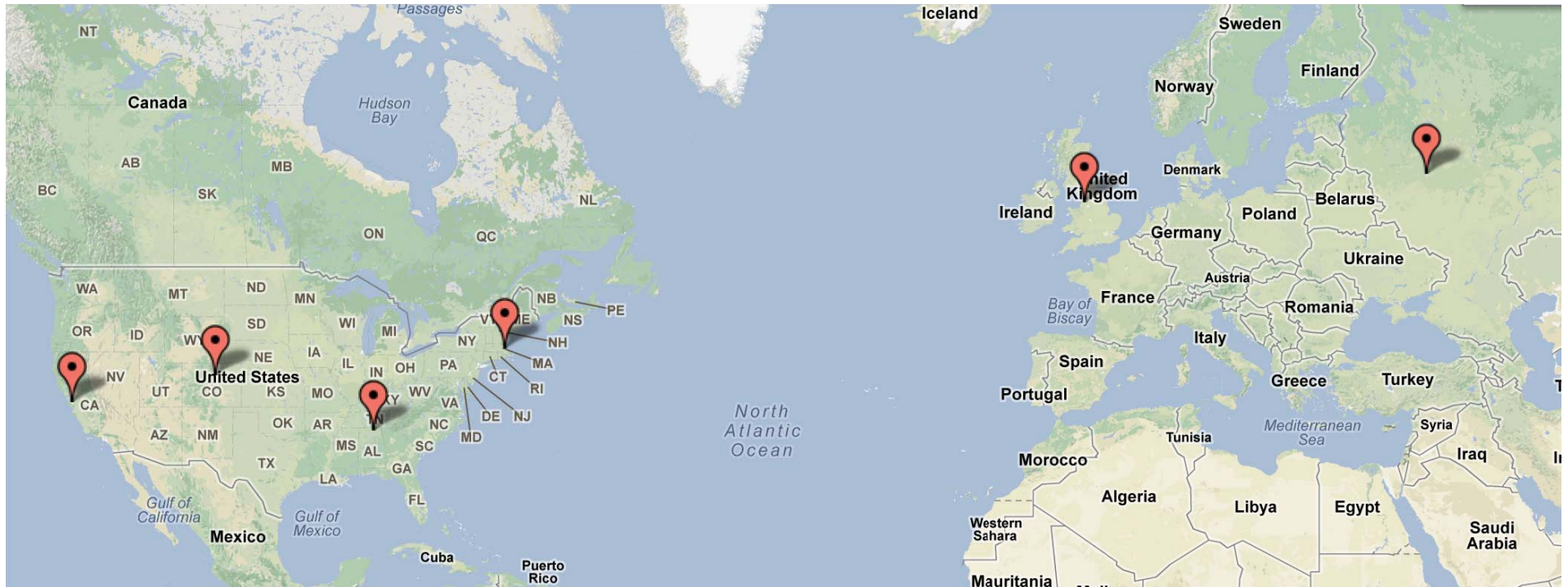


# Hi-C First Results

# Hi-C Partner Institutions



NASA Marshall Space Flight Center (MSFC)

University of Alabama – Huntsville (UAH)

Smithsonian Astrophysical Observatory (SAO)

University of Central Lancashire, UK (UCLAN)

Lockheed Martin Solar and Astrophysical Laboratory (LMSAL)

Southwest Research Institute (SWRI)

Lebedev Institute (LI)

# Hi-C Team Members

**Jonathan Cirtain, PI (MSFC)**

**Science Team:**

Leon Golub (SAO)  
Ken Kobayashi (UAH)  
Kelly Korreck (SAO)  
Robert Walsh (UCLAN)  
Amy Winebarger (MSFC)  
Bart DePontieu (LMSAL)  
Craig Deforest (SWRI)  
Sergey Kuzin (LI)  
Alan Title (LMSAL)  
Mark Weber (SAO)



