Fine-scale Explosive Energy Release at Sites of Magnetic Flux Cancellation in the Core of the Solar Active Region Observed by Hi-C 2.1, IRIS and SDO

Sanjiv K. Tiwari[1,2]

(Navdeep Panesar[1,2], Ron Moore[3,4], Bart De Pontieu[1], Amy Winebarger[3], and the Hi-C 2.1 Science Team)

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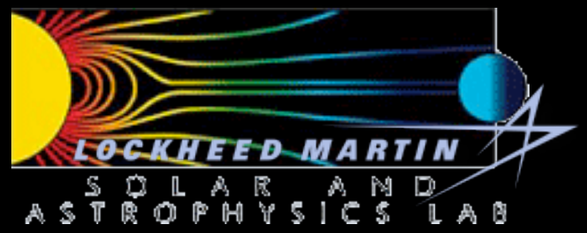
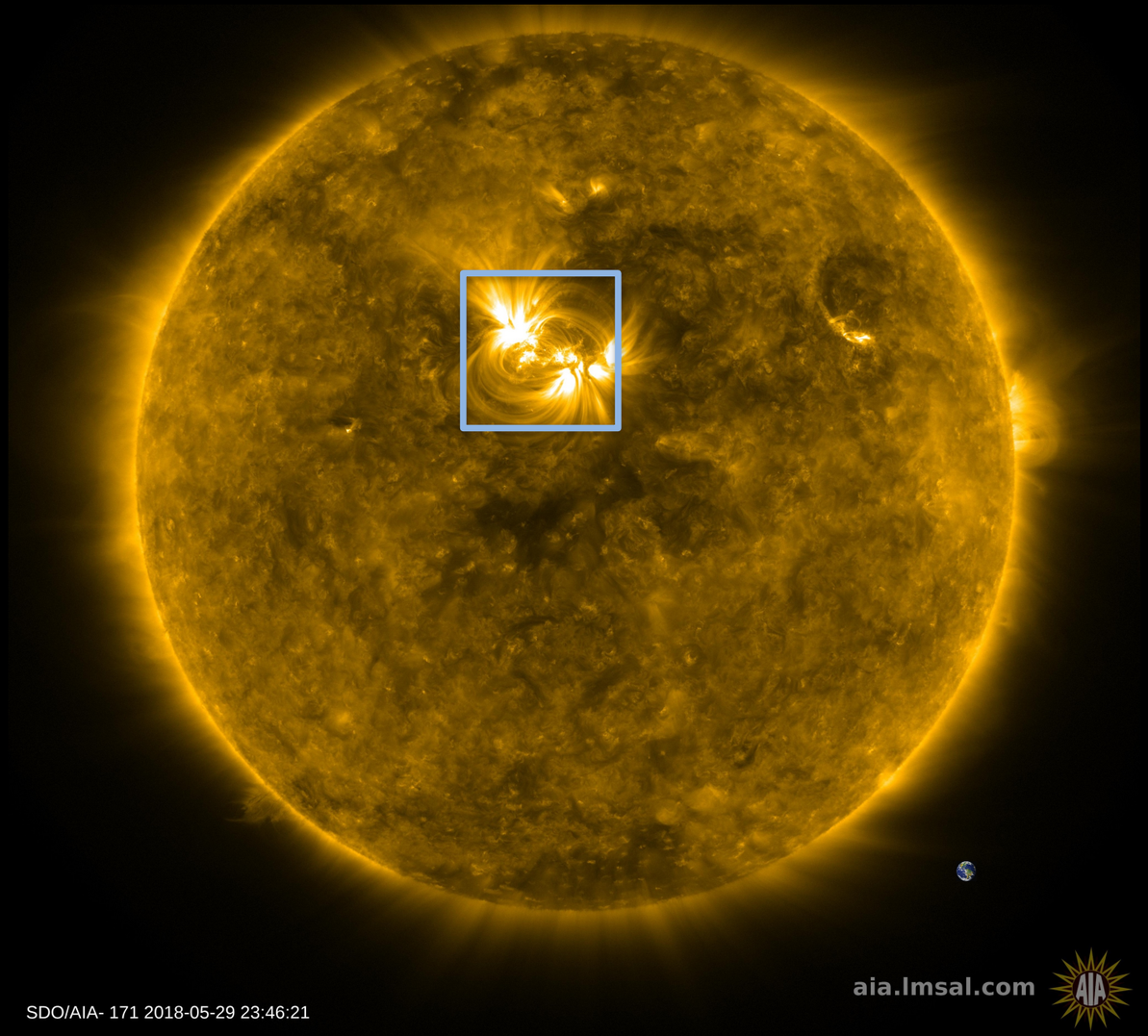
[2]Bay Area Environmental Research Institute, Moffett Field, CA 94035, USA
[3]NASA Marshall Space Flight Center, Huntsville, AL 35805, USA
[4]CSPAR, Univ. of Alabama in Huntsville, AL 35805, USA



November 07, 2019 IRIS-10 Meeting, Bengaluru tiwari@lmsal.com

Introduction

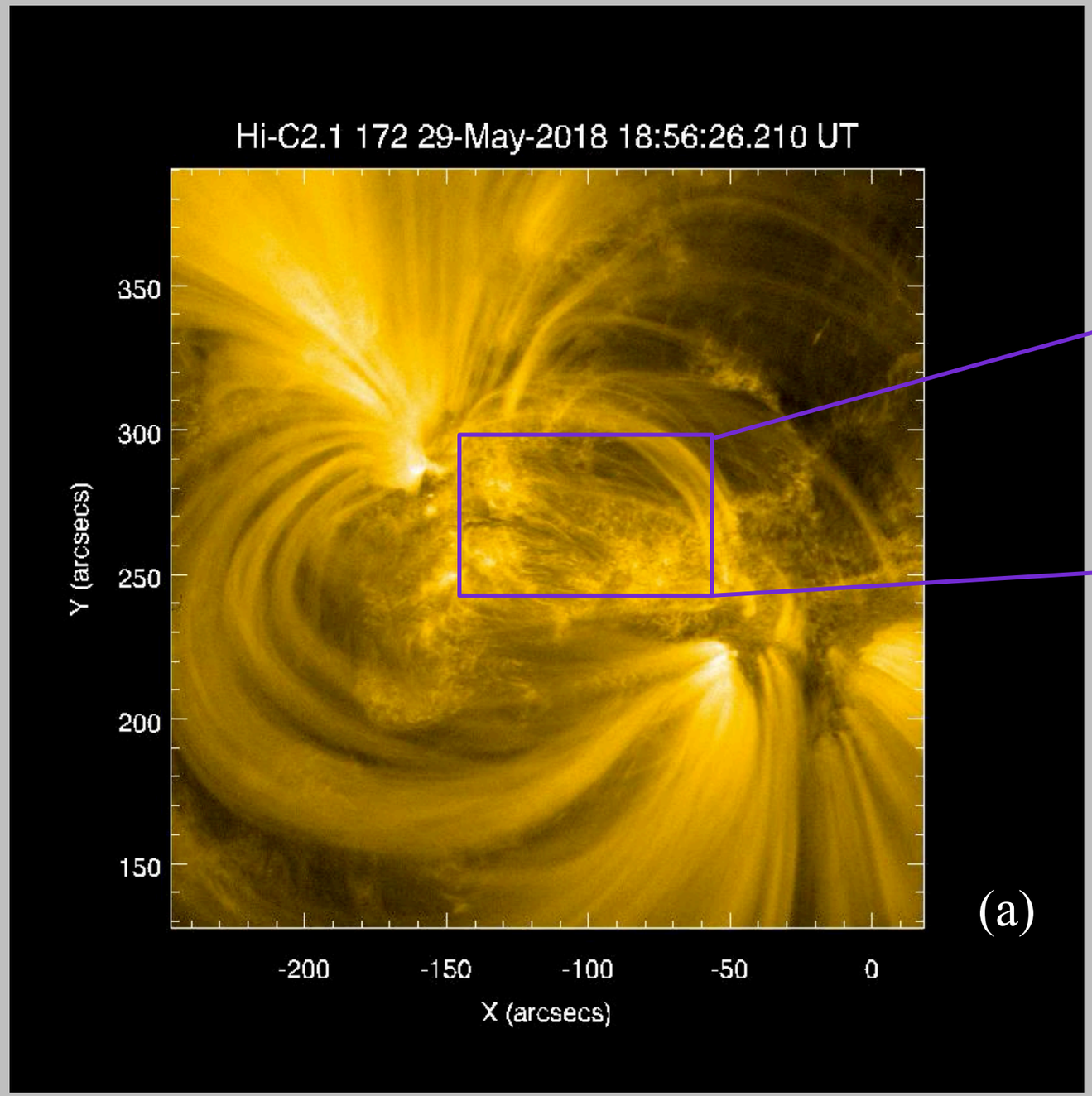
Solar Active Region 12712 on May 29, 2018



AIA 171 Å : 0.7 MK (Fe IX/X)
Hi-C 2.1 172 Å : 0.7 MK (Fe IX/X)
(similar as AIA 171)

- ARs can have magnetic field ≥ 4000 G in sunspots (van Noort et al. 2013; Tiwari et al, 2015, Okamoto & Sakurai, 2018).
- The AR cores are the hottest structures in EUV/X-ray corona (Warren et al. 2012), and have cool arch filament system in the chromosphere (Bruzek, 1967; Frazier 1972; Georgakilas et al. 1990; Tsiropula et al. 1992; Gonzalez Manrique et al. 2018).

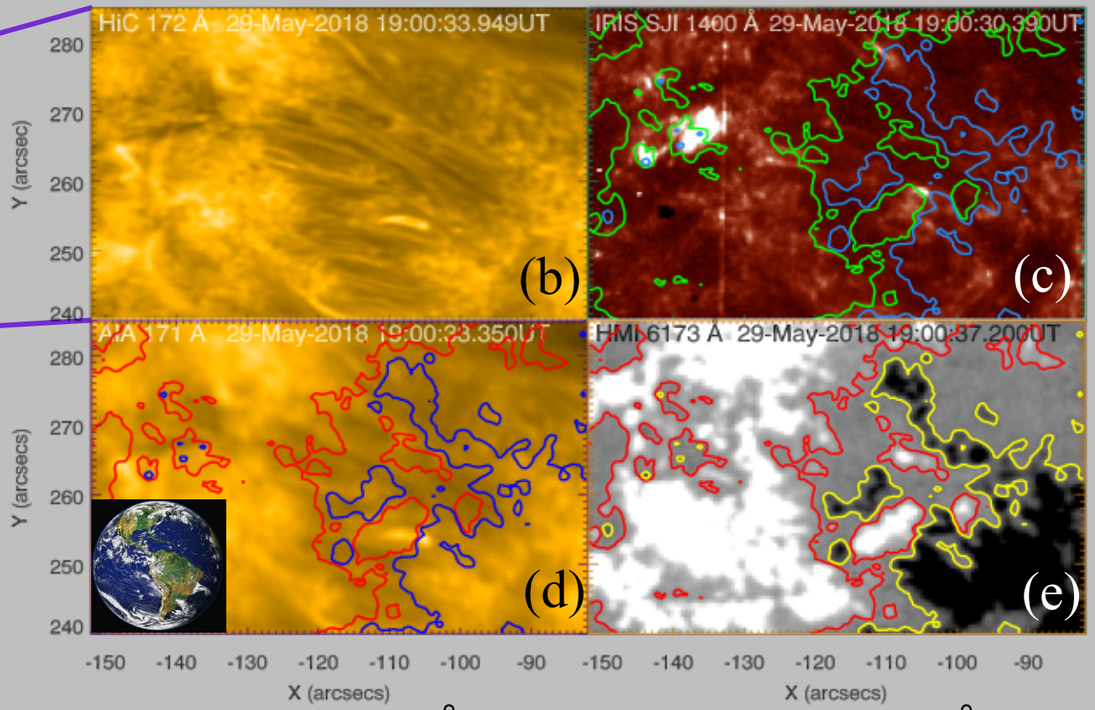
Hi-C 2.1 Observations



Duration: ~ 5 minutes of data
Cadence: 4.4 seconds
Spatial resolution: ~250 km
Hi-C FOV: 300×300 arcsec^2

