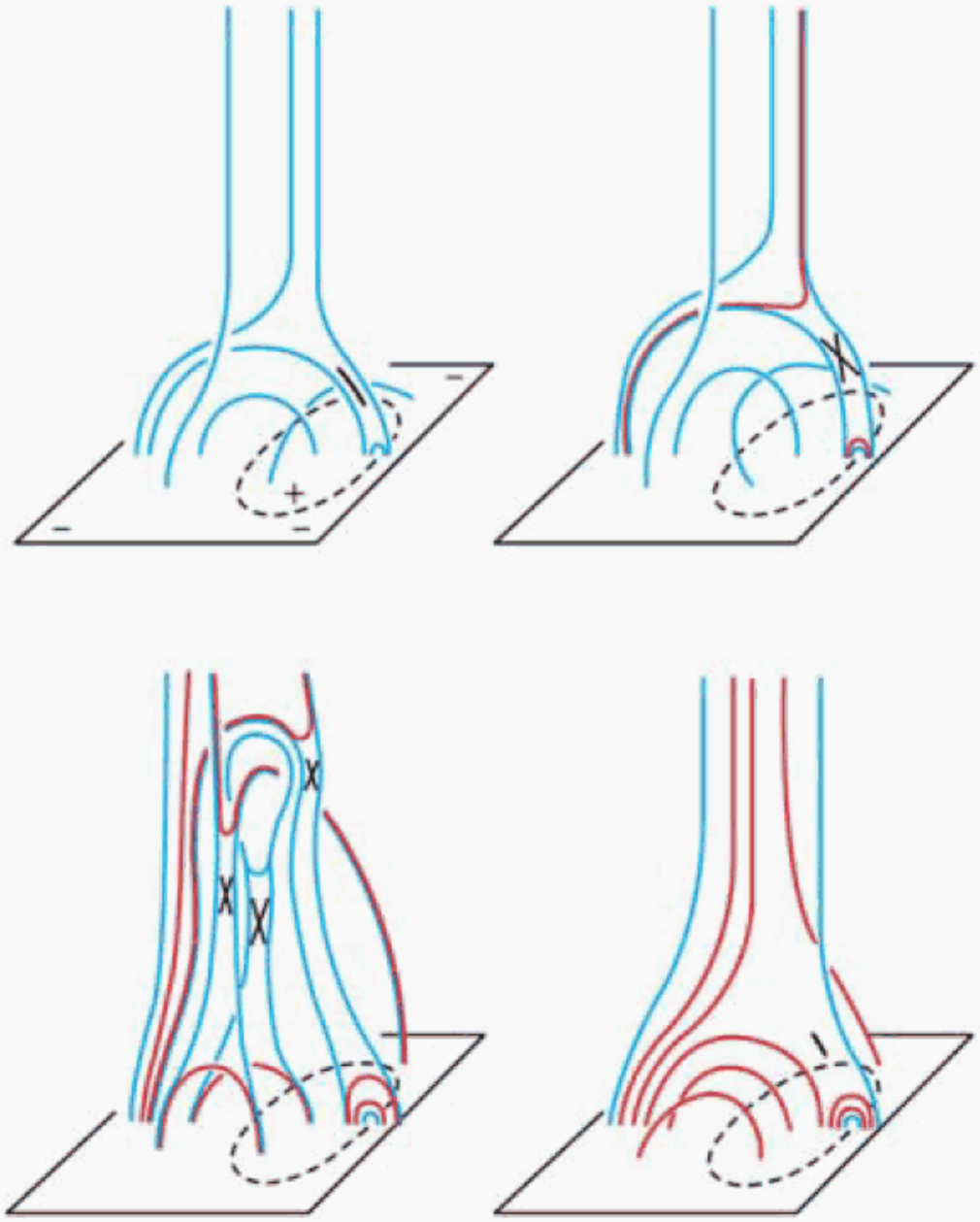
Bemporad et al. (2005)

Eruptions on Still Smaller Scales

- X-Ray jets are prevalent in the polar coronal hole regions (Shibata et al. 1994, Shimojo et al 1998, Certain et al. 2007, Savcheva et al. 2009).
- There is a viable theory for “standard” (non-eruptive) jets (e.g., Shibata et al. 1992, Yokoyama & Shibata 1995, Pariat et al. 2002).
- In addition to standard jets, there are ``blowout jets,'' which make up ~30% of the population (Y.-M. Wang et al 1998, Moore et al. 2010, Nistico et al. 2009).
- Also, observations by Patsourakos et al. 2008; Raouaf et al. (2010), theory by Rachmeler et al. 2010).

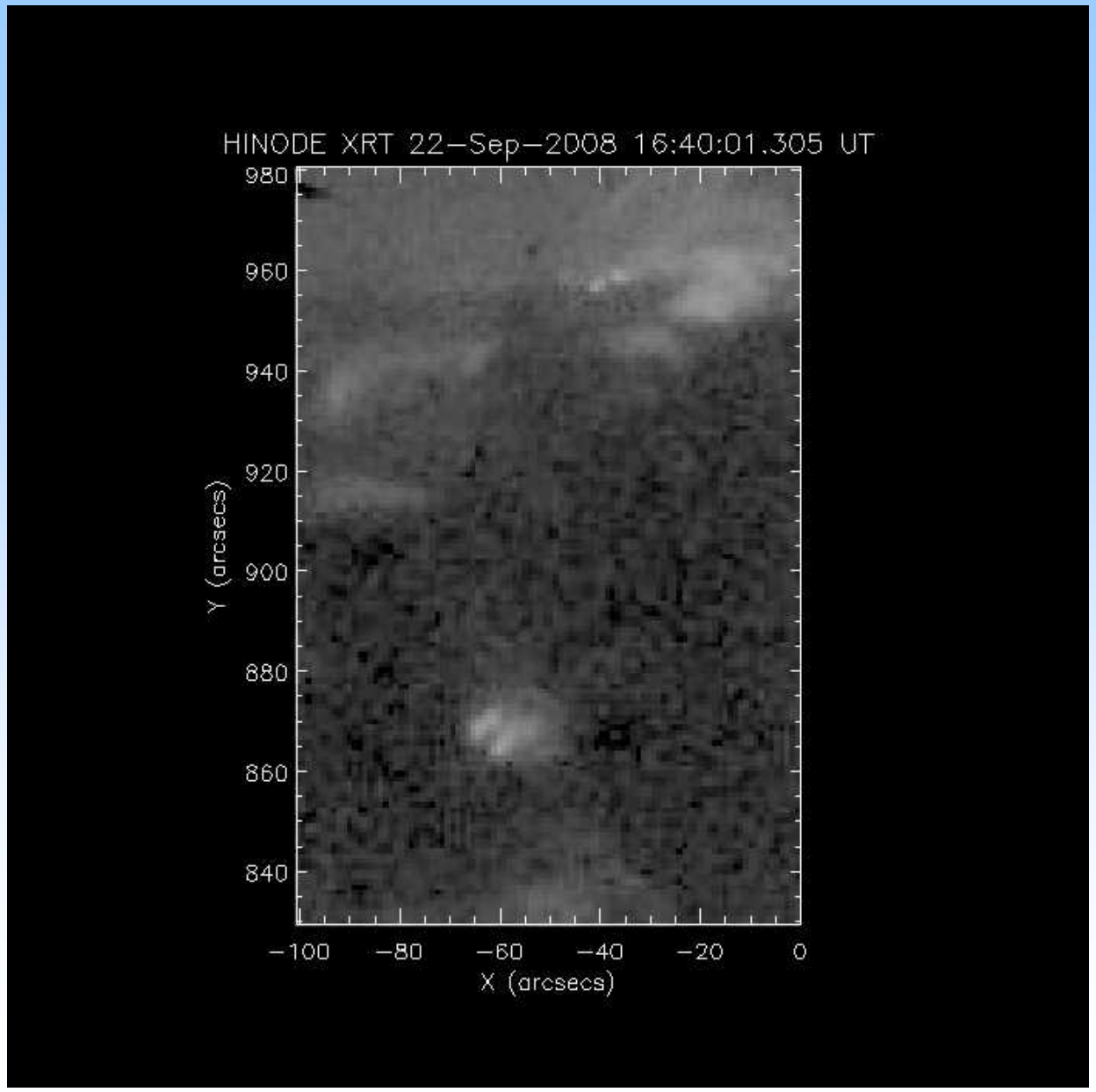


Moore et al. (2010) (after Shibata et al. 1992)