**Engineering Team:**

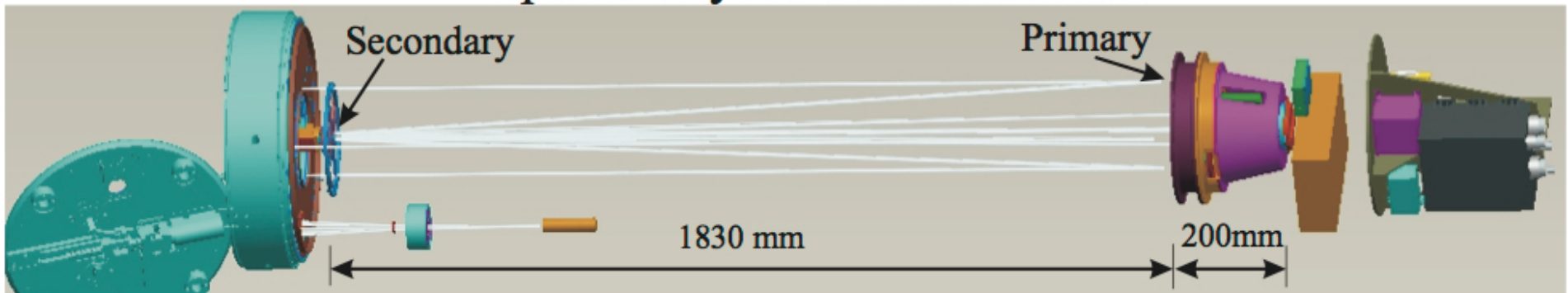
Peter Cheimets (SAO)  
Dyana Beabout (MSFC)  
Brent Beabout (MSFC)  
William Podgorski (SAO)  
Ken McCracken (SAO)

Mark Ordway (SAO)  
David Caldwell (SAO)  
Henry Berger (SAO)  
Richard Gates (SAO)  
Simon Platt (UCLAN)  
Nick Mitchell (UCLAN)

*Image above shows Hi-C launch team standing in front of the Hi-C rocket on the launcher at White Sands Missile Range.*

# High-resolution Coronal Imager (Hi-C)

## Optical Layout with Tolerances



Primary to secondary requirements: Distance:  $\pm 0.05\text{mm}$   
 Tilt:  $36''$   
 De-center:  $0.05\text{mm}$

Focal Plane: Axial Position:  $\pm 1\text{mm}$

## Hi-C Telescope Optical Design

### Telescope Properties:

Focal Length	23.9 m
Plate Scale	$114 \mu\text{m}/\text{arcsec}$
Focal Ratio	f/109
Field of View	$6.8 \times 6.8 \text{ arcmin}$
RMS Spot Diameter (averaged over f.o.v.)	0.08 arcsec

### CCD Camera:

Size	$49.1 \text{ mm}^2$
Scale	$0.1 \text{ arcsec}/\text{pixel}$

### Primary Mirror:

Radius of Curvature	$4000 \pm 4.0 \text{ mm}$
Diameter	240 mm
RMS slope error	$0.4 \mu\text{rad}$

### Secondary Mirror:

Radius of Curvature	$370 \pm 0.5 \text{ mm}$
Conic	$-1.14 \pm 0.10$
Diameter	30 mm
RMS slope error	$0.1 \mu\text{rad}$

Hi-C is a narrowband EUV imager. The wavelength band is centered on  $193 \text{ \AA}$ .

Multilayer coatings by David Windt, RXO LLC.