Hi-C 172 Å

IRIS SJI 1400 Å

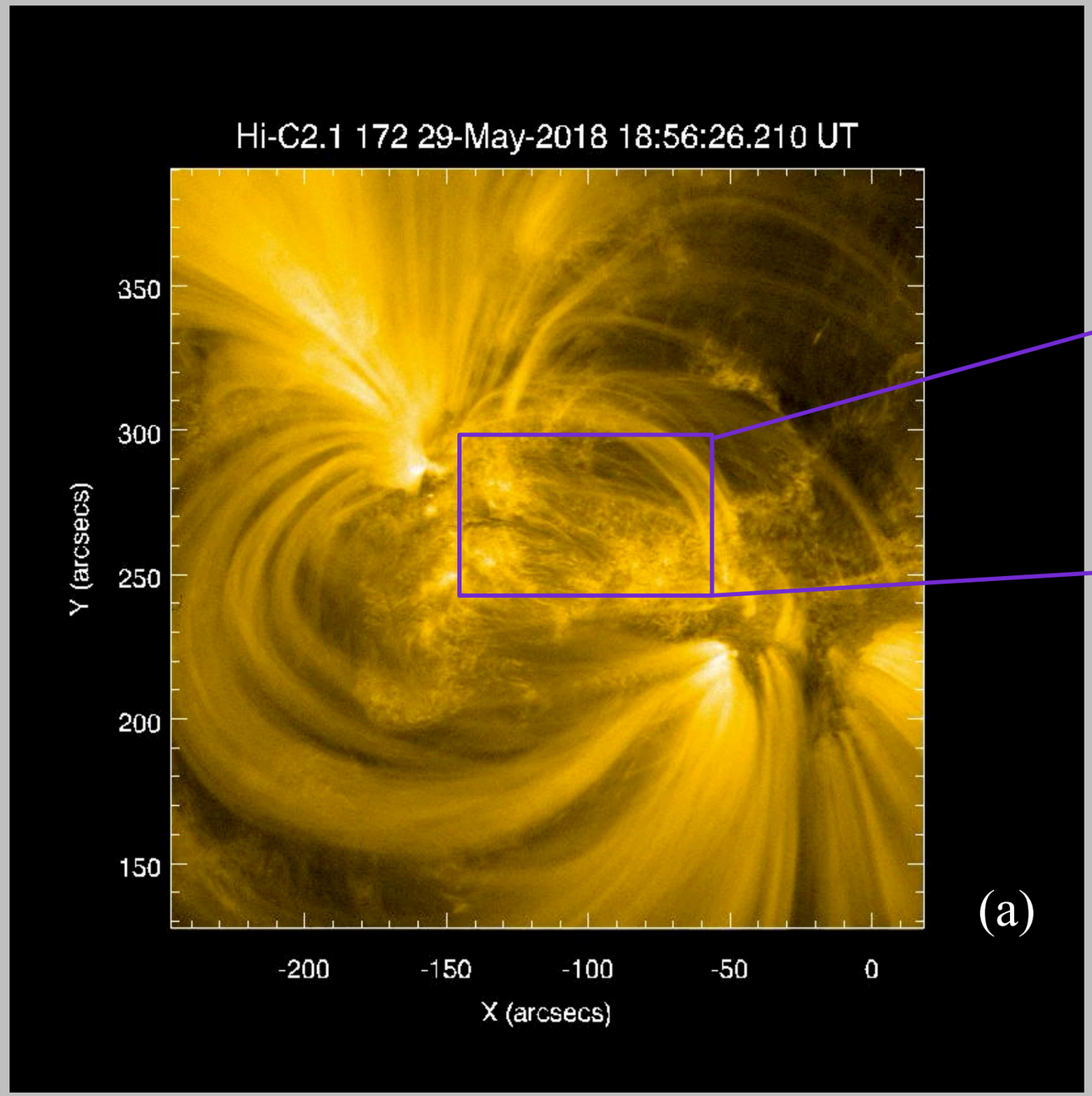


AIA 171 Å

HMI 6173 Å

AIA 171/Hi-C 172: 0.7 MK (Fe IX/X)
IRIS SJI 1400: 80,000 K (Si IV)

Hi-C 2.1 Observations



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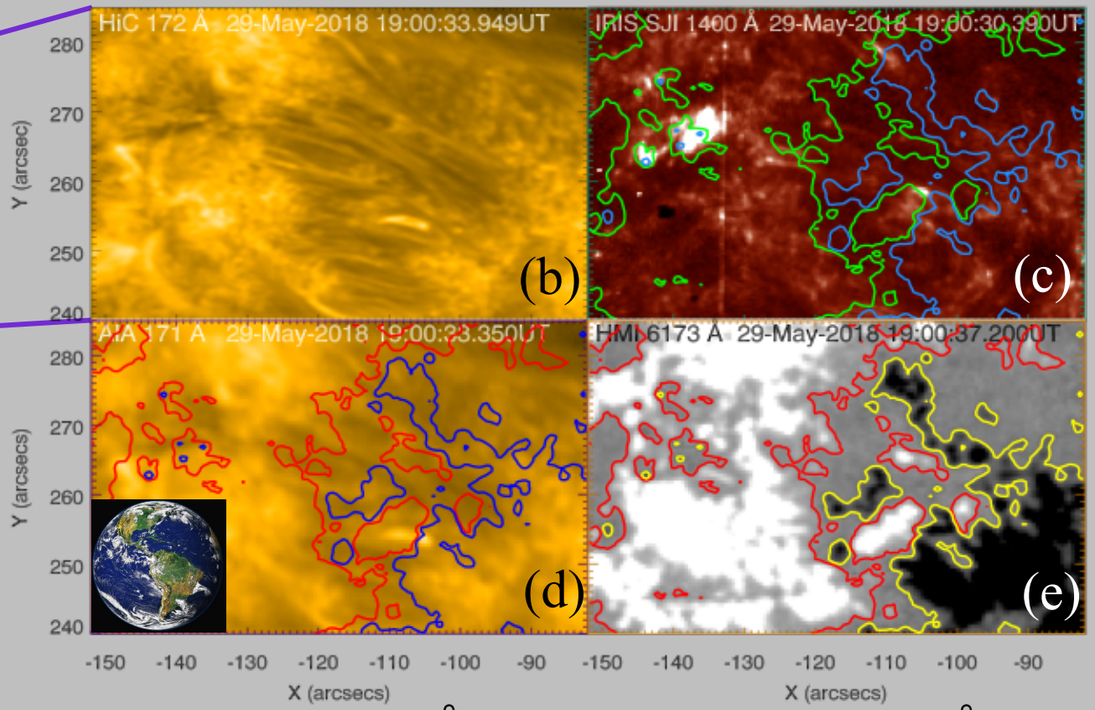
IRIS SJI 1400 Å



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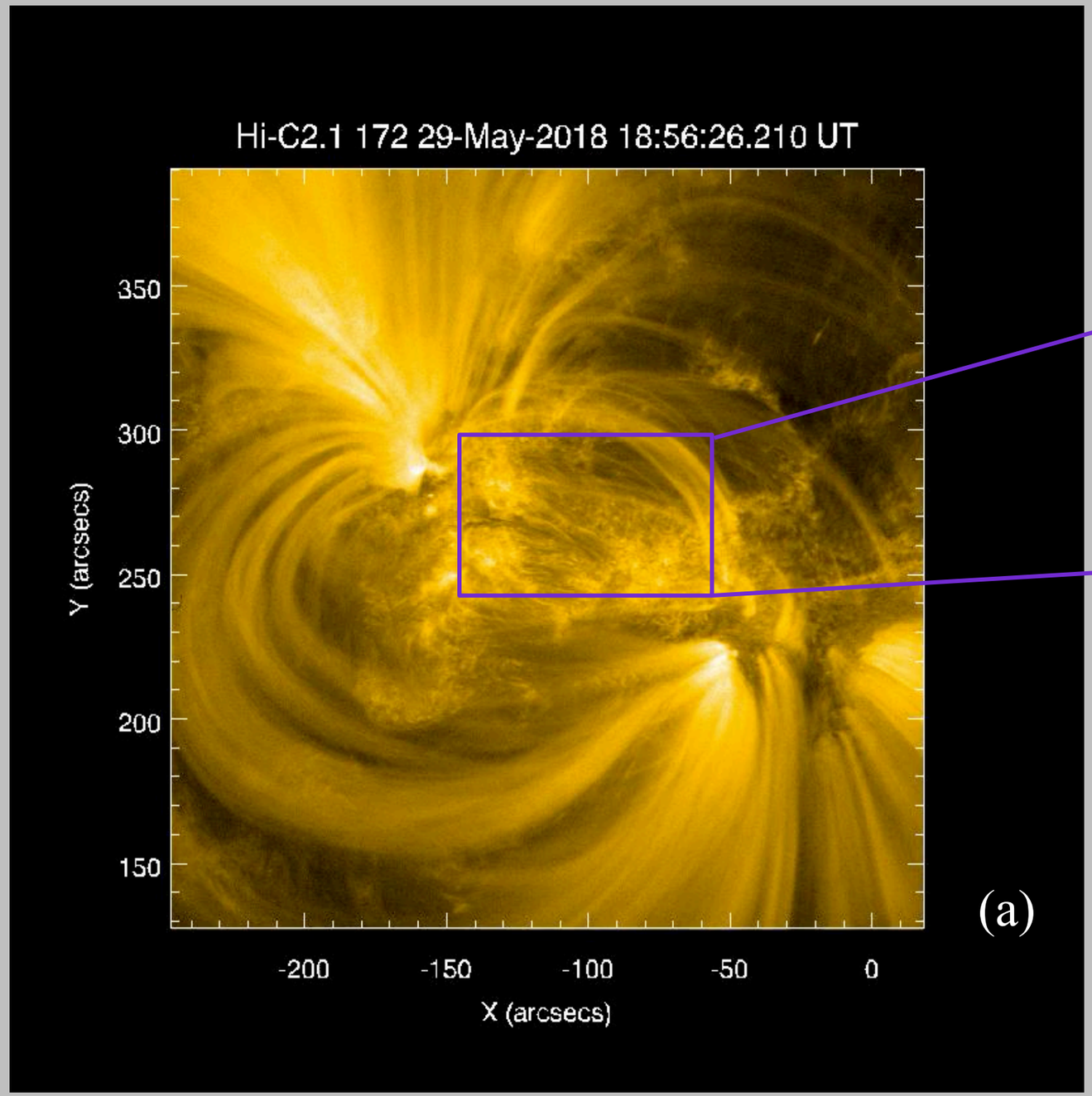
Hi-C 2.1 Observations



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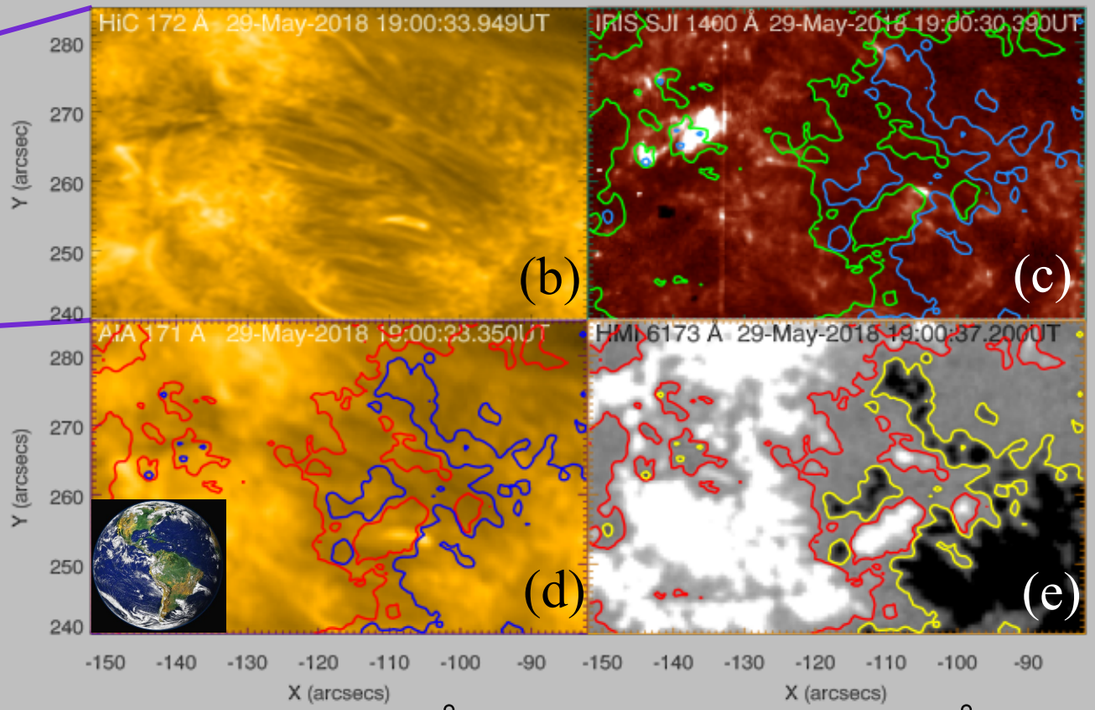
Hi-C 172 Å

