Plasmoids, flows, and jets associated with a failed filament eruption

P. Kumar[1,2], J.T. Karpen[2], S.K. Antiochos[2], C.R. DeVore[2], P.F. Wyper, 2022, ApJ, Under review

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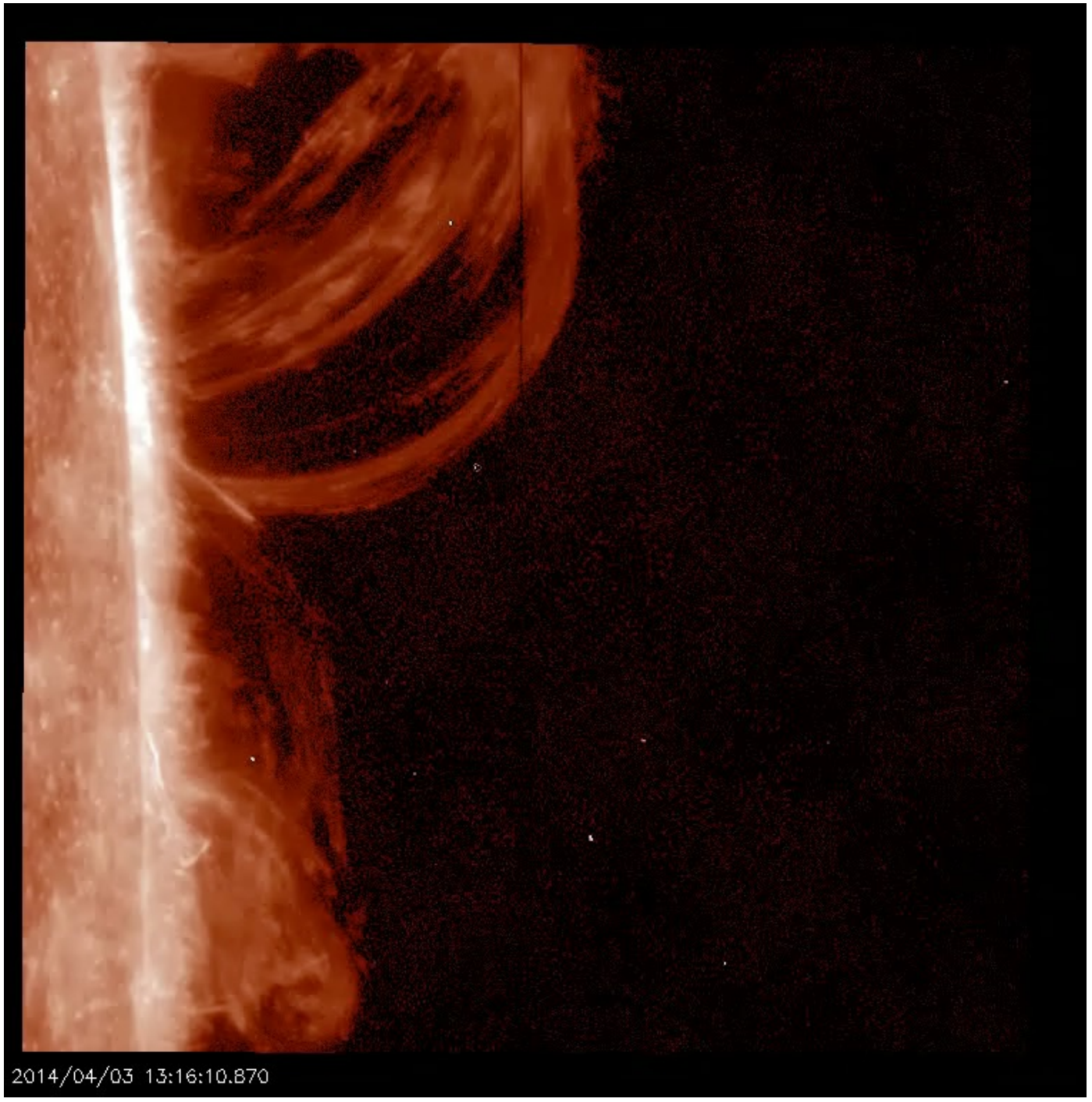
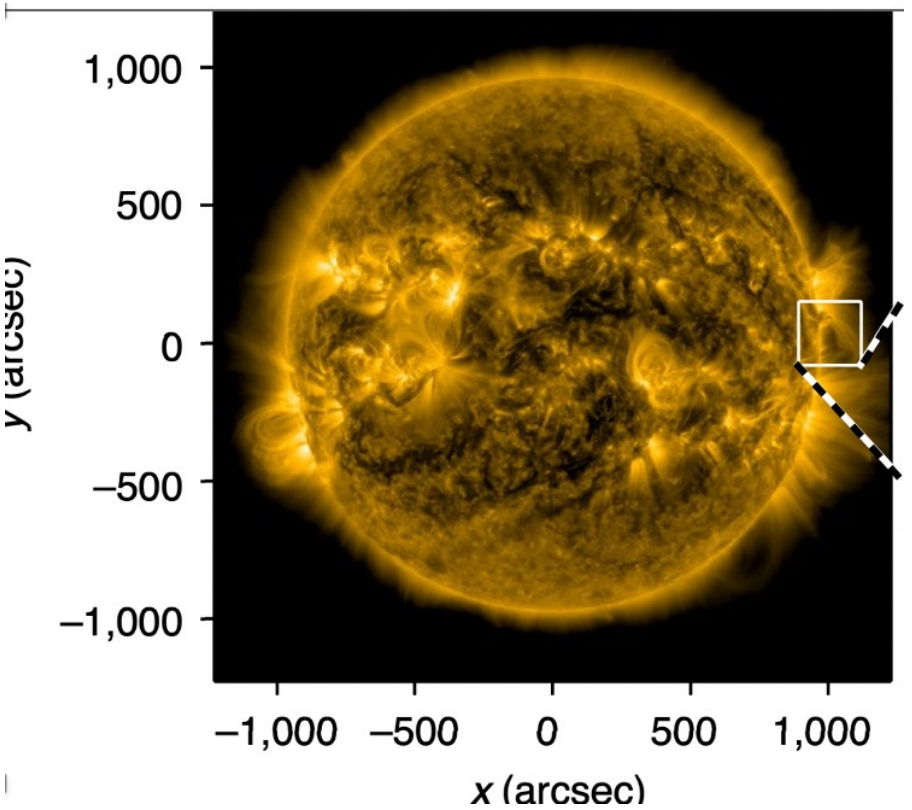


IRIS Si IV 1400

logT (K) ~3.7-5.2



Antolin et al. 2021, Nature astronomy

Discovery of nanoflare associated nanojets?

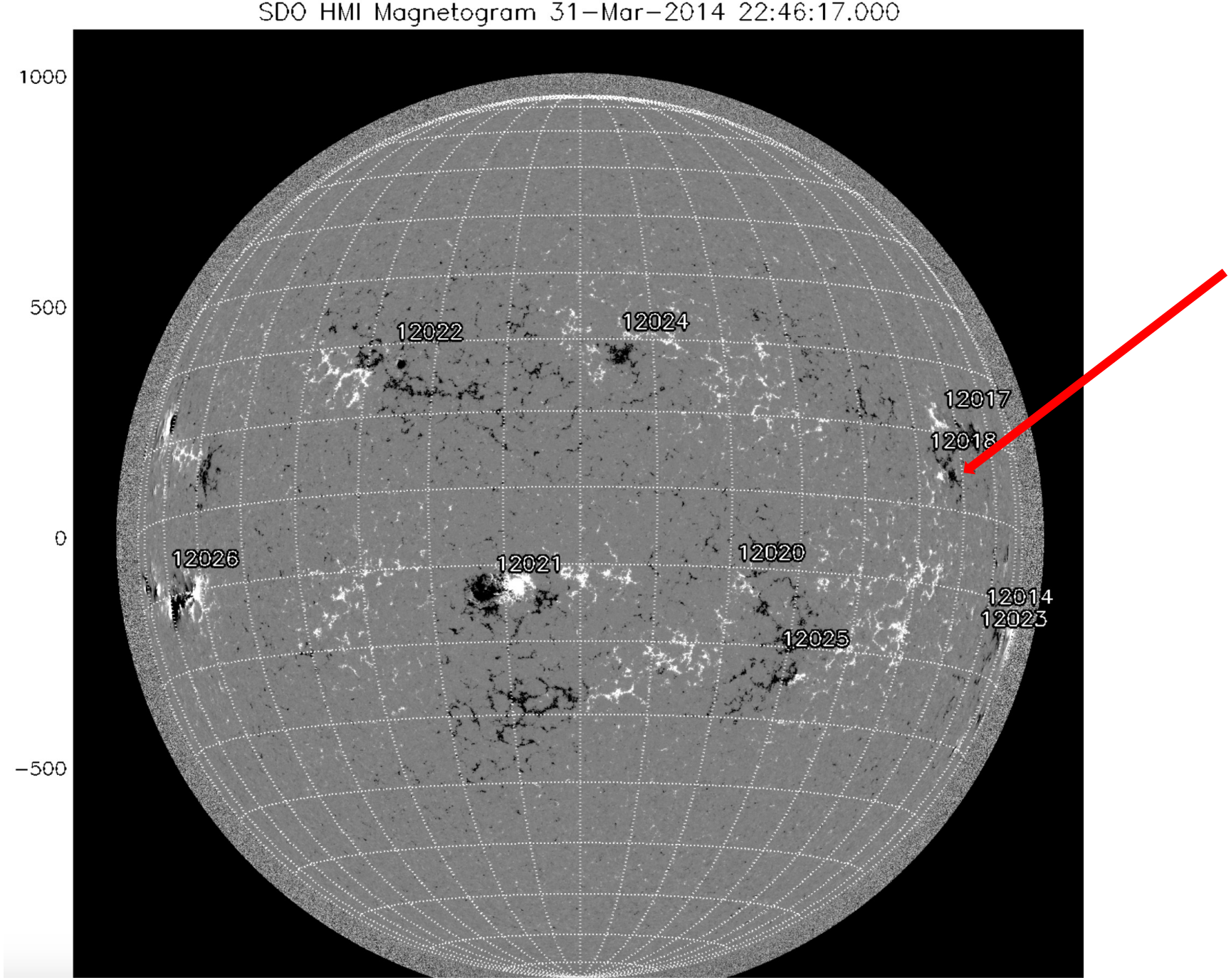
Reconnection nanojets in the solar corona