# Hi-C Launch



Hi-C was launched from White Sands Missile Range on 11 July 2012

# Hi-C Launch and Recovery



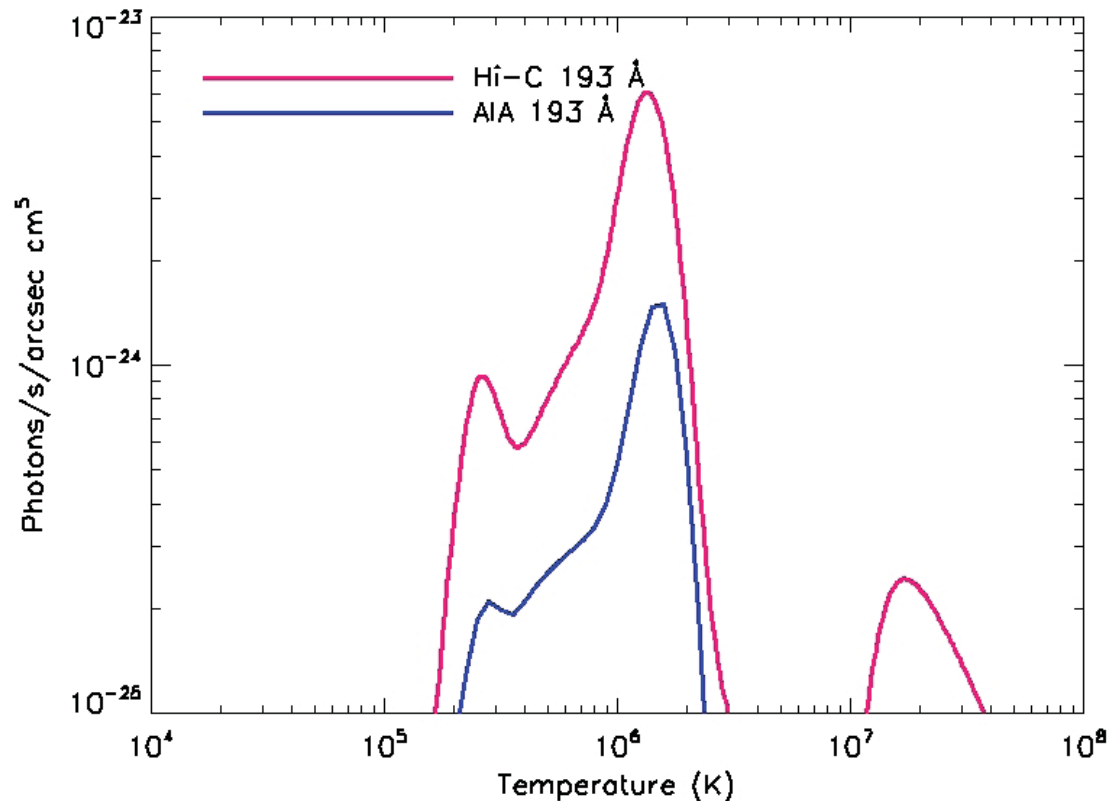
*Hi-C recovery team*



*Hi-C rocket with parachute*

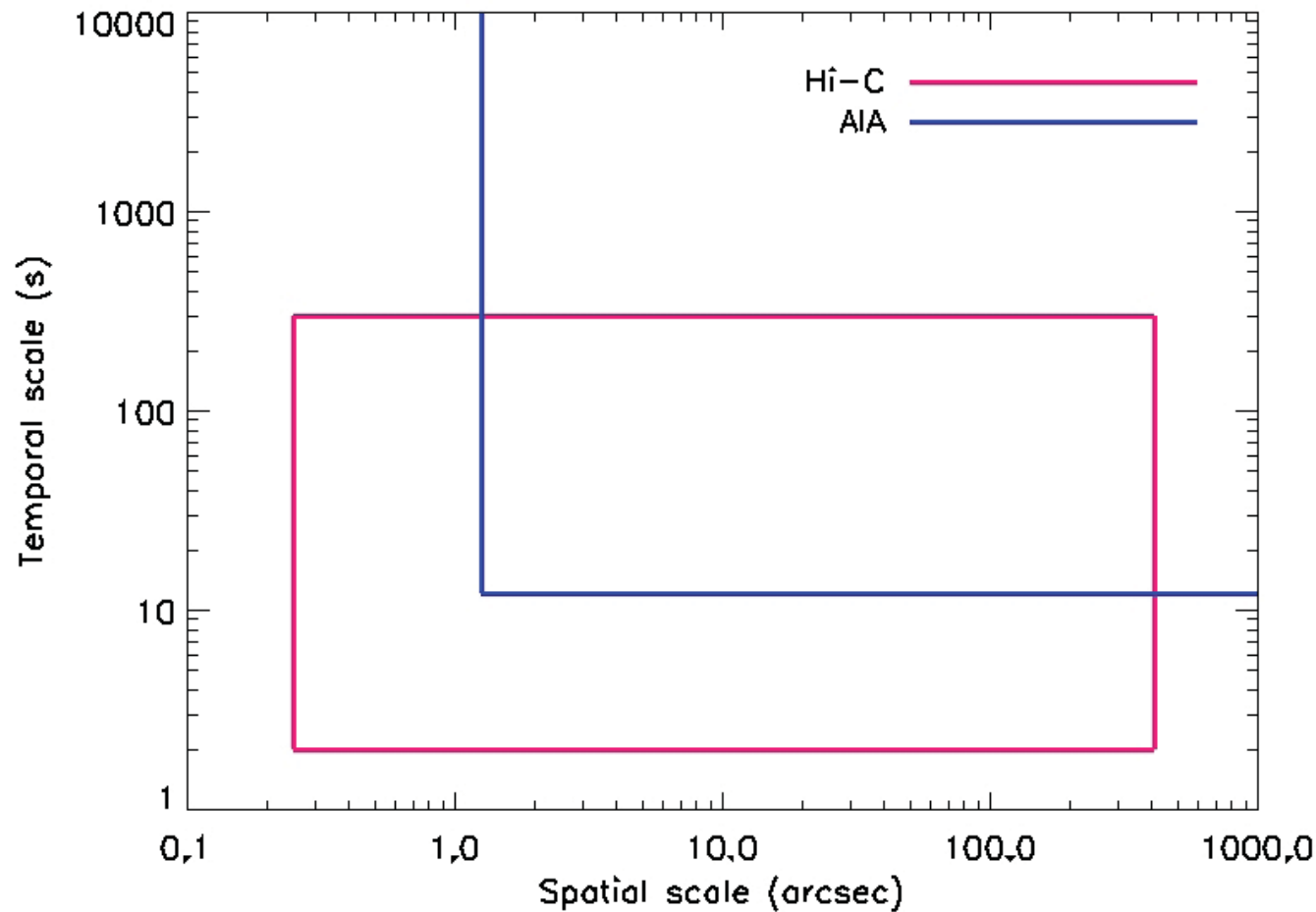
# Hi-C Passband

- The Hi-C 193 Å passband is similar to the 193 Å