IRIS SJI 1400 Å



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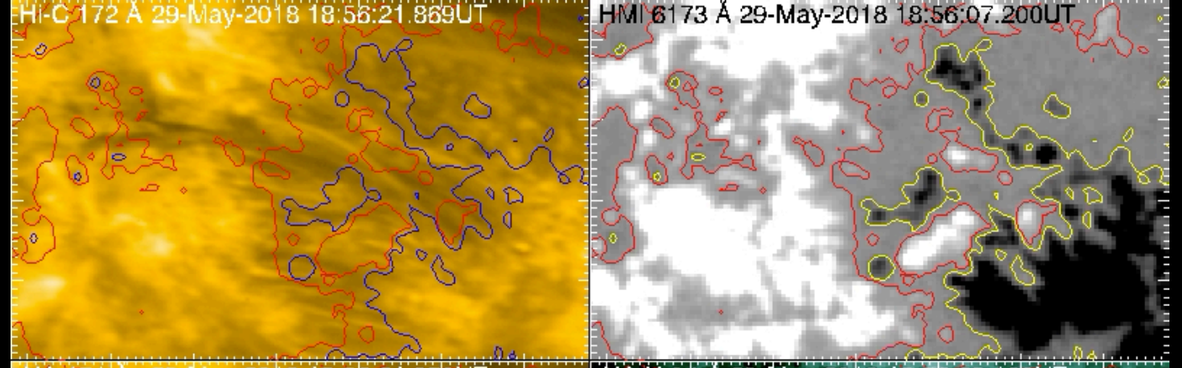
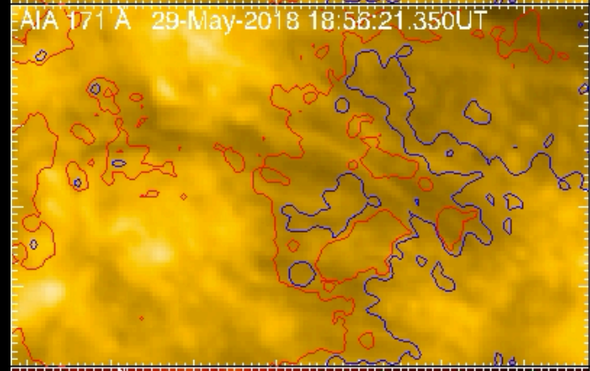
Hi-C 172