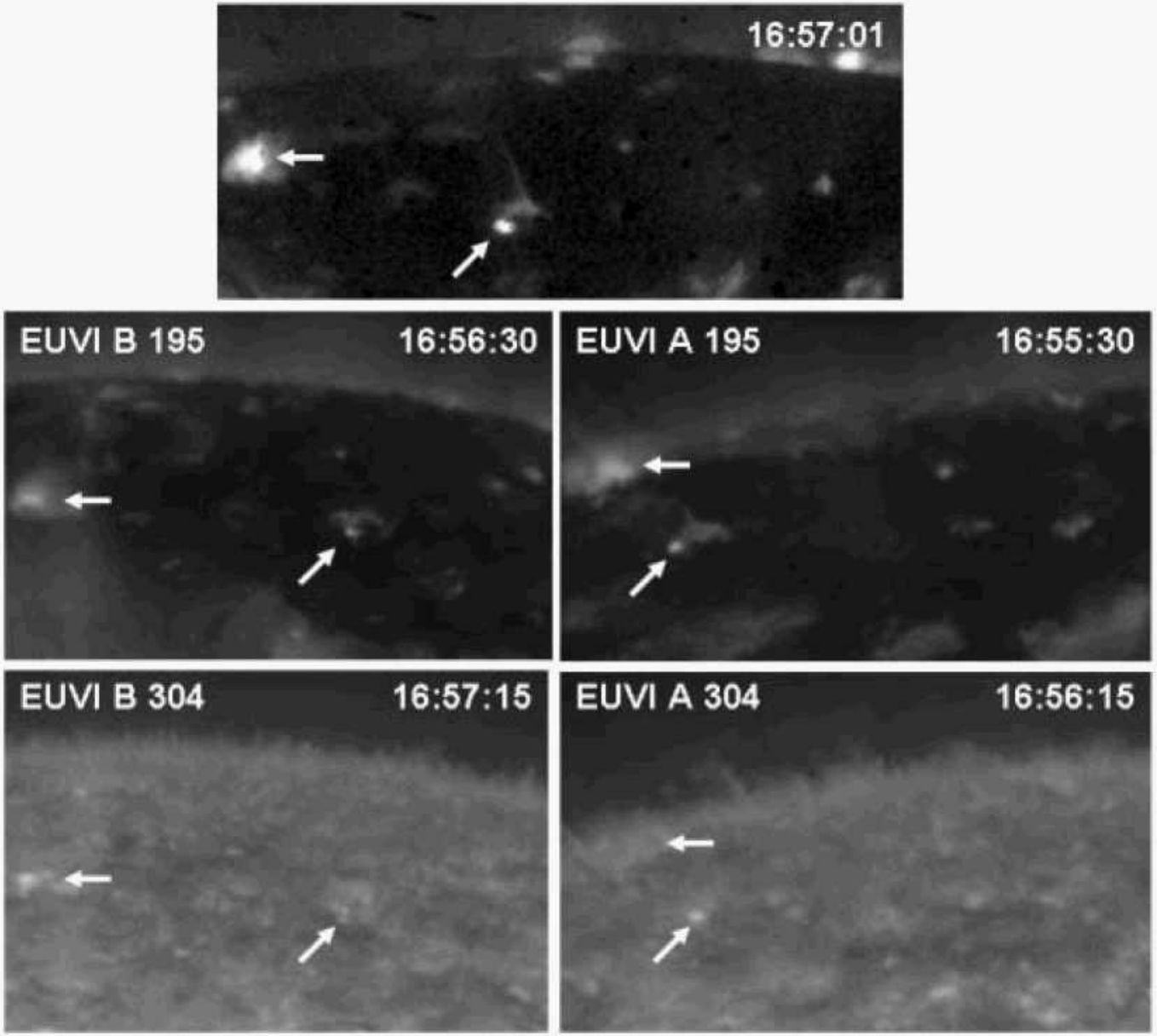


Moore et al. (2010)

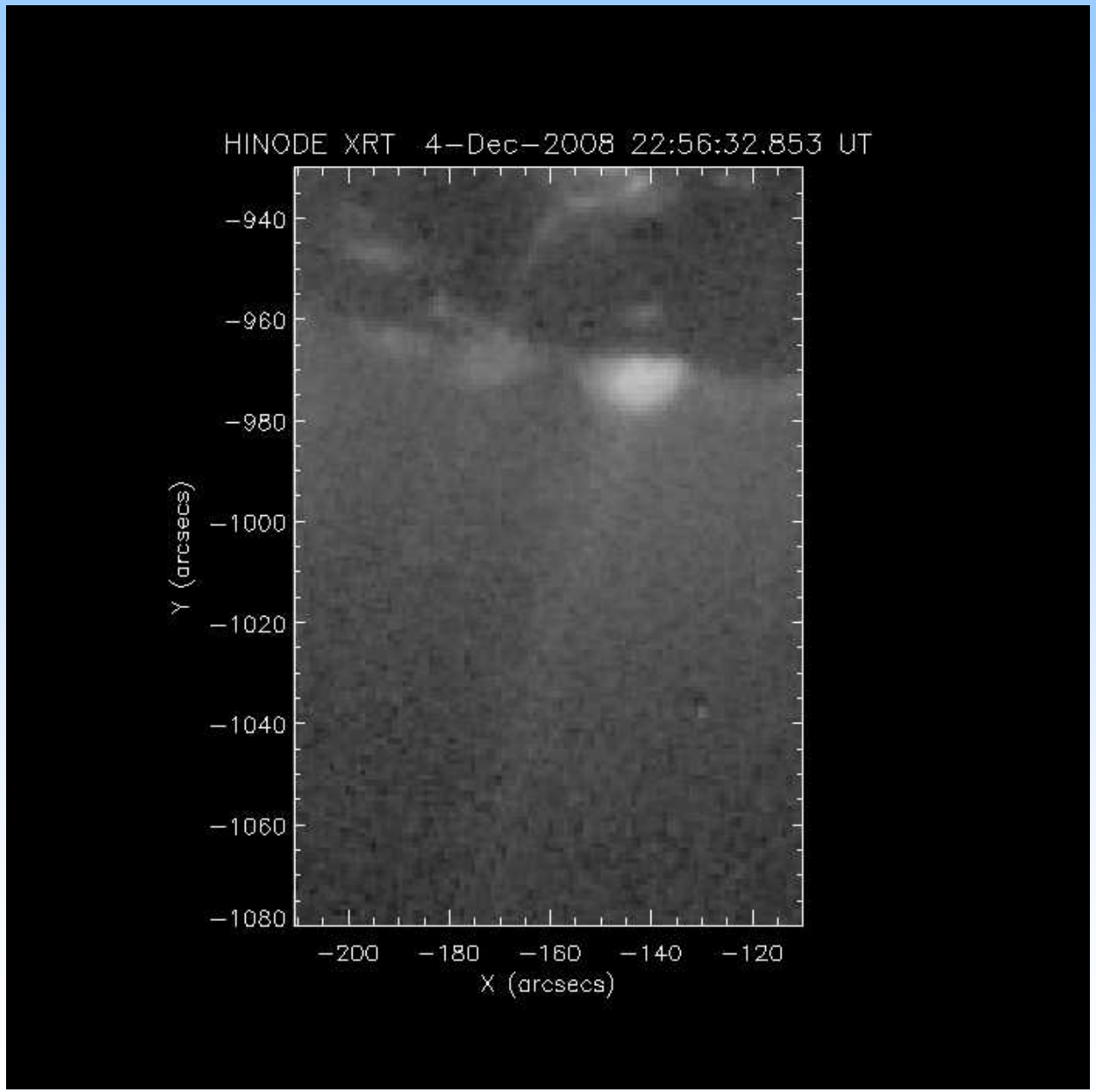
Standard Jet Example

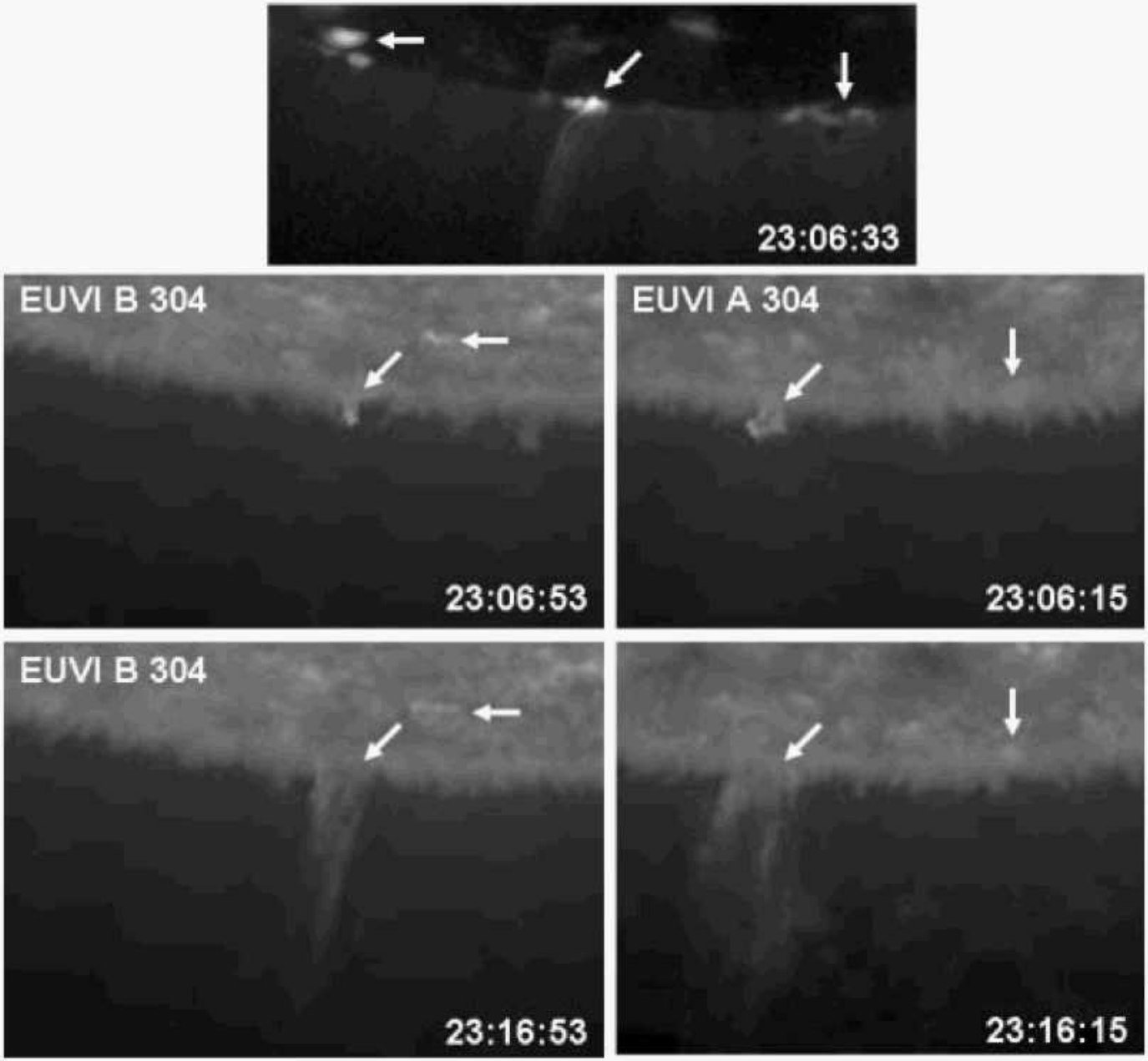


Moore et al. (2010)