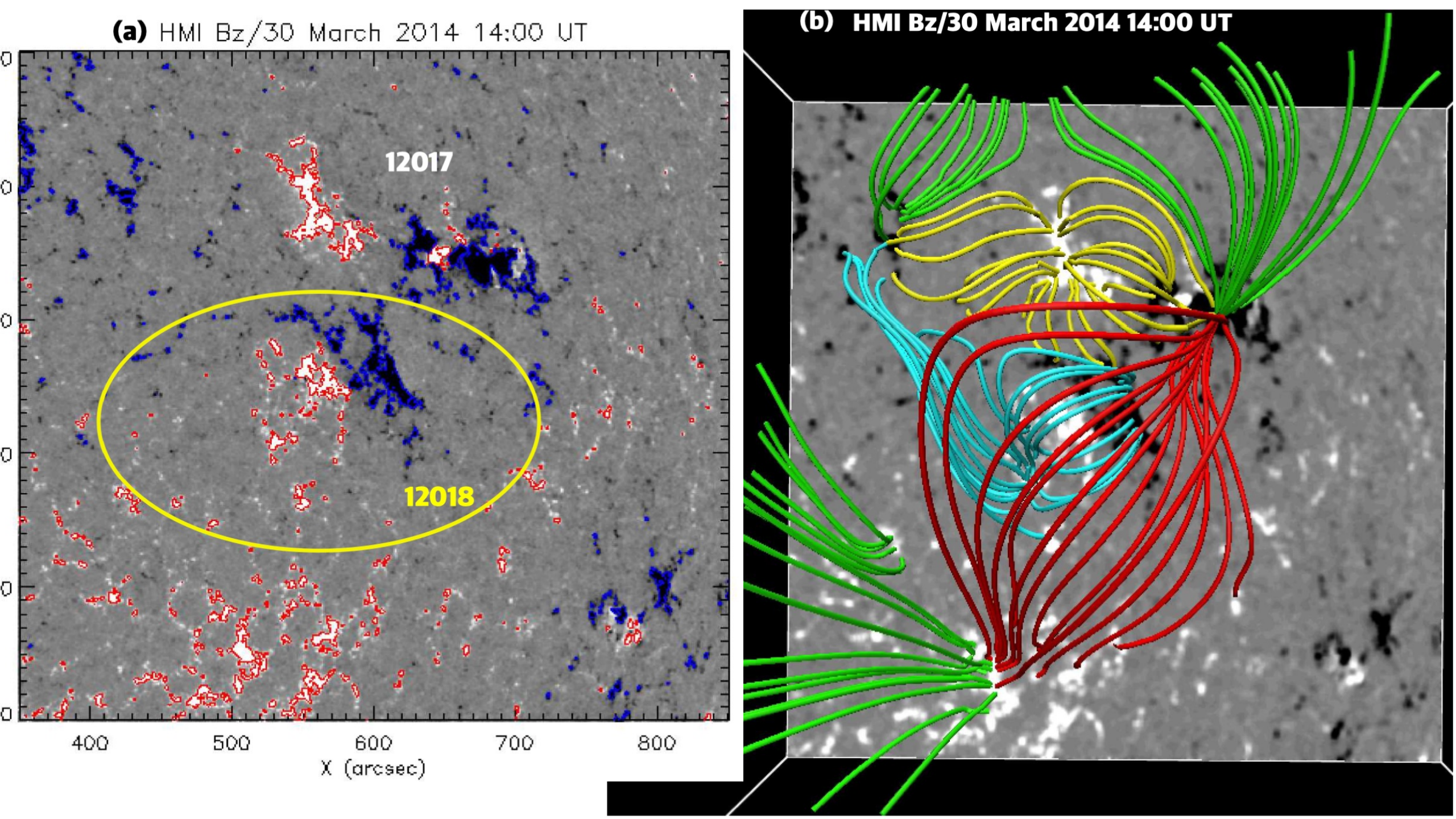
Patrick Antolin[1,2] ✉, Paolo Pagano[2], Paola Testa[3], Antonino Petralia[4] and Fabio Reale[4,5]

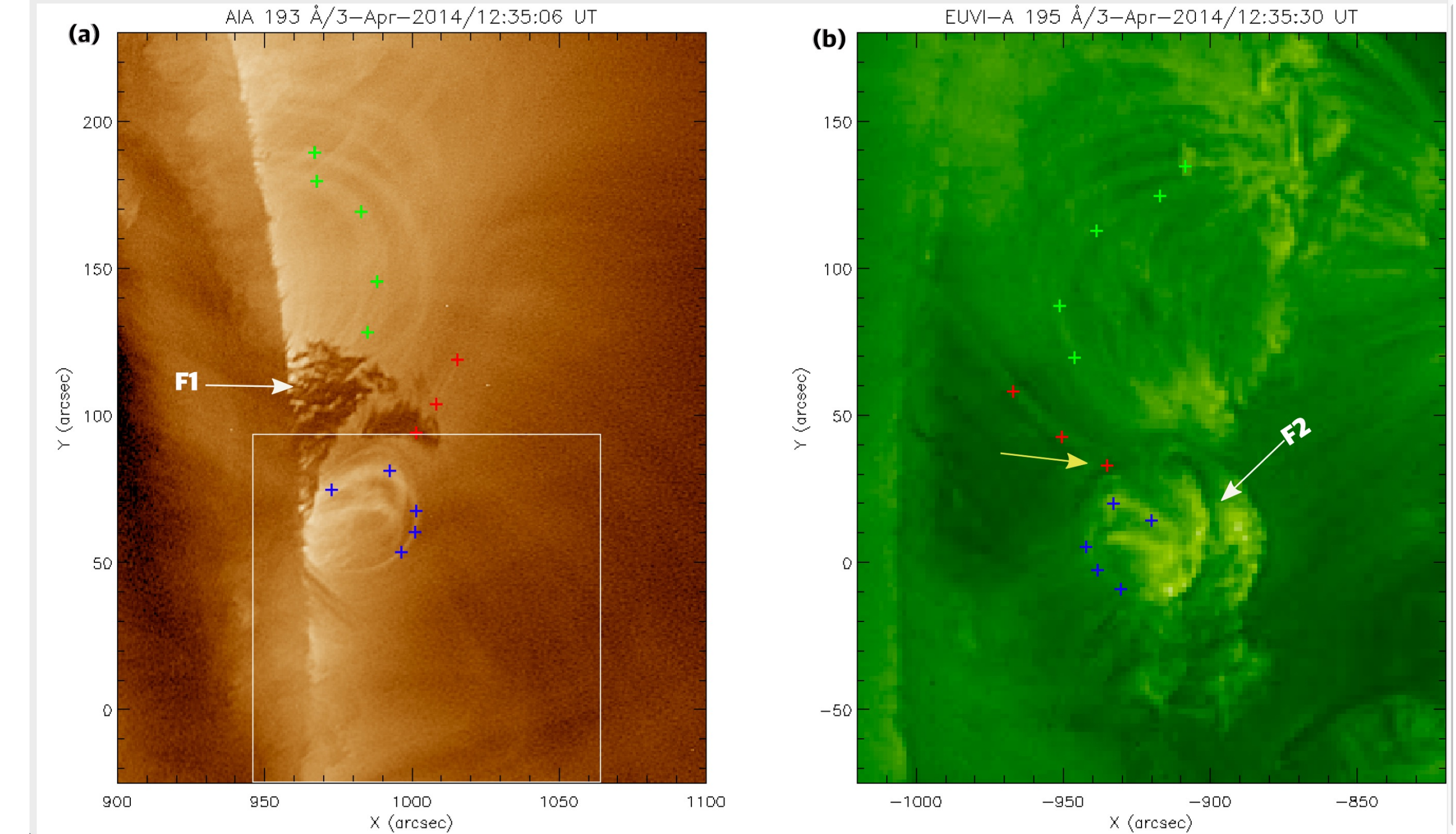
The solar corona is shaped and mysteriously heated to millions of degrees by the Sun's magnetic field. It has long been hypothesized that the heating results from a myriad of tiny magnetic energy outbursts called nanoflares, driven by the fundamental process of magnetic reconnection. Misaligned magnetic field lines can break and reconnect, producing nanoflares in avalanche-like processes. However, no direct and unique observations of such nanoflares exist to date, and the lack of a smoking gun has cast doubt on the possibility of solving the coronal heating problem. From coordinated multi-band high-resolution observations, we report on the discovery of very fast and bursty nanojets, the telltale signature of reconnection-based nanoflares resulting in coronal heating. Using state-of-the-art numerical simulations, we demonstrate that the nanojet is a consequence of the slingshot effect from the magnetically tensed, curved magnetic field lines reconnecting at small angles. Nanojets are therefore the key signature of reconnection-based coronal heating in action.

Magnetic configuration:

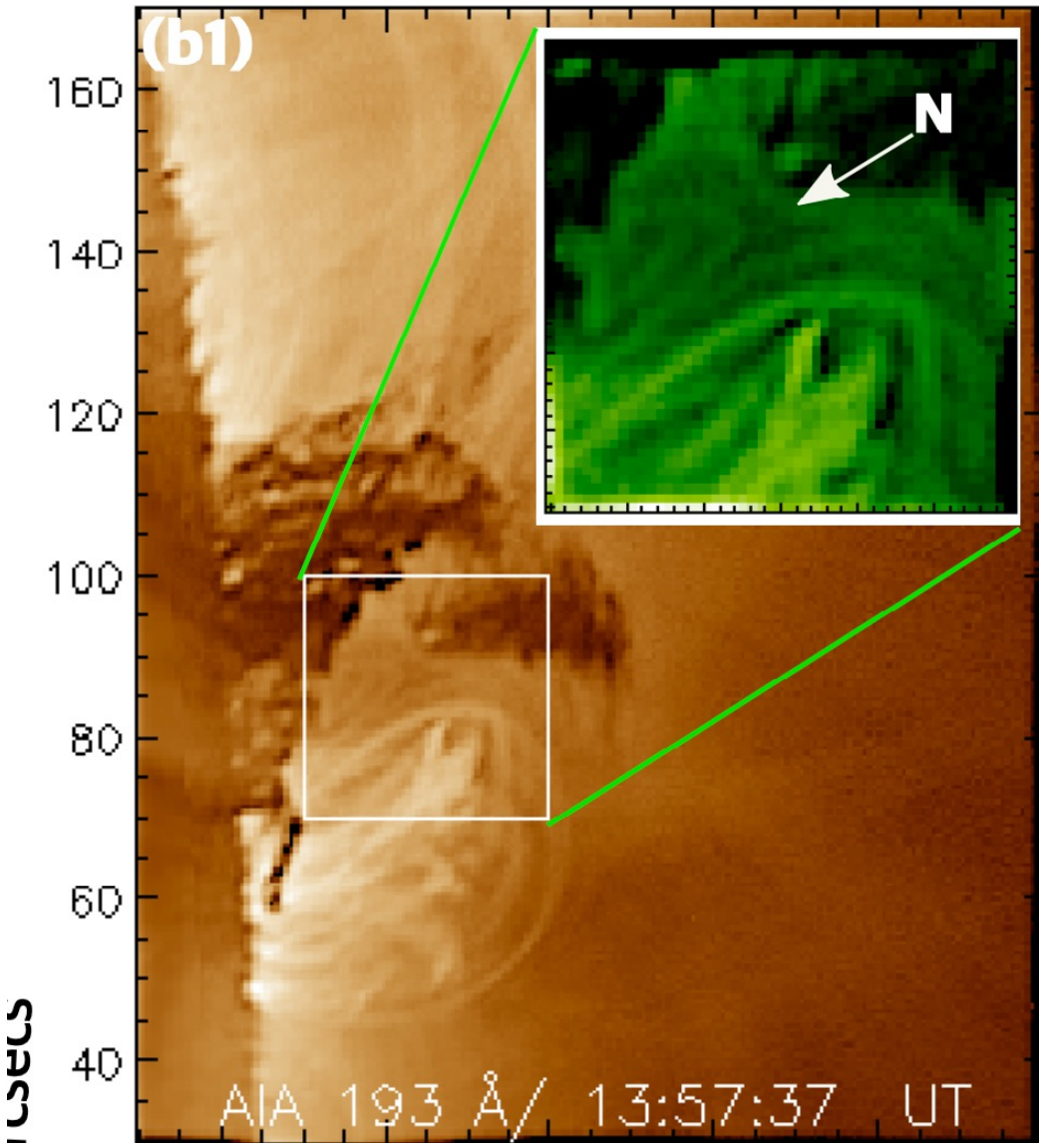
AR NOAA 12018, Apr 3, 2014

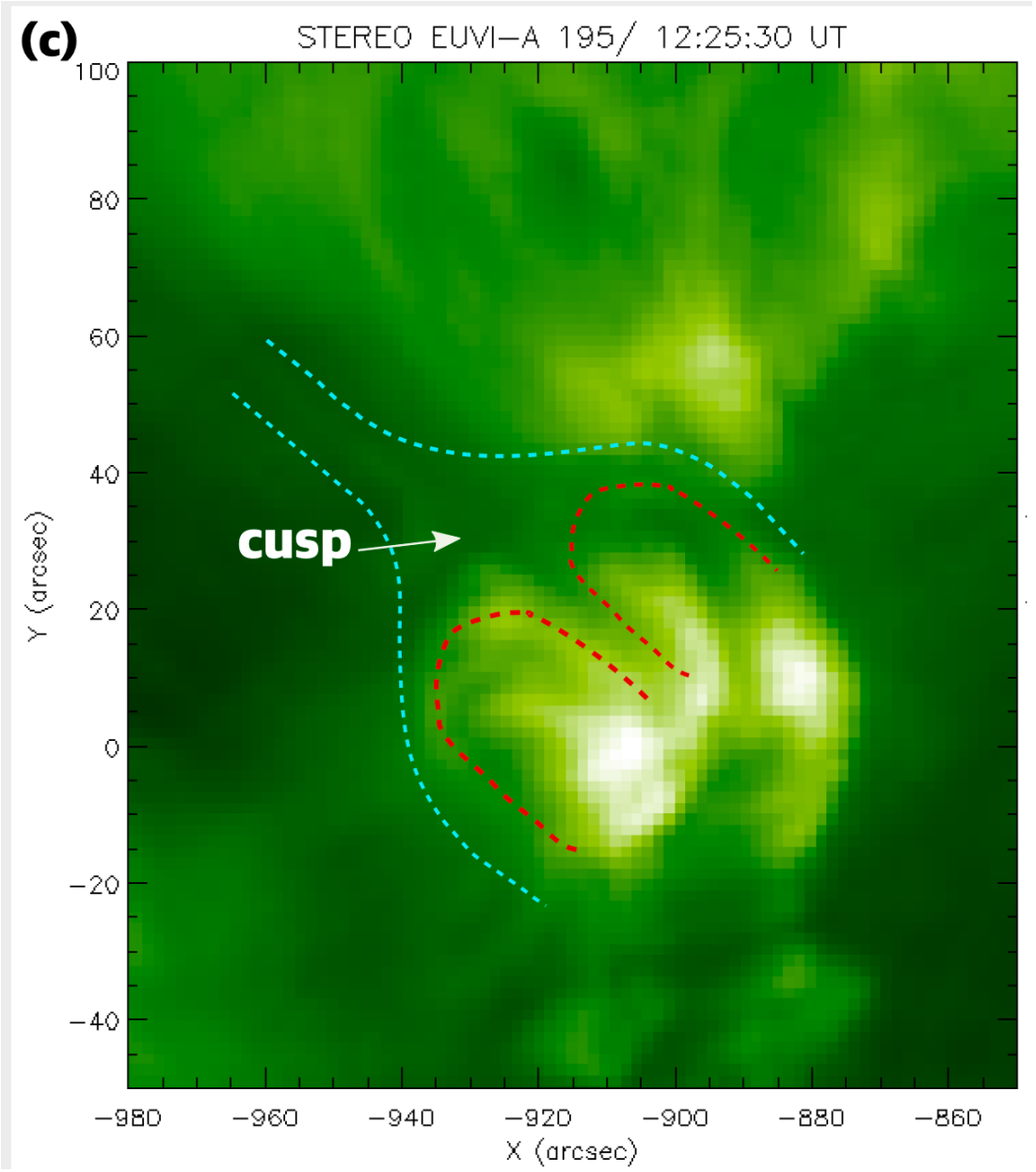

SDO HMI Magnetogram 31-Mar-2014 22:46:17.000
1000
500
0
-500
12022
12024
12017
12018
12026
12021
12020
12014
12023
12025


(a) HMI Bz/30 March 2014 14:00 UT
12017
12018
400
500
600
700
800
X (arcsec)
(b) HMI Bz/30 March 2014 14:00 UT


(a)
AIA 193 Å/3–Apr–2014/12:35:06 UT
F1
Y (arcsec)
X (arcsec)
200
150
100
50
0
900
950
1000
1050
1100
(b)
EUVI–A 195 Å/3–Apr–2014/12:35:30 UT
F2
Y (arcsec)
X (arcsec)
150
100
50
0
−50
−1000
−950
−900
−850

Multiple activities prior to a C-class flare





Sequence of activities:

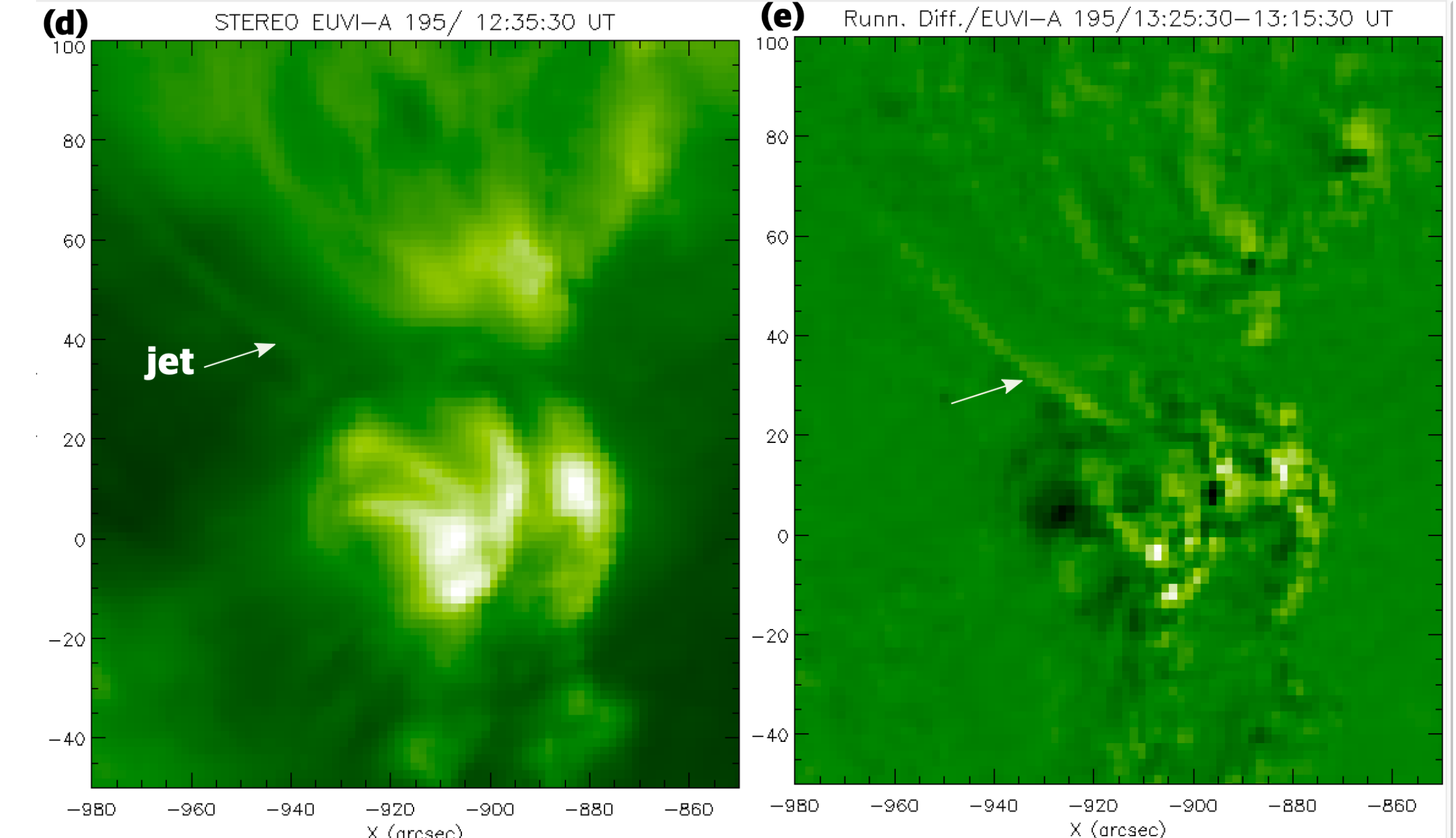
1) Pre-eruption jets from the null

1-2 hours prior to the filament rise

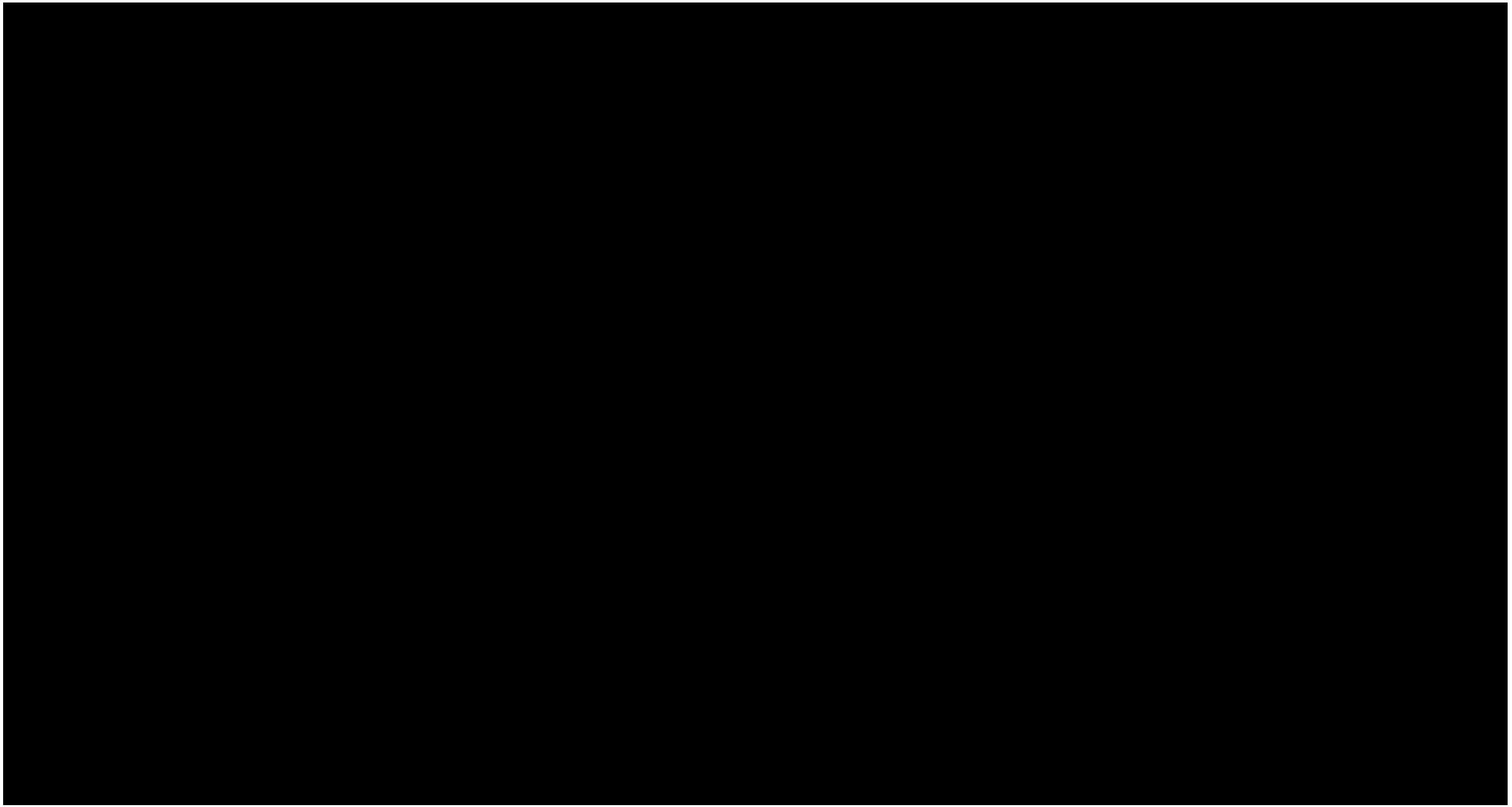
This activity removes a part of close flux above the circular PIL via interchange reconnection

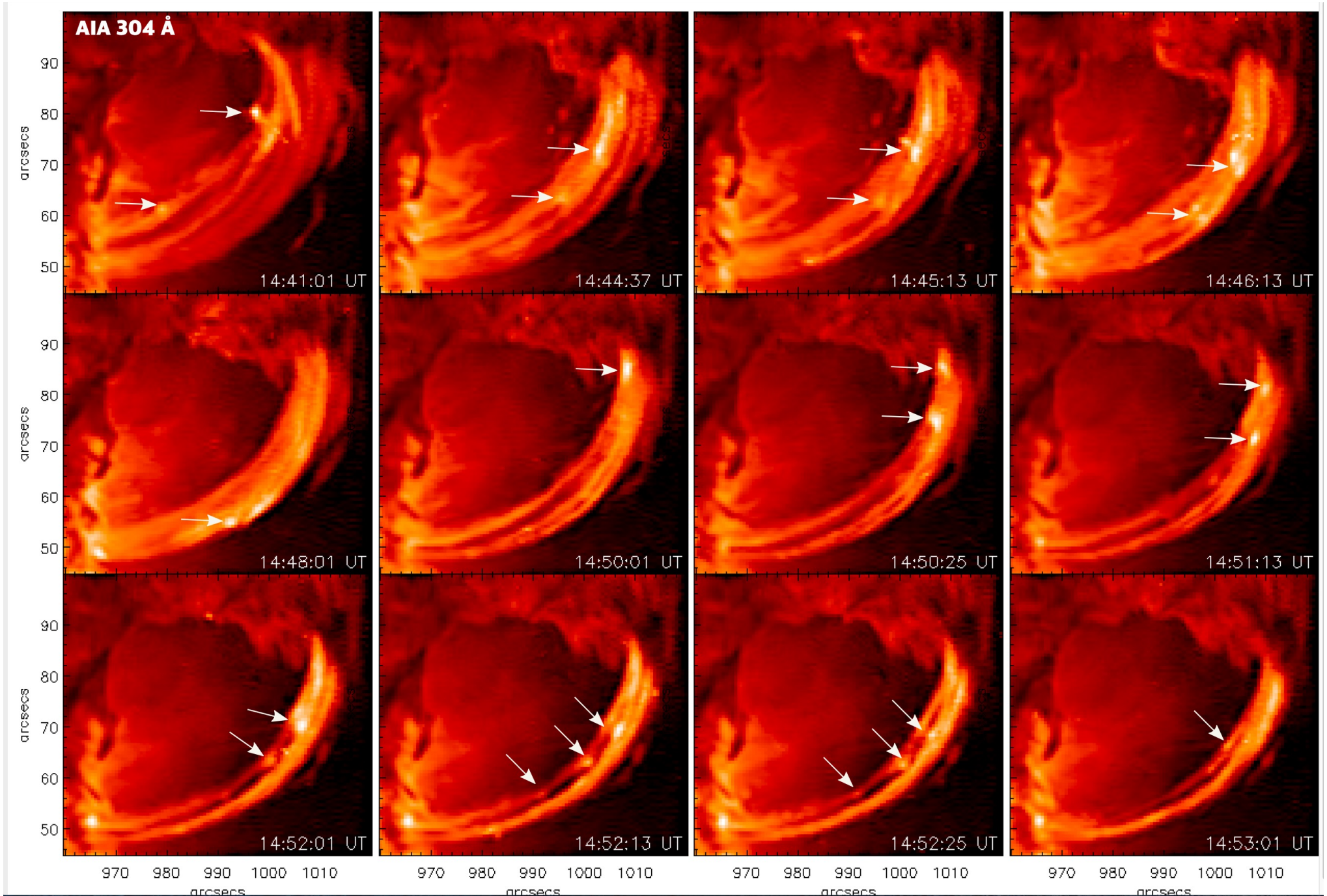
Seen before in multiple Pseudostreamers; Kumar et al. 2019, 2021, ApJ
MHD simulations by Lynch+ 2013, Wyper et al, 2021

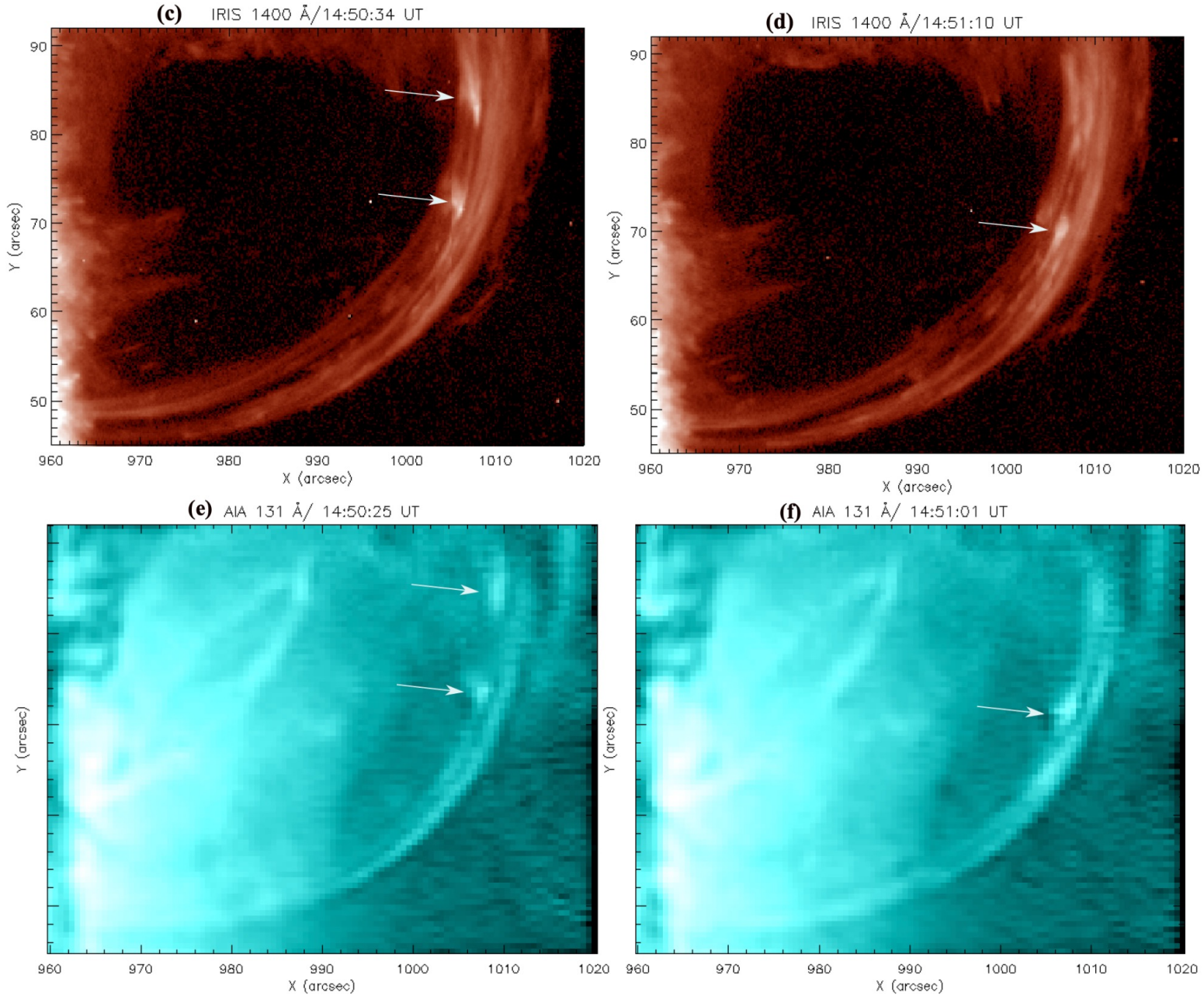
multiple jets V~130 km/s, reverse drifting features=coronal rain