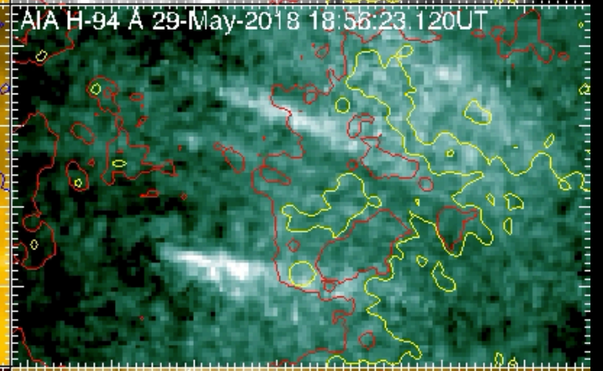
HMI LOS magnetogram



AIA 171

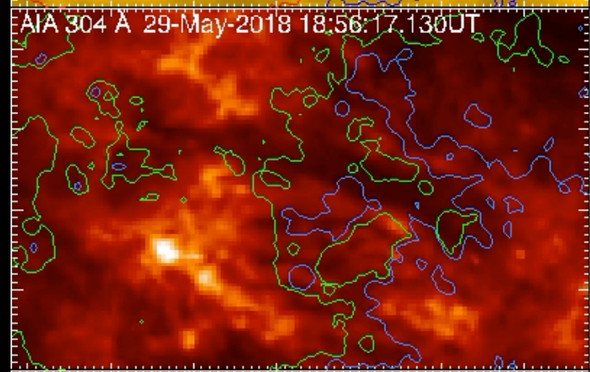
Hot 94

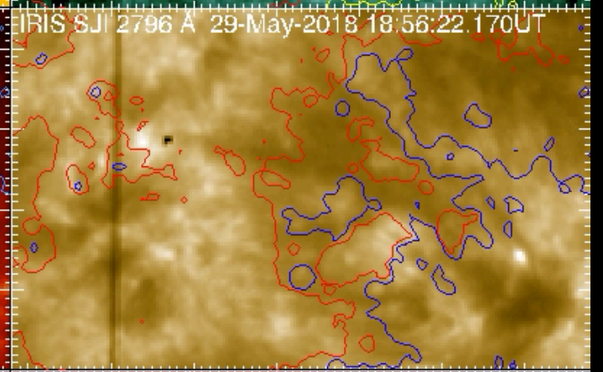




AIA 304

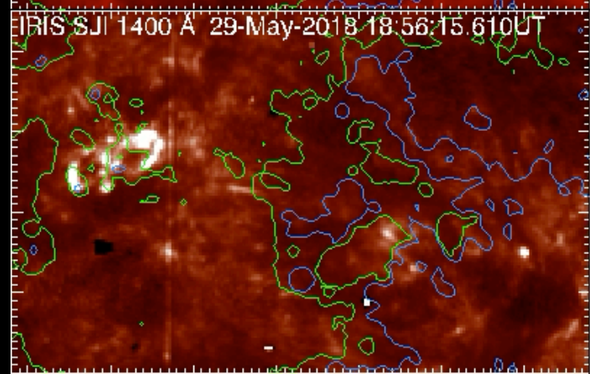
IRIS SJI 2796

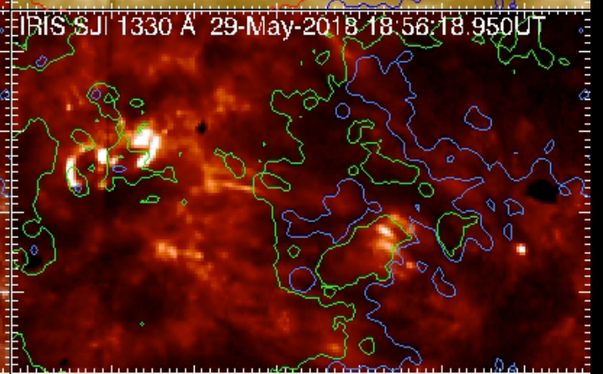




IRIS SJI 1400

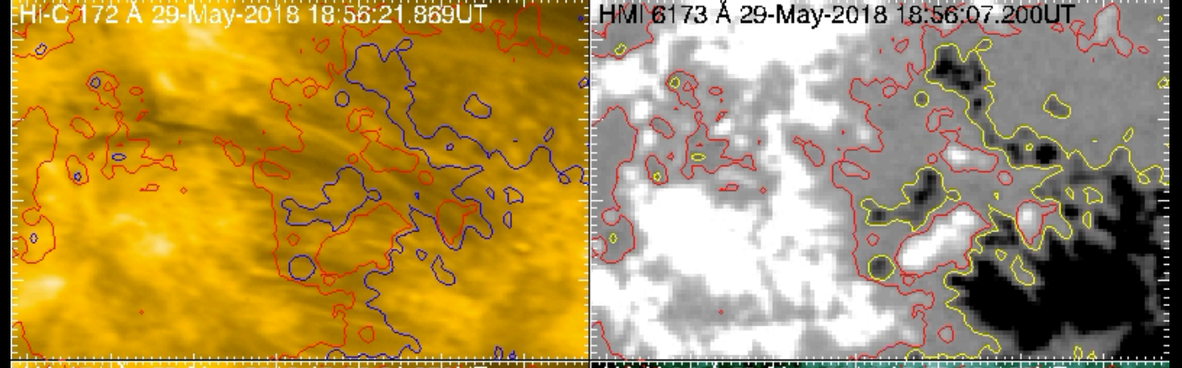
IRIS SJI 1330





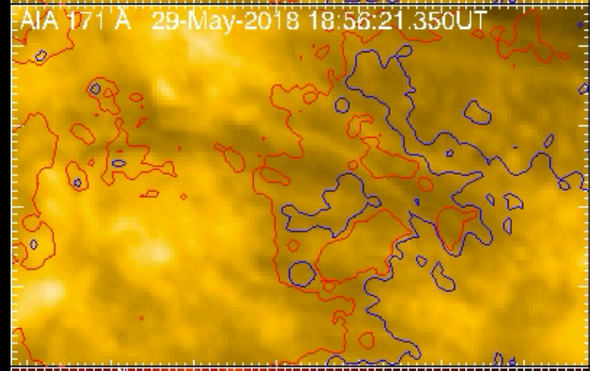
Hi-C 172

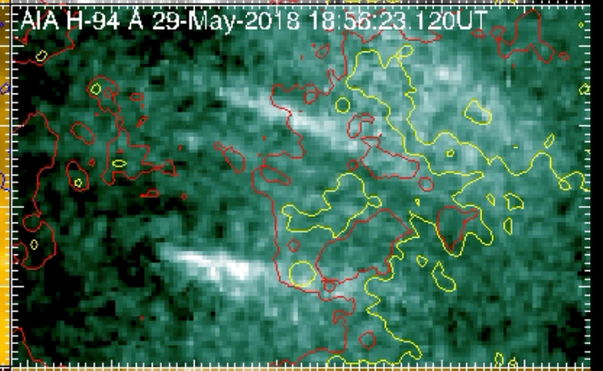
HMI LOS magnetogram



AIA 171

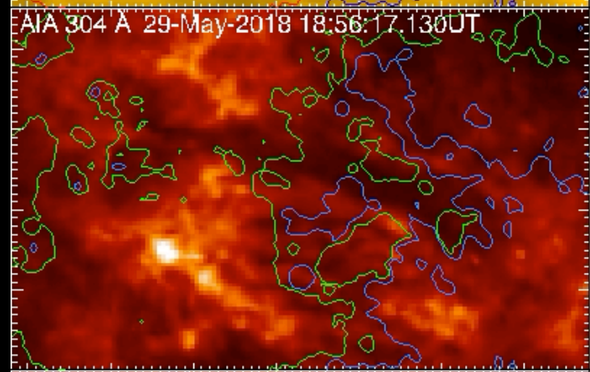
Hot 94

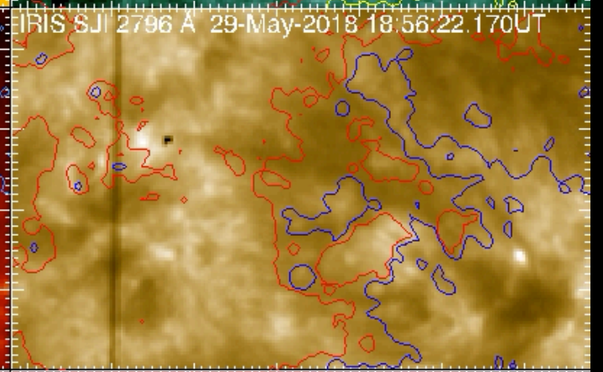




AIA 304

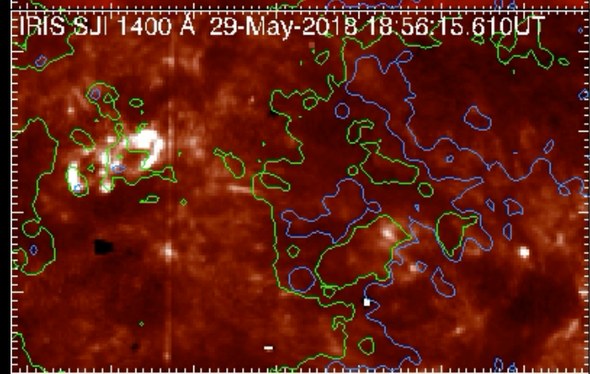
IRIS SJI 2796

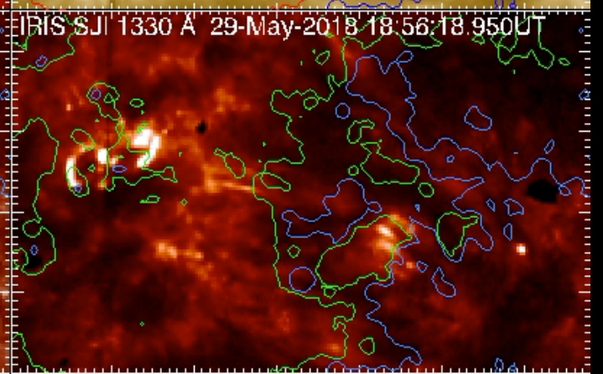




IRIS SJI 1400

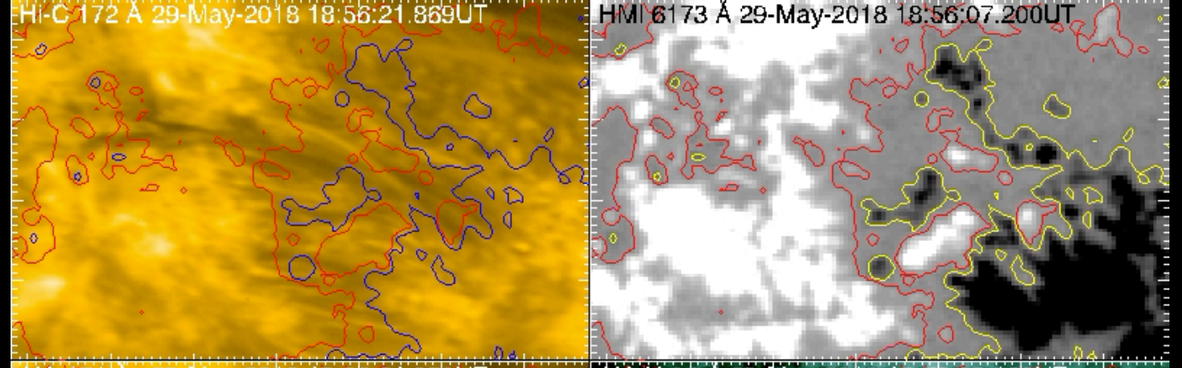
IRIS SJI 1330





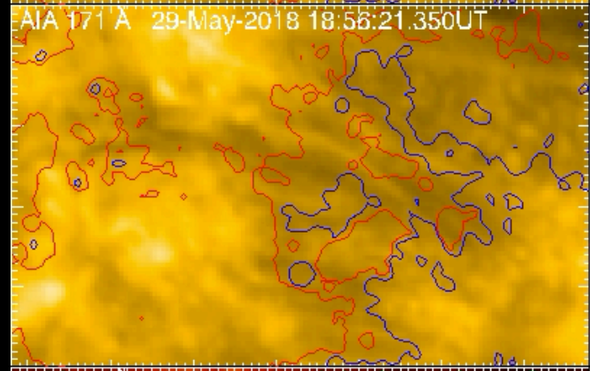
Hi-C 172

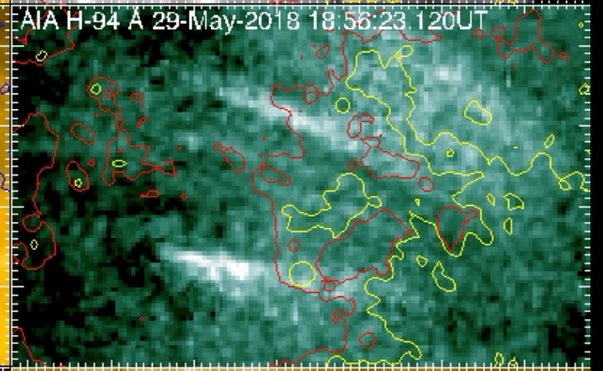
HMI LOS magnetogram



AIA 171

Hot 94





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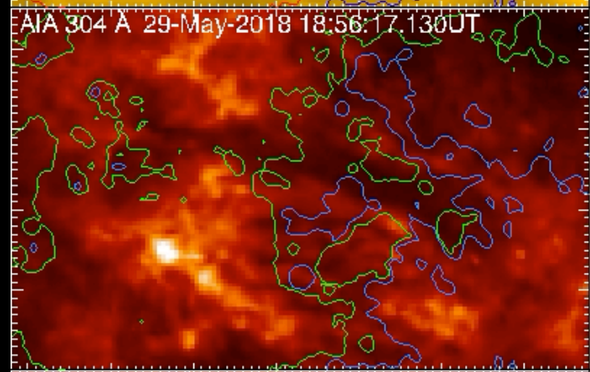
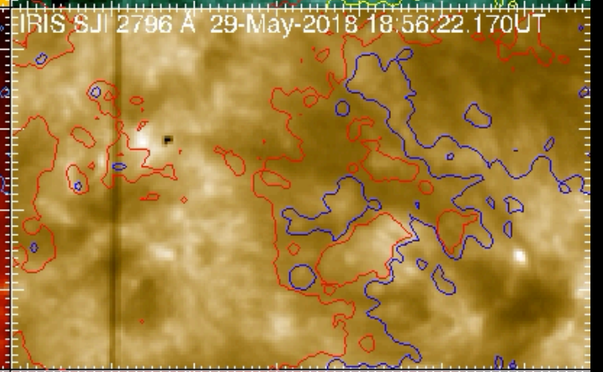
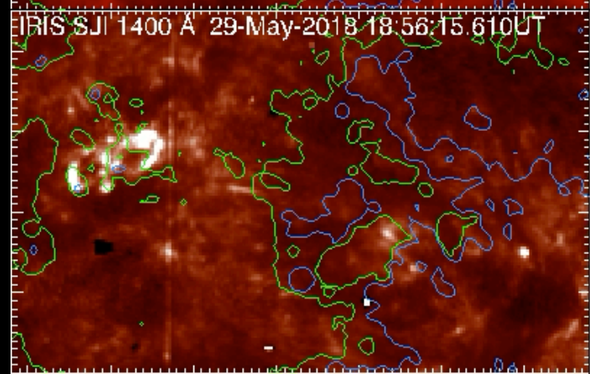
IRIS SJI 2796

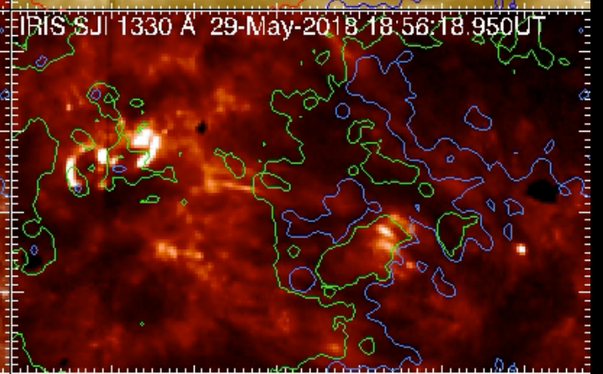




IRIS SJI 1400

IRIS SJI 1330

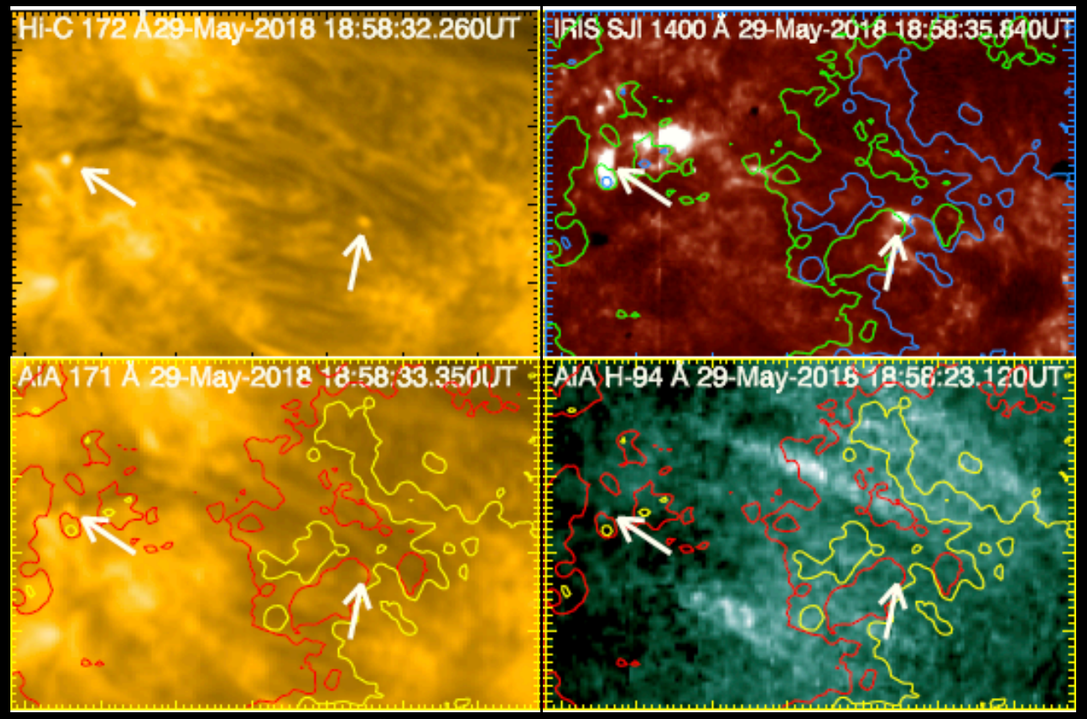




Small-scale Energy-release Event Type I – Dot-like Brightening

Hi-C 172 Å

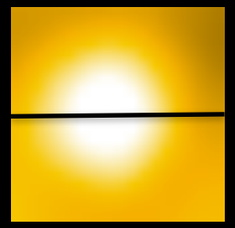
IRIS SJI 1400 Å

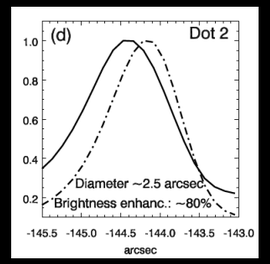


AIA 171 Å

AIA 094 Å

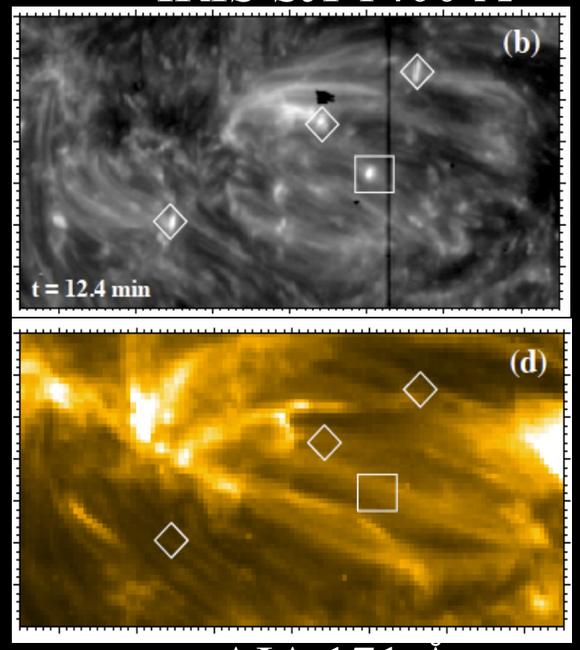
Hot 94 is calculated using the method of Warren et al. (2012)





Diameter: ~1500 km
Lifetime: 70 seconds
Brightness enhancement wrt background: ~80%

