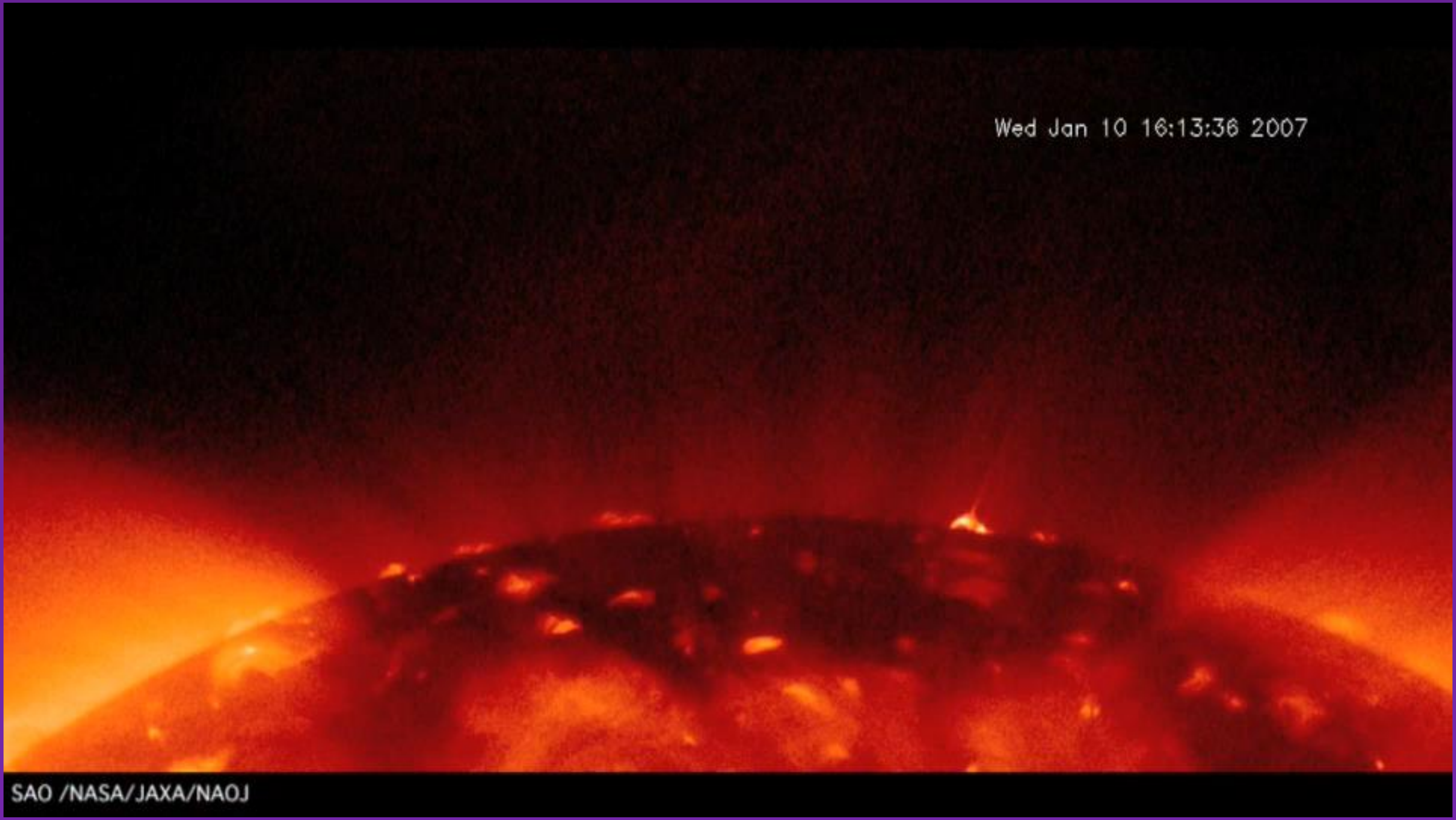
Update on Solar Coronal Jets

Alphonse C. Sterling

Contributions from:
Ronald L. Moore
Navdeep Panesar
David Falconer
Sachiko Akiyama
Seiji Yashiro
Nat Gopalswamy

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



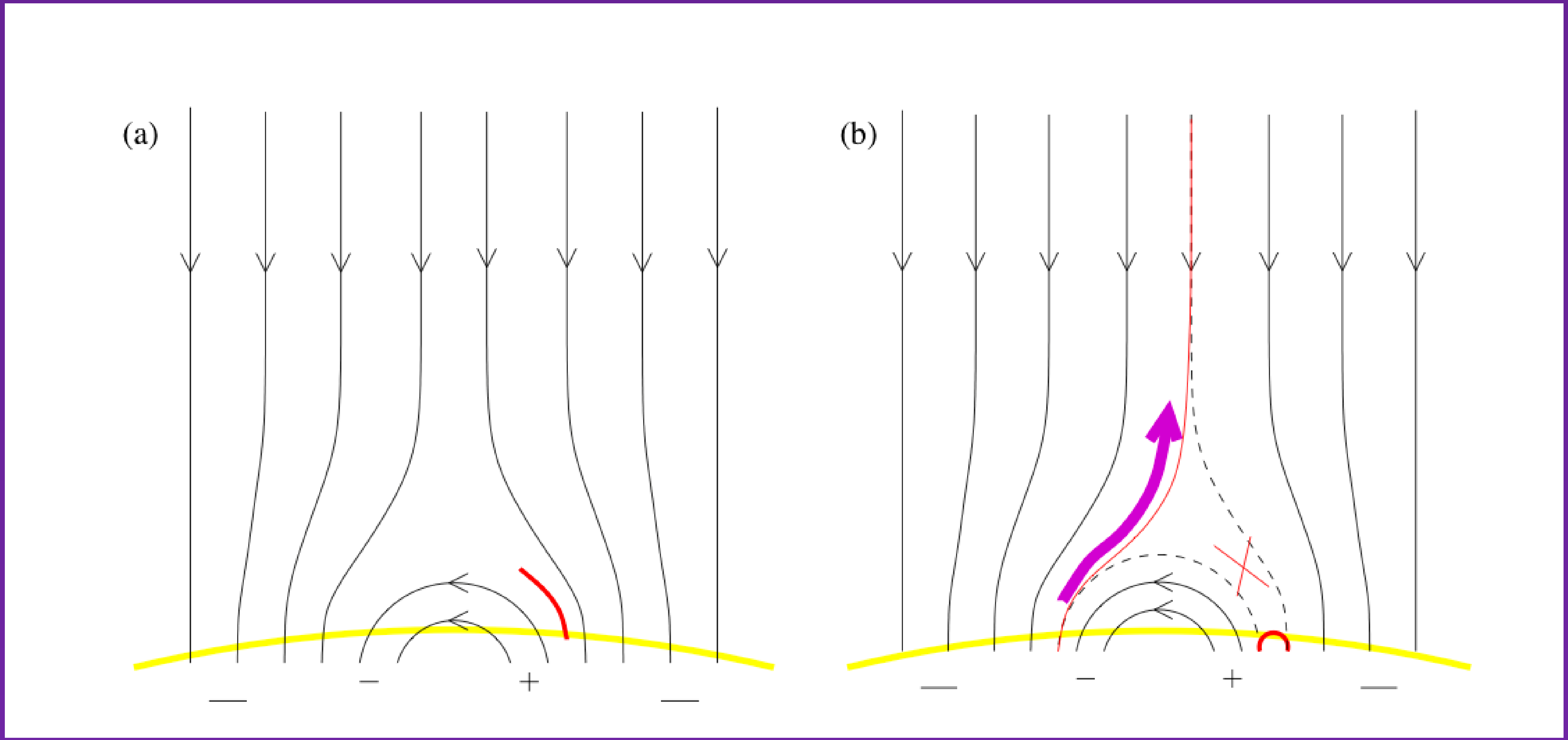
Cirtain et al. (2007)

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.)
- 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.

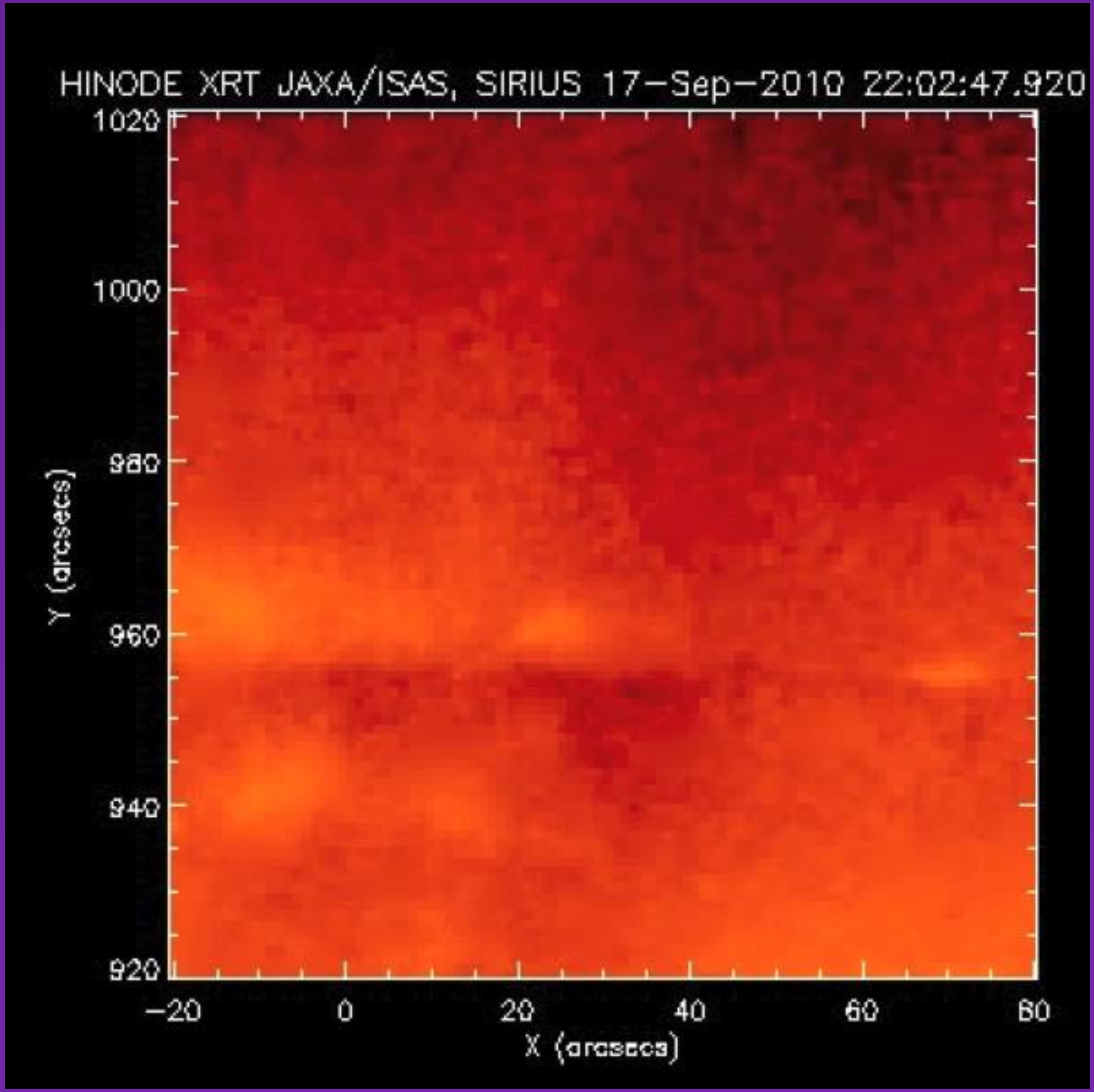
Emerging-Flux Model for (X-Ray) Jets



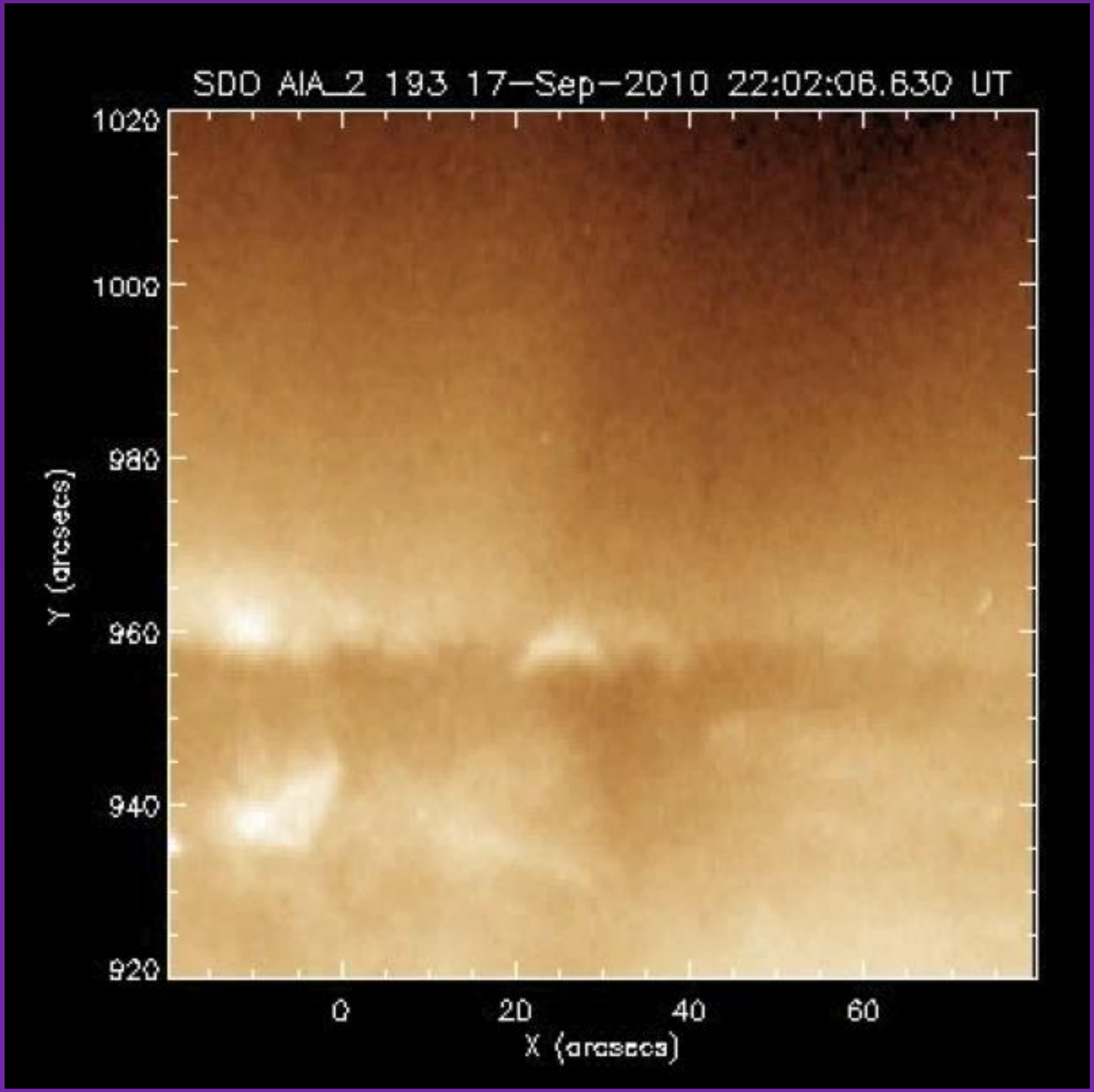
Supported by numerical simulations: Yokoyama & Shibata (1995), Nishizuka et al. (2008), Archontis et al. (2013), Moreno-Insertis et al. (2013), Fang et al. (2014), etc. (Cf. Heyvaerts, Priest, & Rust 1977.)

Coronal Hole Jets: "Minifilament eruptions"