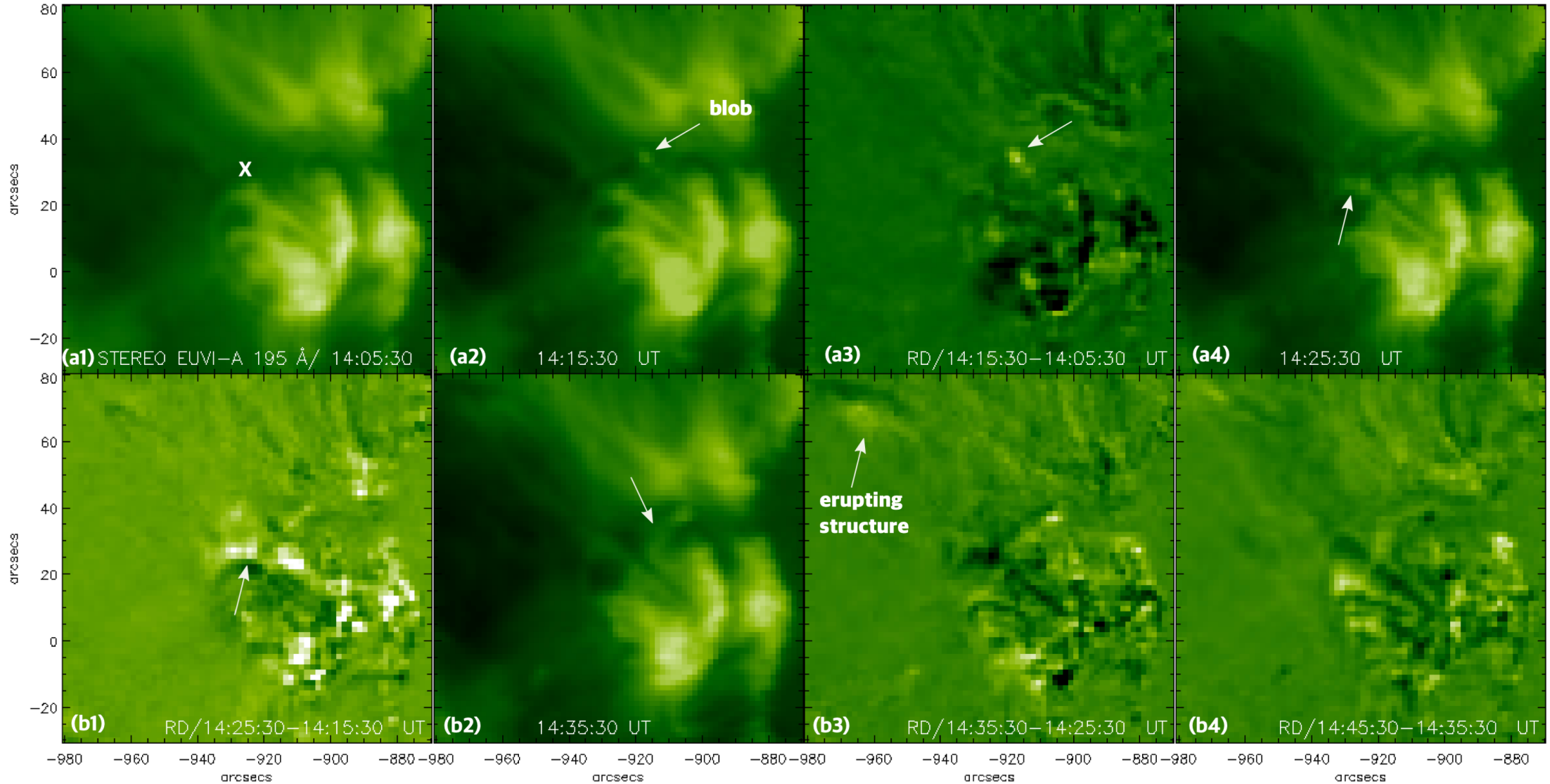

(d)
STEREO EUVI–A 195/ 12:35:30 UT
jet
(e)
Runn. Diff./EUVI–A 195/13:25:30–13:15:30 UT
100
80
60
40
20
0
−20
−40
−980
−960
−940
−920
−900
−880
−860
X (arcsec)

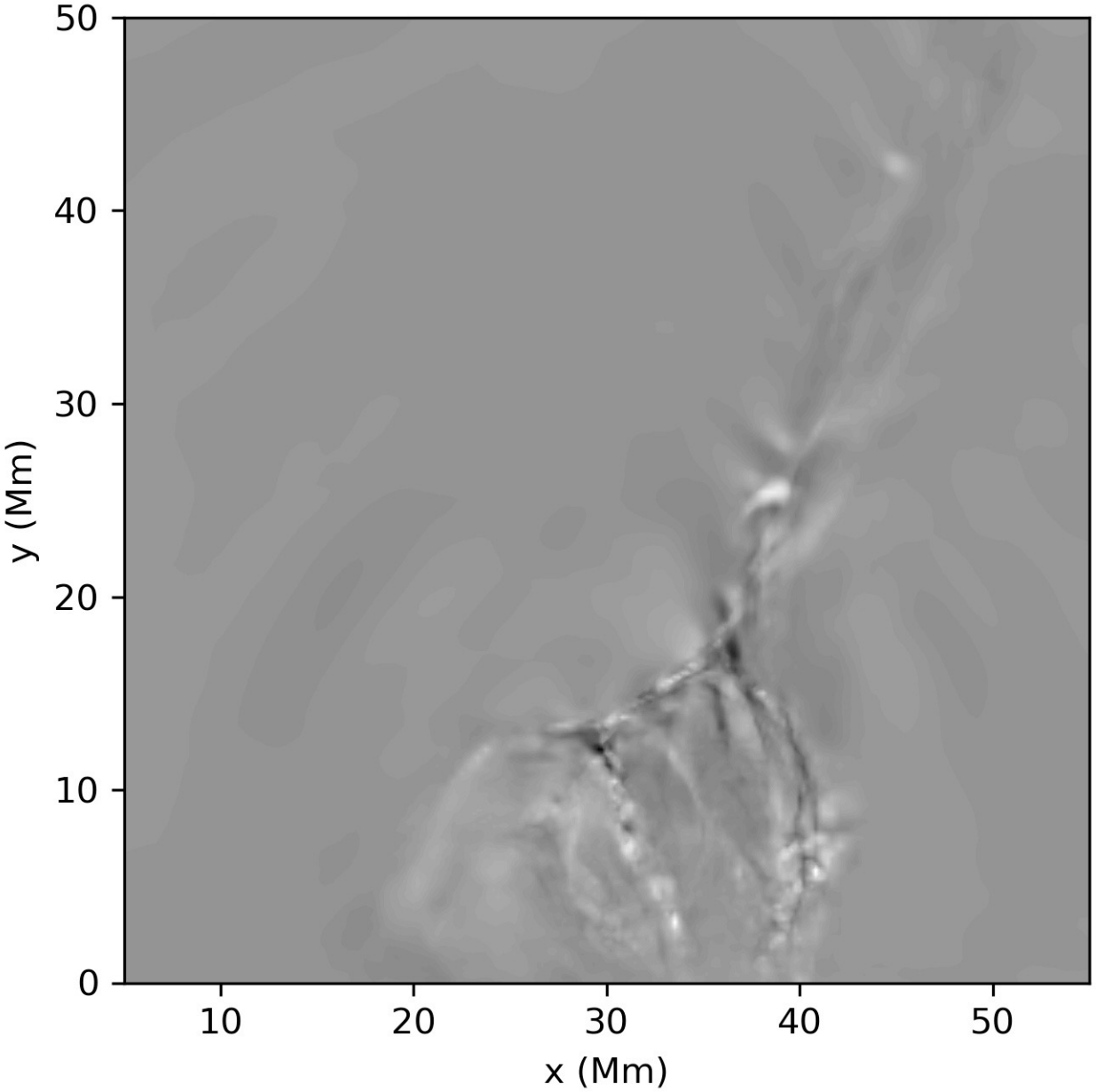
2) Filament slow-rise, preflare activity, blobs along the fan loops




AIA 304 Å
14:41:01 UT
14:44:37 UT
14:45:13 UT
14:46:13 UT
14:48:01 UT
14:50:01 UT
14:50:25 UT
14:51:13 UT
14:52:01 UT
14:52:13 UT
14:52:25 UT
14:53:01 UT
arcsecs
90
80
70
60
50
970
980
990
1000
1010