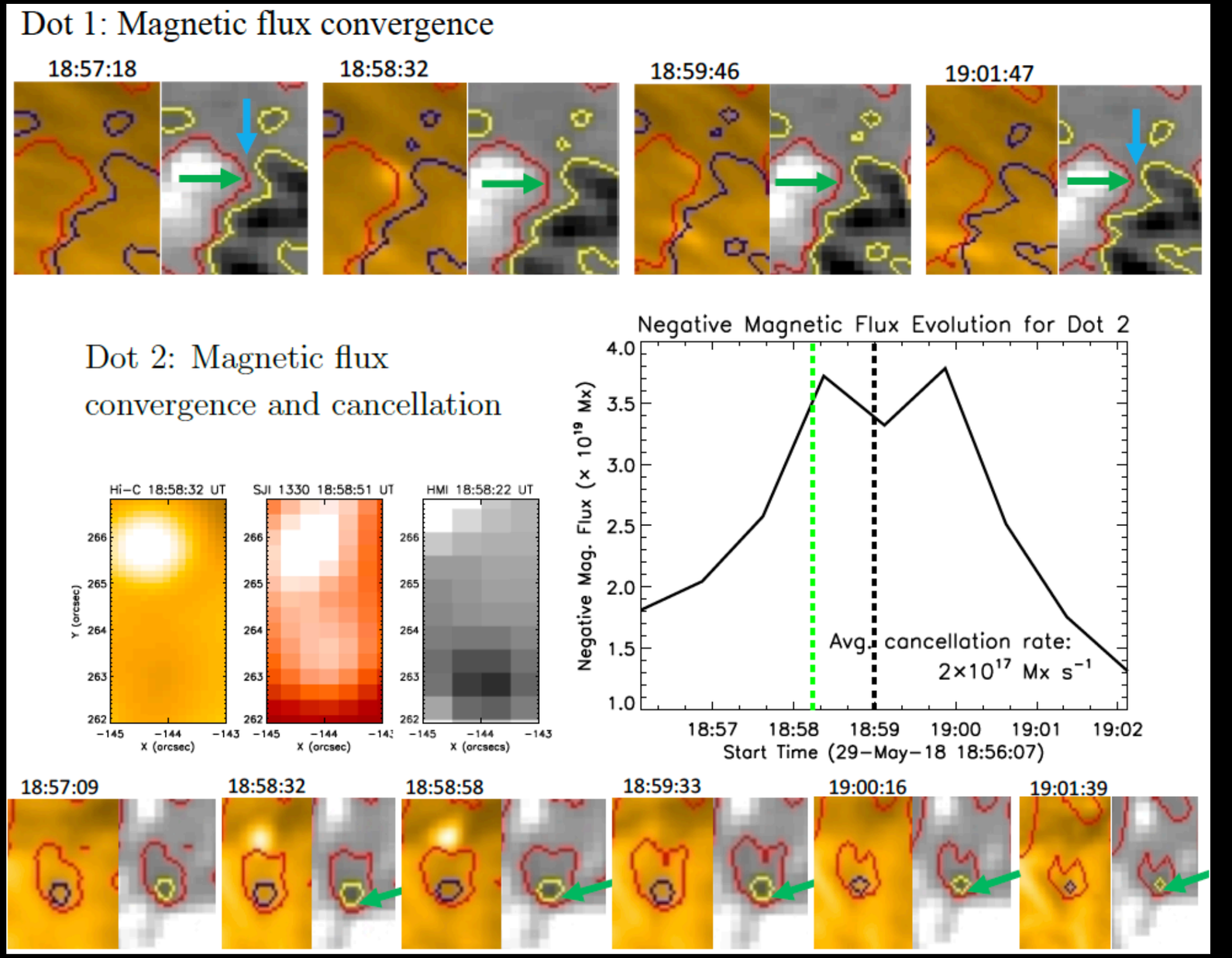
IRIS SJI 1400 Å



AIA 171 Å

Peter et al. 2014; IRIS bombs (IBs/UV Bursts) are not visible in AIA 171 Å! Our dots have a lifetime of 70 seconds; IBs have a lifetime of 8 minutes.

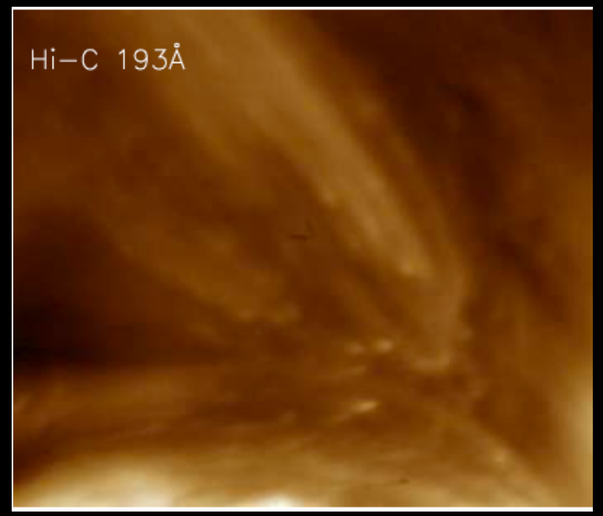
Magnetic flux evolution on the Dot base



Small-scale Energy-release Event Type I – Dot-like Brightening

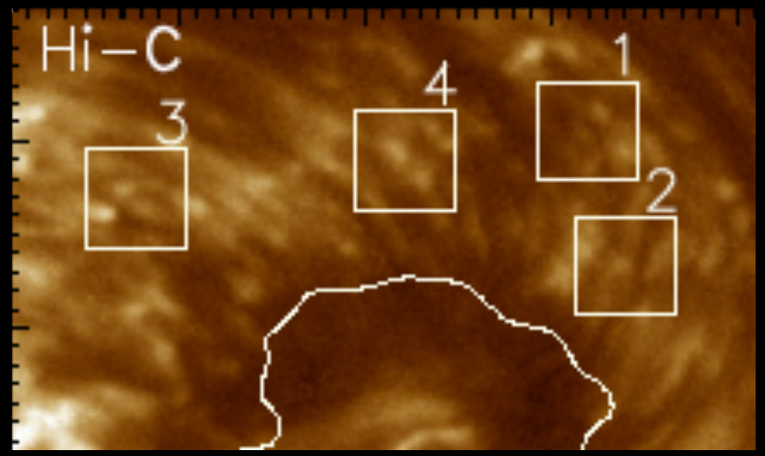
Other known bright dots

Hi-C EUV Bright Dots: EBDs



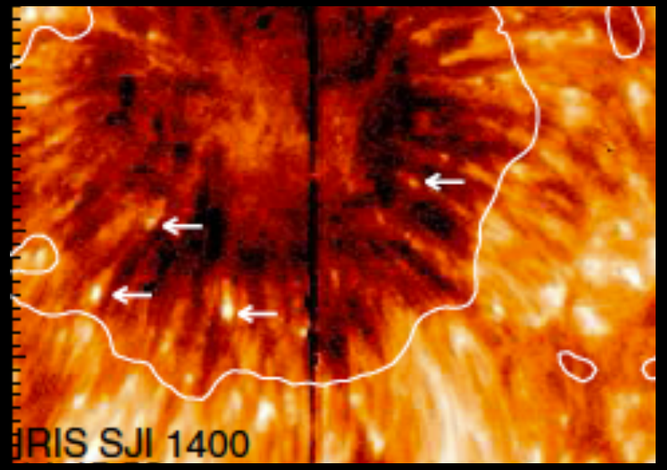
Regnier et al. 2014

Hi-C Penumbral Bright Dots: PBDs



Alpert et al. 2016

IRIS PBDs



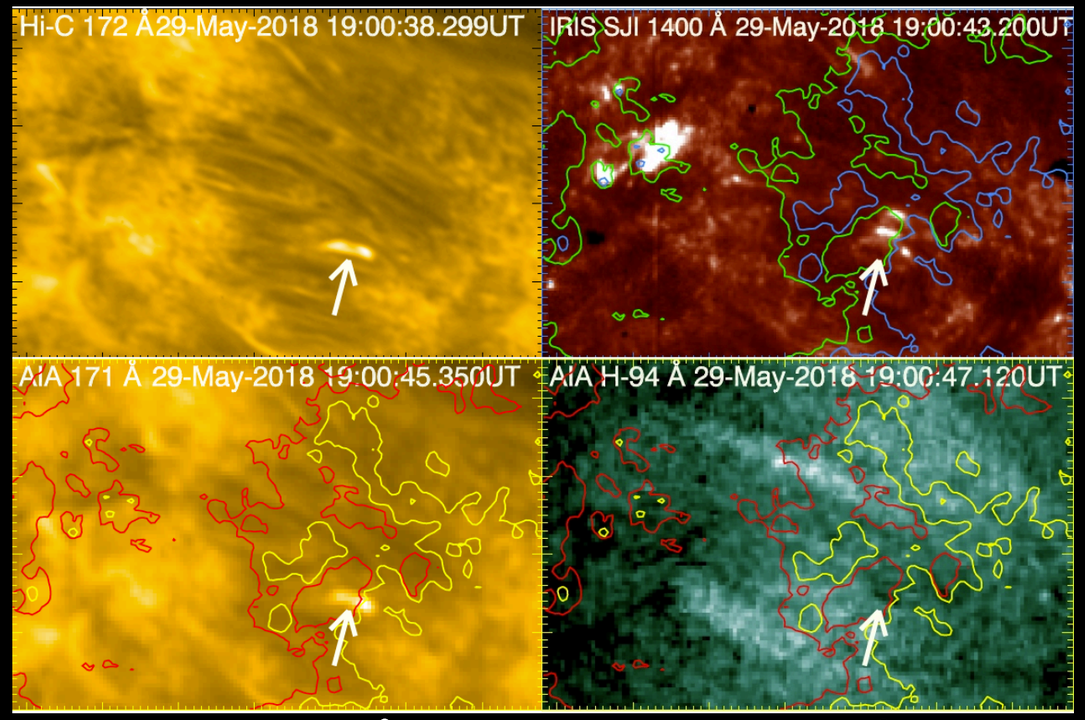
Tian et al. 2014
Samanta et al. 2017

EBDs (as compared to our Dots):
- Similar or smaller in size (~700 km)
- Have shorter lifetimes of ~25 s
- Footpoints of loops (our dots are tiny loops)
- Both are impulsive energy-release events

PBDs (as compared to our dots):
- Hi-C PBDs have longer (~250 s) but IRIS PBDs have shorter (~40 s) lifetimes
- Smaller in size Hi-C/IRIS: ~600/500 km
- Formation: impact of strong downflows? Reconnection? Mixed-polarity field?)

Small-scale Energy-release Event
Type II – Loop-like Brightening

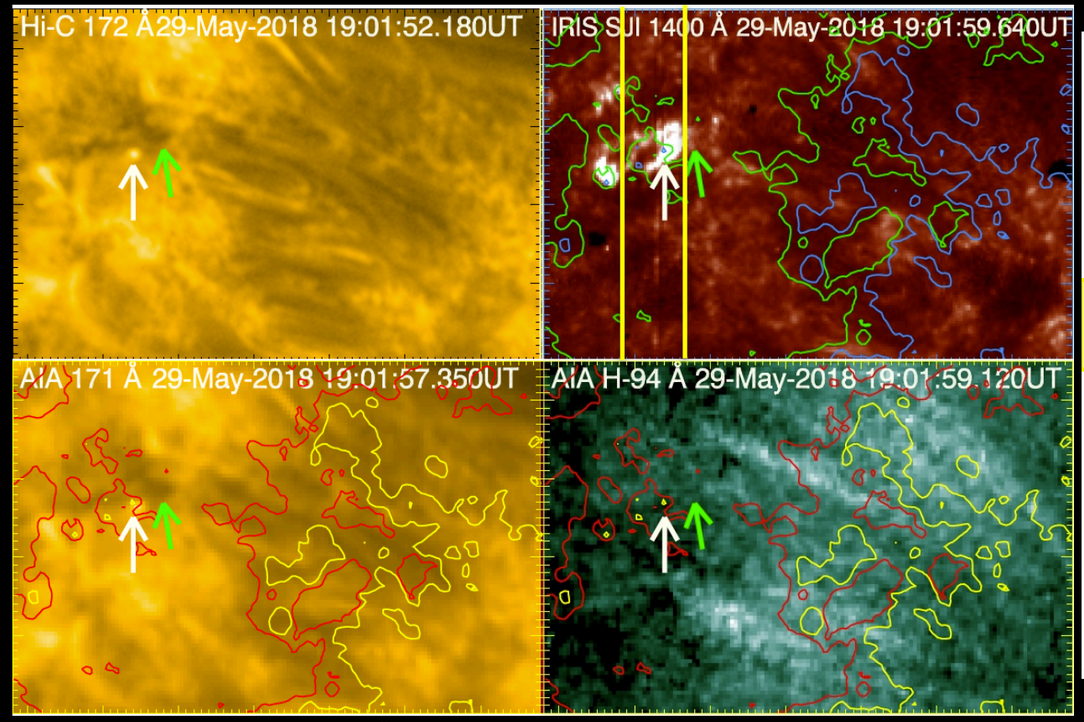
Hi-C 172 Å | IRIS SJI 1400 Å



AIA 171 Å | AIA 094 Å

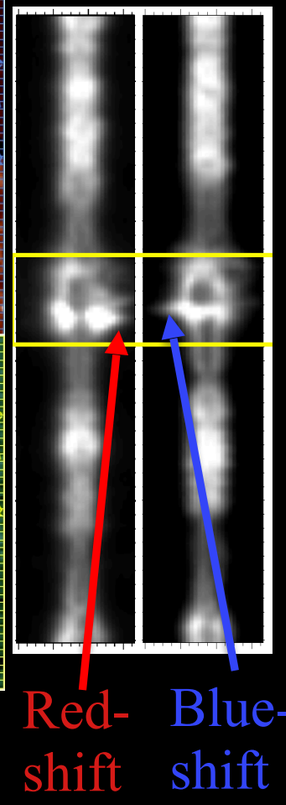
Small-scale Energy-release Event
Type III – Surge/Jet-like Brightening