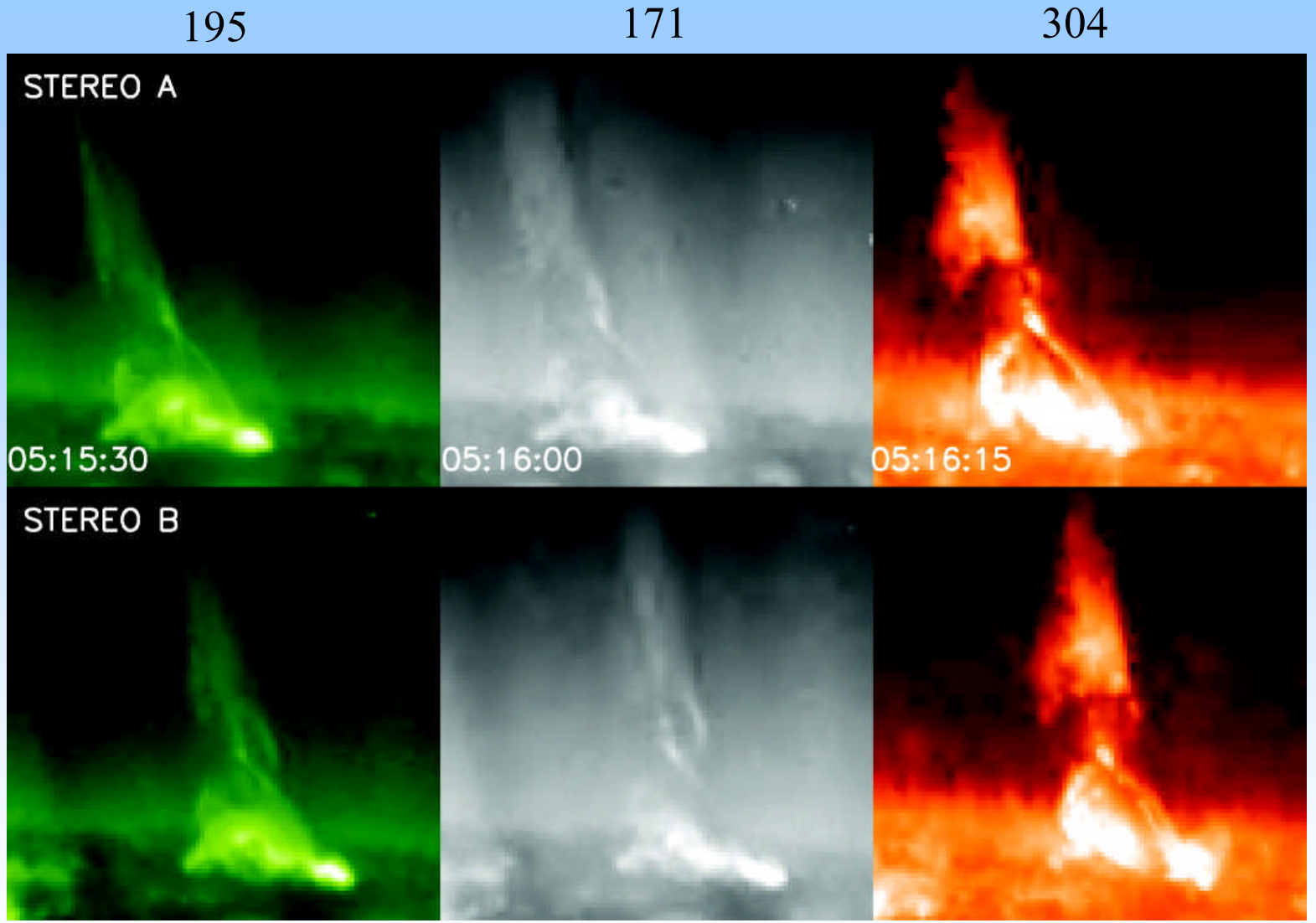

16:57:01
EUVI B 195
16:56:30
EUVI A 195
16:55:30
EUVI B 304
16:57:15
EUVI A 304
16:56:15

Blowout Jet Example




23:06:33
EUVI B 304
23:06:53
EUVI A 304
23:06:15
EUVI B 304
23:16:53
23:16:15

Another Blowout Jet



Patsourakos et al. (2008)

Conclusions and Discussion

- Solar eruptions occur on many different scales. (Schrijver 2010: bipole eruptions more frequent as size decreases.)
- Trigger might be any of several different candidates, working independently or in tandem.
- How about larger scales than (solar) CMEs? (Stellar eruptions.)
- How about smaller scales than X-ray jets? (Spicules? Moore 1989)

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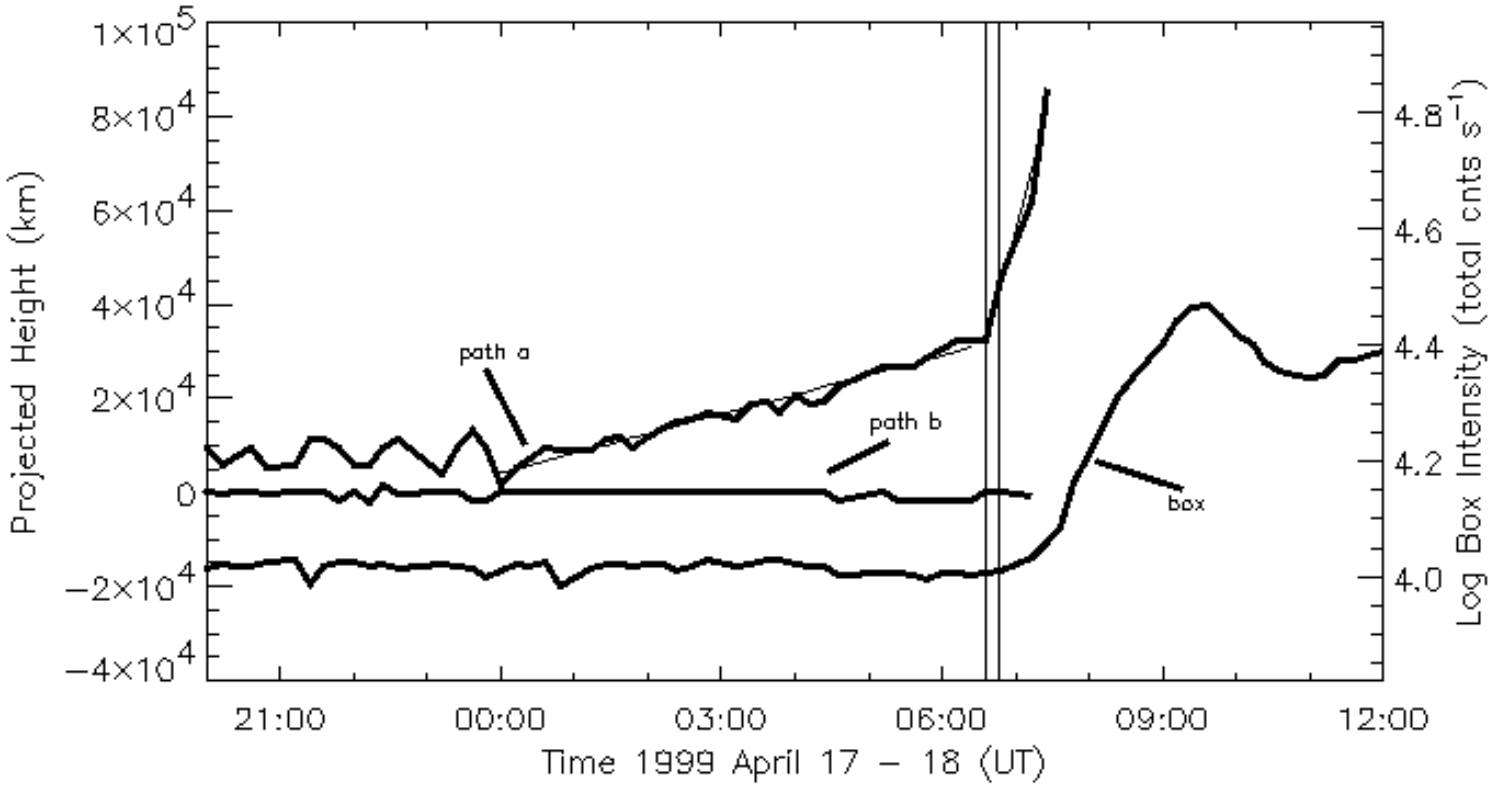
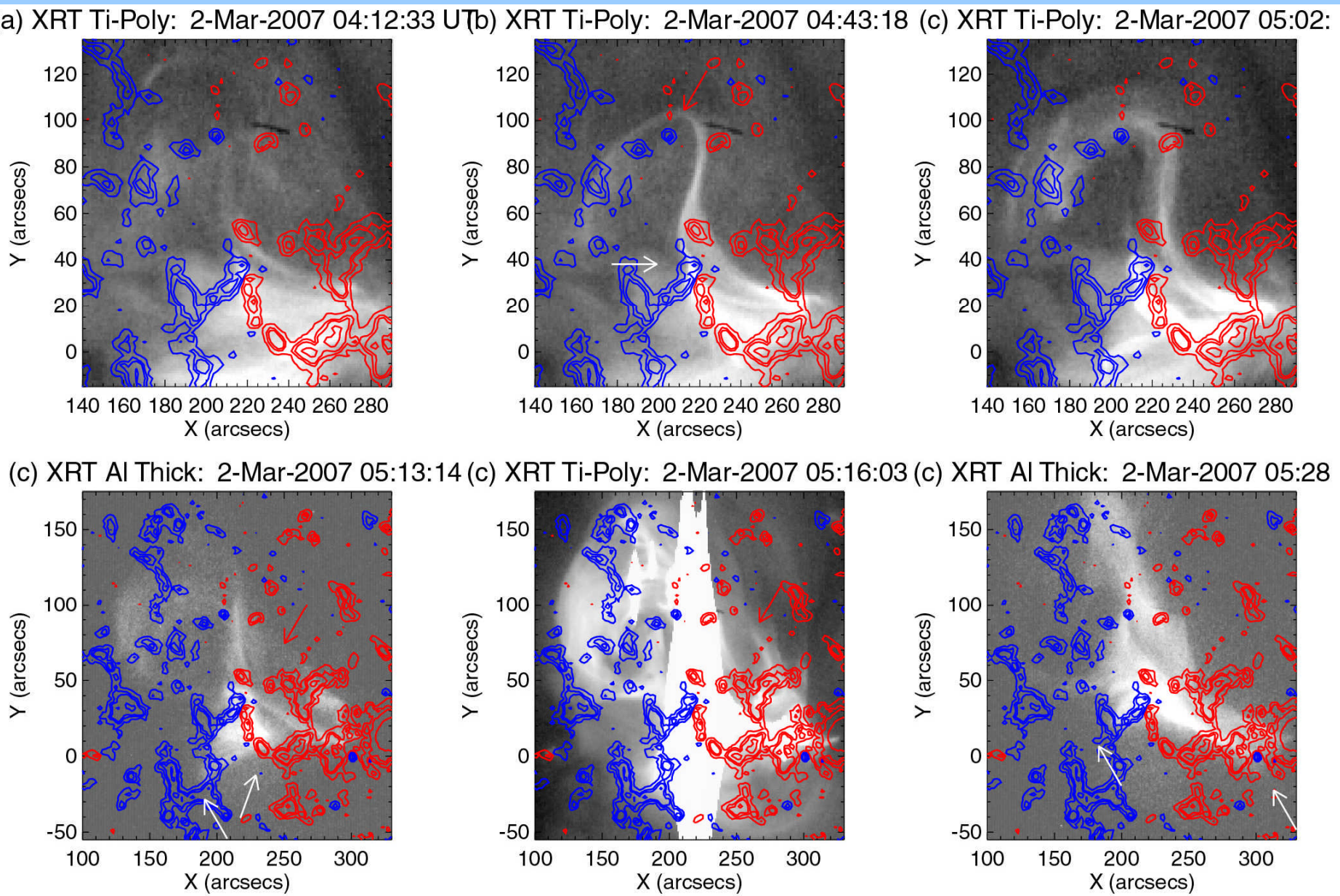
Filament pre-eruption, pre-flare **slow-rise phase**