XRT



AIA 193



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

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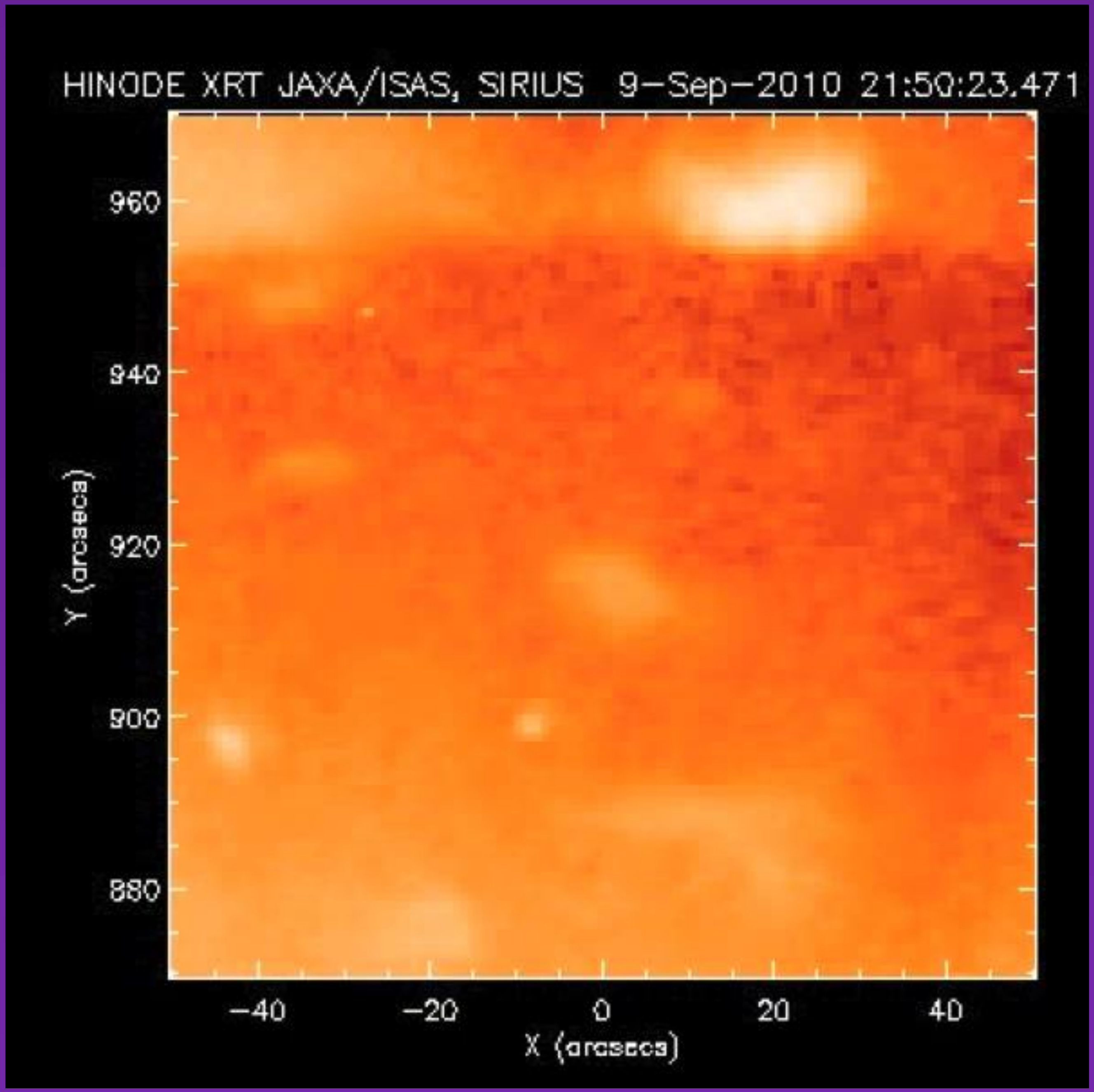
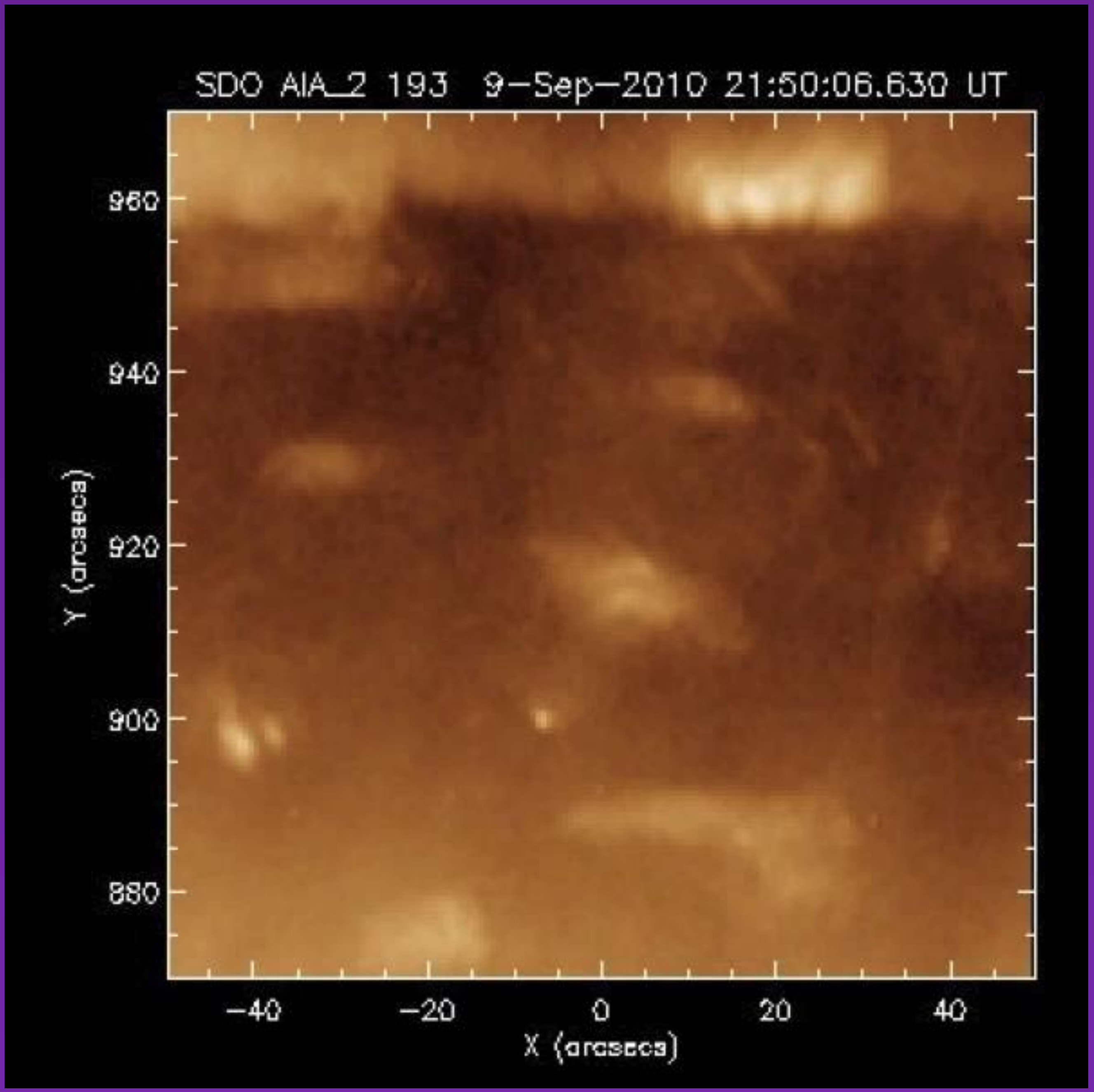
XRT

AIA 193

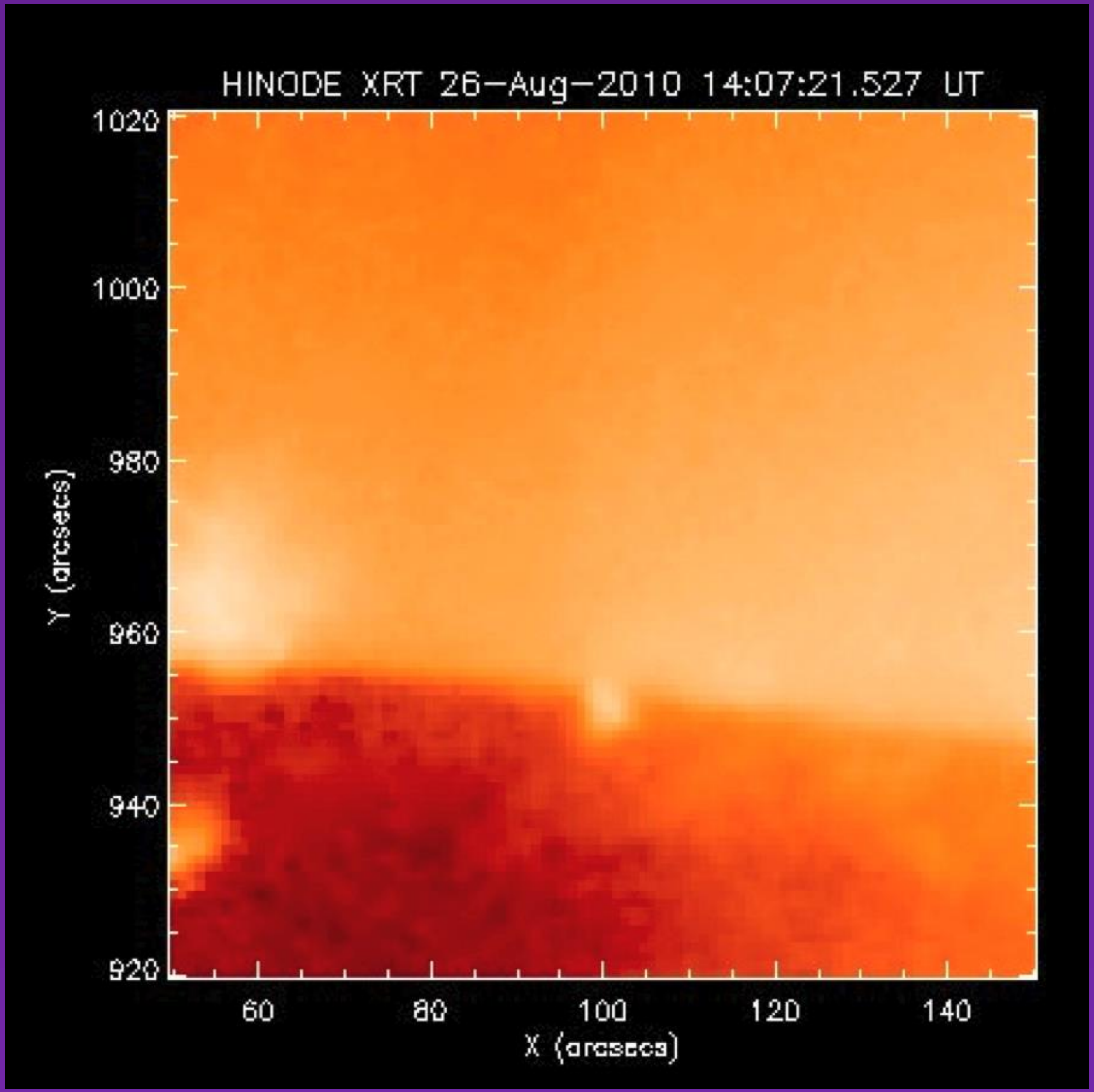


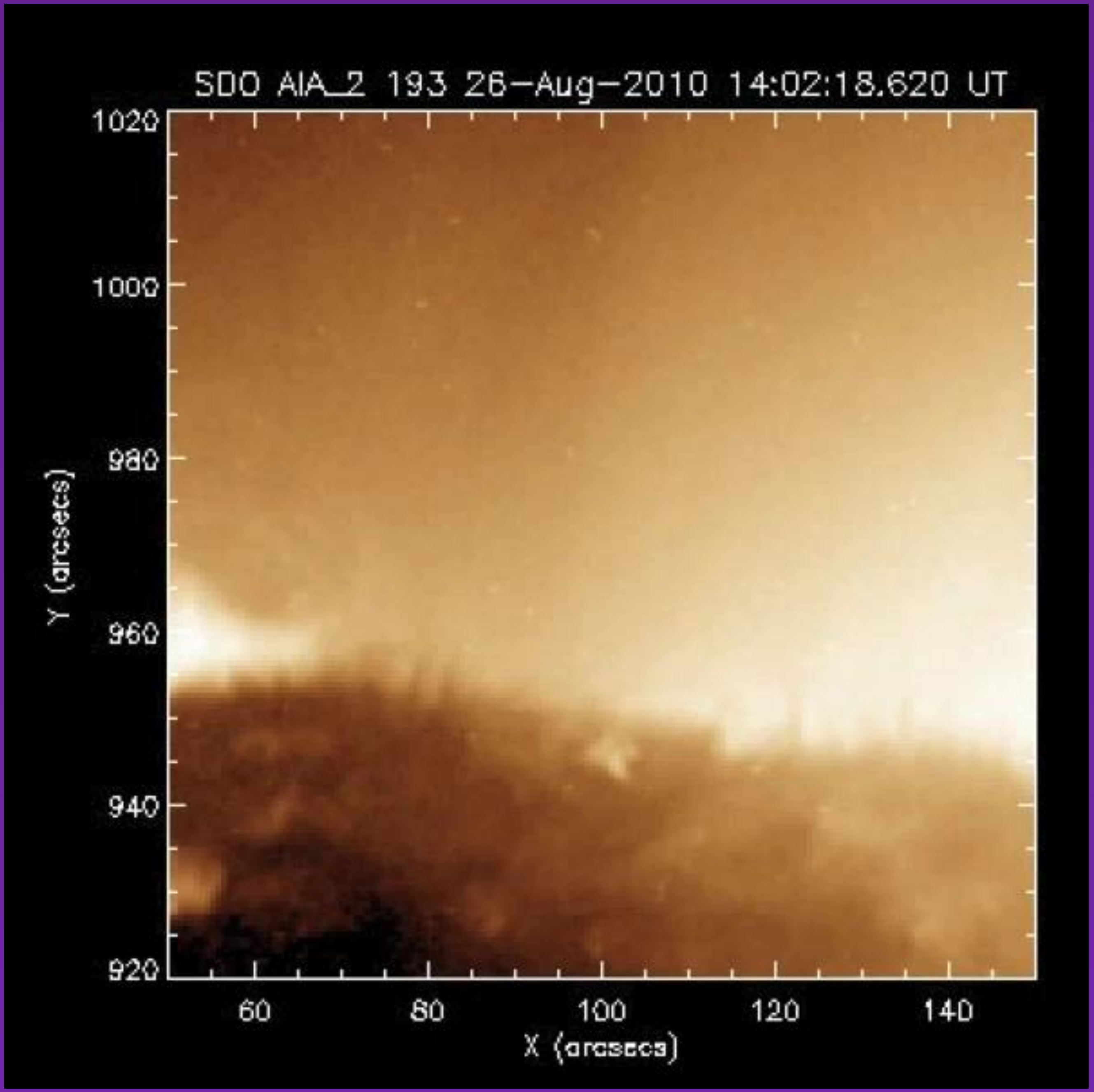


Event 12

XRT

AIA 193





Event 3

“Normal” Filament Eruption (TRACE)

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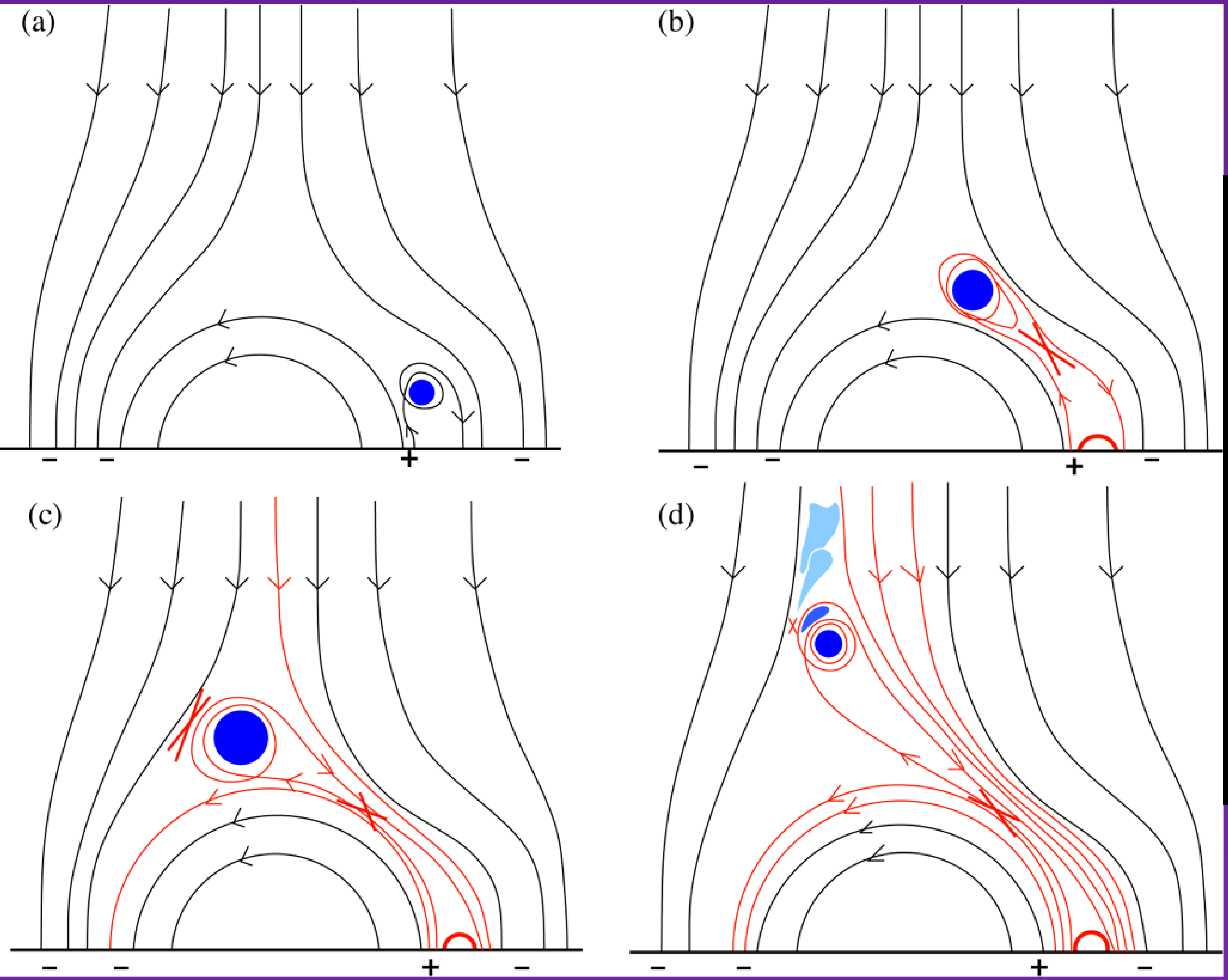
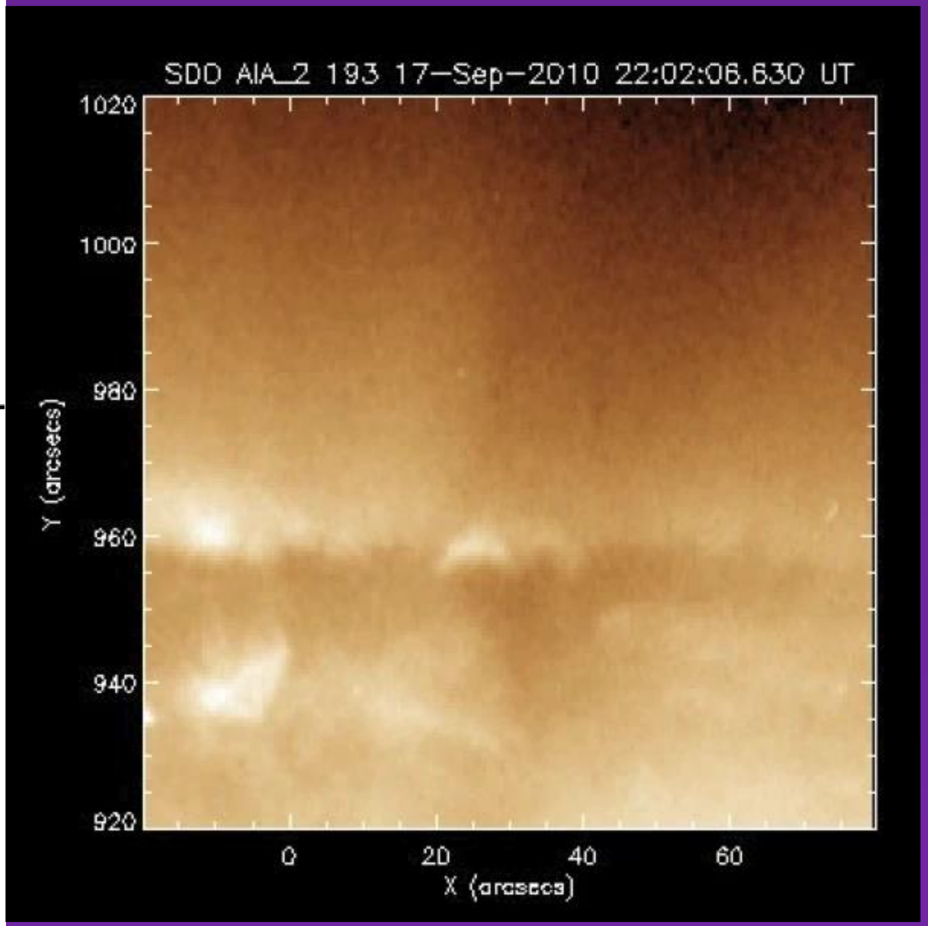
Minifilament-Eruption Model for (X-Ray) Jets