passband on the Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA).
- Hi-C has roughly 5 times the effective area of AIA.



# Hi-C Discovery Space

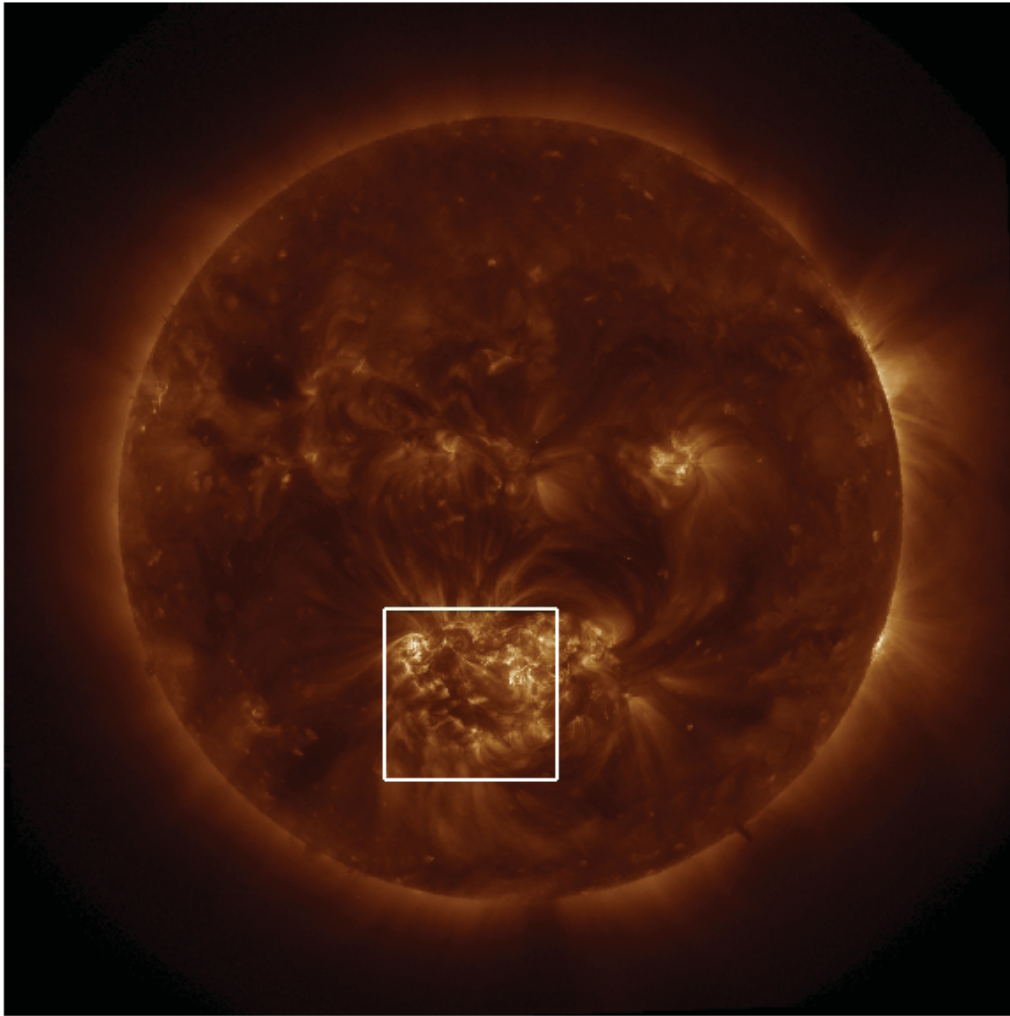
- The spatial resolution of Hi-C is five times better than AIA .
- The cadence of Hi-C is 2.5 – 6 times better than AIA.