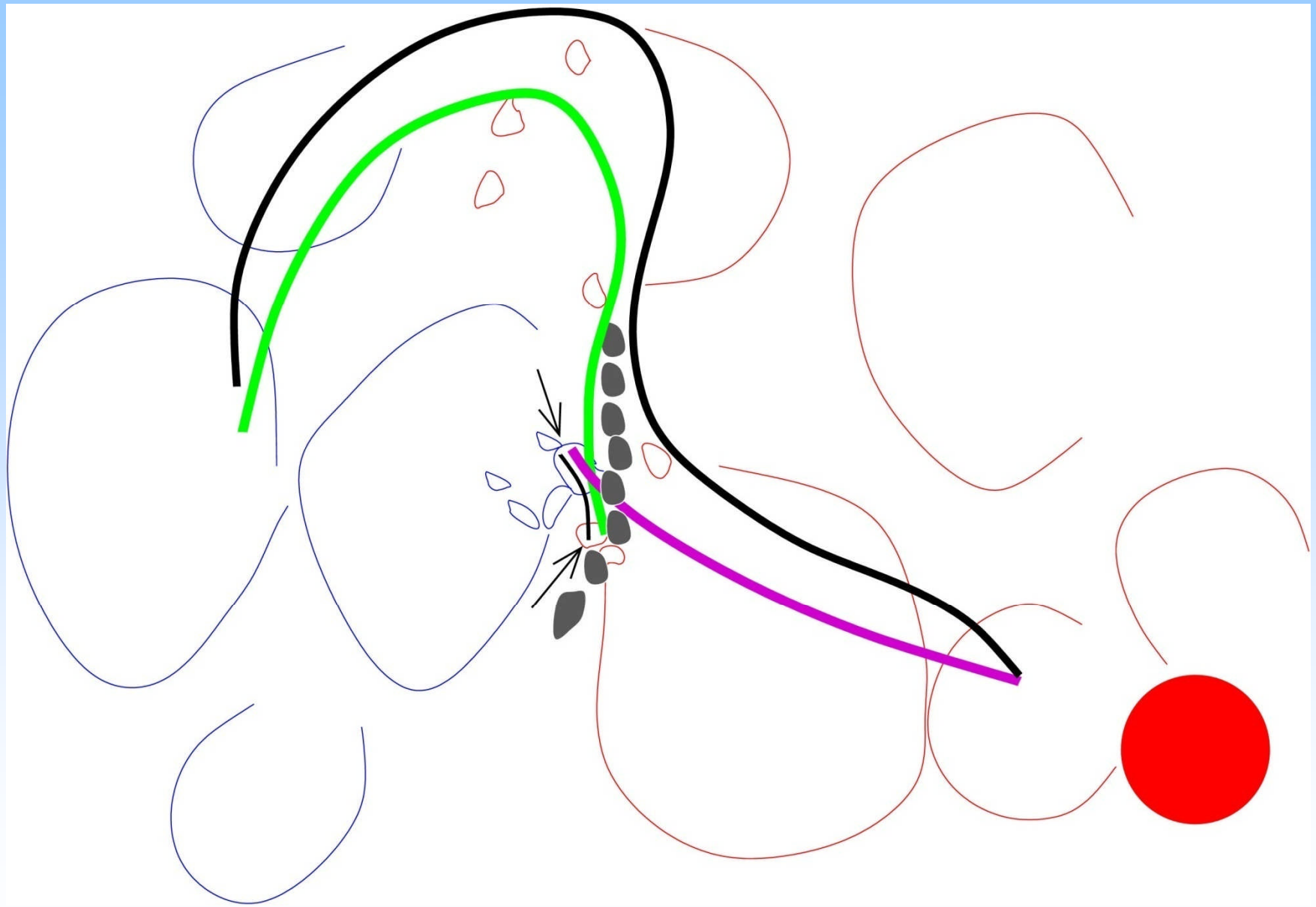


Sterling, Moore, Thompson (2001)

(e.g., Tandberg-Hanssen et al. 1980, Kahler et al. 1988)

XRT on MDI


(a) XRT Ti-Poly: 2-Mar-2007 04:12:33 UT
(b) XRT Ti-Poly: 2-Mar-2007 04:43:18
(c) XRT Ti-Poly: 2-Mar-2007 05:02:
(c) XRT Al Thick: 2-Mar-2007 05:13:14
(c) XRT Ti-Poly: 2-Mar-2007 05:16:03
(c) XRT Al Thick: 2-Mar-2007 05:28
Y (arcsecs)
X (arcsecs)



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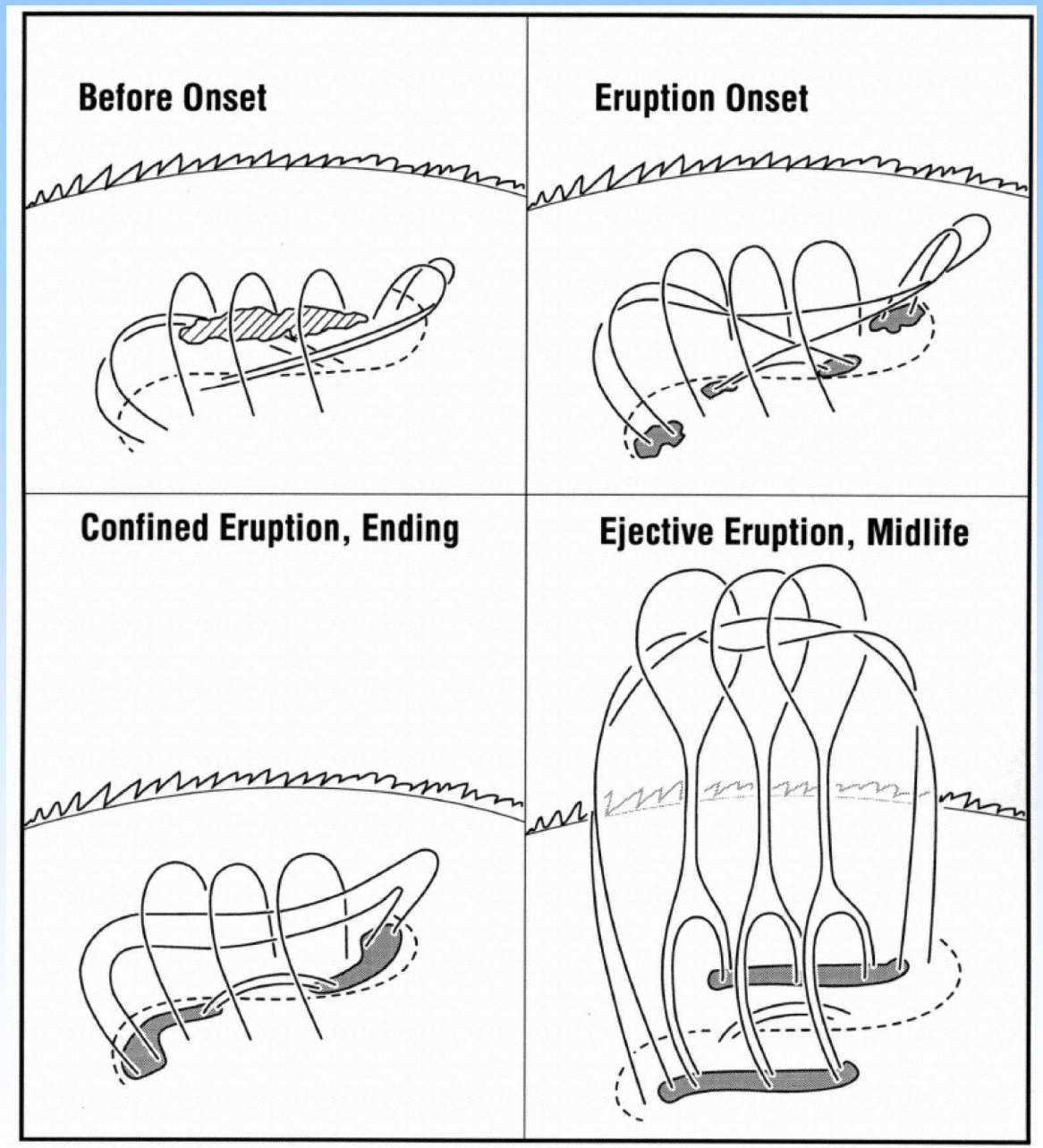