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)

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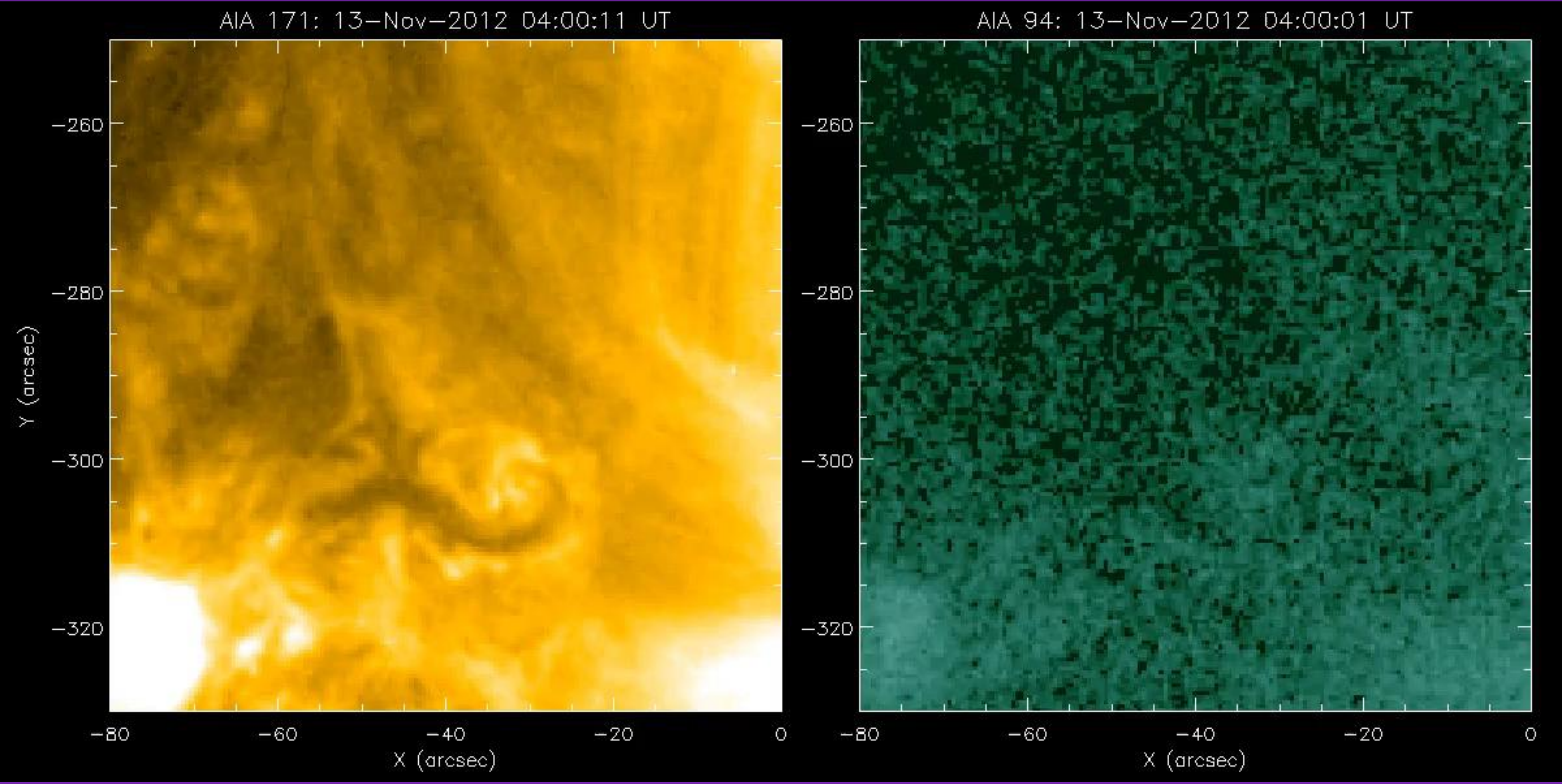
Quiet Sun Jets — Similar to PCH jets

AIA 171 AIA 94



(Panesar et al. 2016b)

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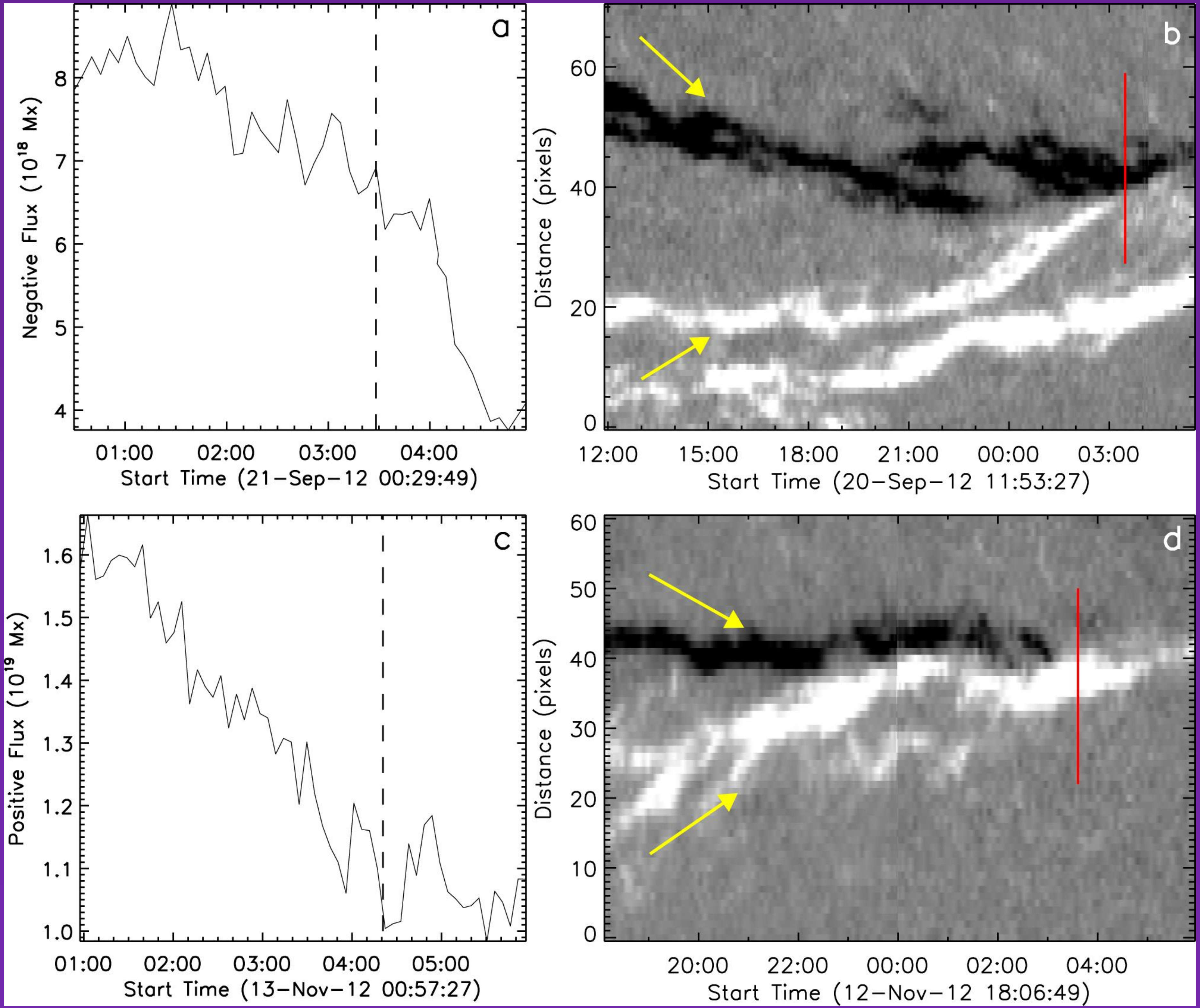
Same for QS jets: Occur at cancelation sites.

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



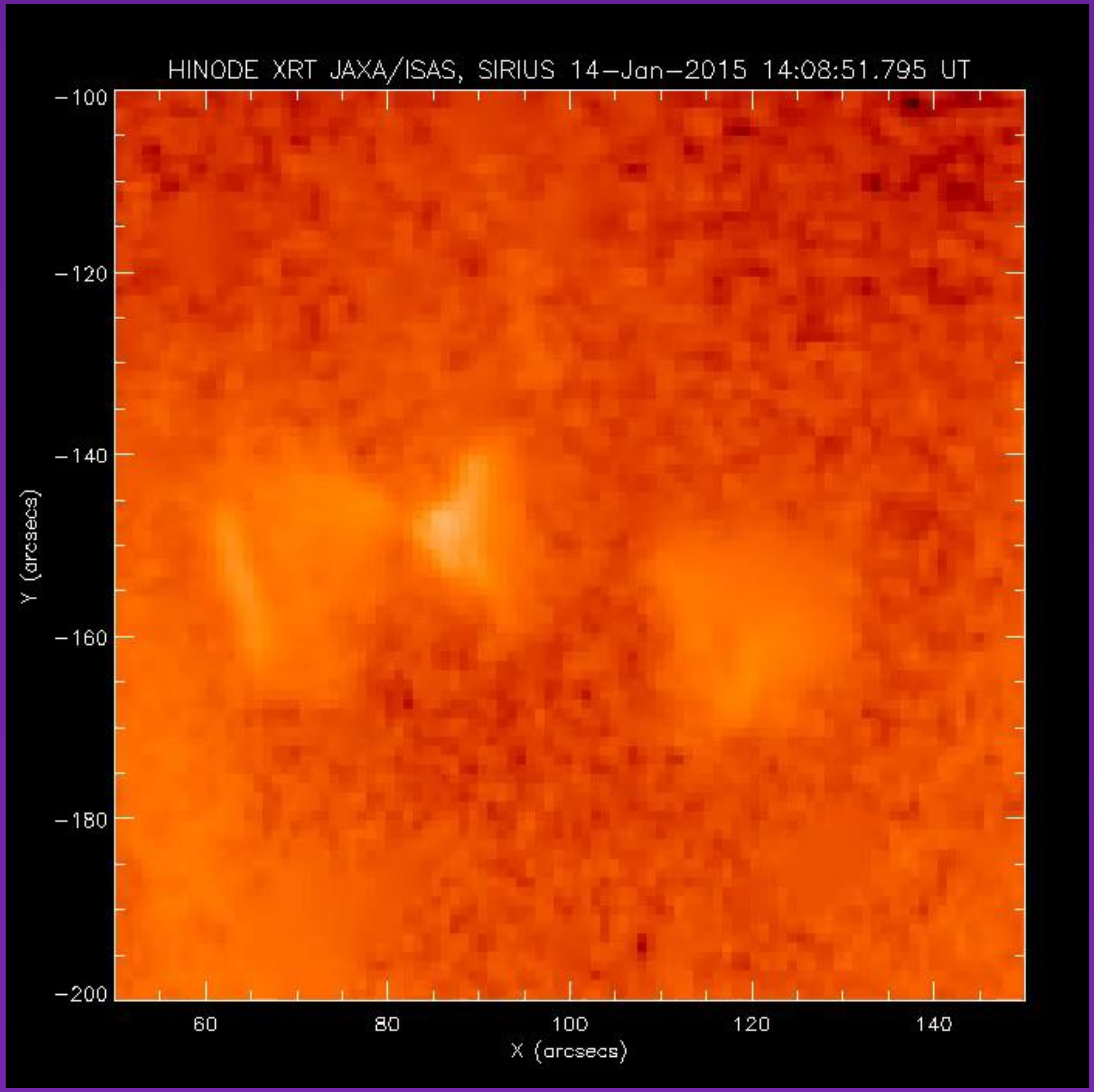
Panesar, Sterling, & Moore (2016b) — 10 jets.

Active Region Coronal Jets

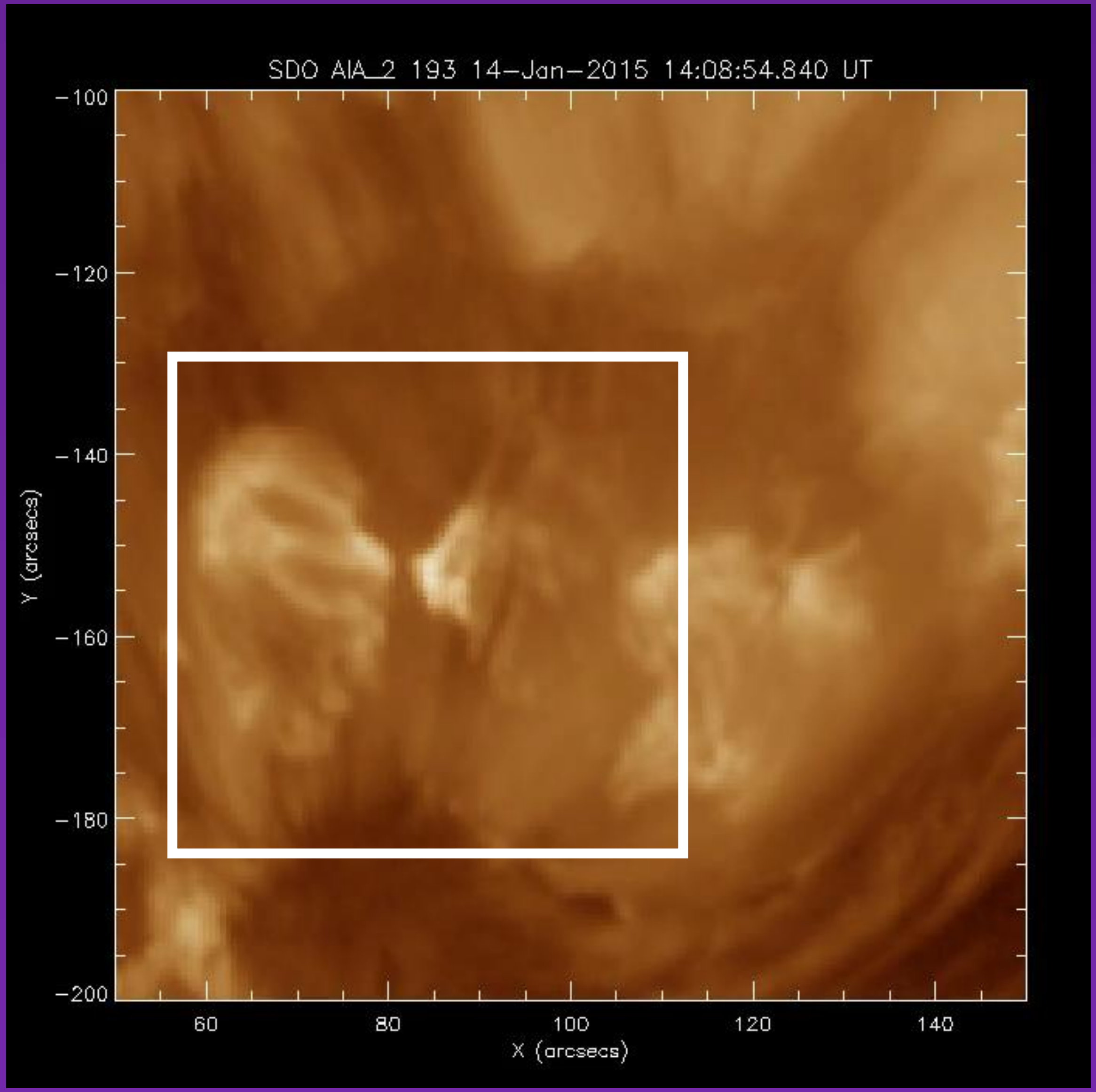
- Yohkoh studies (Shibata et al., Shimojo et al., many others).
- Raouafi et al. (2016).
- Panesar et al. (2016a).
- Sterling et al. (2016, 2017).