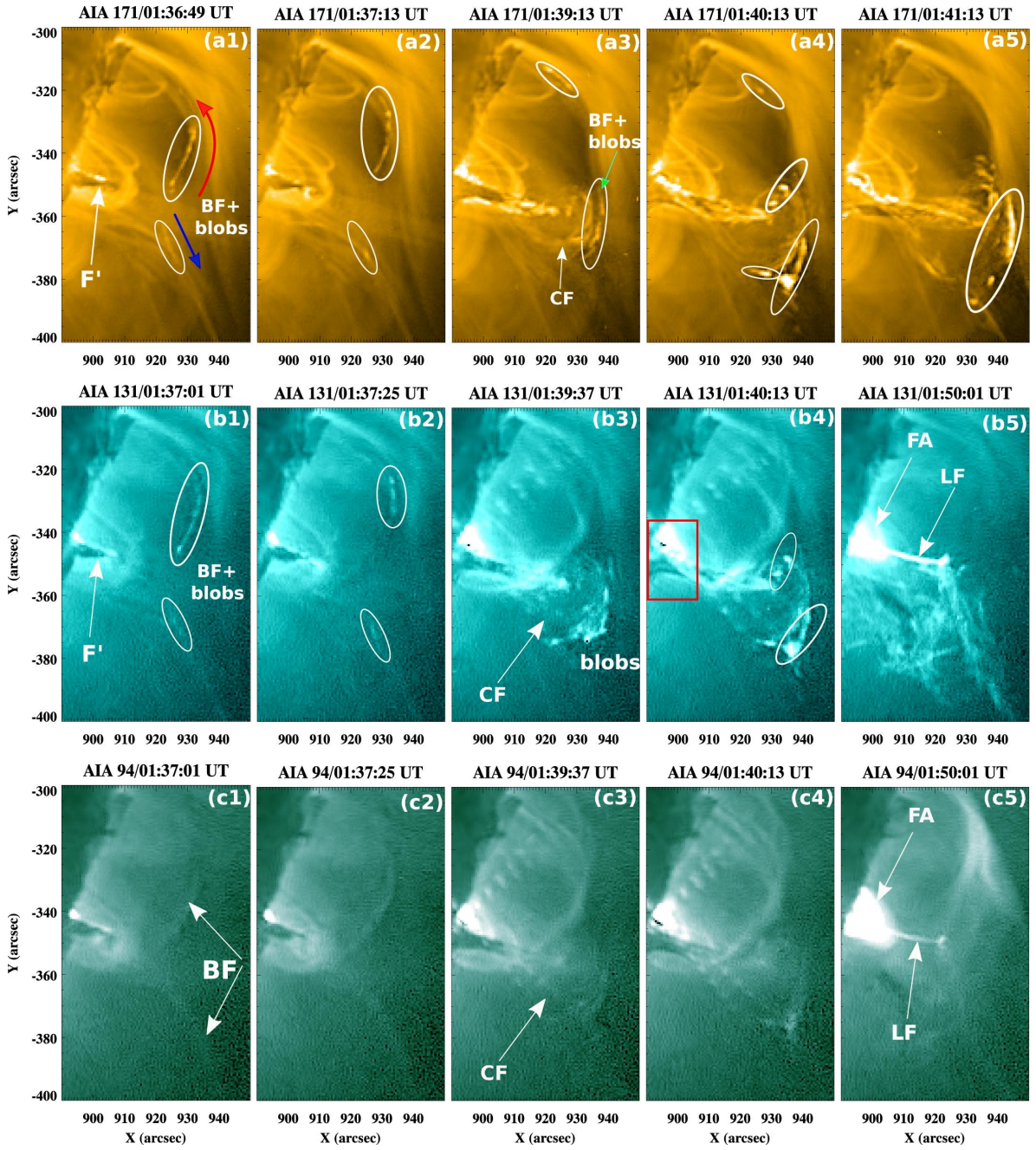

(c) IRIS 1400 Å/14:50:34 UT
(d) IRIS 1400 Å/14:51:10 UT
(e) AIA 131 Å/ 14:50:25 UT
(f) AIA 131 Å/ 14:51:01 UT
Y (arcsec)
X (arcsec)
90
80
70
60
50
960
970
980
990
1000
1010
1020


(a1) STEREO EUVI–A 195 Å/ 14:05:30
X
(a2) 14:15:30 UT
blob
(a3) RD/14:15:30–14:05:30 UT
(a4) 14:25:30 UT
(b1) RD/14:25:30–14:15:30 UT
(b2) 14:35:30 UT
(b3) RD/14:35:30–14:25:30 UT
erupting structure
(b4) RD/14:45:30–14:35:30 UT
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
arcsecs
80
60
40
20
0
−20
−980
−960
−940
−920
−900
−880

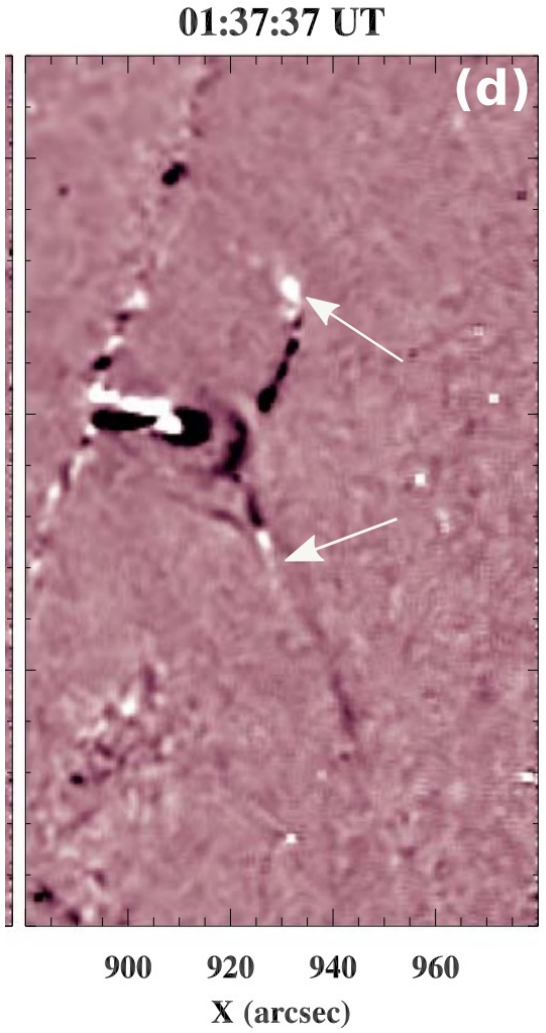


Wyper et al. (2018)

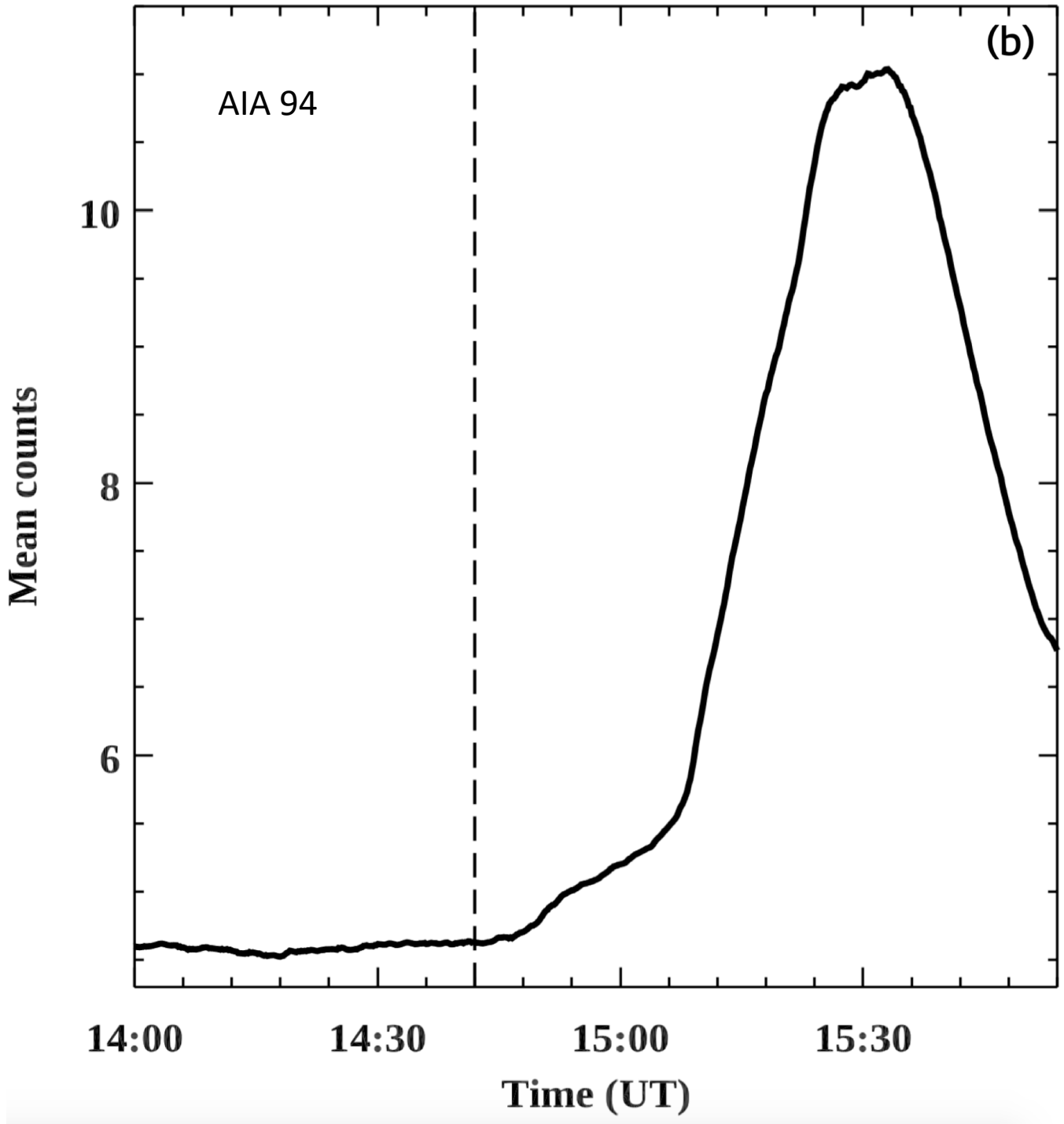
First Detection of Plasmoids from Breakout Reconnection on the Sun