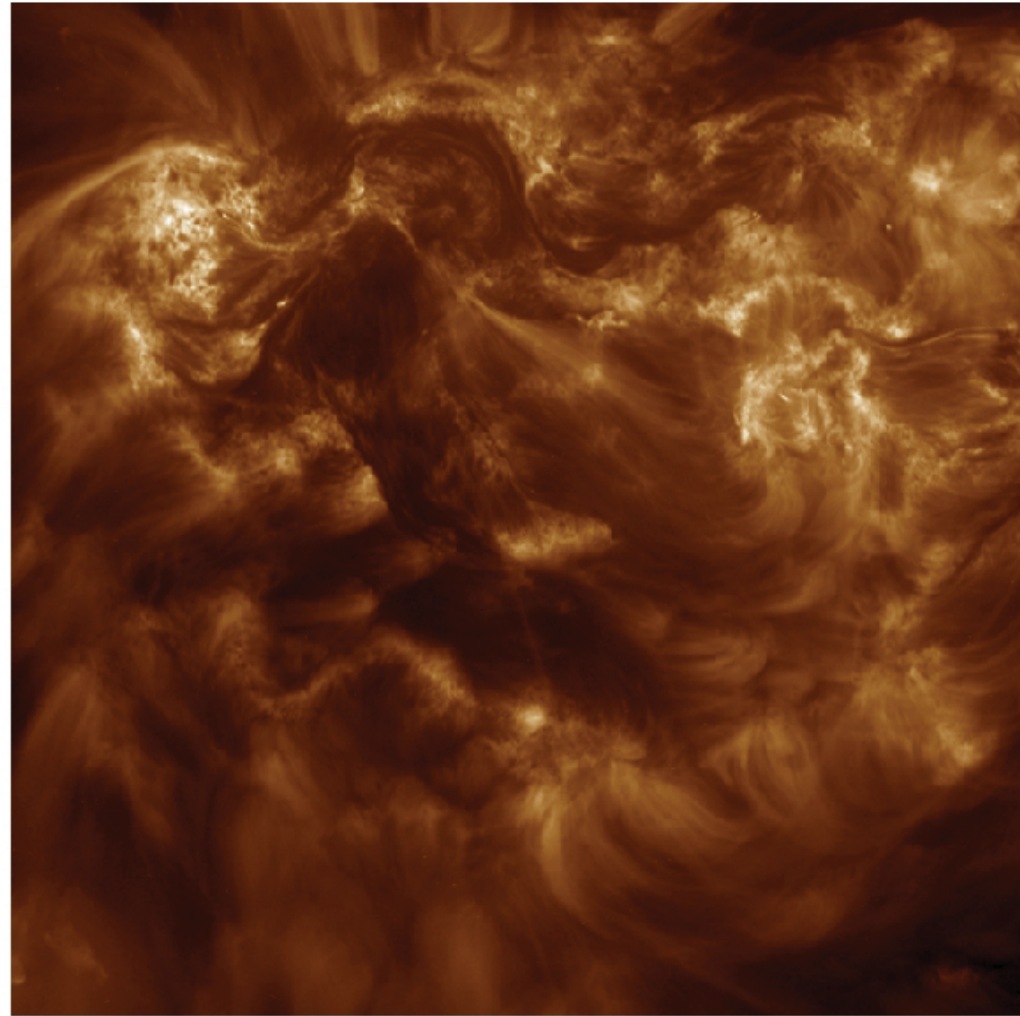


# Hi-C Target

AIA 193-Å 11-Jul-2012 18:55:07



Hi-C Field of View

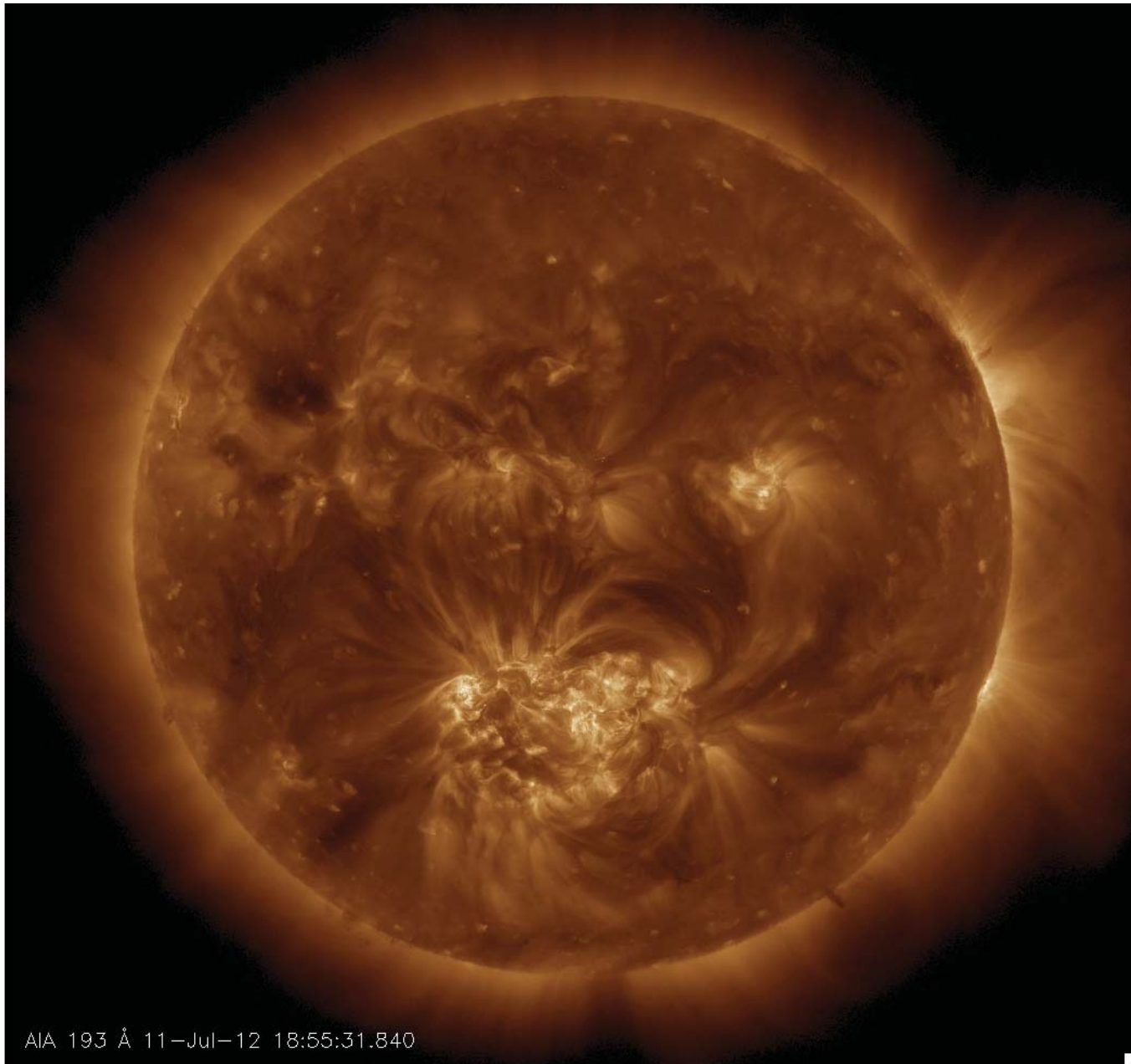


The Hi-C target was Active Region 11520

# Hi-C Data

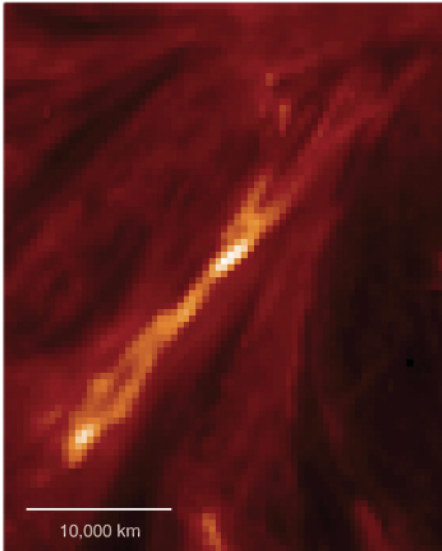
- Hi-C collected data for 345 s.
- Small shift in pointing during flight
- Full frame (4kx4k) data
  - 30 full resolution images
  - 2 s exposures / 5 s cadence
- Partial frame (1kx1k) data
  - 86 full resolution image
  - 0.5 s exposures / 1.4 s cadence