An Example: AR Jets

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



Hinode/XRT



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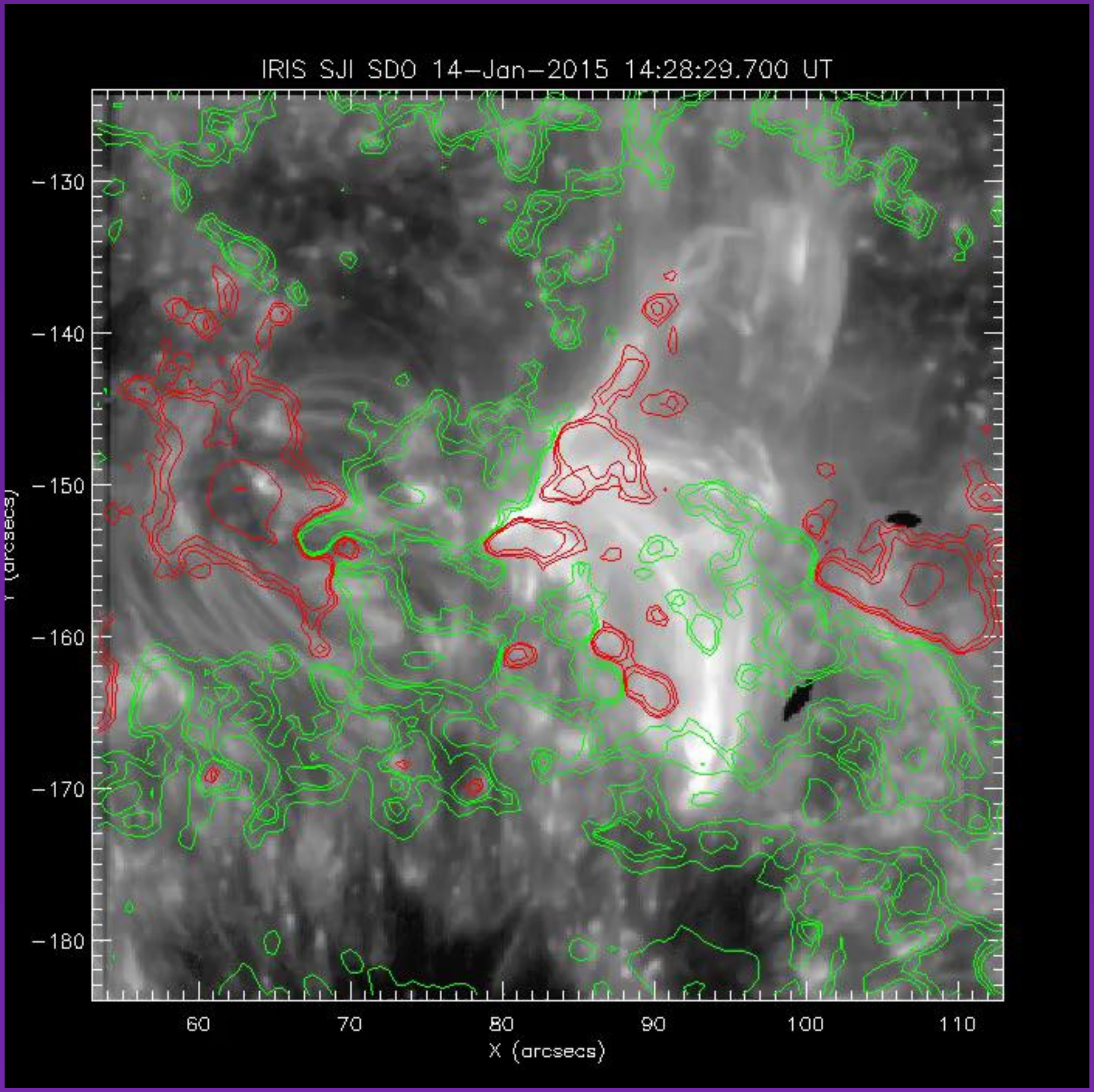
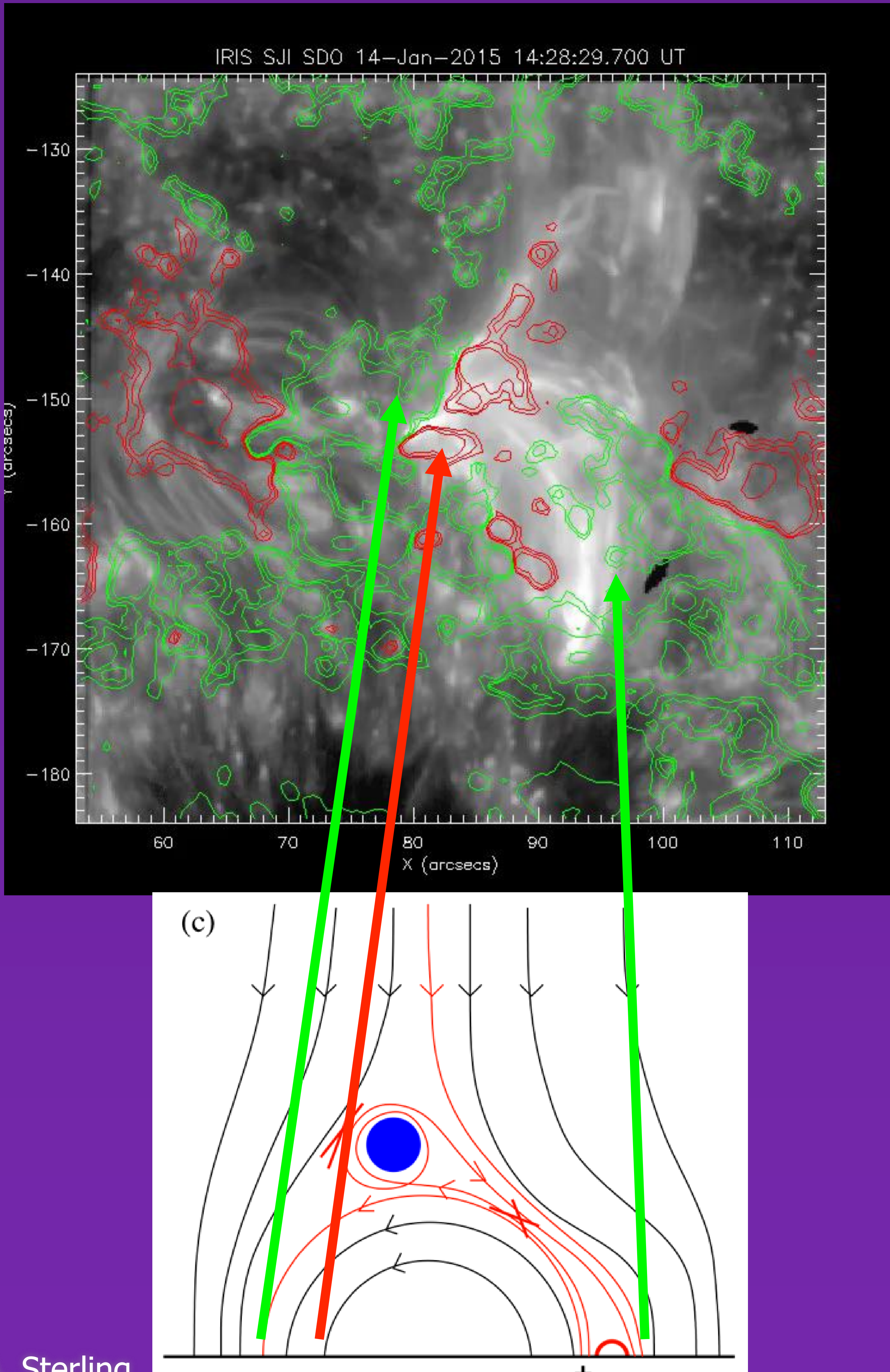
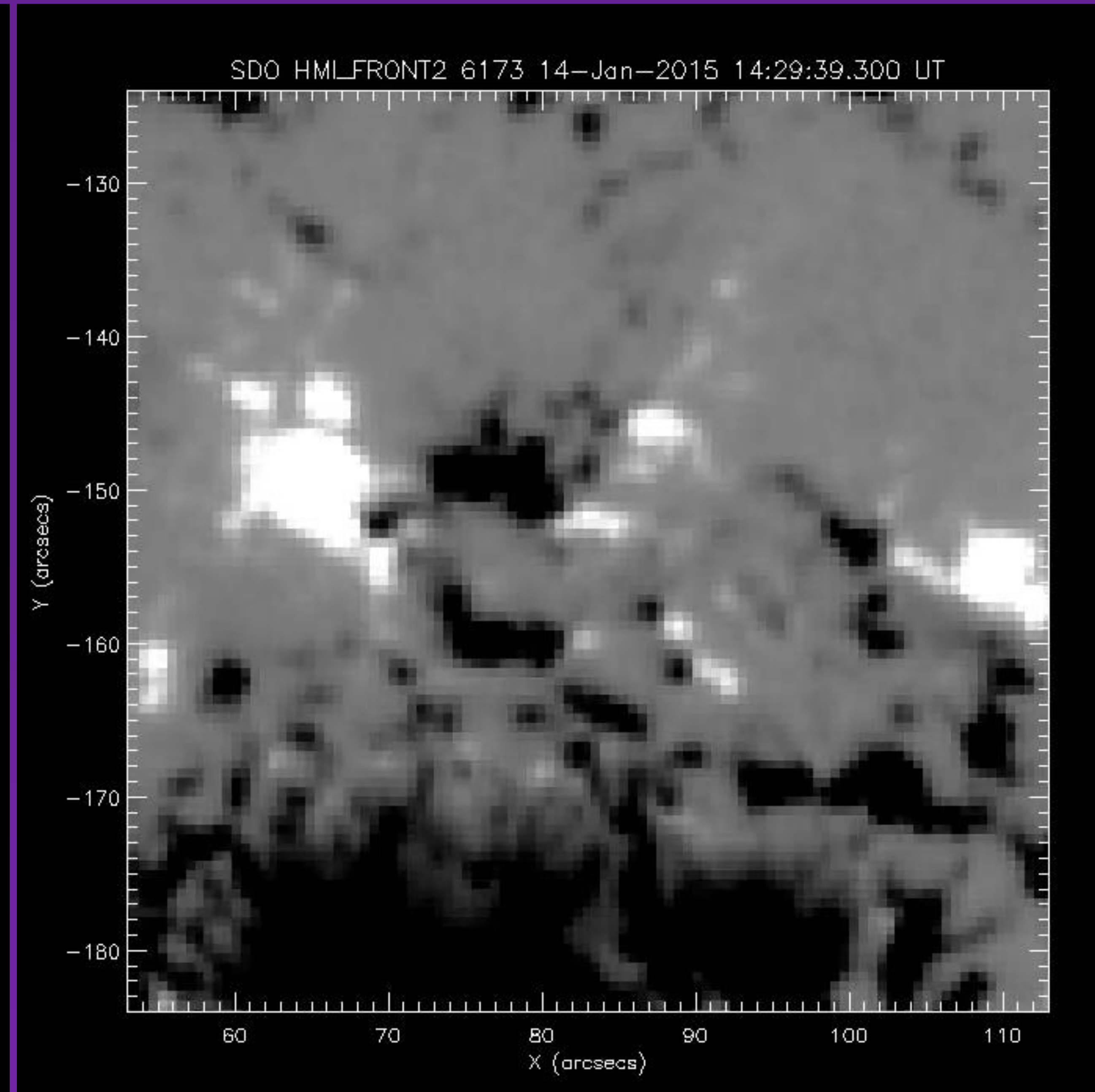
Coronal Jets in Active Regions



Sterling et al. (2017)





Sterling et al. (2017)

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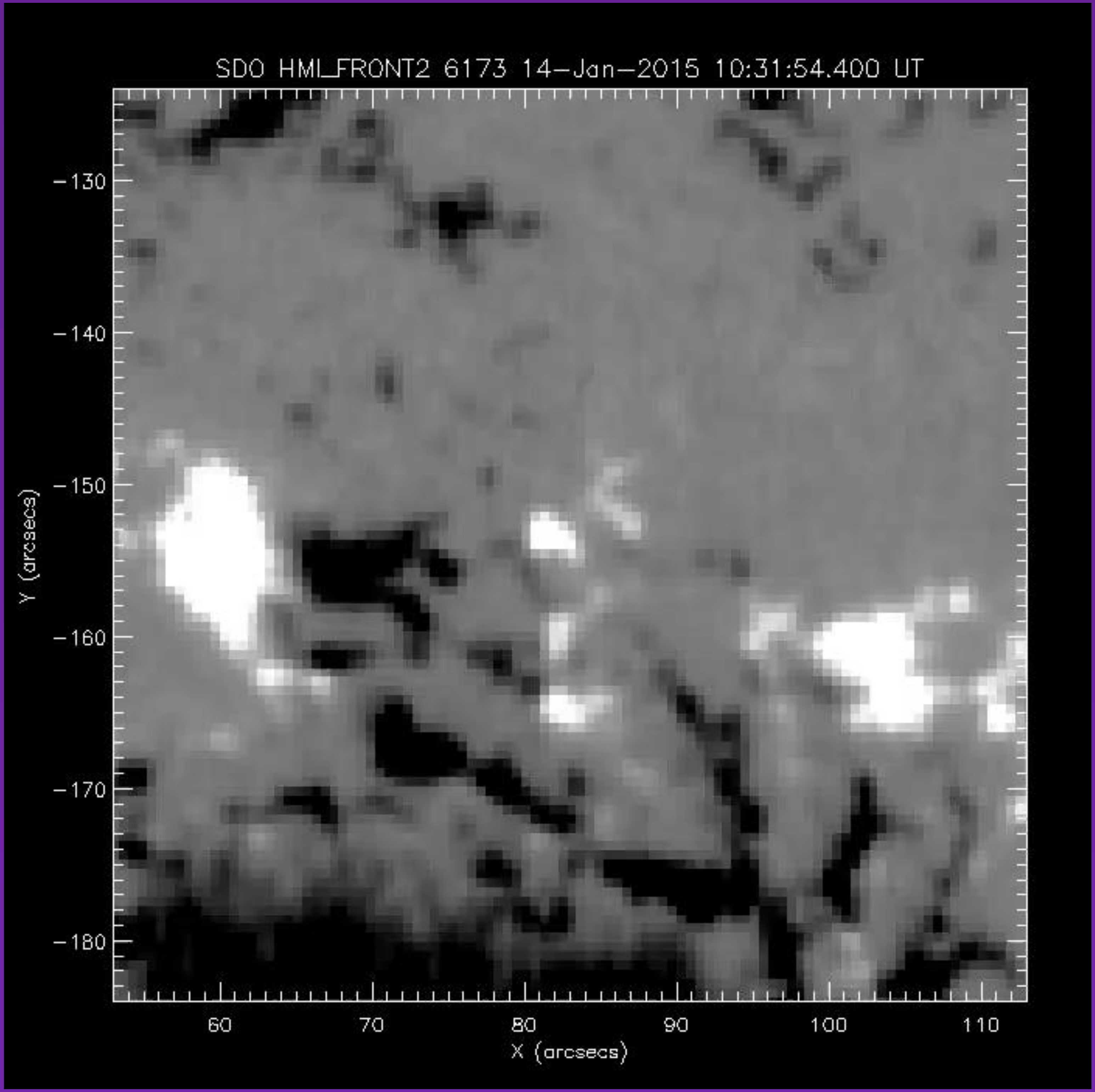
HMI of jetting region



Jets occur at *flux cancelation* locations!

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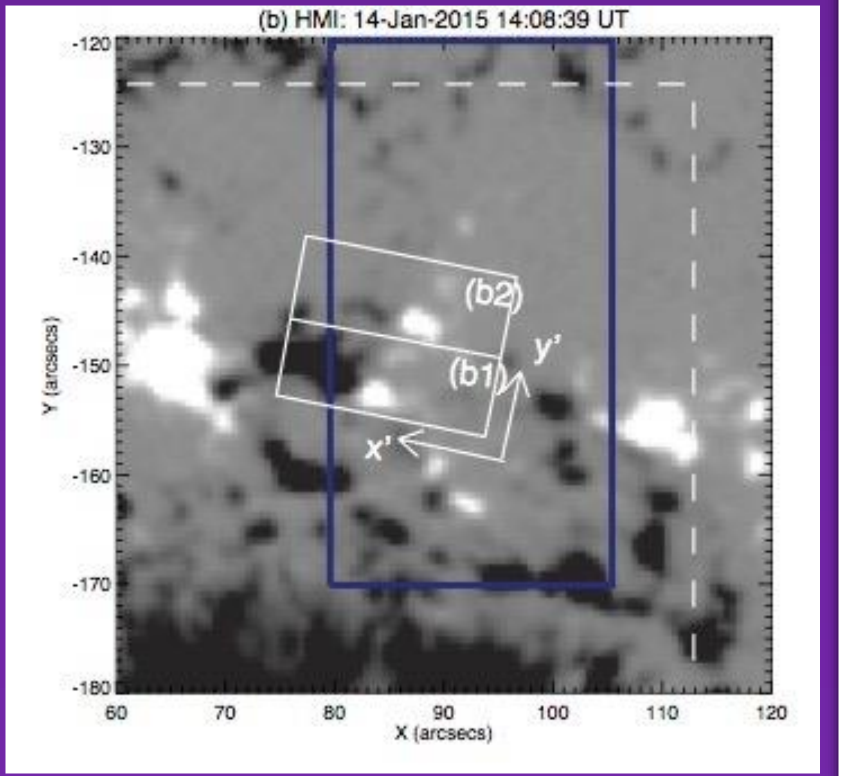
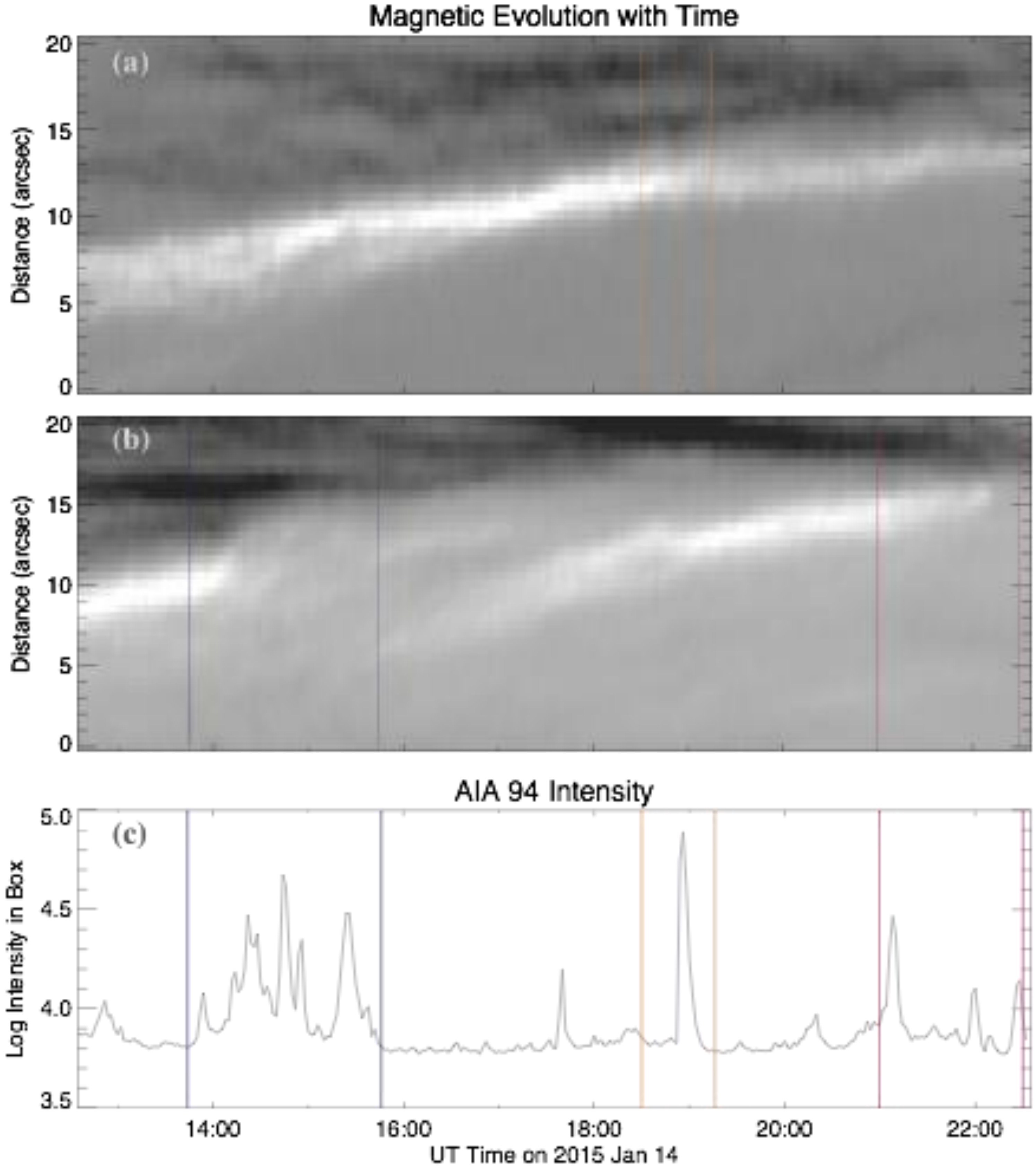
AR jets (Sterling et al. 2017)





Jets and CMEs: History (sampling)

- Wang et al. (1998) - EIT and LASCO white-light jets.
  - Gilbert et al. (2001), Dobrzycka et al. (2003); "narrow CMEs" (angular width $\lesssim 15^{o}$).
- Nisticò et al. (2009) - STEREO; 5/79 "micro-CMEs"/jets.
- Several single-event studies:
  - Hong et al. (2011) - Single-event study of a micro-CME originating from a blowout jet triggered by flux cancelation.
  - Shen et al. (2012) - Bubble-like CME from a blowout jet (SDO, STEREO, Hα).
- See Raouafi et al. (2016) review for more.