Hi-C 172 Å | IRIS SJI 1400 Å



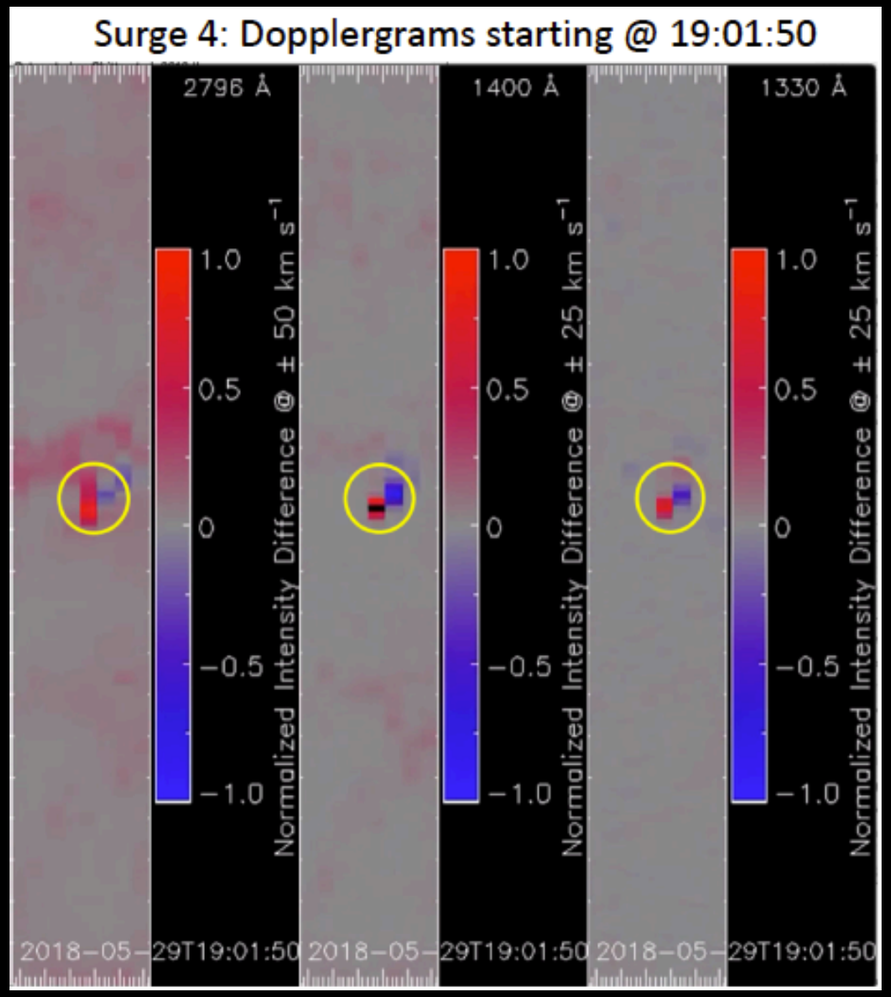
AIA 171 Å | AIA 094 Å

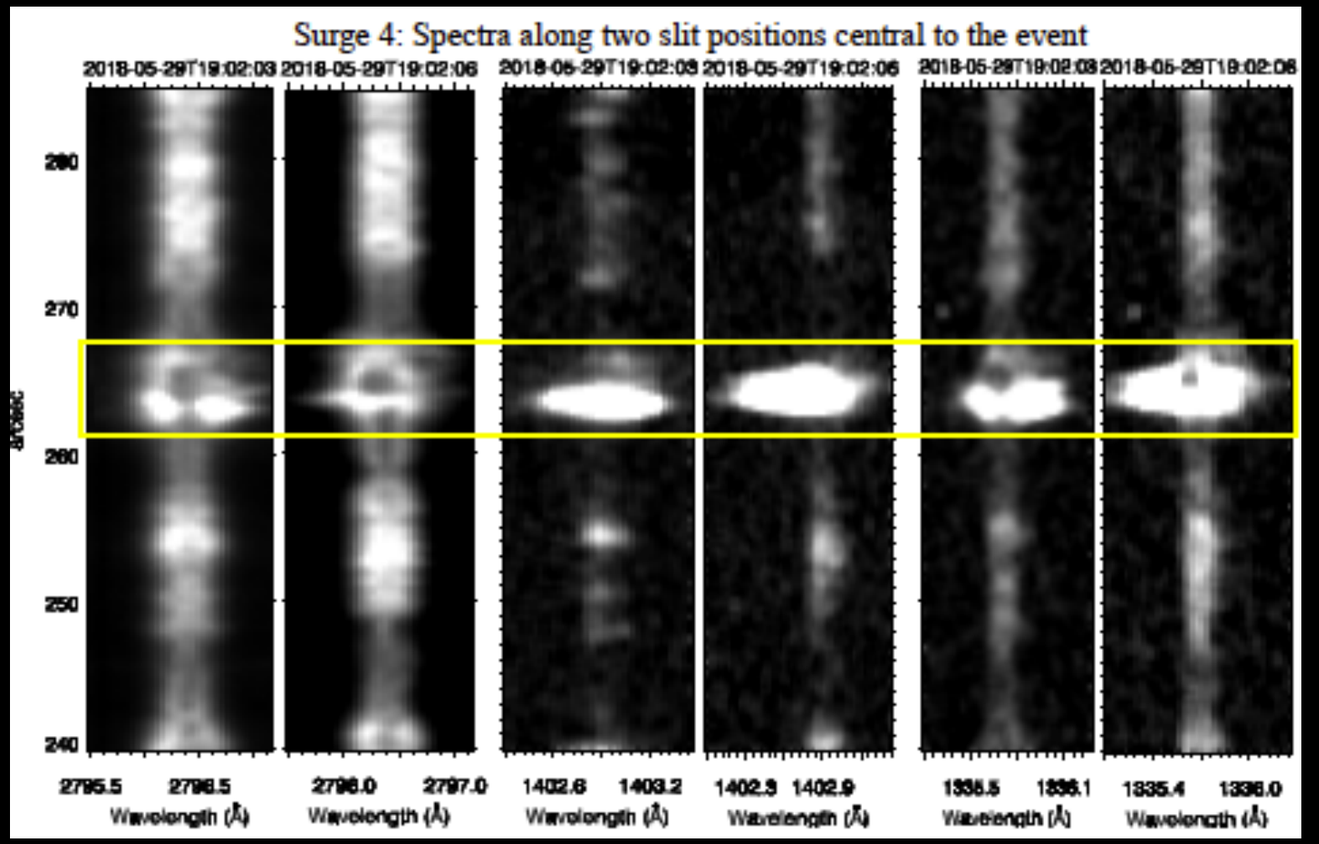
IRIS 2796 Spectra



Plasma outflows, seen in surges, are not seen in Dot-like Type I brightening events!

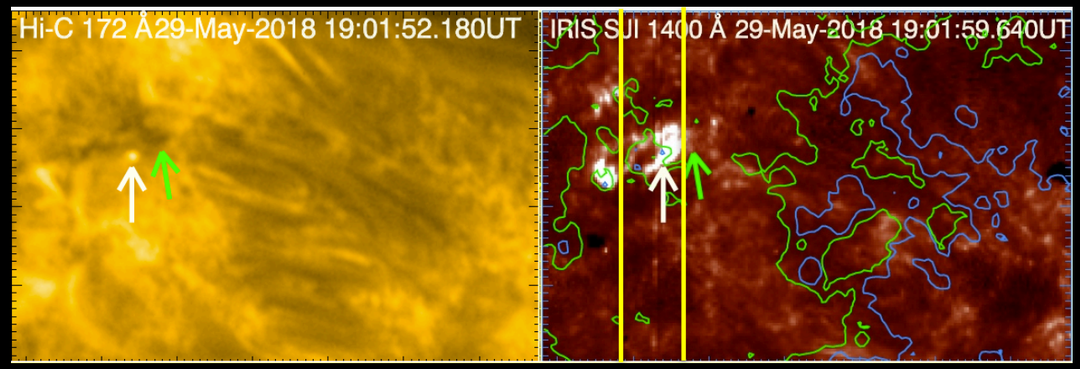
Doppler Flows in Surges:
Dopplergrams from IRIS spectra





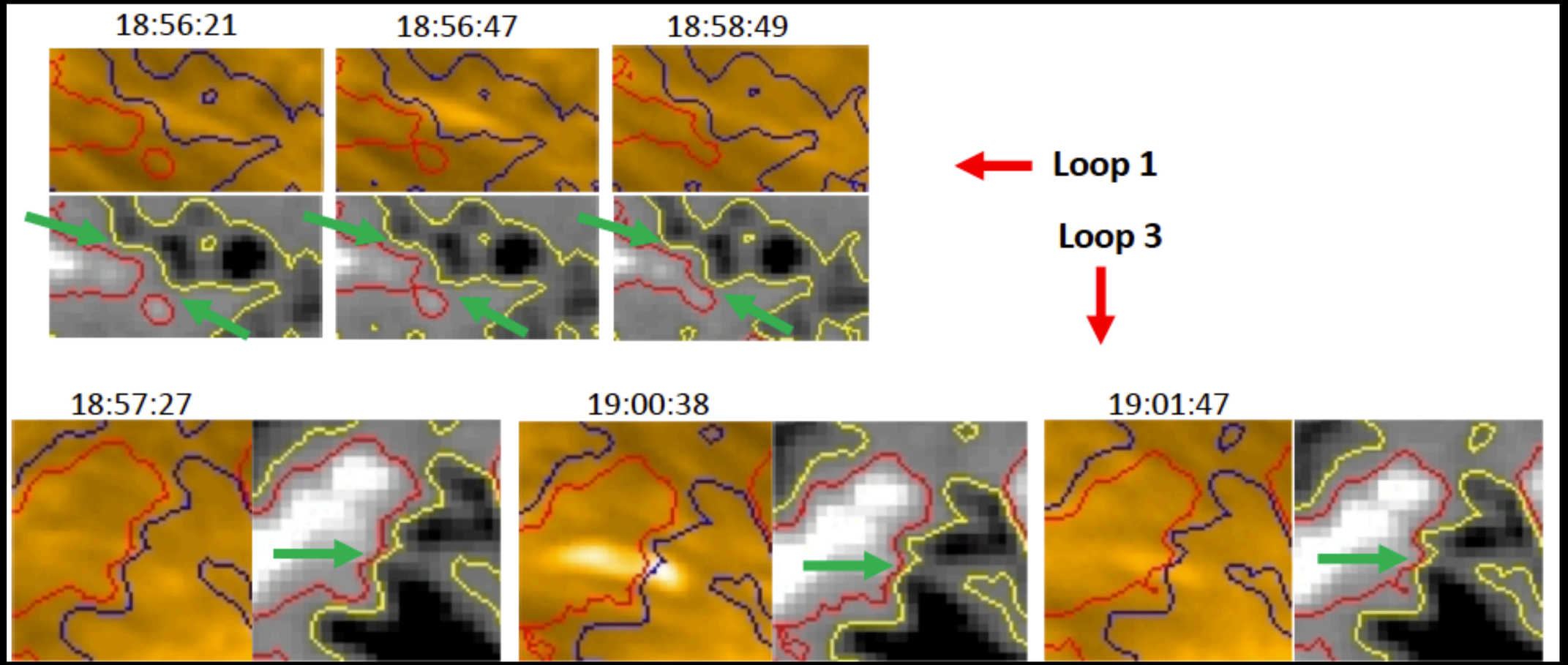
Hi-C 172 Å

IRIS SJI 1400 Å



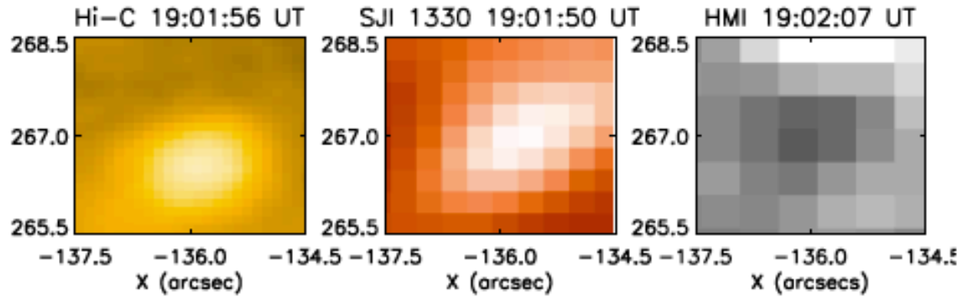
Consistent with outflows in Canfield et al. 1996