# Hi-C First Results

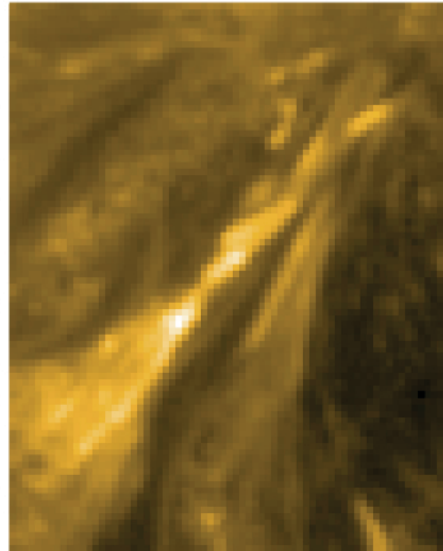


# Component Reconnection

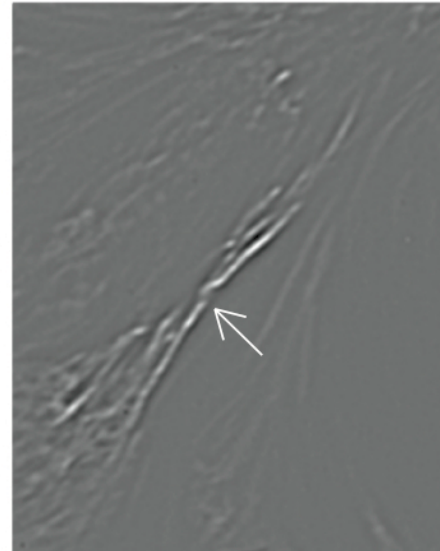
a AIA 304-Å: He II (0.1 MK) 18:55:20



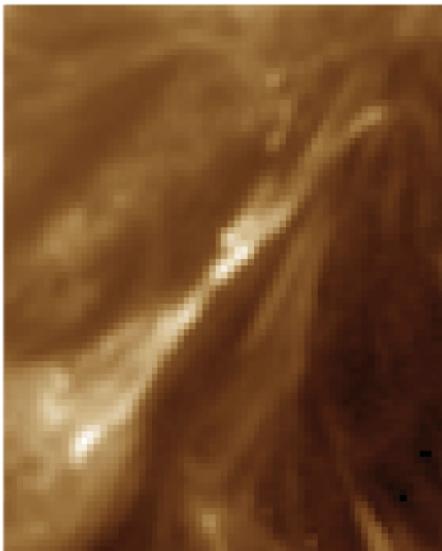
b AIA 171-Å: Fe IX/X (1 MK) 18:55:24



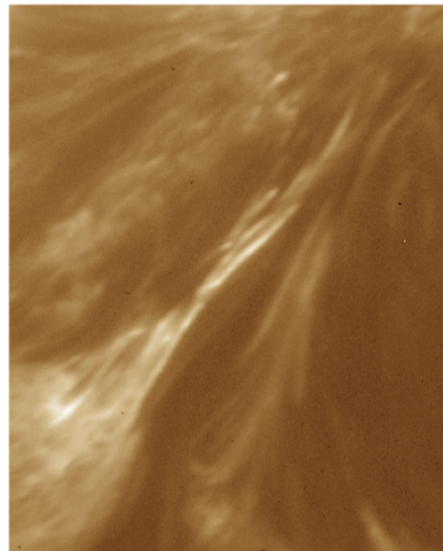
c Hi-C Unsharp Masked Image 18:56:04