Jets and CMEs: Some recent investigations

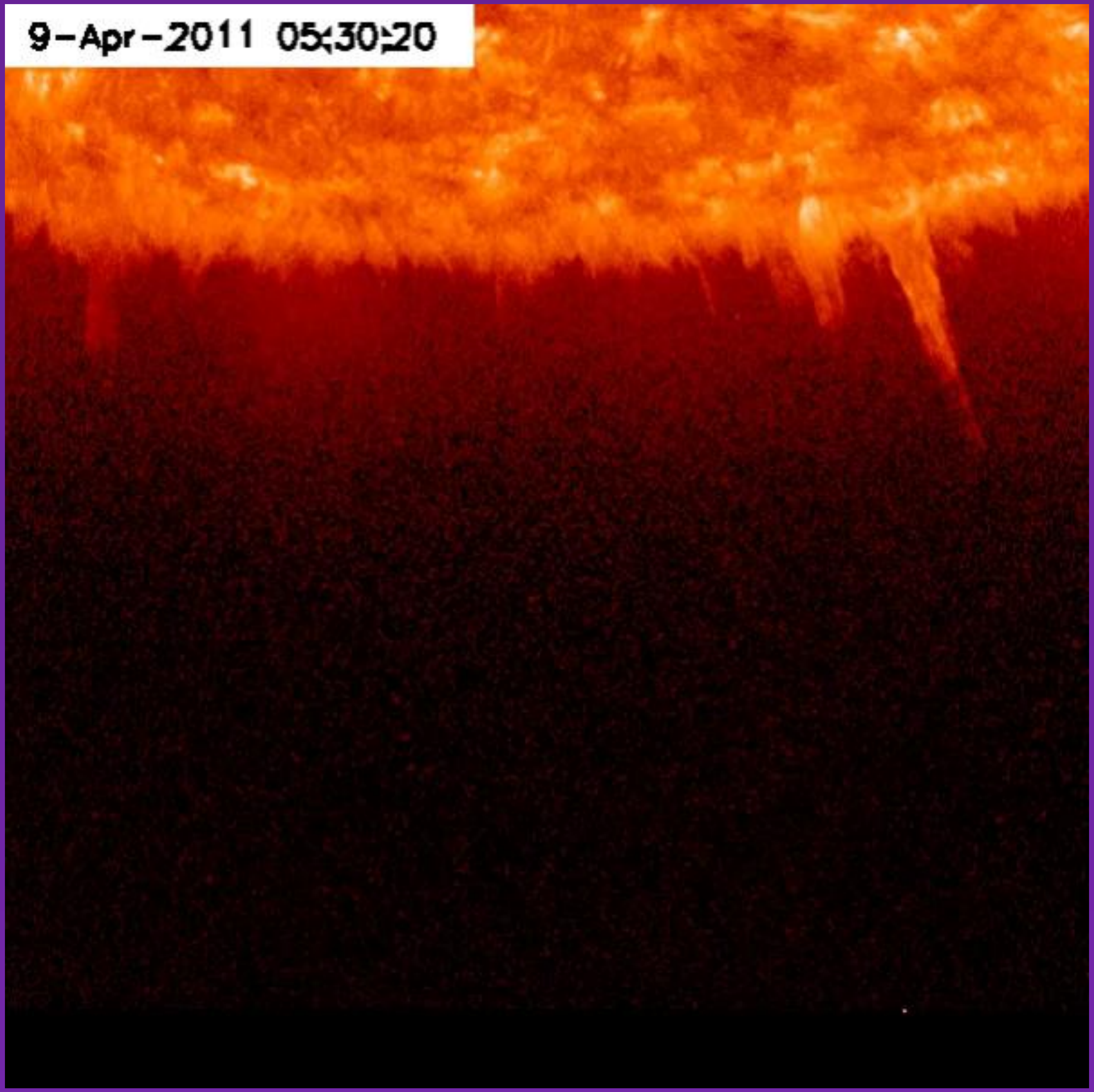
- Moore et al. (2015): Polar coronal hole jets that extend into outer corona.
- Sterling et al. (2016): “CMEs” from AR jets.
- Panesar et al. (2016a): A “different type” of CME from AR jets. (Bemporad et al. 2005.)
- (Narrow CMEs = white-light jets.)

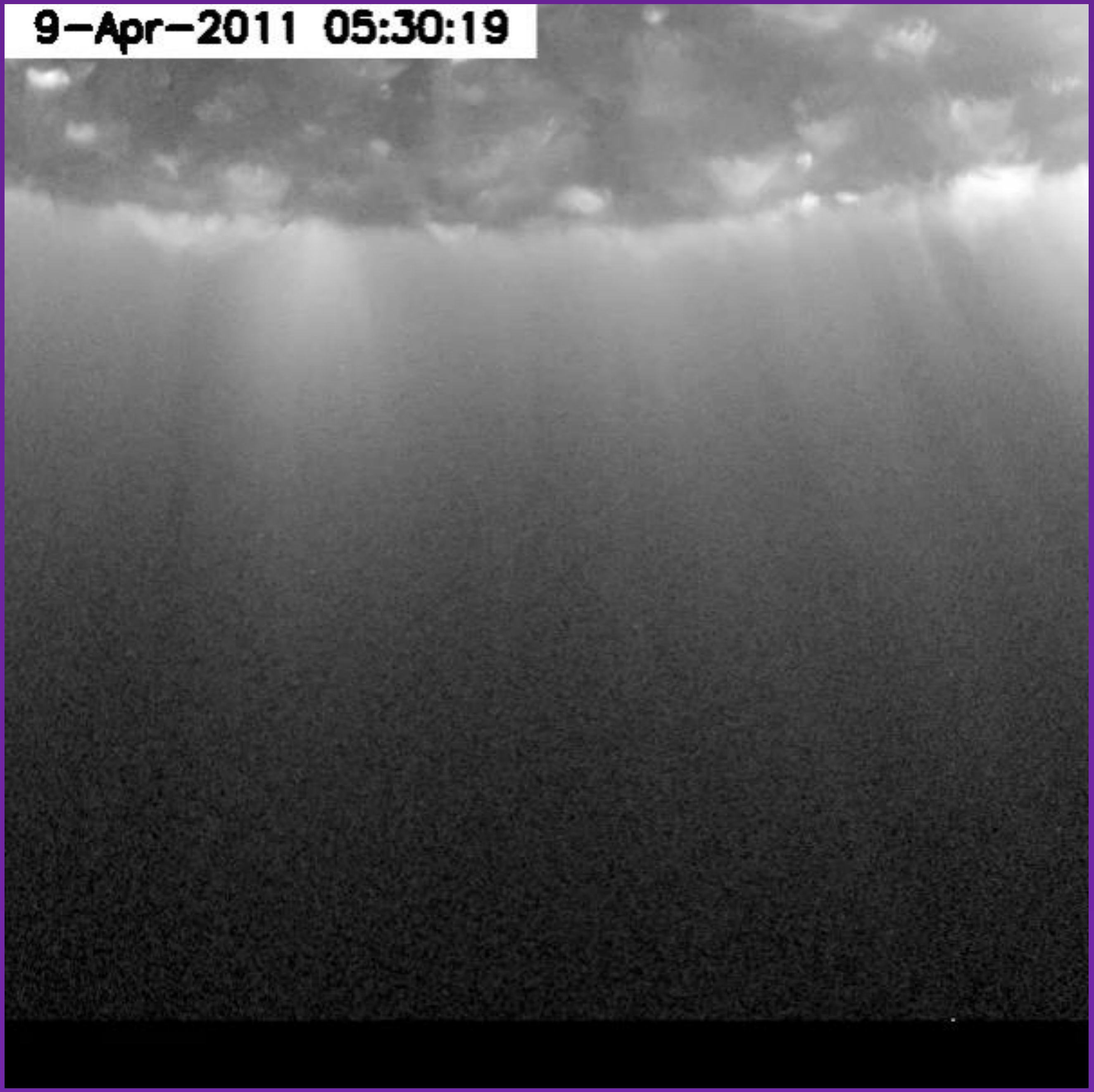
Moore et al. (2015)

- Selected 14 polar CH jets, that extended into LASCO/C2 FOV.
- Looked for narrow (width $\lesssim 10^{o}$) LASCO features.
- AIA/EUV jet.
- Found that narrow-CME-producing jets tended to have large twist.

AIA 304

AIA 193





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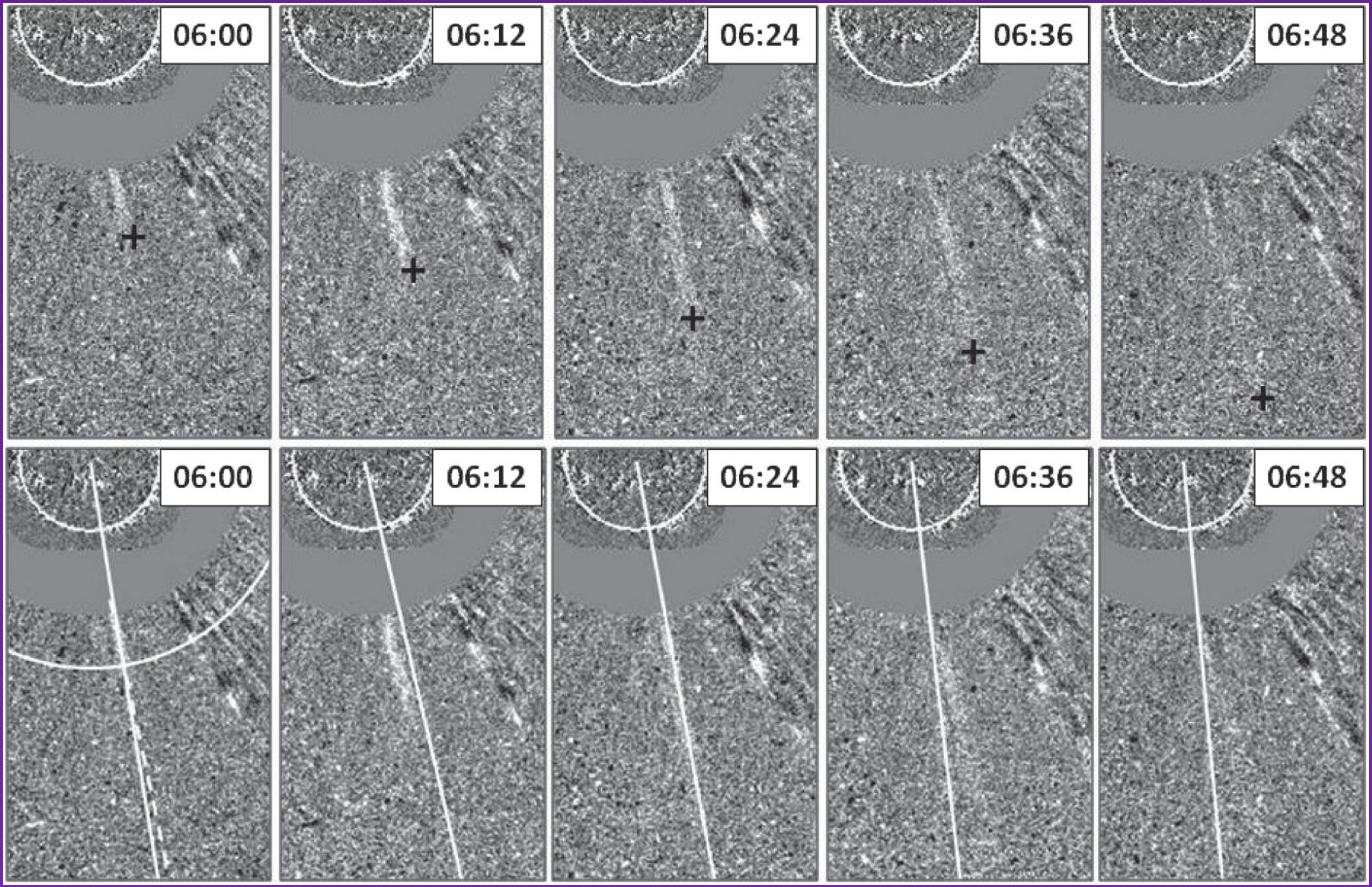

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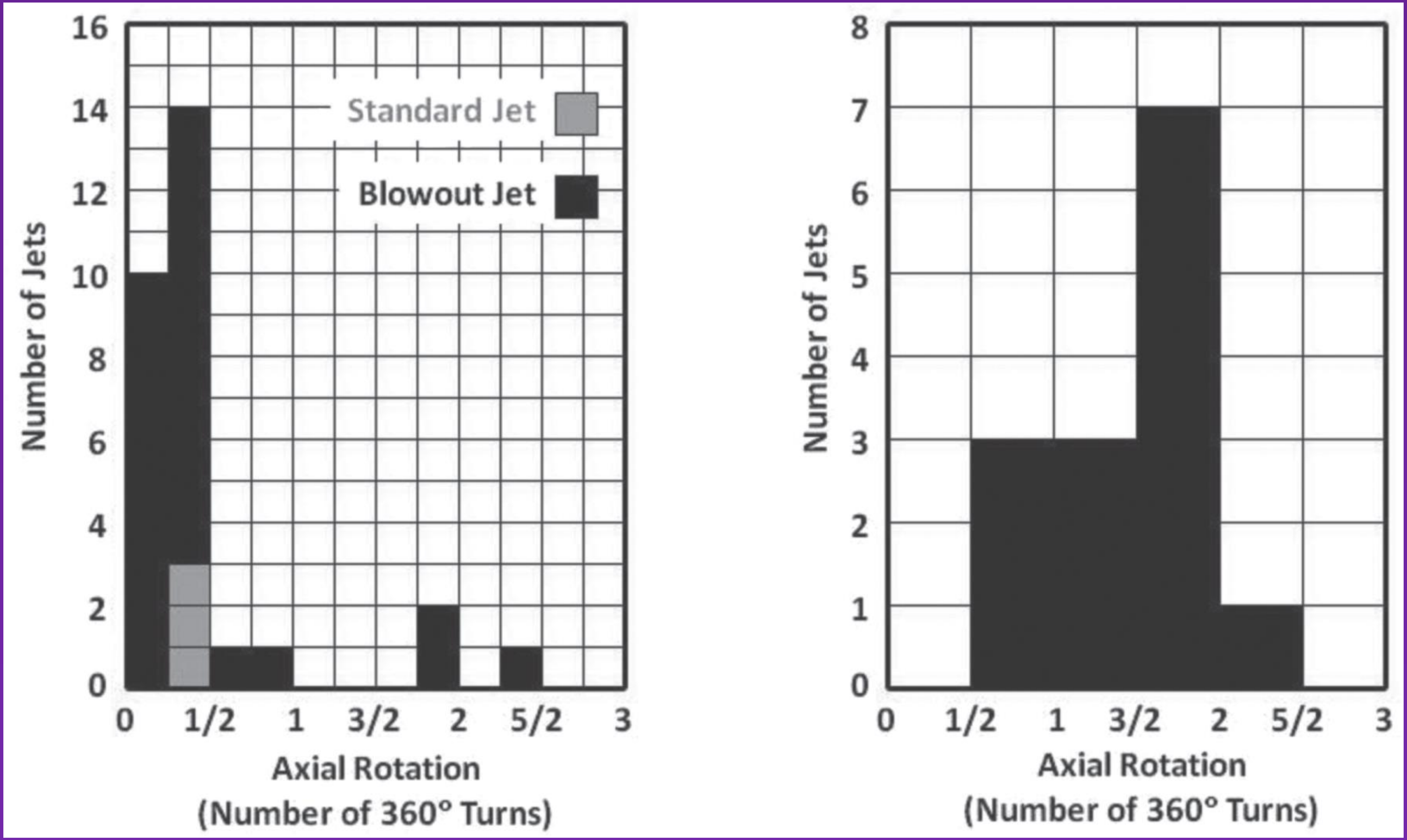
Twist in Jets



Random twisting PCH jets with cool component: Moore et al. (2013)

Narrow-CME-Producing Jets: (Moore et al. 2015)

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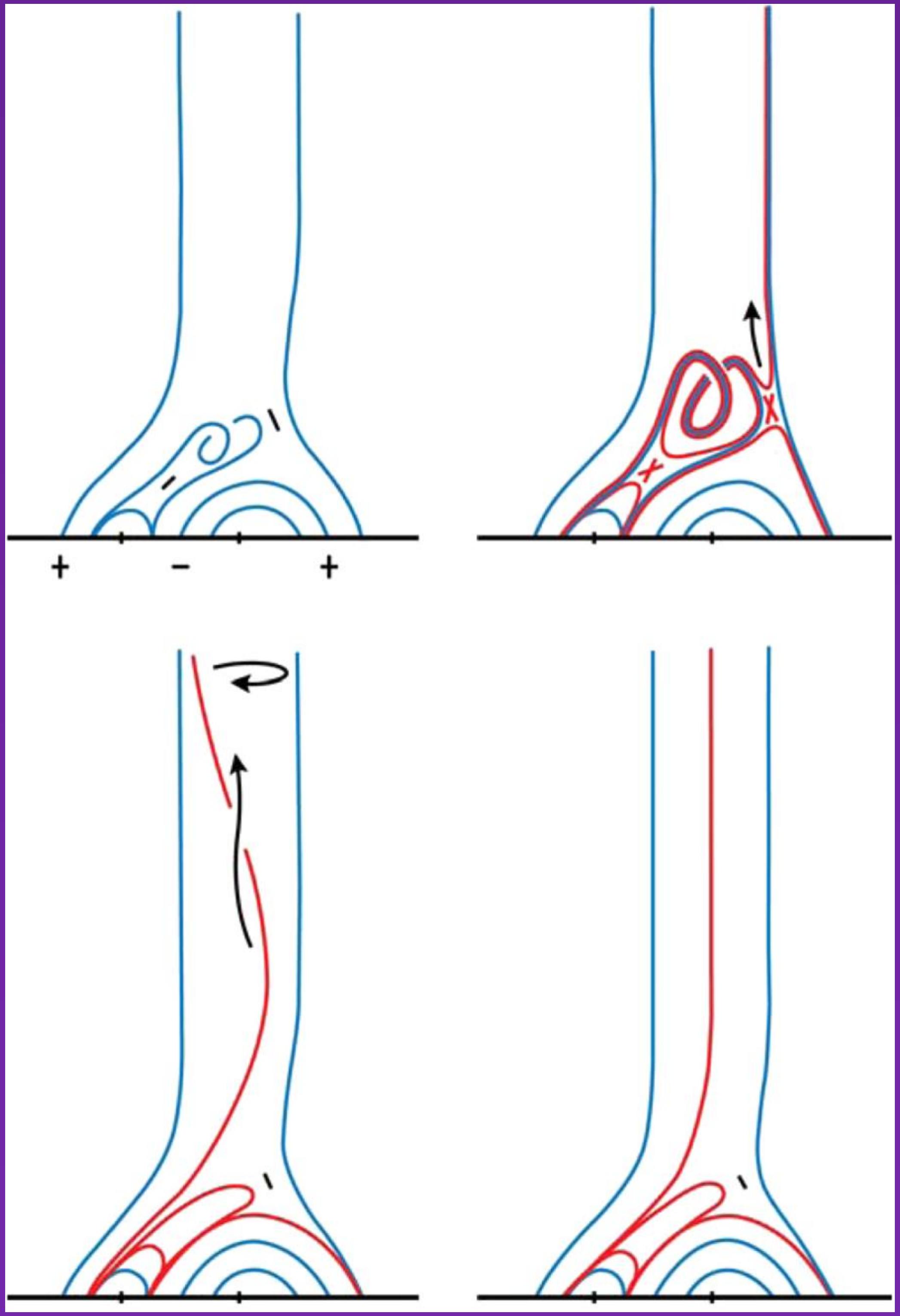
This suggests that: “polar jets having more axial rotation usually extend to greater heights than polar jets having less axial rotation.”