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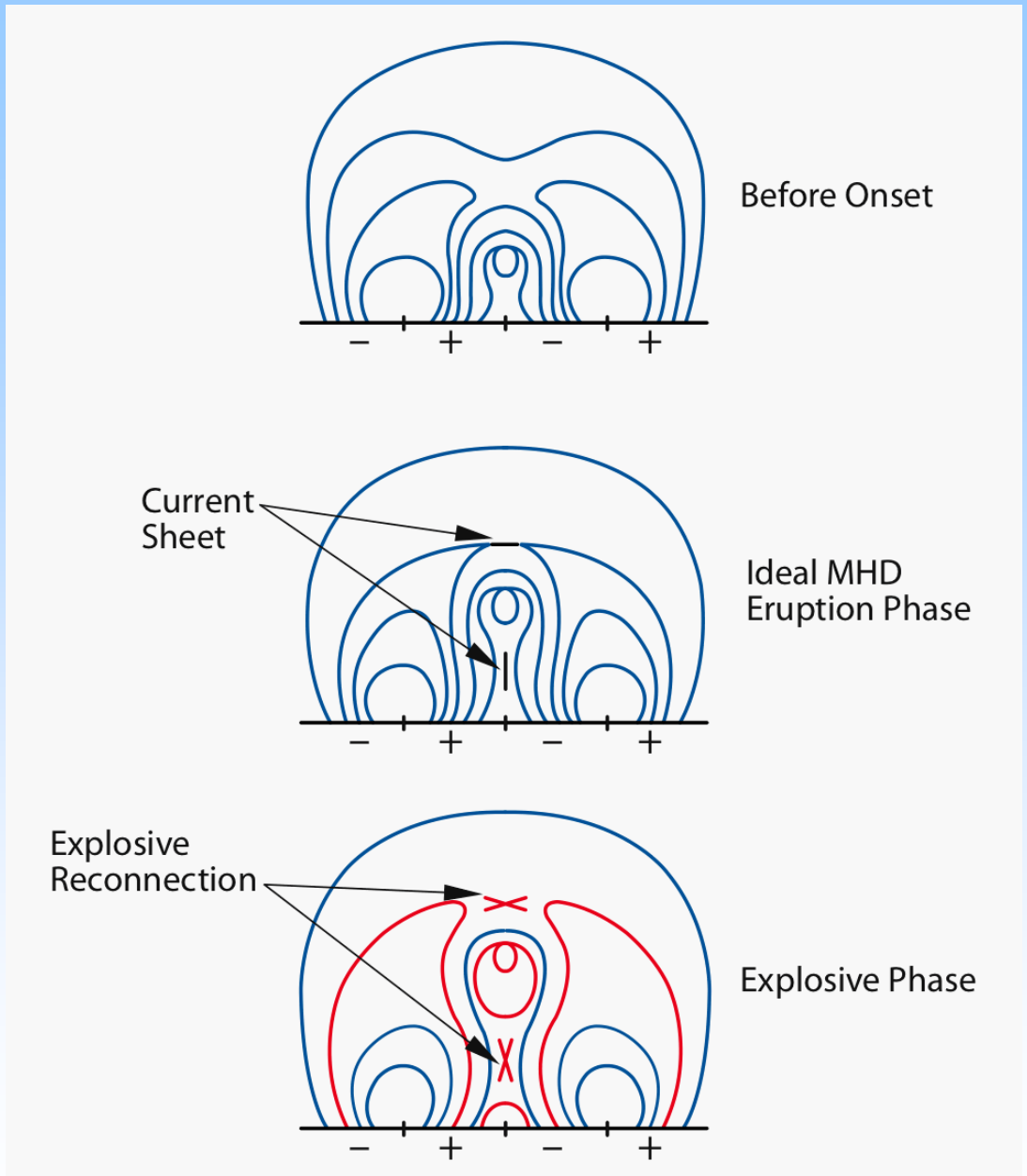
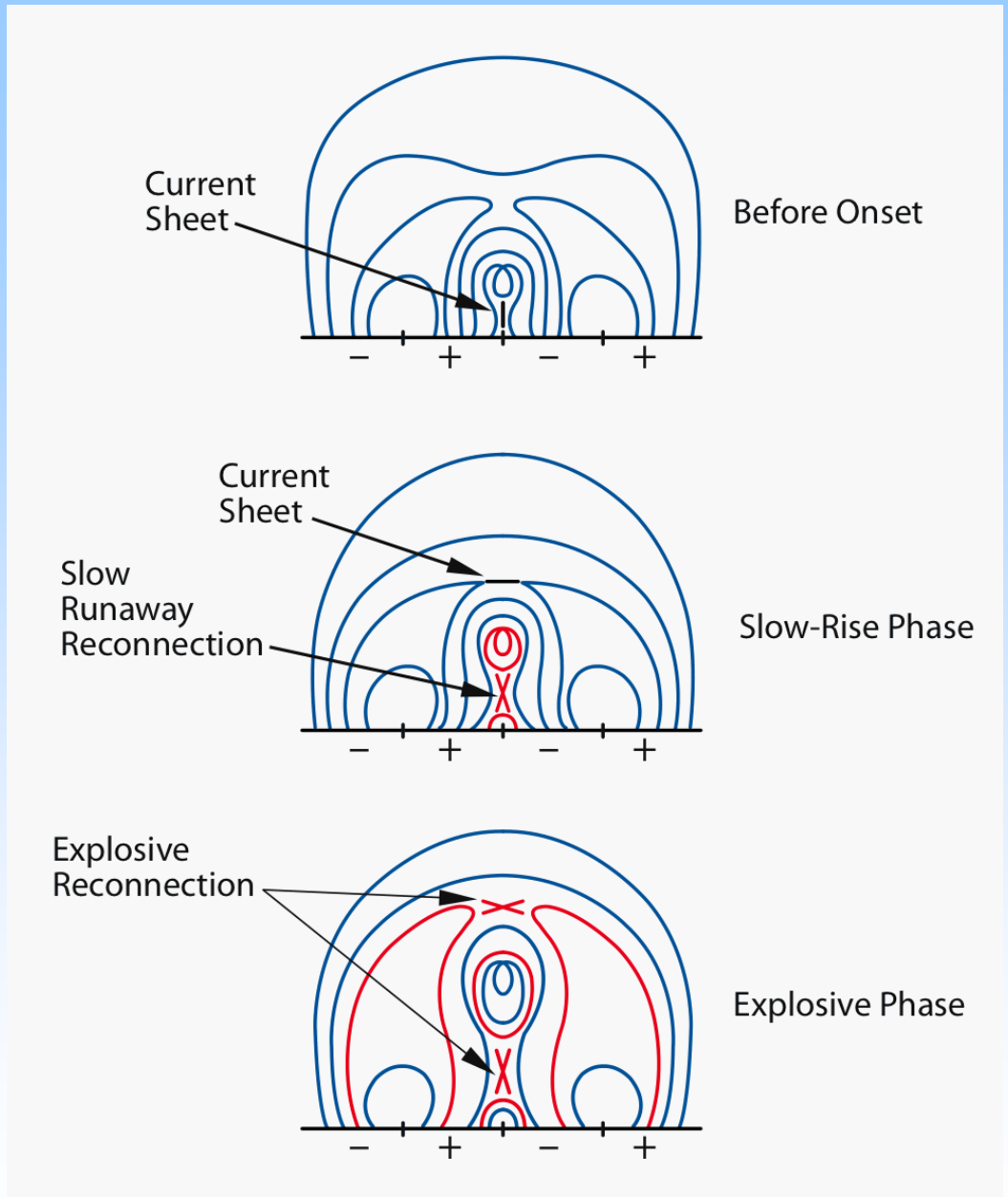
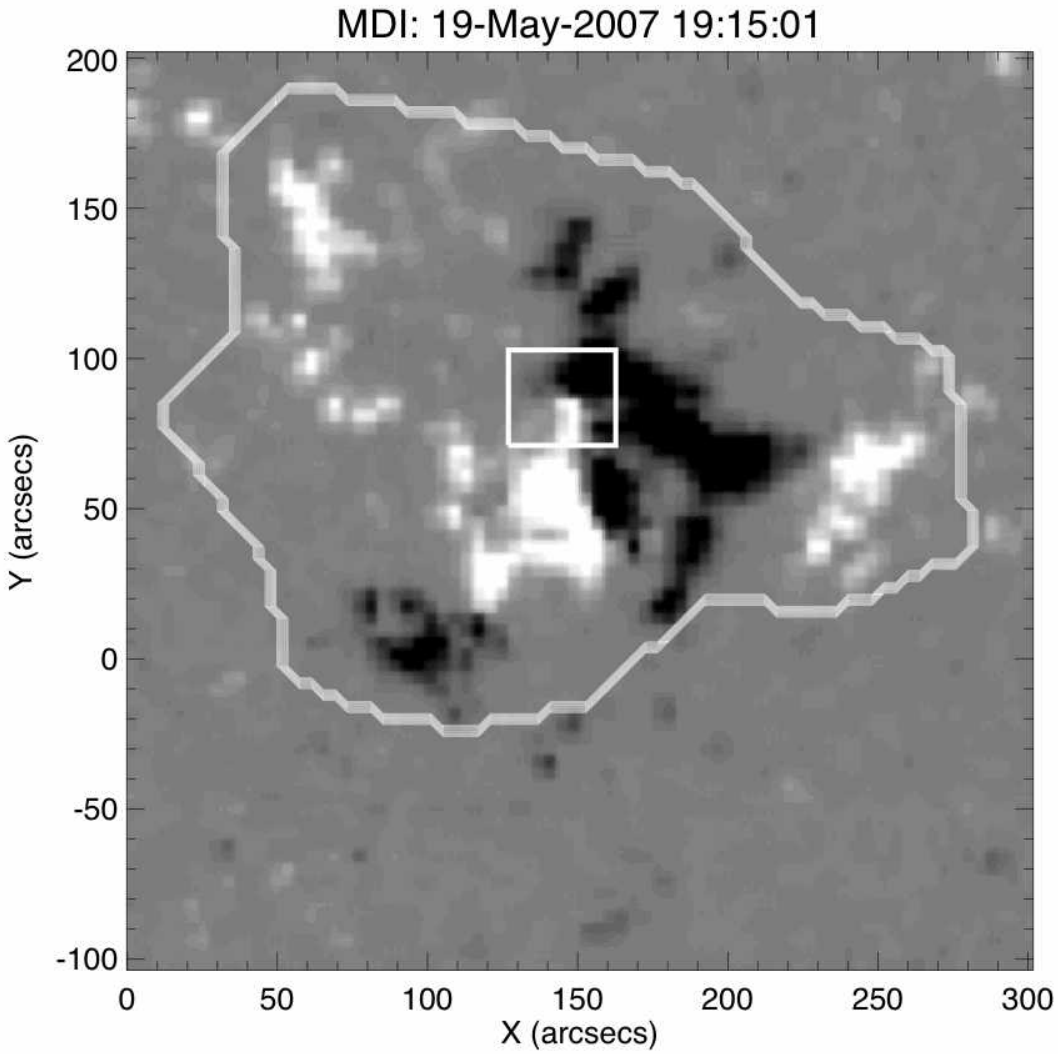
Moore et al. (2001)