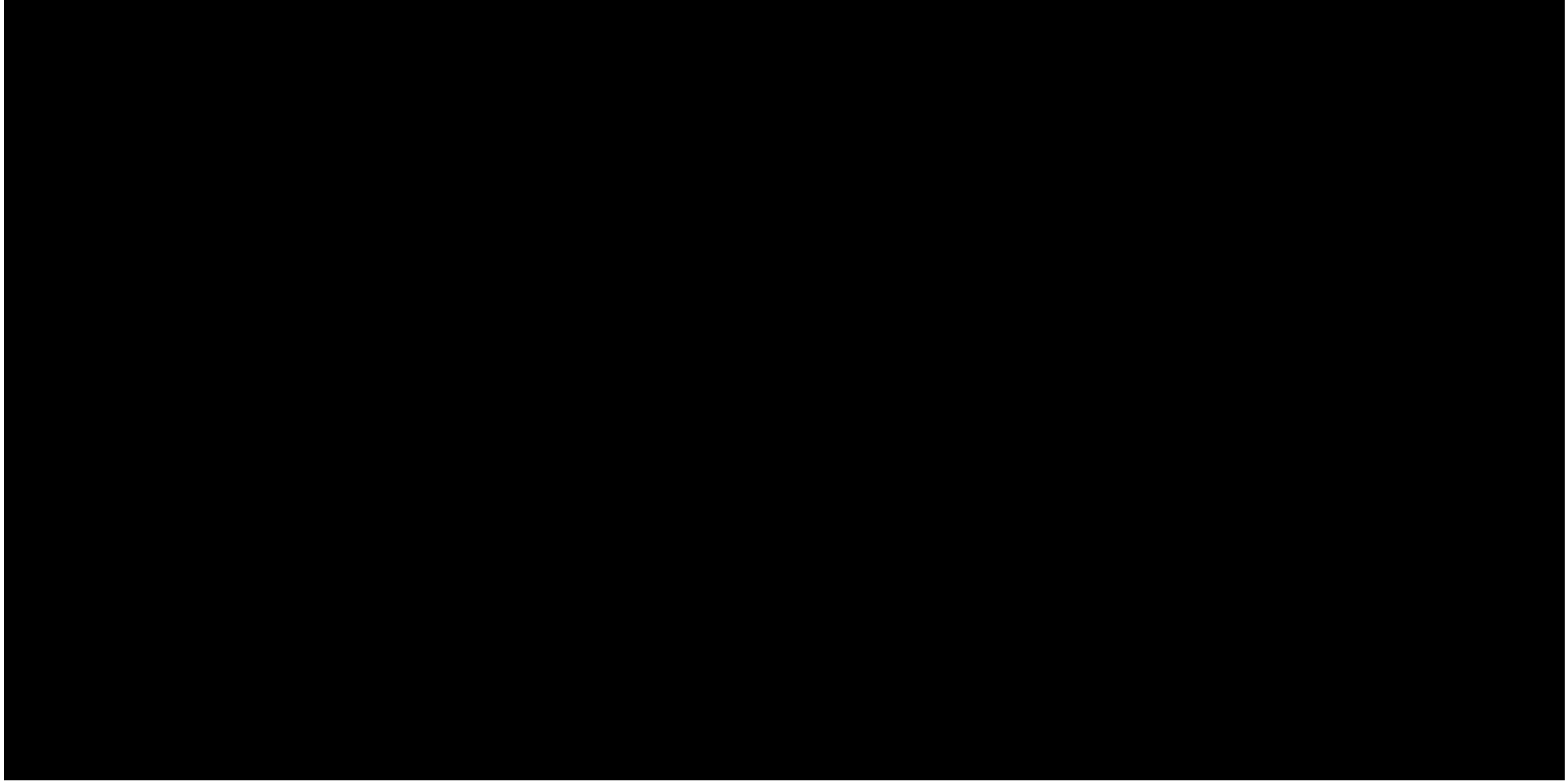


- Bidirectional plasmoids in breakout current-sheet (BCS) above the flux rope (2-3 arcsec width)



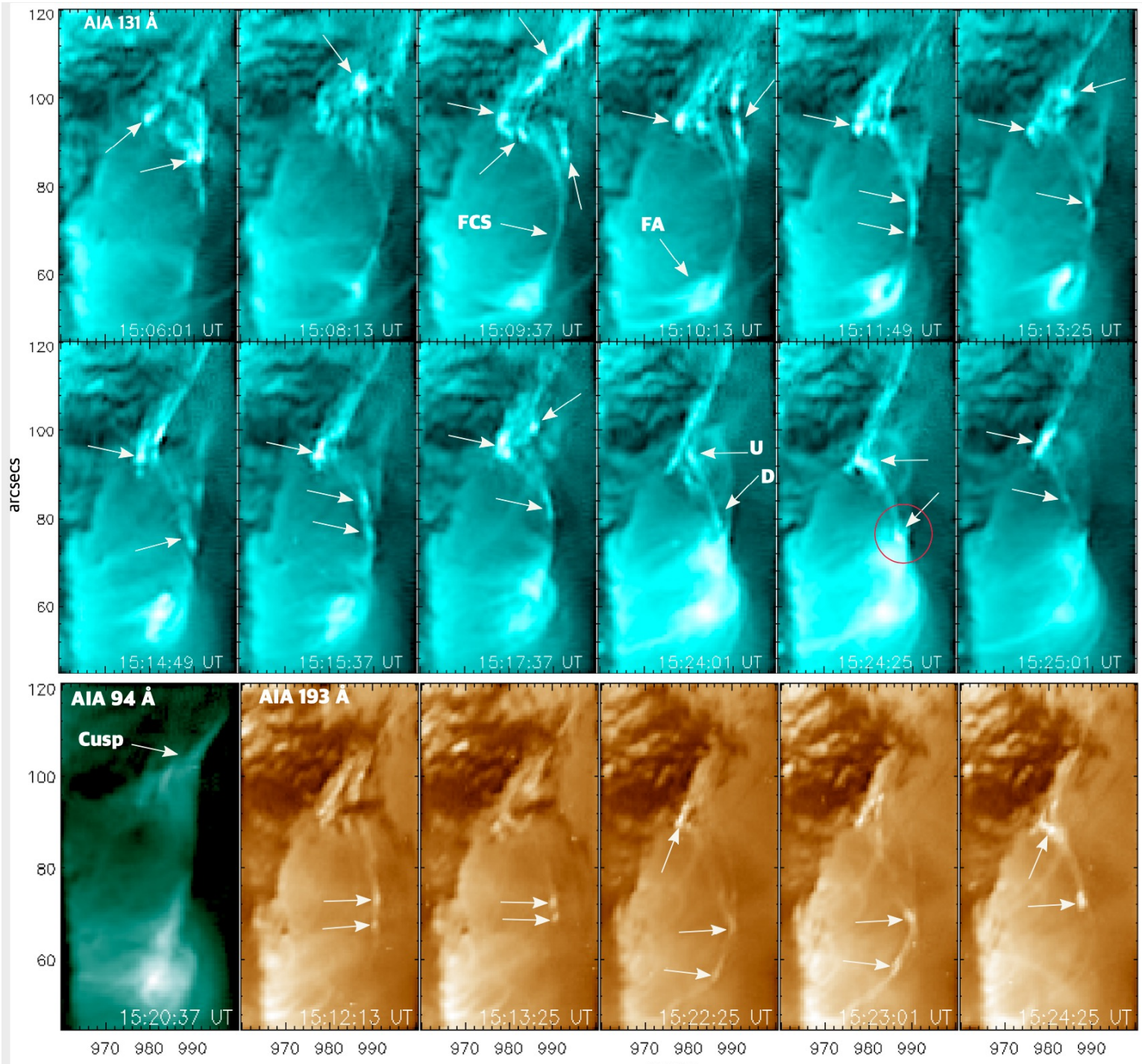
Kumar et. al 2019, ApJ Letters


(b)
AIA 94
10
8
6
Mean counts
14:00
14:30
15:00
15:30
Time (UT)