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

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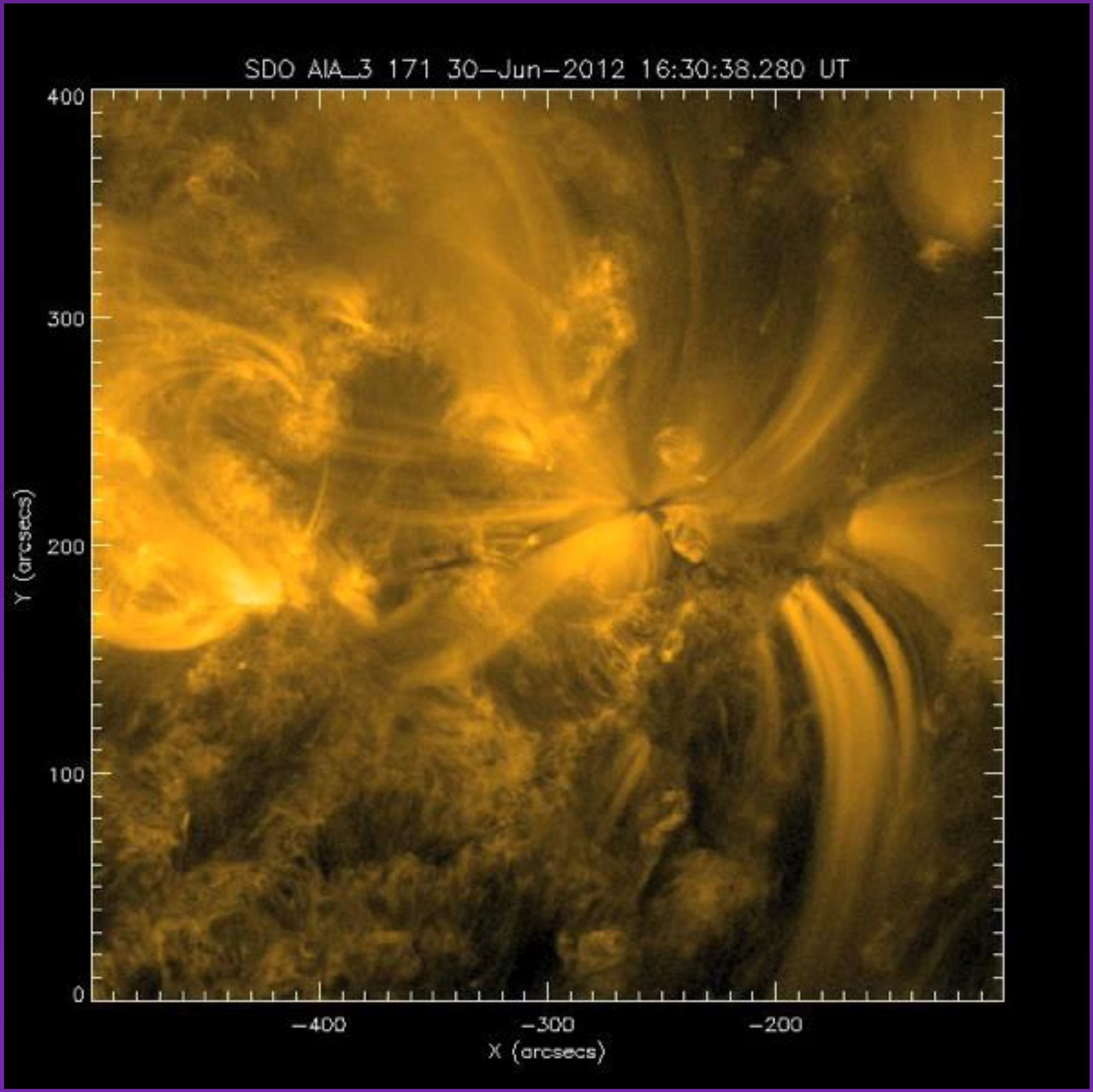
CMEs from AR Jets:

Sterling et al. (2016)

AIA 171



Sterling et al. (2016, ApJ)

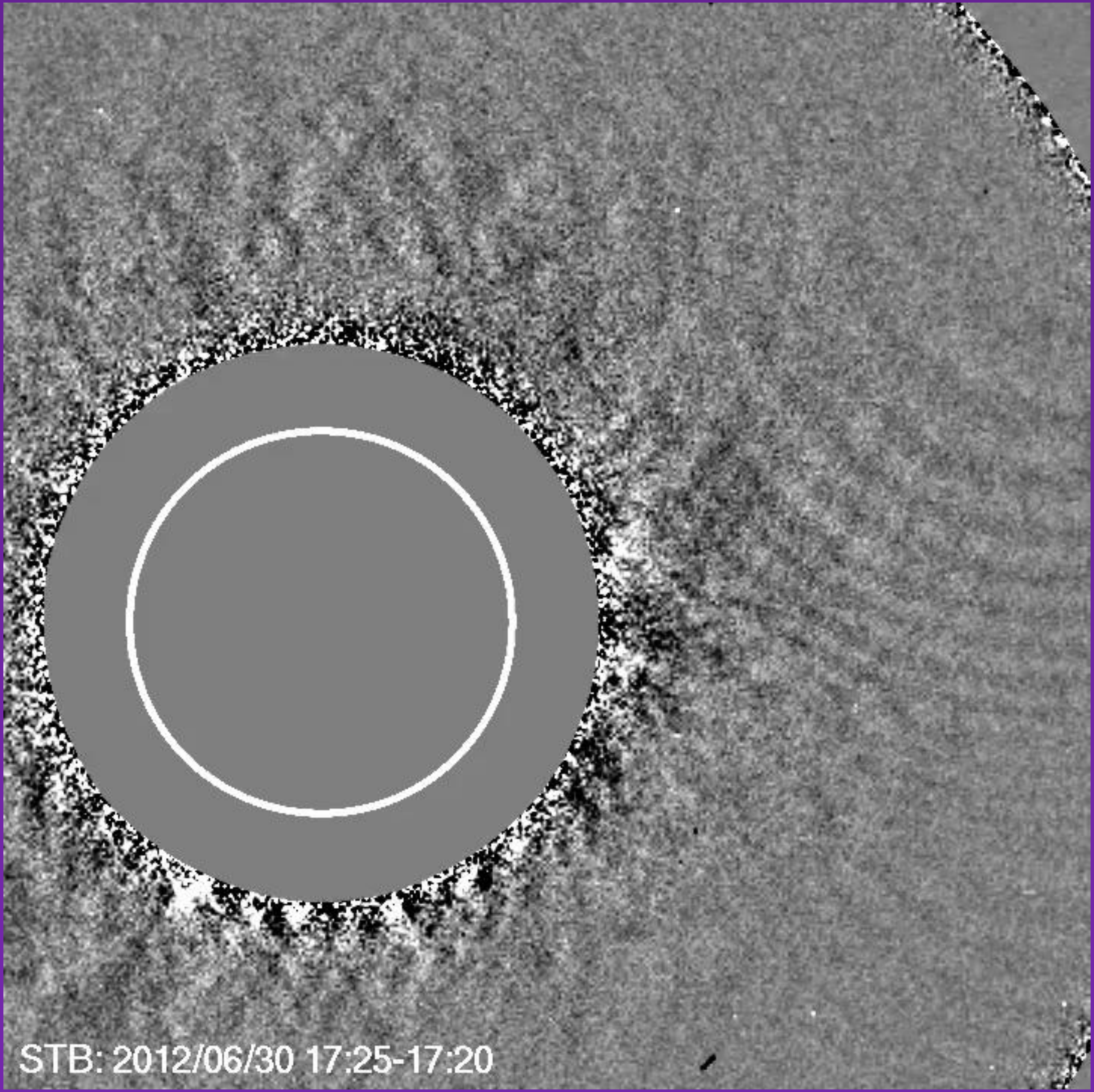


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Table 1
GOES List for Events of Figure 4, and CME Properties

Jet/Event	Time (UT)[a]	Flare	Region[b]	CME?[c]	CME Time (UT)[c]	Width (deg)[c]	Velocity (km s^{-1})[c]
1	17:28	B6.0	C	Probably	17:35	4.0 ± 0.6	458 ± 66
2	17:47	B7.0	A	No	...	...	...
3	18:12	C1.6	B	Yes	18:10	62.8 ± 1.4	300 ± 9
4	18:33	M1.6	D	Probably	18:40	26.7 ± 3.6	482 ± 102
5	19:32	B7.0	C	Yes	19:40	7.7 ± 1.6	368 ± 44
6	20:19	B8.0	C	Probably	20:20	4.3 ± 0.6	479 ± 17
7	20:28	B9.0	A	Probably	20:35	3.3 ± 0.6	521 ± 32
8	21:26	C1.6	C	Yes	21:30	7.2 ± 2.5	841 ± 10
9	22:37	C1.1[d]	C	Maybe	22:45	2.6 ± 0.9	356 ± 61
10	23:54	C1.0	D	Maybe	23:50	8.0 ± 2.8	515 ± 39
11	00:09	B6.0	A and C	No	...	...	...

Notes.
[a] Time of peak brightening (within $\lesssim$1 minute) in *GOES* 1–8 Å X-ray flux on 2012 June 30 (July 1 for event 11); event 3 is a filament eruption, while other events are jets. In some cases the CME appears prior to the peak in X-ray flux, but this is consistent with other observations (e.g., Harrison 1986).
[b] Region in Figure 3(a) where the source of the event is located.
[c] Indicates whether a CME was detected from the event in *STEREO-B*/Cor1 images. If not "no," then entries in column 5 reflect the level of confidence that the observed CME originates from the event. Subsequent columns give the time of the CME's first appearance in *STEREO-B* Cor1 images, and the angular width and plane-of-sky velocity of the CME. Widths and velocities are averages of four measurements, and uncertainties are 1σ standard deviations.
[d] Much or most of this emission is from a different active region, AR 11514 (S17E18).

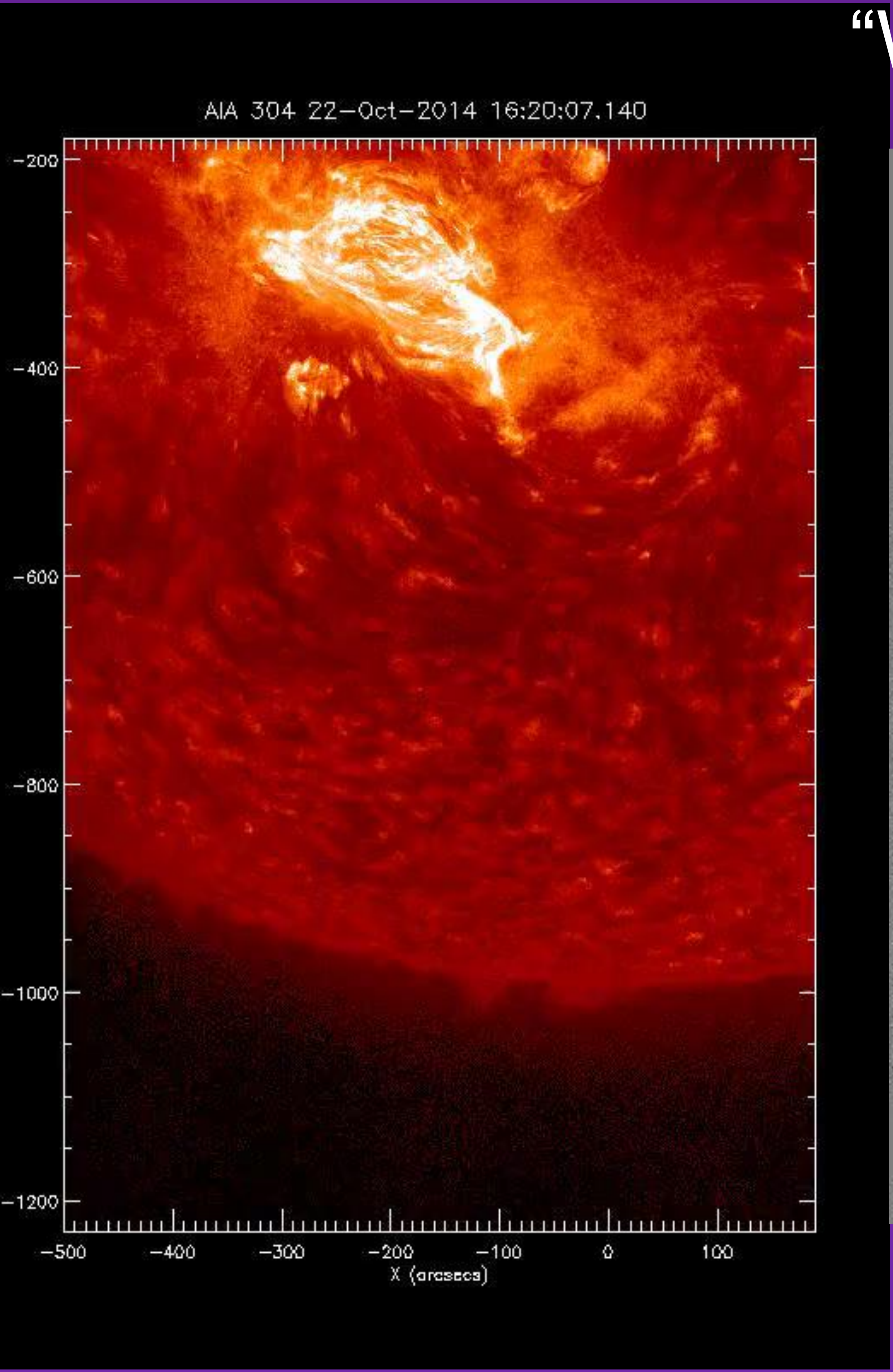
Most of AR jets made/likely made narrow CMEs/WLJs (width $\lesssim 10^o$).

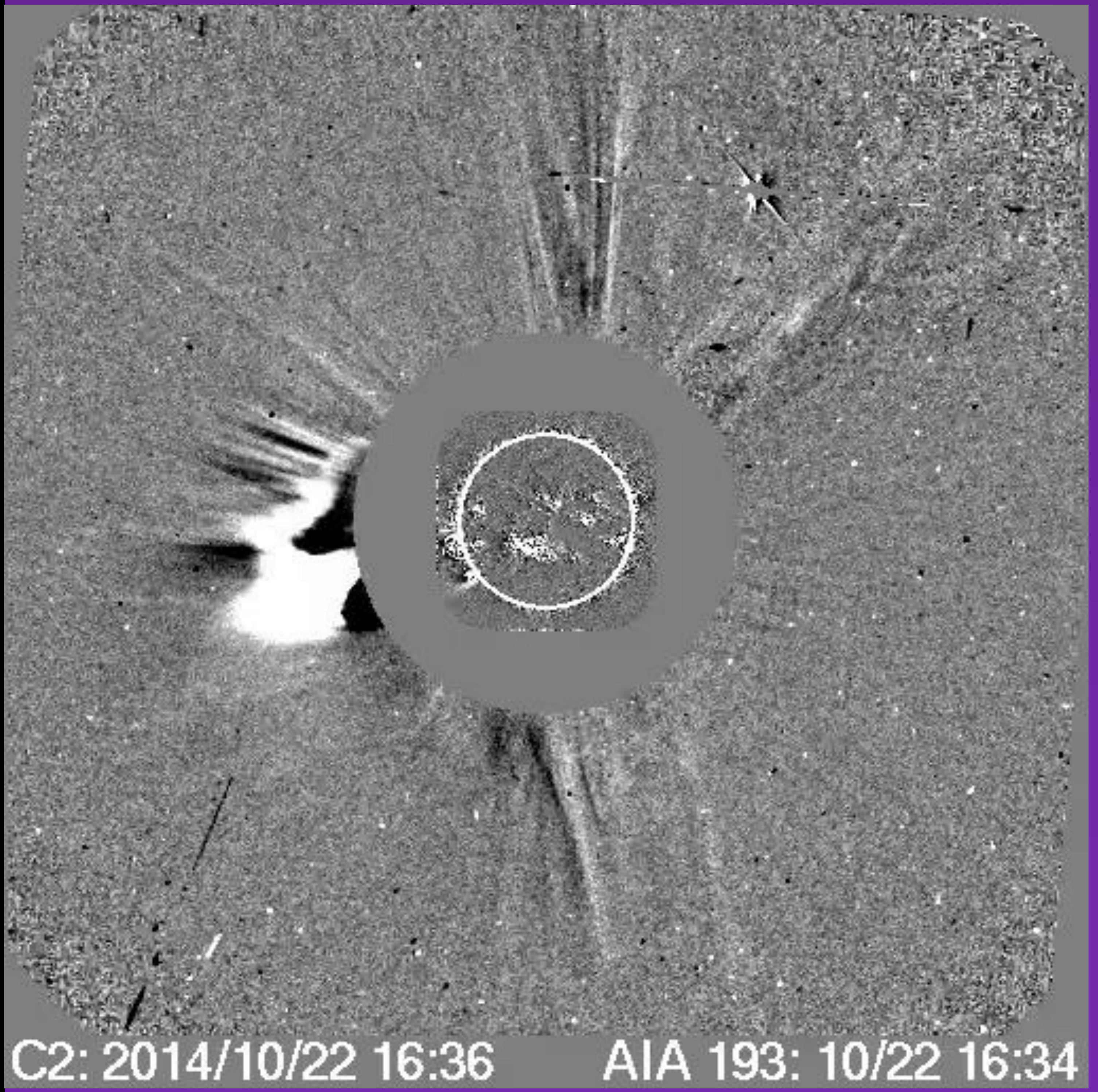
(NB. Event 3 is a large-scale eruption; Event 4 is a surge/jet.)