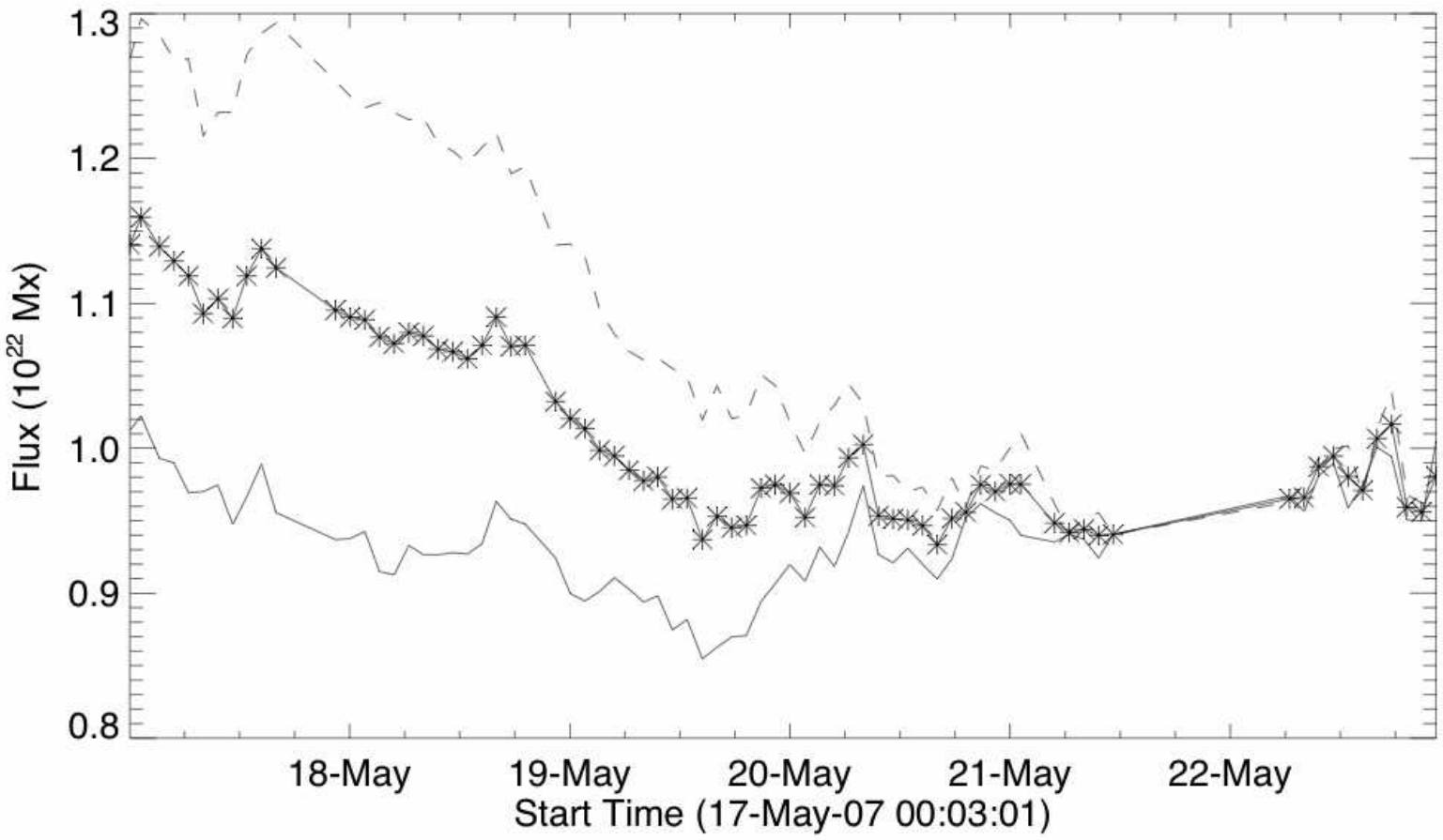


Moore & Sterling (2006)

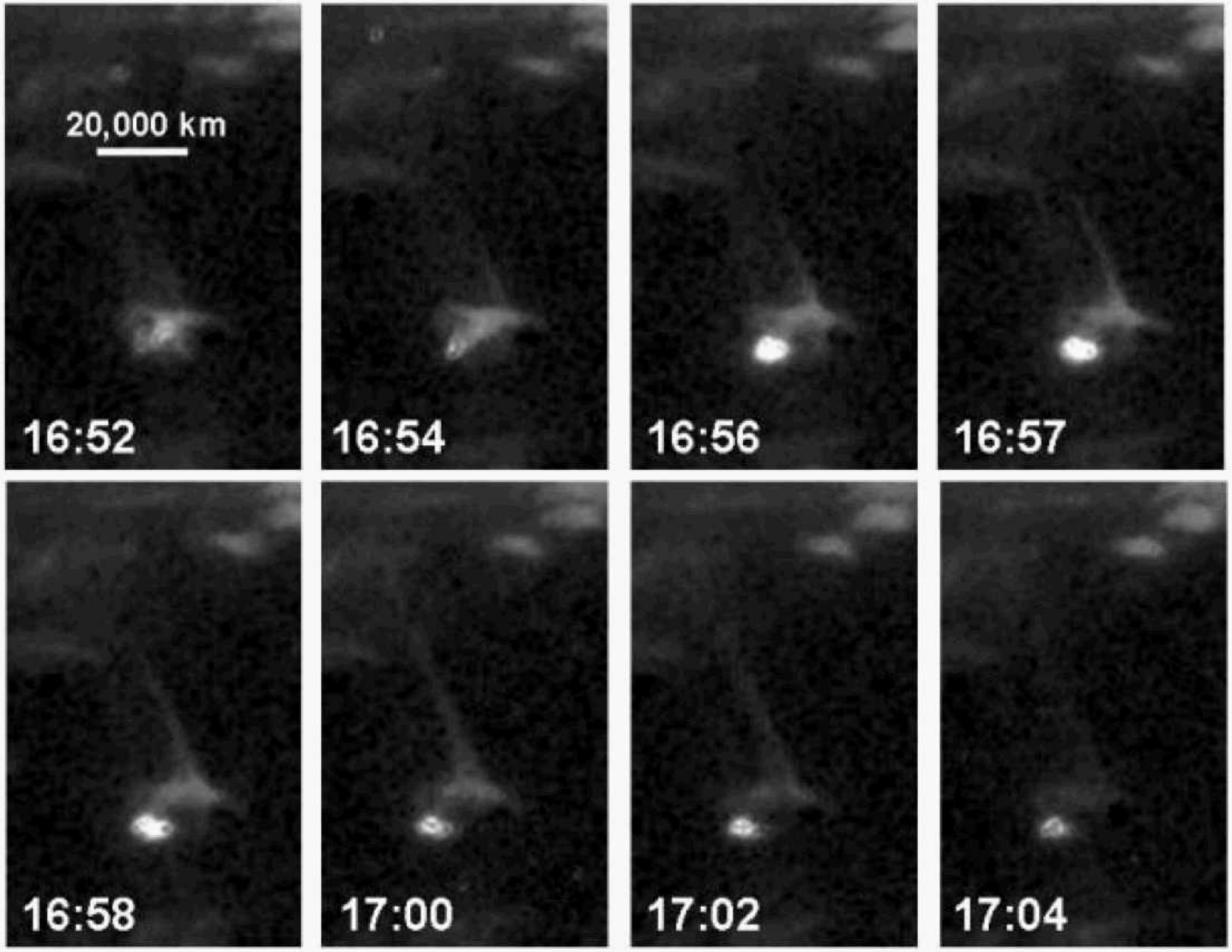


Moore & Sterling (2006)