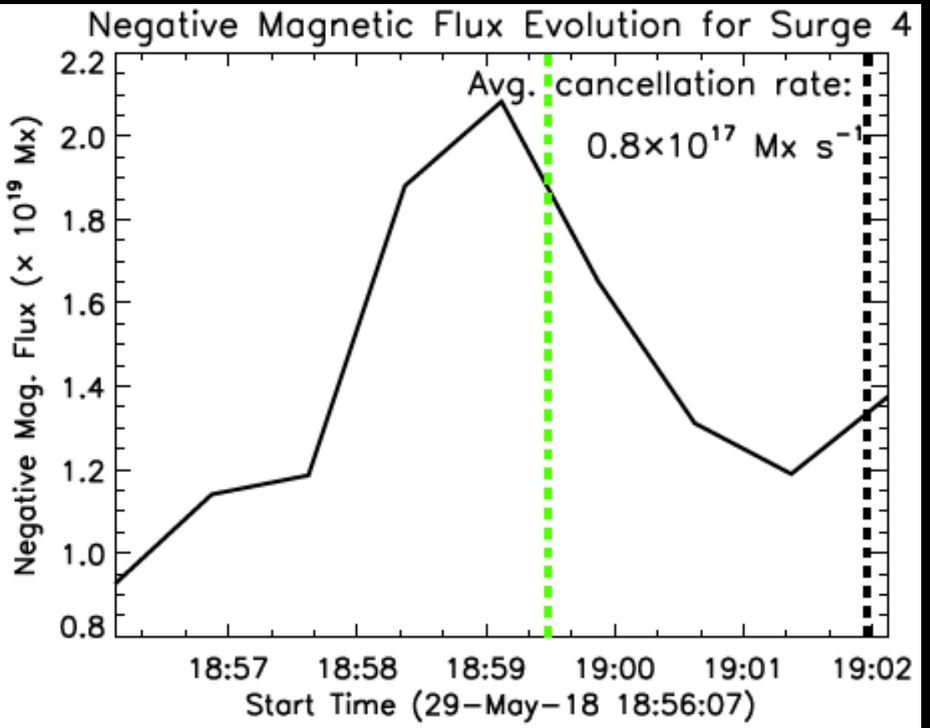
Magnetic flux evolution on the Loop base

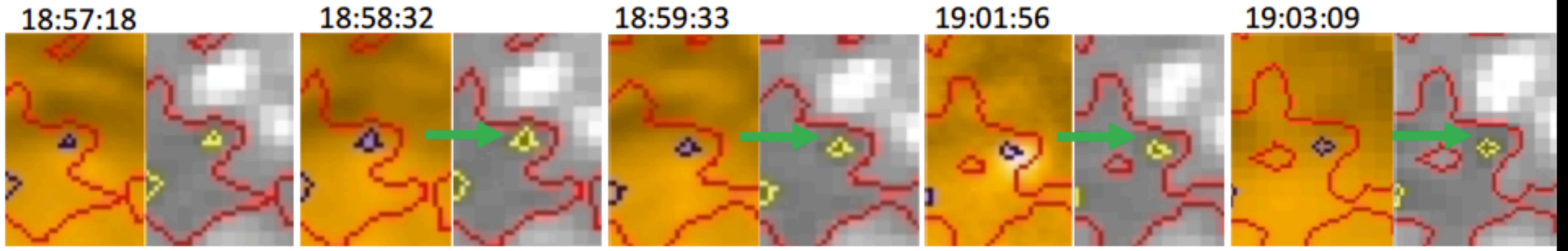


Magnetic flux evolution on the Surge base

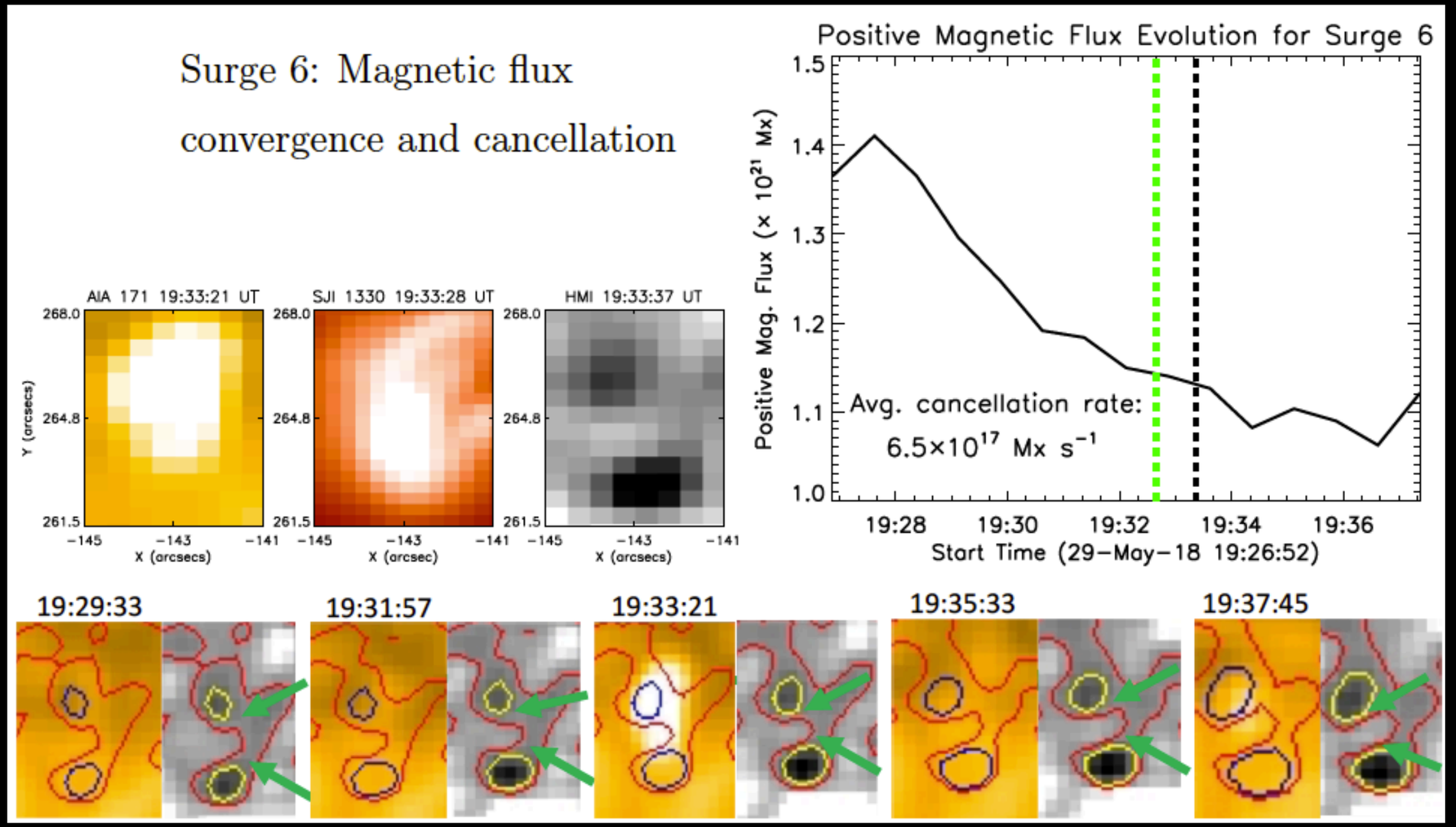
Surge 4: Magnetic flux convergence and cancellation







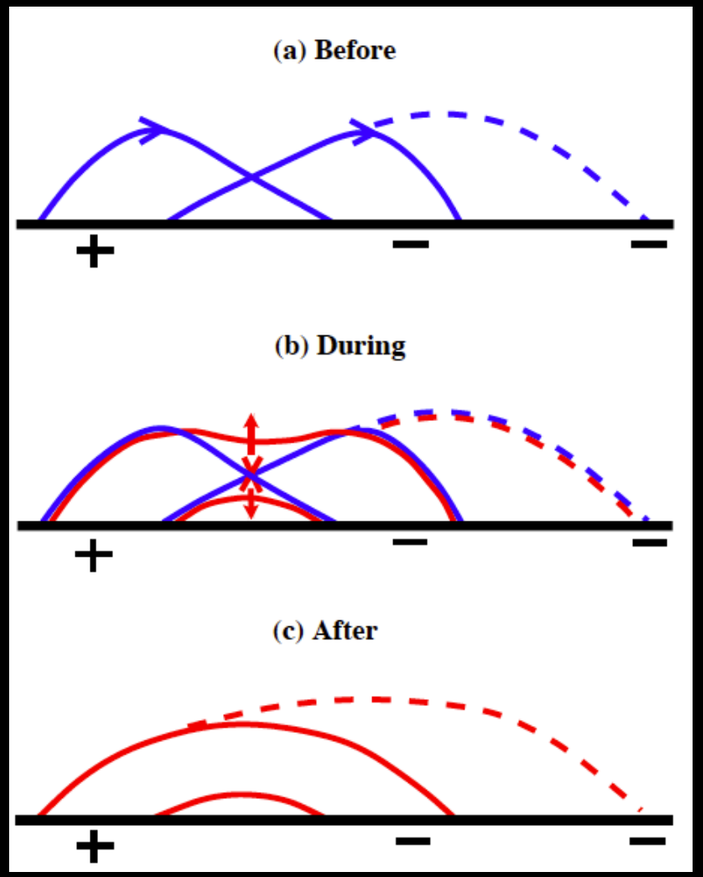
Magnetic flux evolution on the Surge base



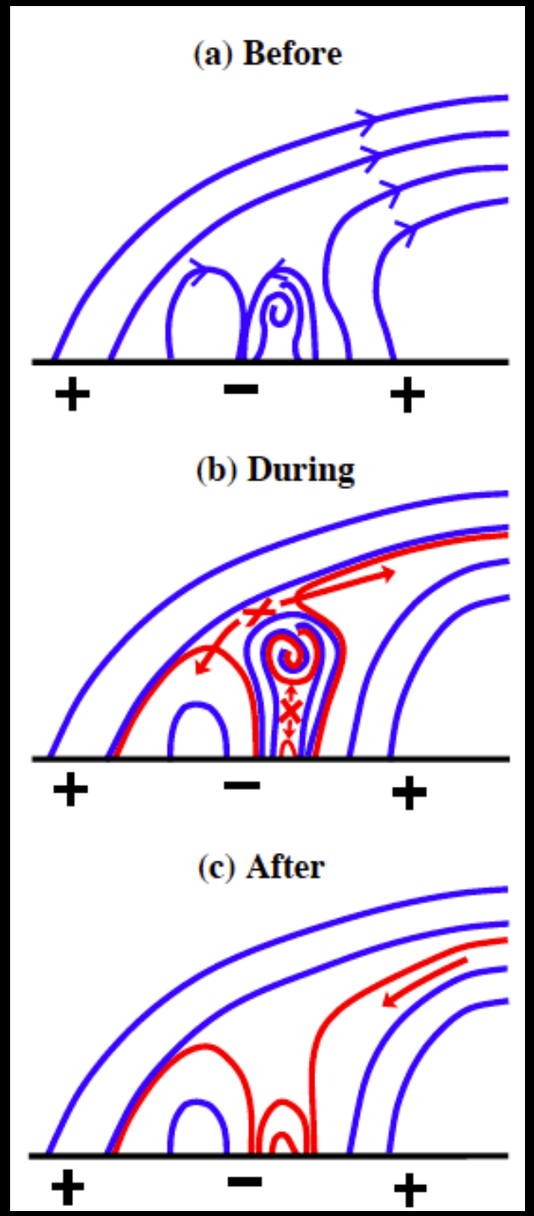
- All events are seated at sharp converging neutral lines!
- Convergence-driven cancellation most plausibly prepares and triggers the magnetic field to explode.

Proposed Configuration and Reconnection of the Magnetic Field in Each Evet Type

(based on van Ballegooijen & Martens 1989; Moore & Roumeliotis 1992)



Schematic depiction of the proposed configuration and reconnection of the sheared and twisted bipolar magnetic field in fine-scale explosive energy release events of Type I (dot-like) in solid lines and Type II (loop-like) in dashed lines.