(Wide) CMEs from AR Jets

Panesar et al. (2016a)

“Weak” CMEs from AR 12192





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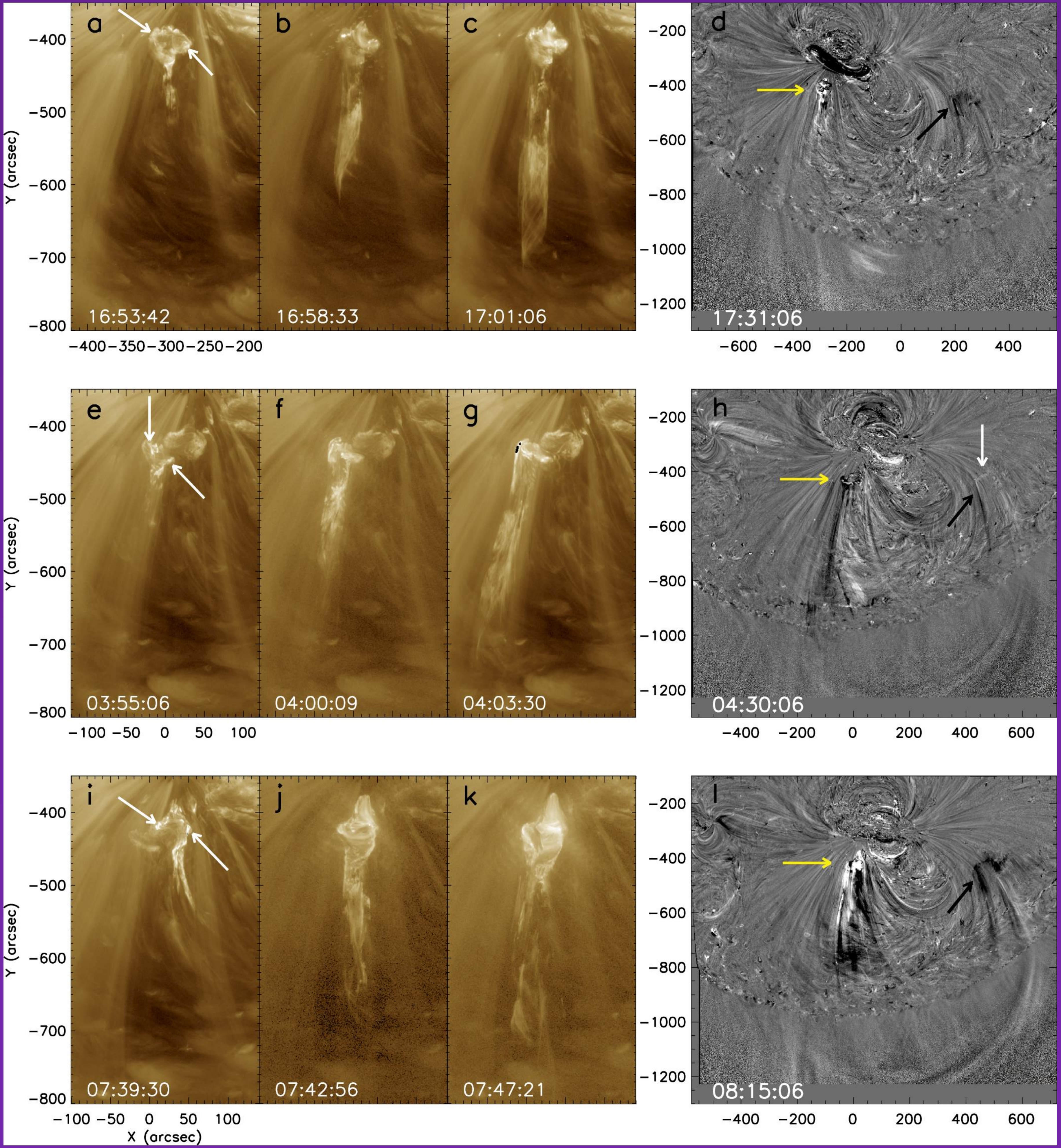
a
b
c
d
16:53:42
16:58:33
17:01:06
17:31:06
e
f
g
h
03:55:06
04:00:09
04:03:30
04:30:06
i
j
k
l
07:39:30
07:42:56
07:47:21
08:15:06
Y (arcsec)
X (arcsec)

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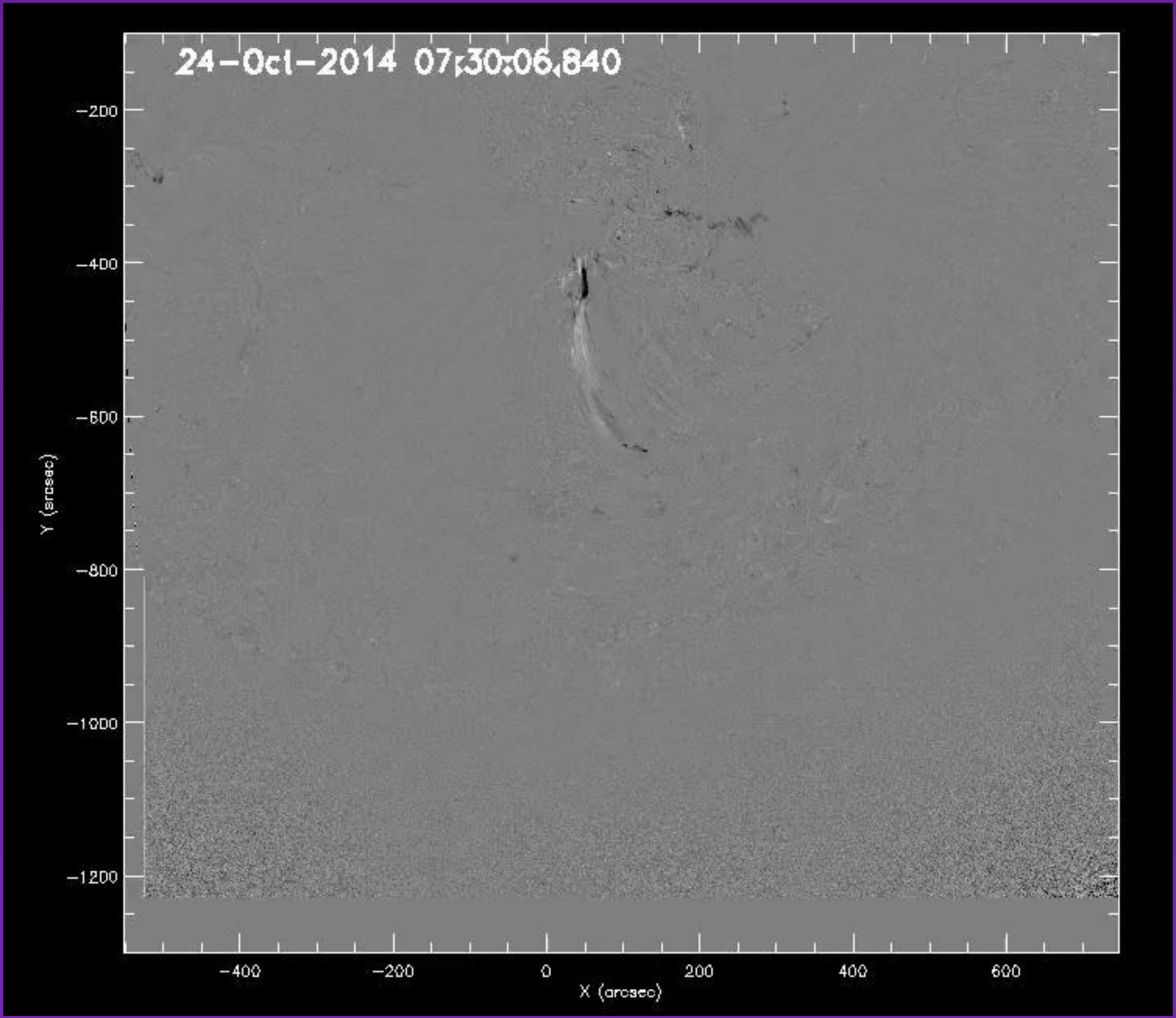
24-Oct-2014 07:30:06.840
-200
-400
-600
-800
-1000
-1200
Y (arcsec)
-400
-200
0
200
400
600
X (arcsec)

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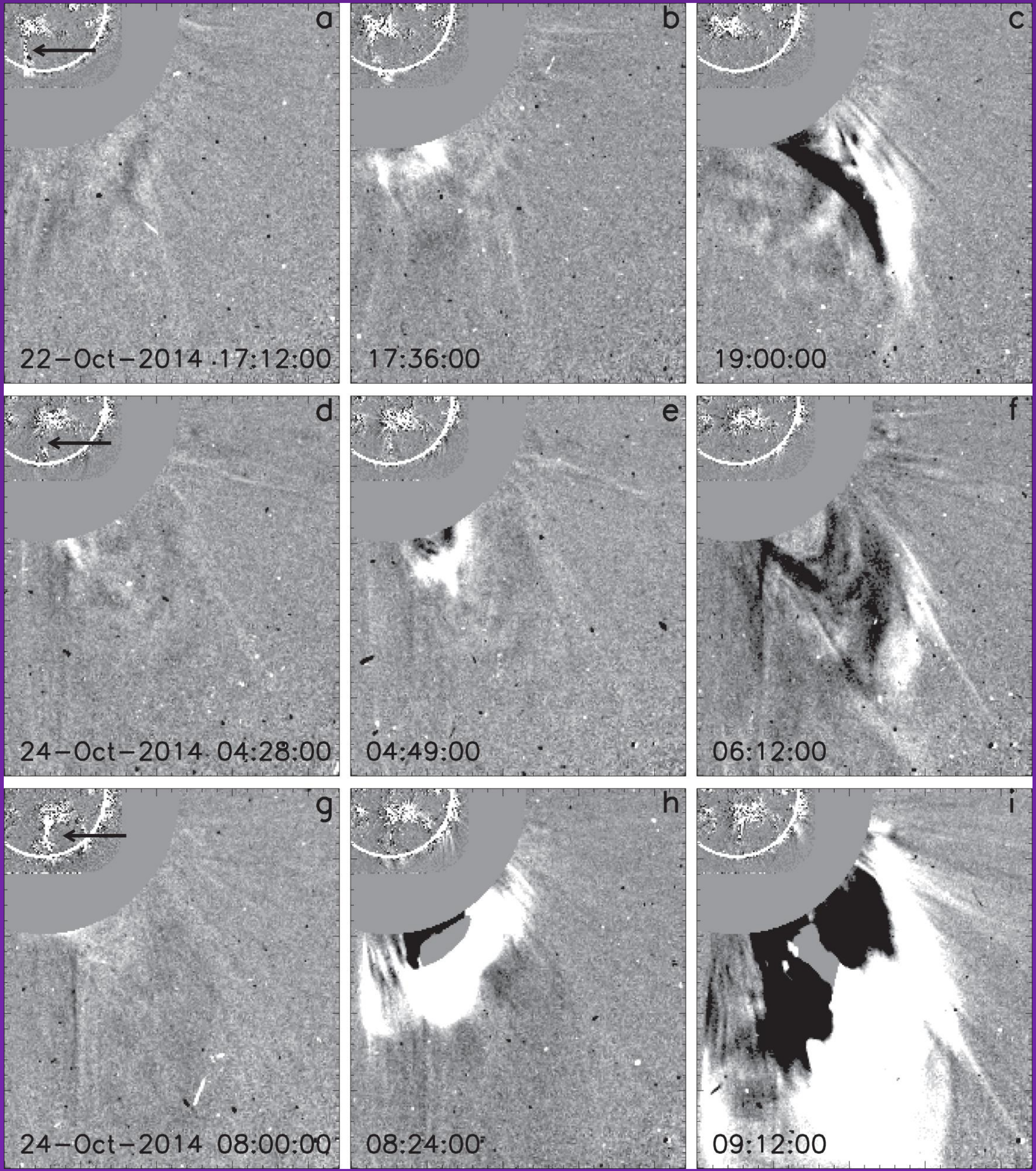
a
22-Oct-2014 17:12:00
b
17:36:00
c
19:00:00
d
24-Oct-2014 04:28:00
e
04:49:00
f
06:12:00
g
24-Oct-2014 08:00:00
h
08:24:00
i
09:12:00

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Table 1
Date and Time for the Observed Jets and Their Measured Parameters

Jet No	Date (UT)	Time[a]	Flare Class	CME Speed[b,c] (km s^{-1})	CME Angular Width (°)	Jet Speed[d] (km s^{-1})	Jet Rise Dur. (±5 minute)	Jet Width[e] (±1500 km)	Remote Bri. and Dim.
(a) CME-producing Jets									
J1	20 Oct 14	18:43	C6.2	187	40	190 ± 10	20	34000	Yes
J2	22 Oct 14	16:52	C5.8	281	20	310 ± 20	30	38000	Yes
J3	23 Oct 14	19:11	C3.3	239	35	330 ± 20	50	26000	No
J4	24 Oct 14	03:56	C3.6	250	30	300 ± 20	45	34000	Yes
J5	24 Oct 14	07:37	M4.0	677	50	400 ± 40	35	86000	Yes
J6	27 Oct 14	17:33	M1.4	186	25	ambiguous[f]	…	…	…[g]
(b) Non-CME-producing Jets:									
J8	22 Oct 14	02:31	…	…	…	75 ± 10	35	19000	…
J9	22 Oct 14	05:51	…	…	…	120 ± 20	10	15000	…
J10	22 Oct 14	10:46	C1.9	…	…	140 ± 20	15	11000	…
J11	22 Oct 14	12:56	…	…	…	50 ± 10	20	16500	…
J12	22 Oct 14	17:30	C3.0	…	…	ambiguous[h]	10	13000	…
J13	22 Oct 14	20:11	C3.0	…	…	150 ± 20	10	16000	…
J14	22 Oct 14	23:15	C1.1	…	…	110 ± 10	25	13000	…

Notes.
[a] ftp://ftp.ngdc.noaa.gov/STP/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/2014/
[b] http://cdaw.gsfc.nasa.gov/CME_list
[c] Uncertainty in the CMEs speed measurement is less than 10% (Yashiro et al. 2004).
[d] Uncertainties are estimated from the time–distance plots.
[e] Measured at a projected height of ~72,000 km from jet base.
[f] This jet shows up well in the AIA 94 Å images, but not in 304 Å images. Due to its poor visibility in 304 Å images, we were unable to follow the jet plasma well enough to measure its speed.
[g] AR was close to the west limb, obscuring any remote brightening/dimming.
[h] Slower velocity (250 km s^{-1}) in the beginning, but faster (>650 km s^{-1}) later when a plug of plasma separates.

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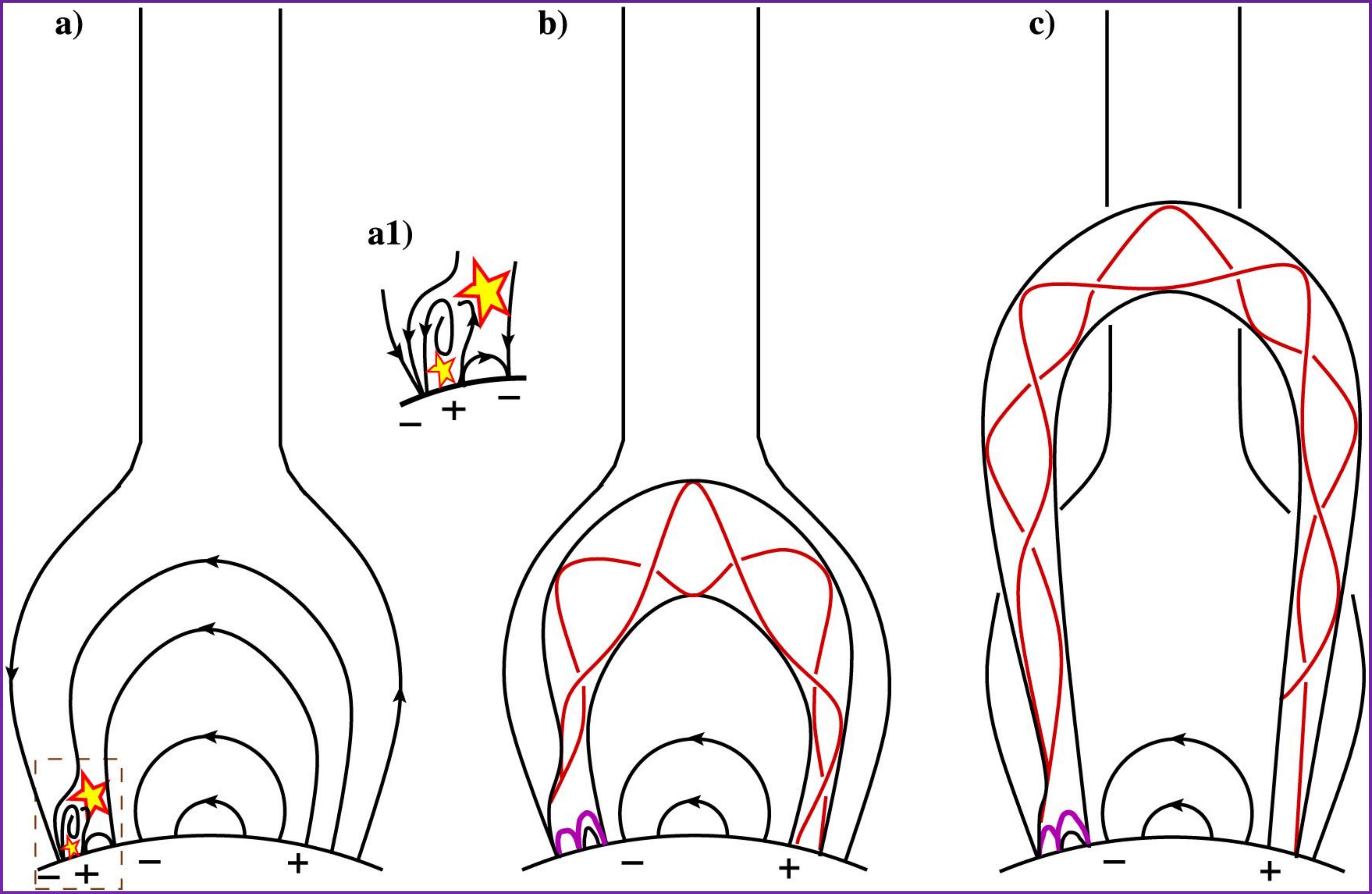
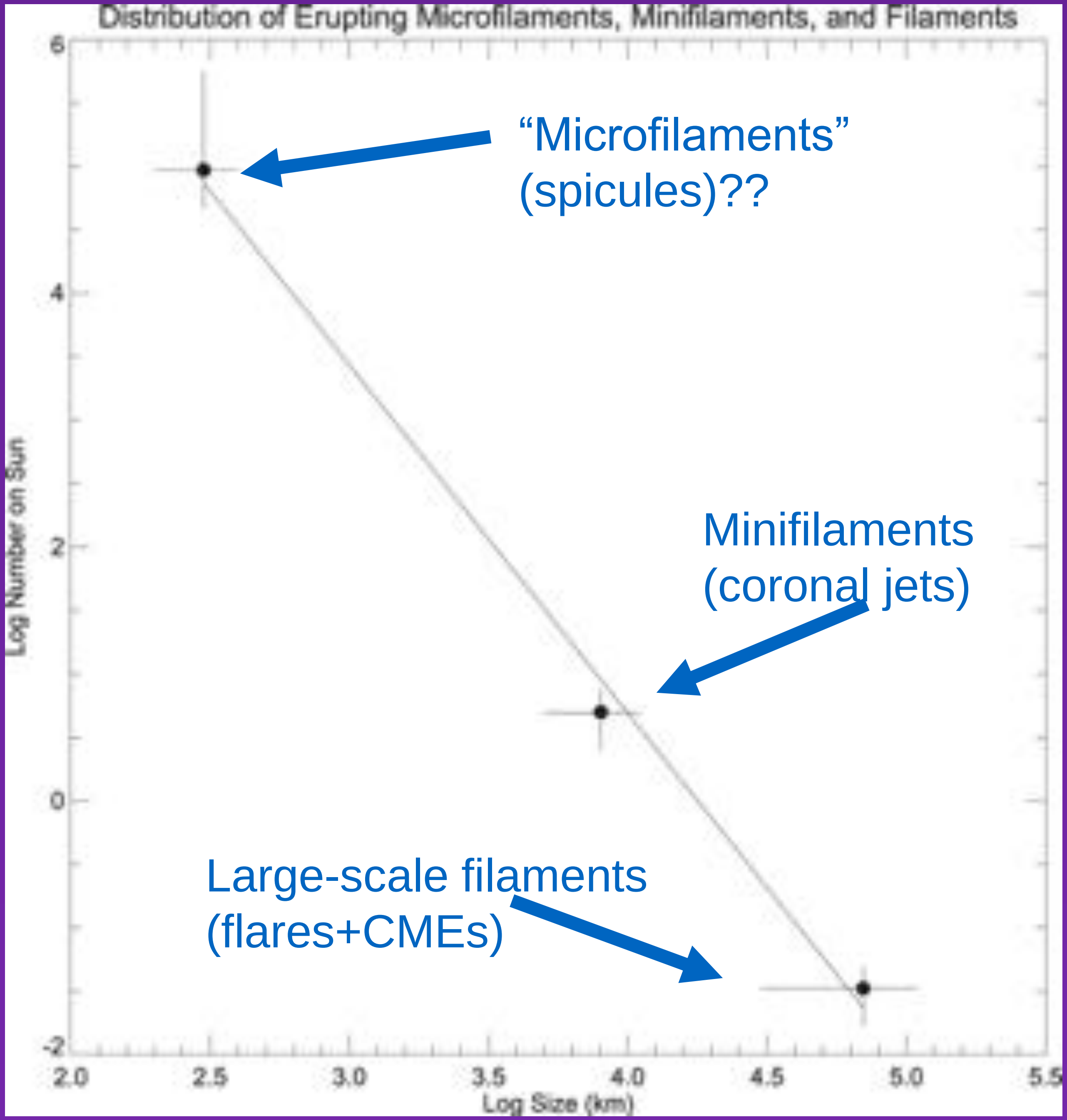