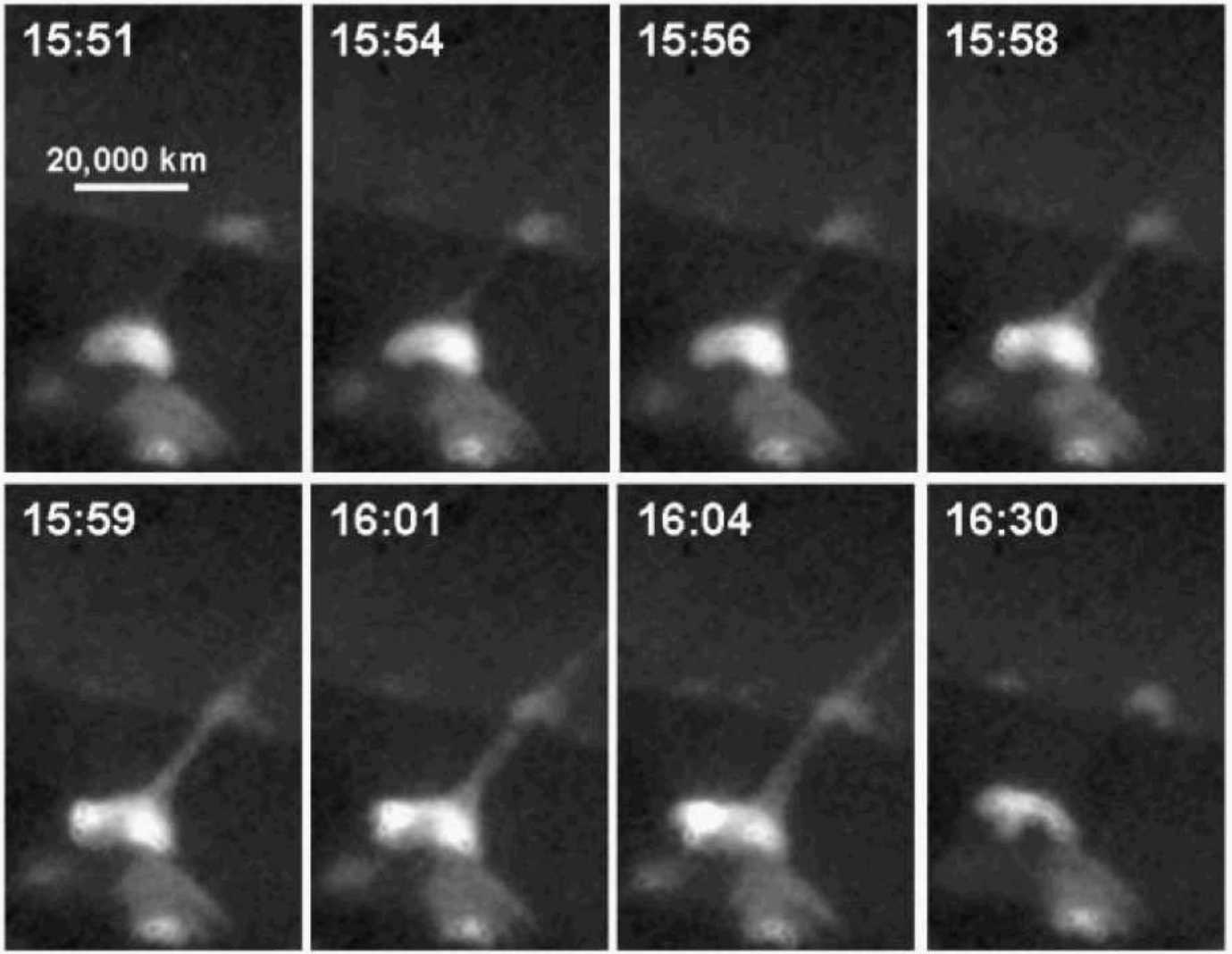

MDI: 19-May-2007 19:15:01
200
150
100
50
0
-50
-100
Y (arcsecs)
0
50
100
150
200
250
300
X (arcsecs)

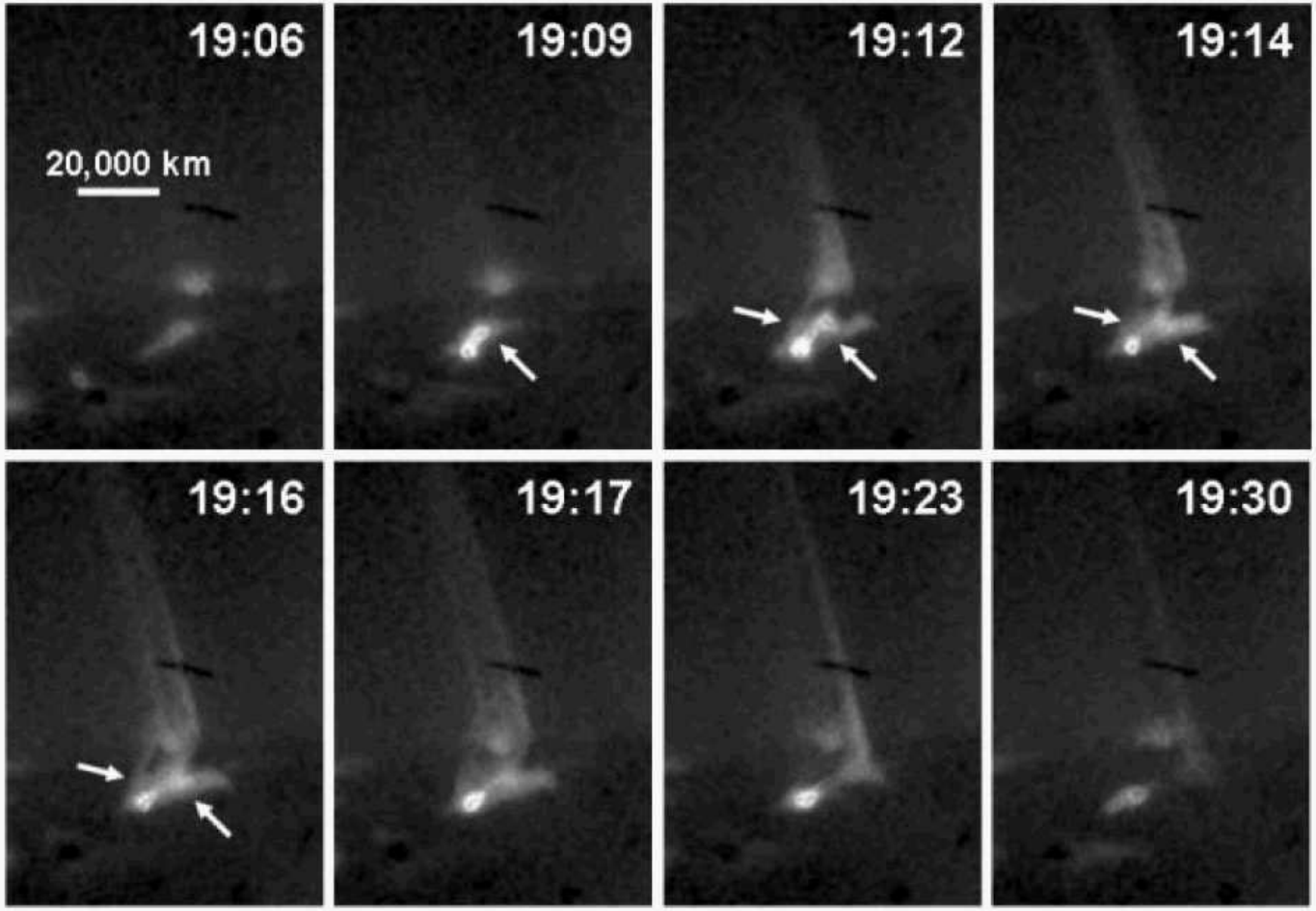


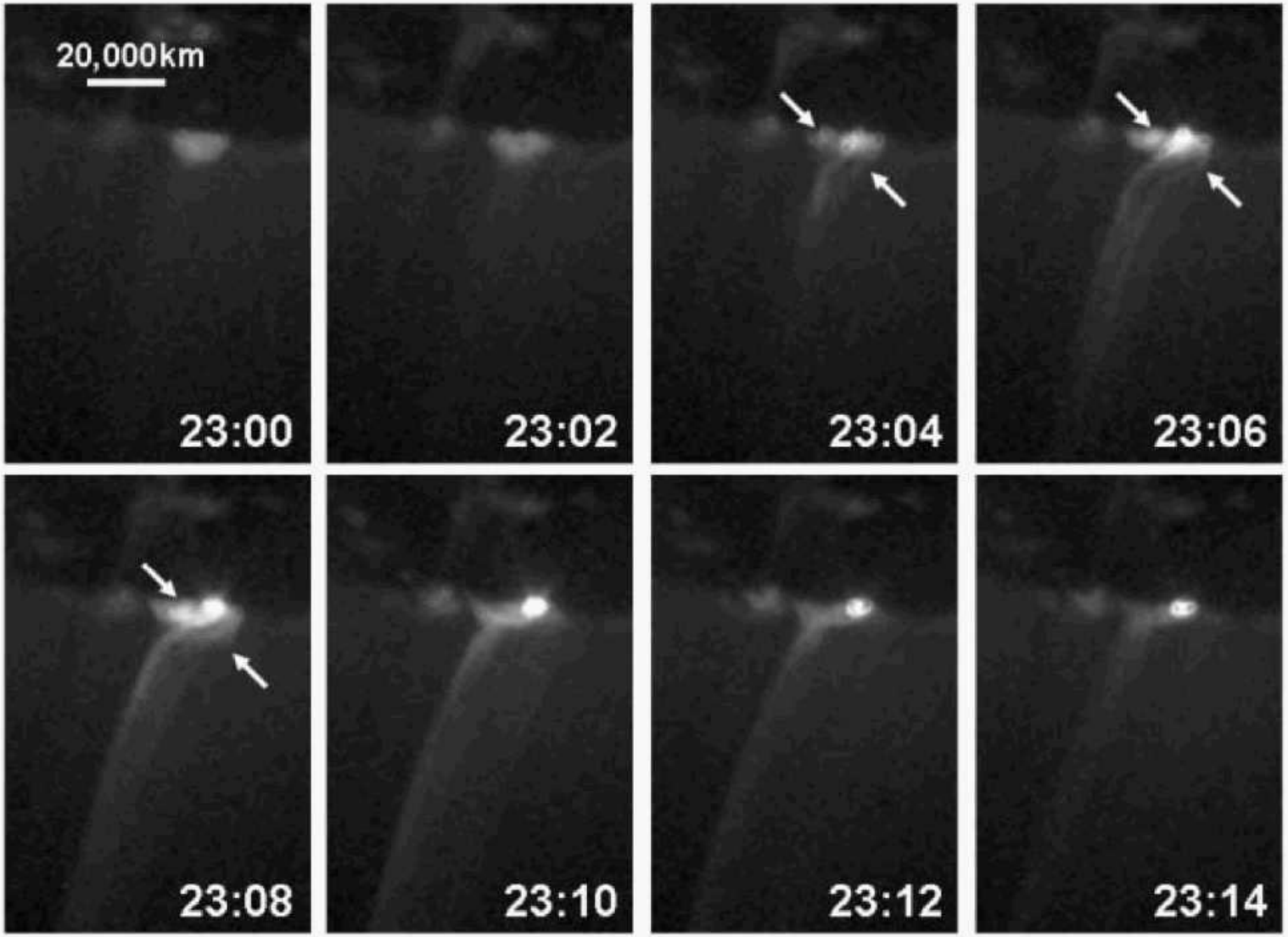
Flux decrease of ~10% in 24 hrs from 18 May 12 UT.