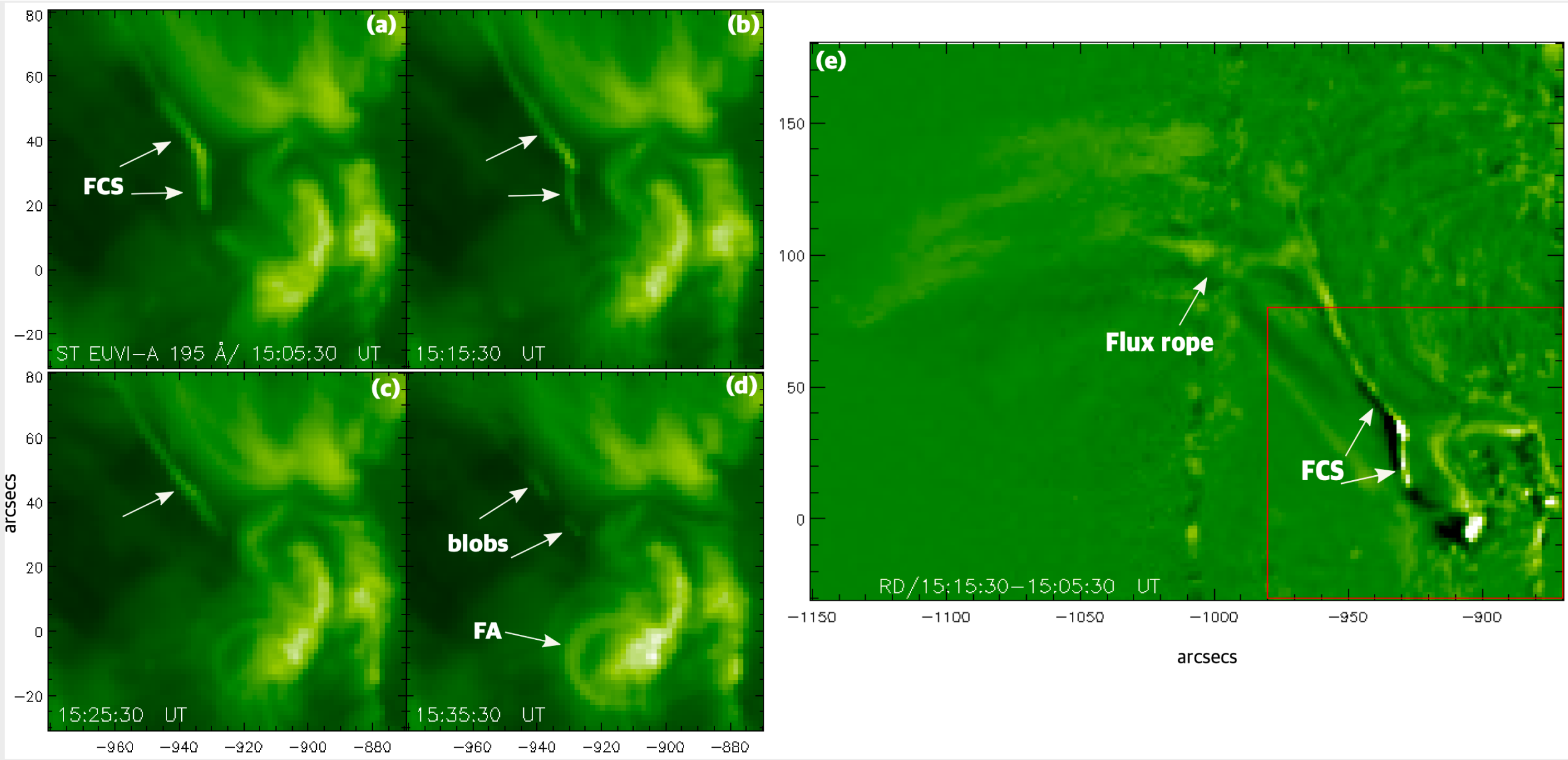


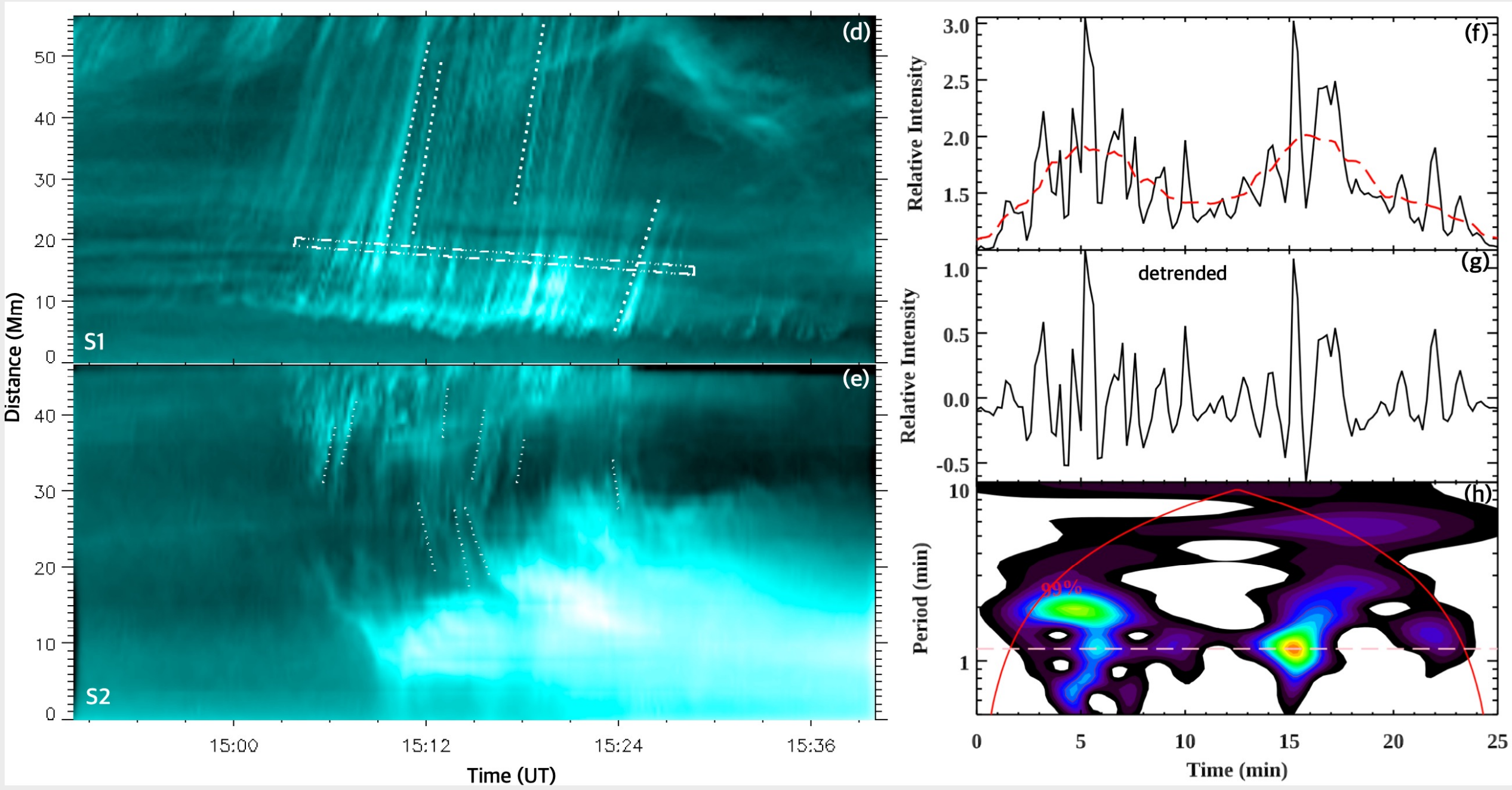
Explosive flare reconnection in FCS: outflows/blobs

Bidirectional flows/blobs



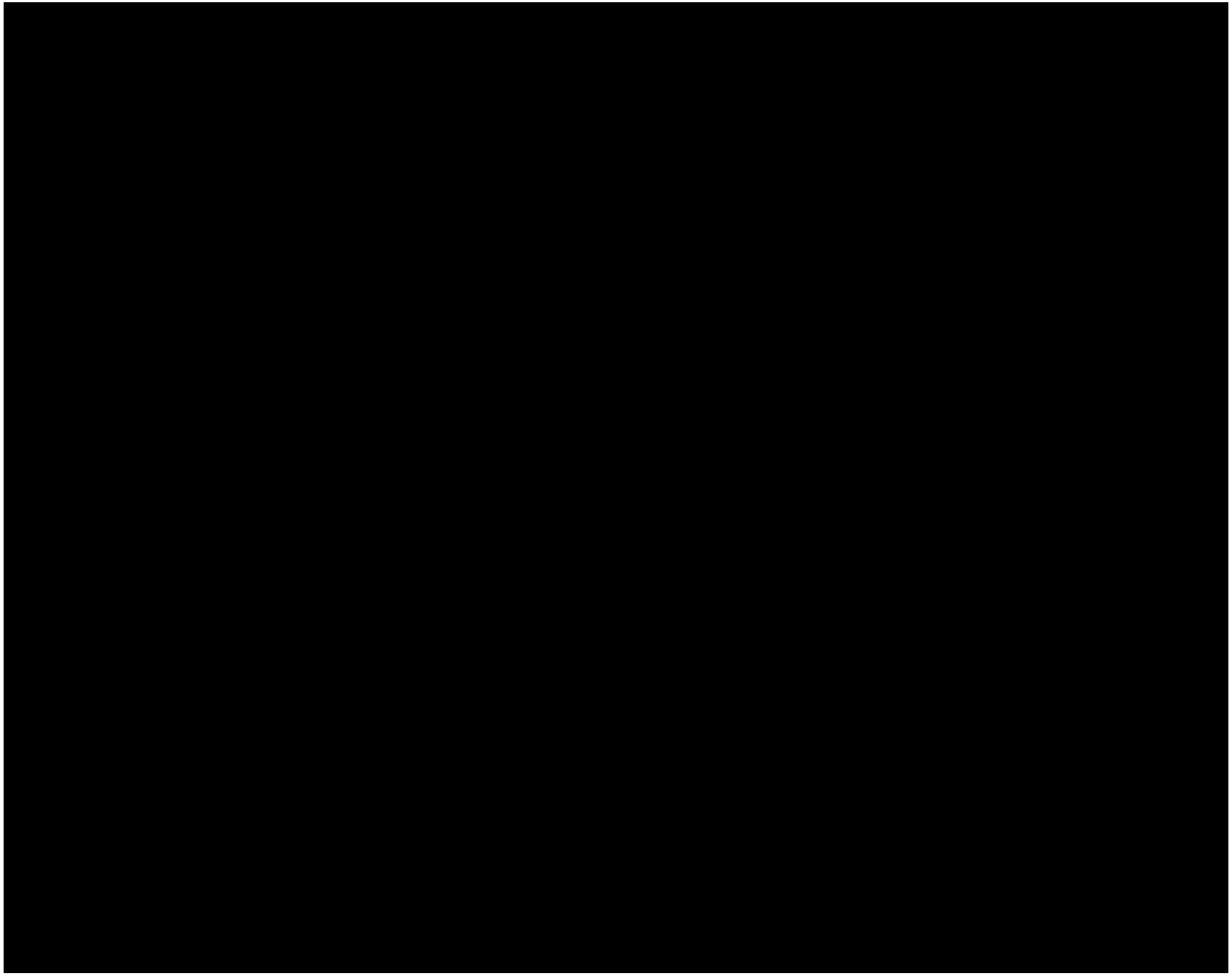
Multiple bidirectional plasmoids in the flare current-sheet


(a)
(b)
(c)
(d)
(e)
FCS
ST EUVI−A 195 Å/ 15:05:30 UT
15:15:30 UT
15:25:30 UT
15:35:30 UT
blobs
FA
Flux rope
FCS
RD/15:15:30−15:05:30 UT
arcsecs
arcsecs



speed 100-285 km/s, period 70 s

Contraction of dome/fan loops



Summary

- Pre-eruption faint jets, v=130 km/s
- Filament slow-rise+interaction near 3D null=bidirectional flows with multiple blobs (v~100 km/s).
- The analysis does not support nanoflare (associated nanojet) claim in this event, because the downflows/jets were detected during the preflare phase, filament slow-rise, and slow reconnection at the null (bidirectional flows/blobs).
- Explosive flare reconnection with bidirectional flows/plasmoids (v=100-285 km/s), P~70-s
- Contraction (V~13 km/s) of the fan loops during the explosive flare reconnection

Table 1. Time history of the event

Time (UT)	Activity	Observations
12:30, 13:15	Pre-eruption jets	AIA and STEREO
14:05, 14:15	Filament F1 slow rise	Observed partially in high-resolution SOT† and IRIS⋆ images, complete eruption covered in AIA and STEREO
14:41-14:53	Blobs during the filament eruption, Preflare phase, loops expansion/disappearance in AIA 171/193 Å, flows near the null in AIA 94 Å, dome/fan contraction.	AIA, IRIS, STEREO
14:55-15:38	Multiple blobs and flows in the flare plasma sheet, filament fast rise, ($P \approx 70$ s) during the filament eruption	AIA, STEREO

† Hinode SOT observation ends at 14:30 UT.

⋆ IRIS Observation ends at 14:53 UT.