(Update to Bemporad et al. 2005 picture of "streamer puff" CMEs.)

Do Jets Exist on Smaller Size Scales?

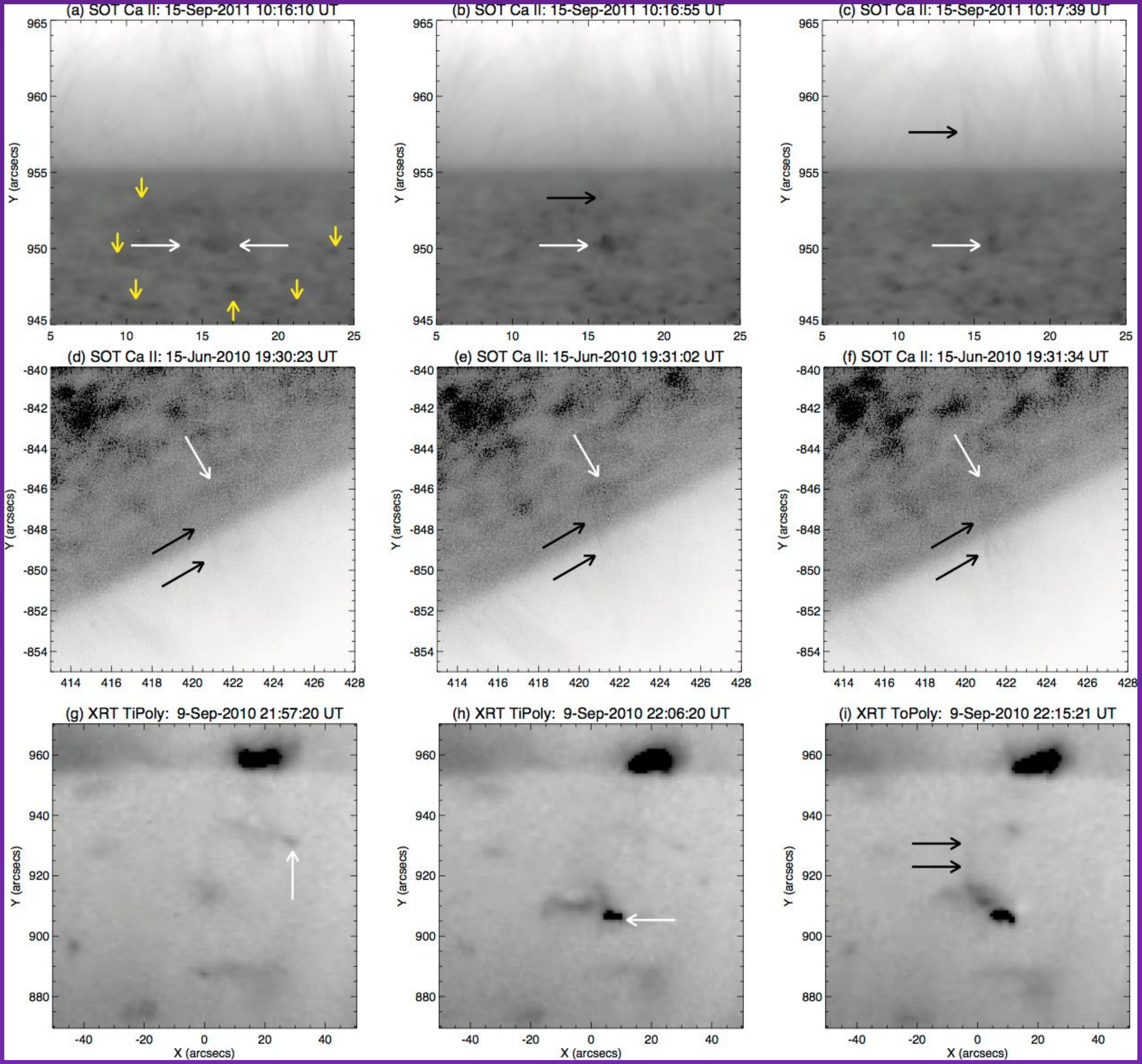
Filament-Like Feature Eruptions on Smaller Scales??

Log Number of Eruptions

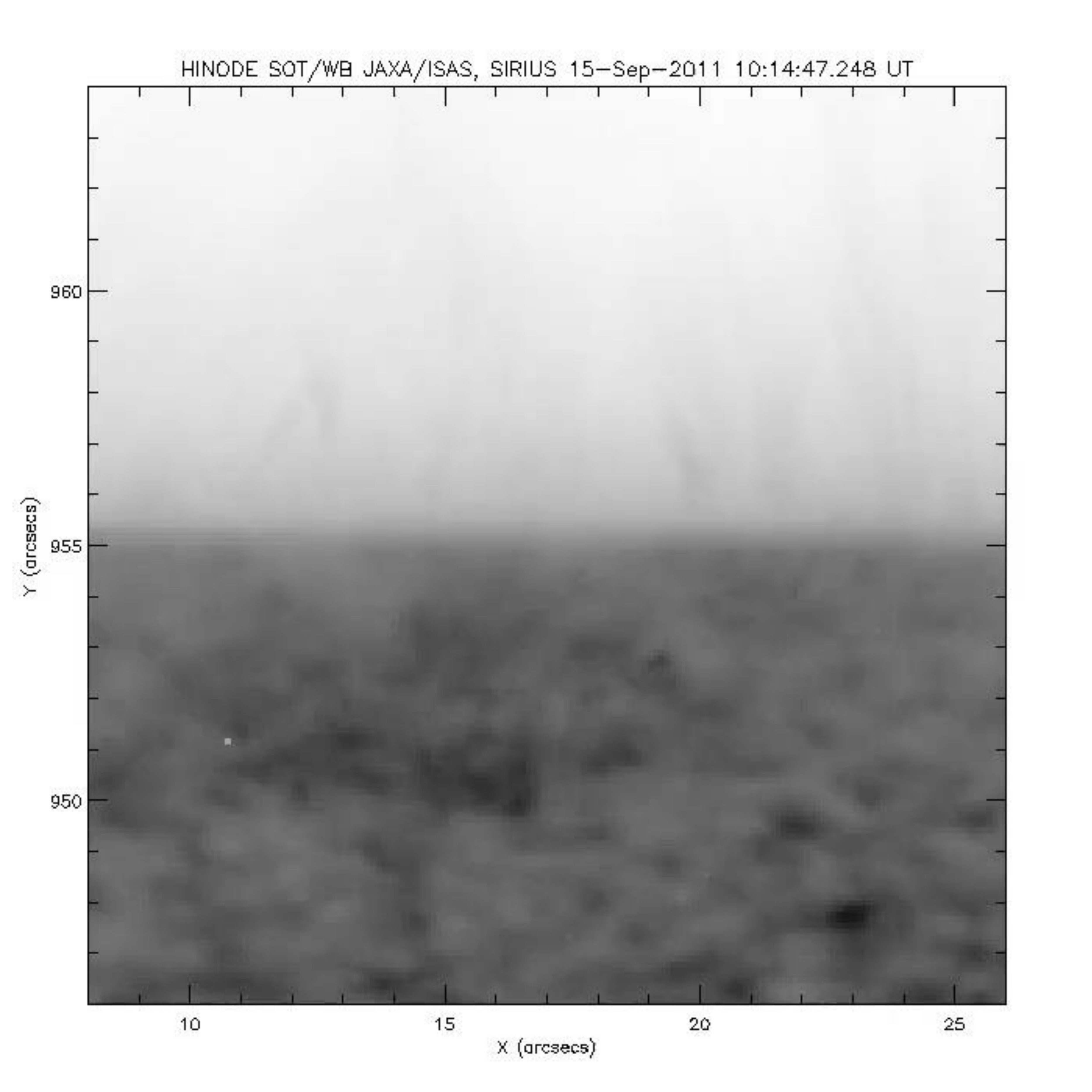


Log "Filament" Size

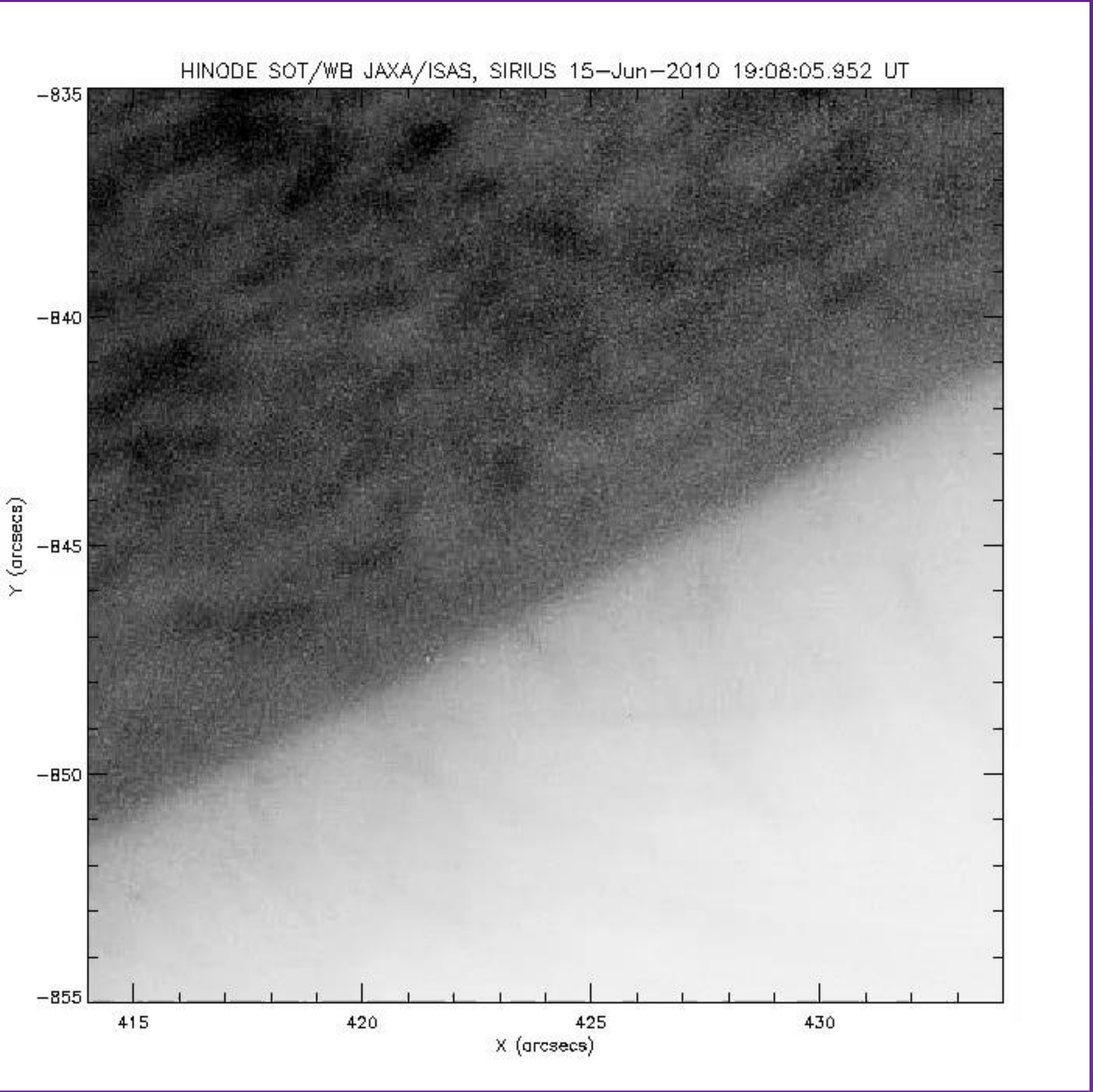
Sterling & Moore (2016)



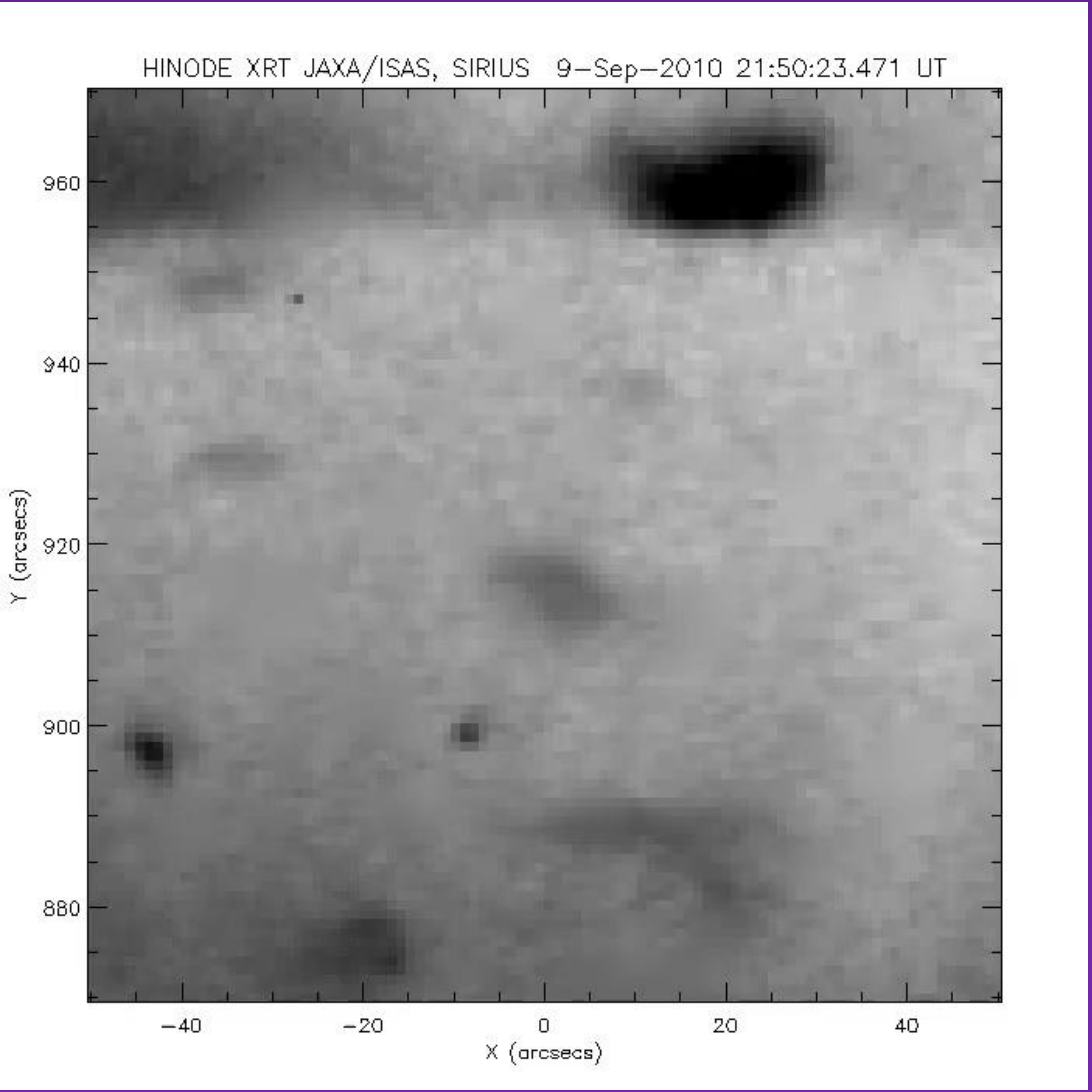
Sterling & Moore (2016)



Sterling & Moore (2016)



Sterling & Moore (2016)



Sterling & Moore (2016)

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.
- Many (virtually all?) minifilament eruptions triggered by flux cancelation.
- At least two types of CMEs from jets:
  - Extensions of jets (narrow CMEs/white light jets).
  - Broader CMEs can be triggered by jets (streamer puff CMEs).
- Smallest-scale jets might make up some percentage of the spicule population.

Image:
Alphonse Sterling
21 August 2017,
Lewisville, Idaho