Moore et al. (2010)


15:51
20,000 km
15:54
15:56
15:58
15:59
16:01
16:04
16:30


19:06
20,000 km
19:09
19:12
19:14
19:16
19:17
19:23
19:30


20,000km
23:00
23:02
23:04
23:06
23:08
23:10
23:12
23:14

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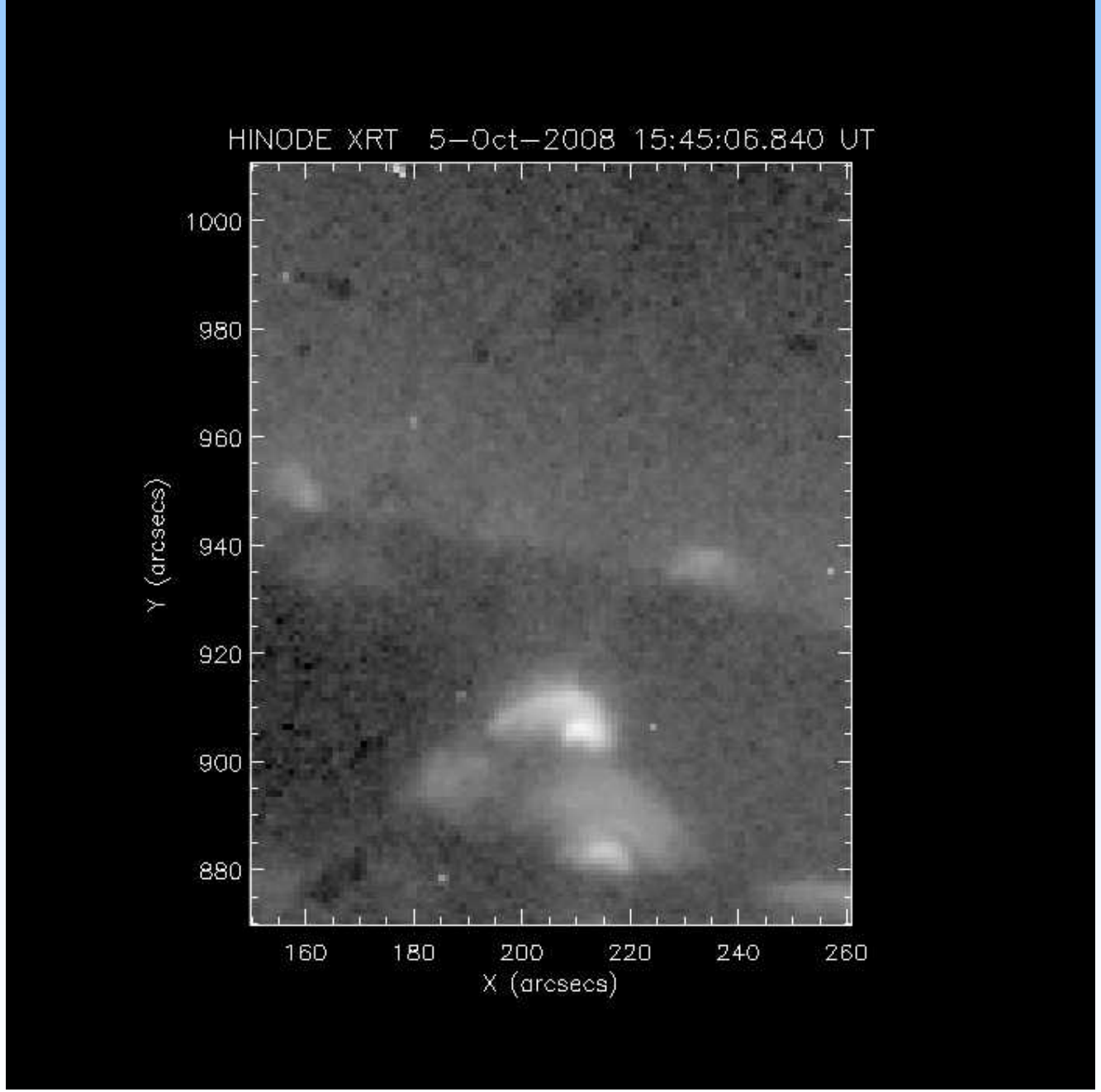
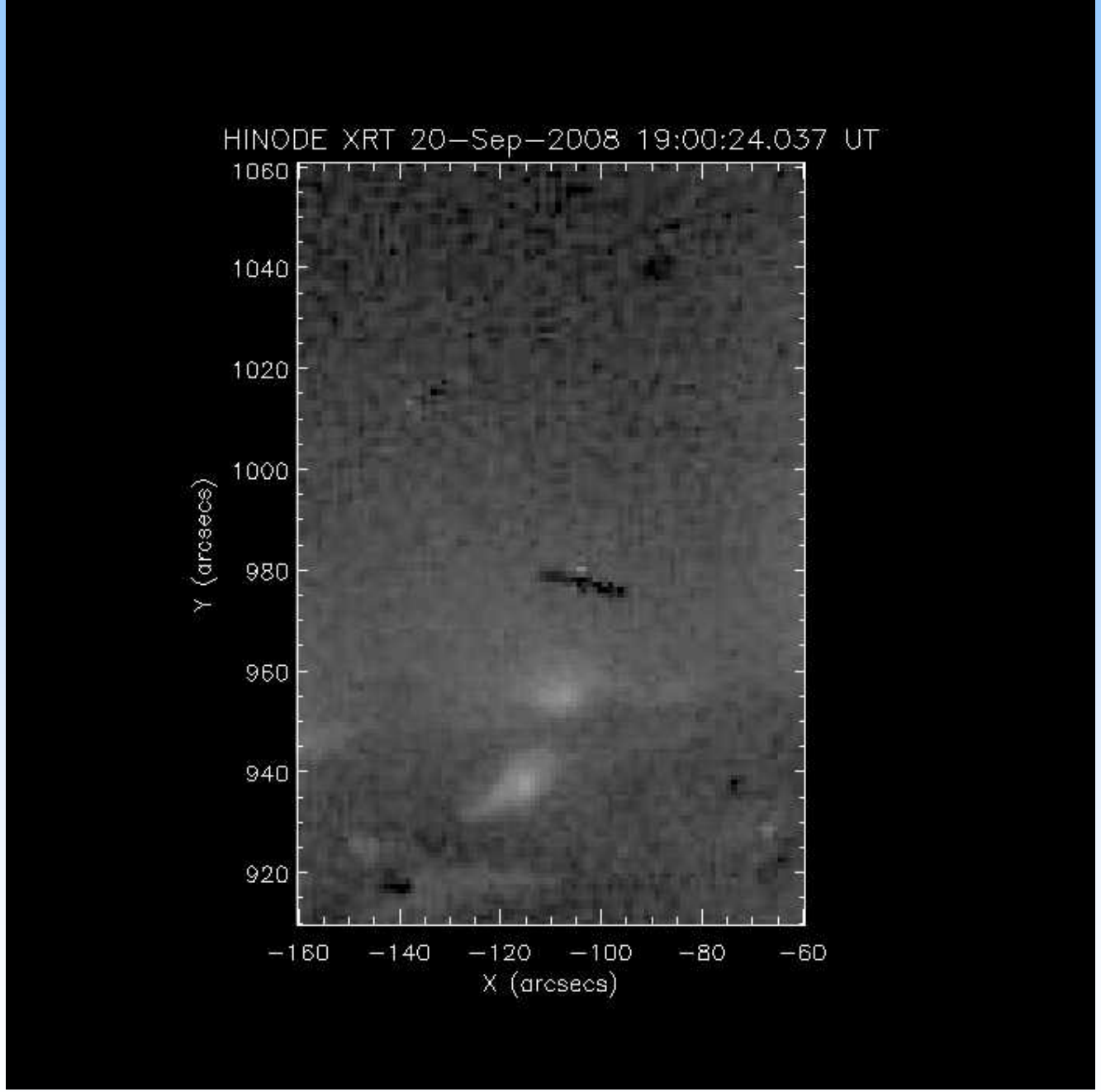

HINODE XRT 5-Oct-2008 15:45:06.840 UT
1000
980
960
940
920
900
880
Y (arcsecs)
160
180
200
220
240
260
X (arcsecs)


HINODE XRT 20-Sep-2008 19:00:24.037 UT
1060
1040
1020
1000
980
960
940
920
Y (arcsecs)
-160
-140
-120
-100
-80
-60
X (arcsecs)