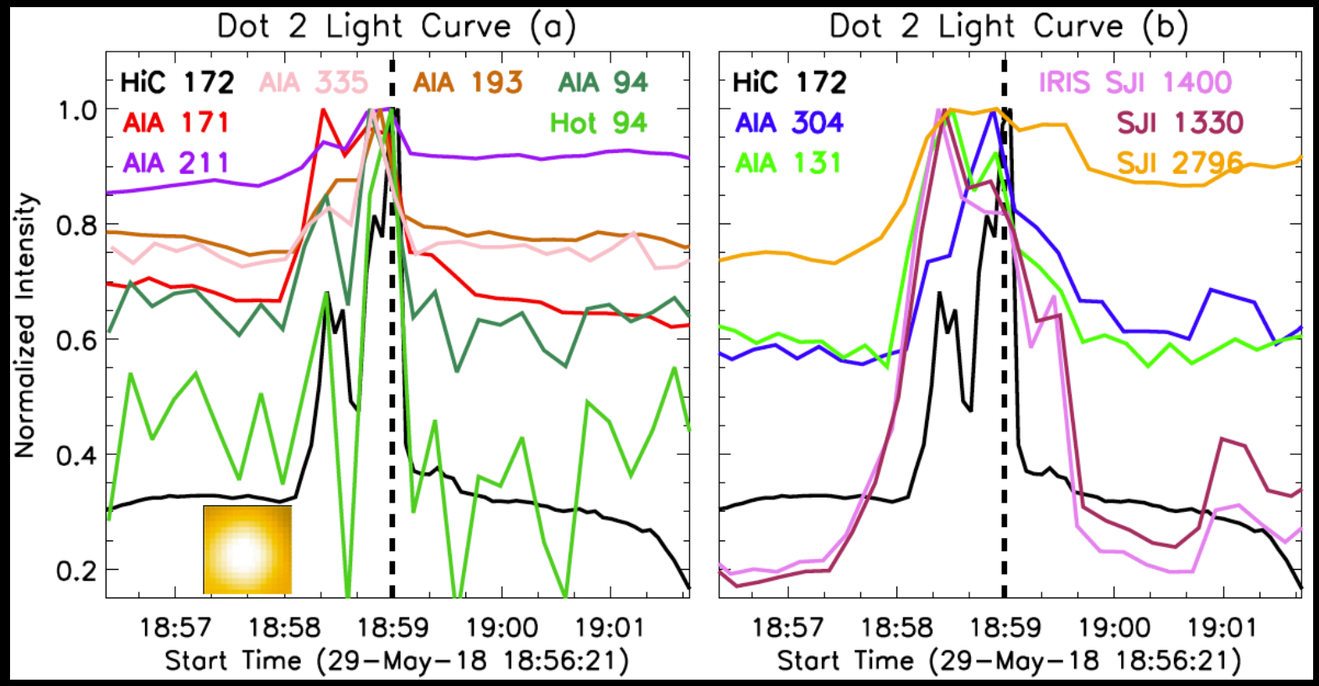


Schematic depiction of explosive energy release events of Type III, each of which is a surge/jet-like eruption from a fine-scale island of minority-polarity (negative) flux that is undergoing cancellation with the majority-polarity (positive) flux in the east end of the arch filament system. (a) Sheared tiny flux rope at sharp neutral line built by convergence and cancellation (b) further cancellation triggers internal reconnection that triggers external reconnection and plasma outflow is seen on the right, and inflow is seen on the left, consistent with our Doppler flows. (c) Some plasma drains back in some cases.

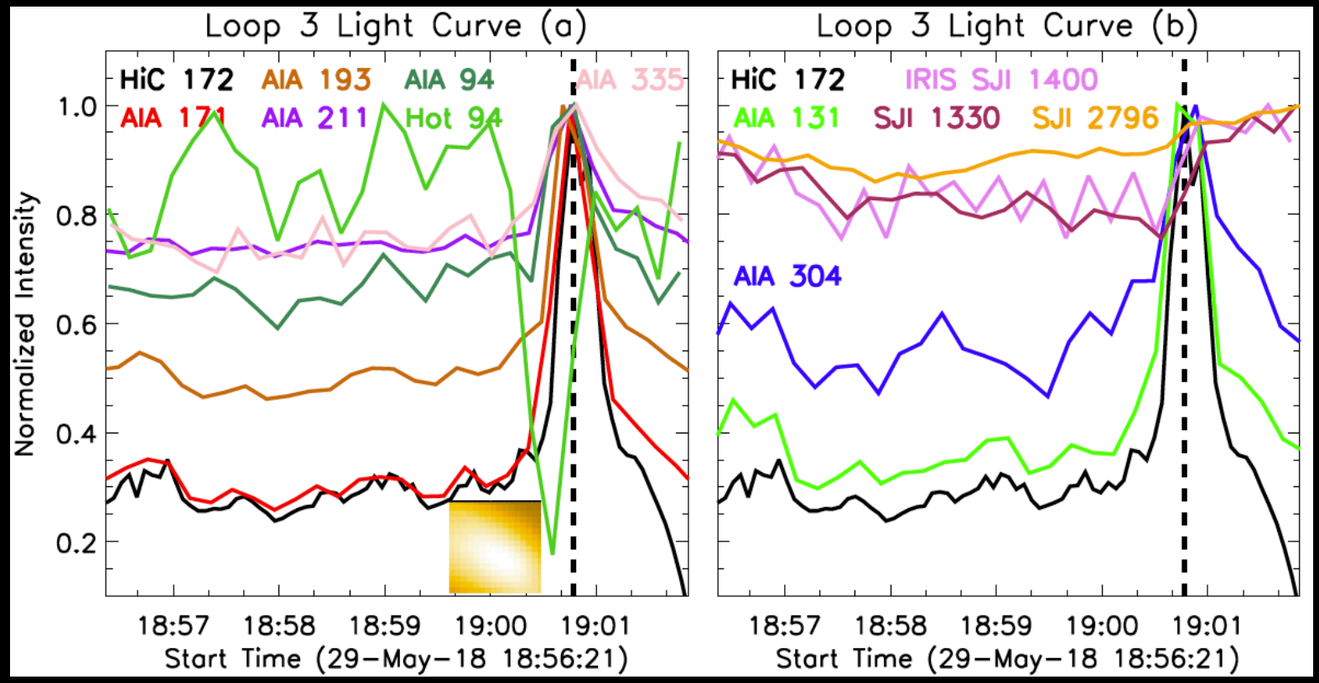
Supported by simulations of Wyper et al. 2018; Peter et al. 2019

Light curves:

For a dot →



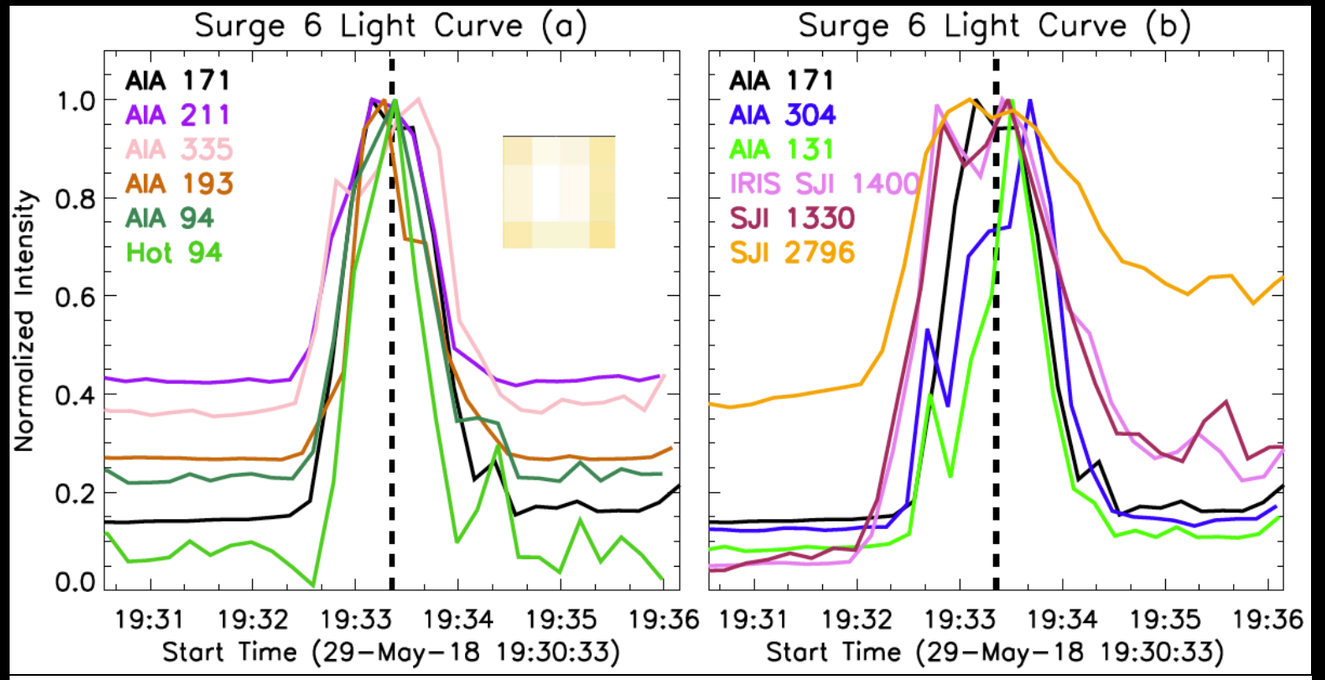
For a loop →



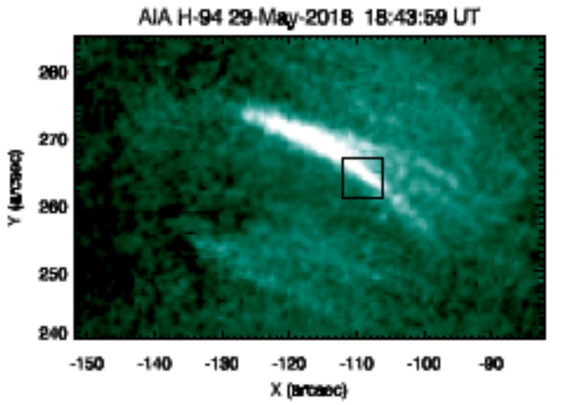
Light curves:

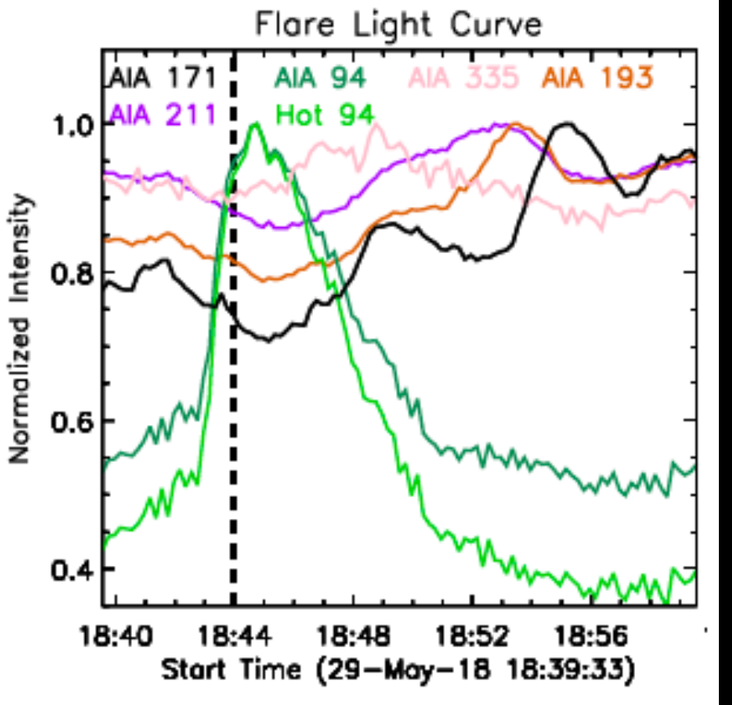
For a surge →

- Most events peak nearly simultaneously in all waves – these form in cooler/lower atmosphere (chromosphere/ transition region)
- None of our 15 events follows a typical flare light curve profile (showing a cooling sequence).



For a sub-flare →





Summary and Conclusions

- We observed three types of small-scale energy-release events (dot-like, loop-like, surge/jet-like) in the core of a solar AR by using unprecedented data of Hi-C 2.1, accompanied with the IRIS and SDO observations in multiple UV/EUV wavelengths!

- All these events are seated at sharp neutral lines: flux convergence-driven cancellation (resulted from the submergence of lower reconnected loops) apparently triggers all three types of events.

- The light curves in all waves for each type event peak nearly simultaneously, unlike typical flares, thus these are lower solar atmospheric events.

- Based on the observed magnetic configuration (and flux evolution) and Doppler flow patterns, we propose possible formation mechanisms, to be confirmed with future MHD simulations!

See for details: Tiwari et al. 2019, ApJ, in press. (https://arxiv.org/abs/1911.01424)

Thanks for your attention!