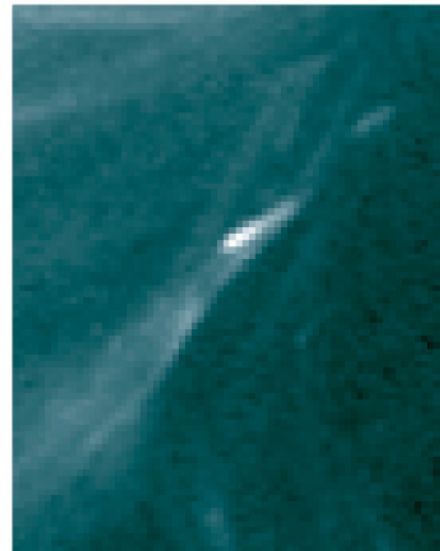
d AIA 193-Å: Fe XII (1.5 MK) 18:55:19



e Hi-C 193-Å: Fe XII (1.5 MK) 18:56:04

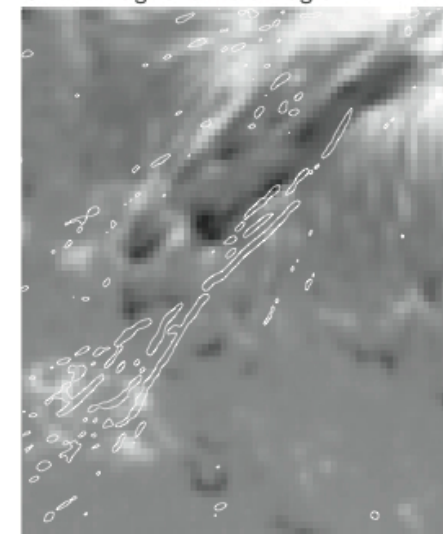


f AIA 94-Å: Fe XVIII (6.3 MK) 18:55:26



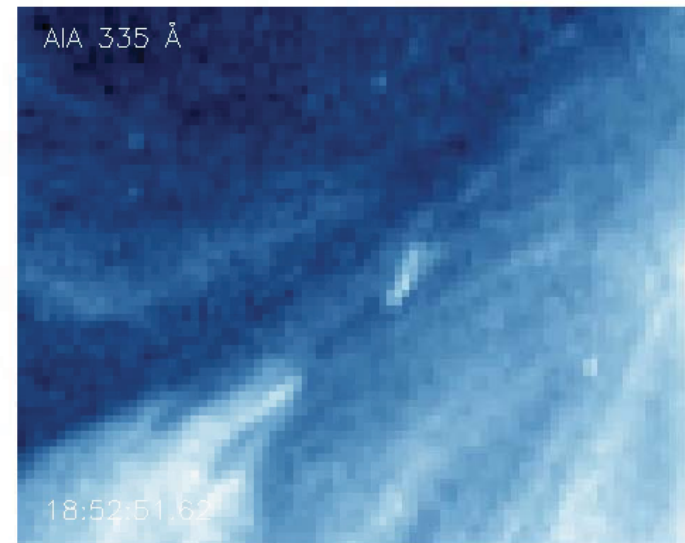
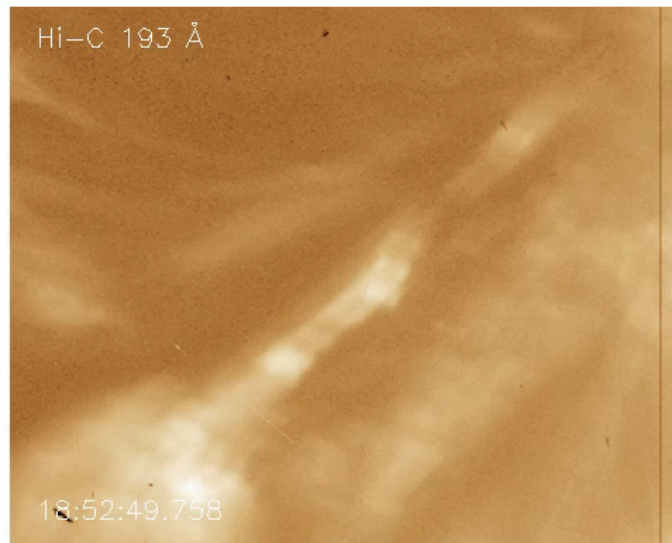
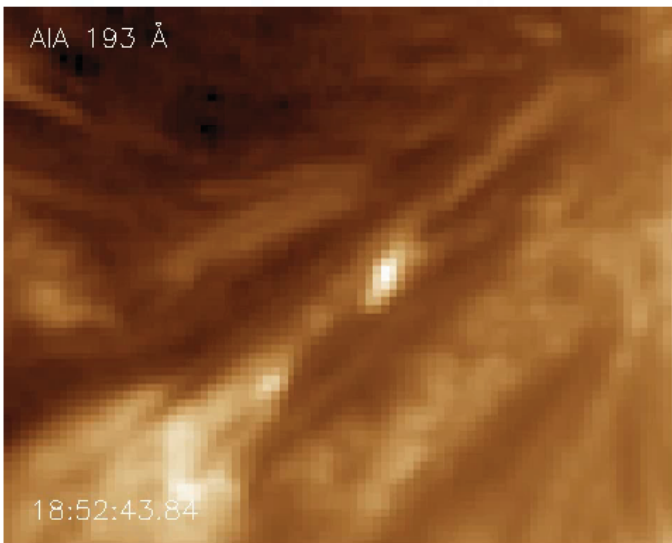
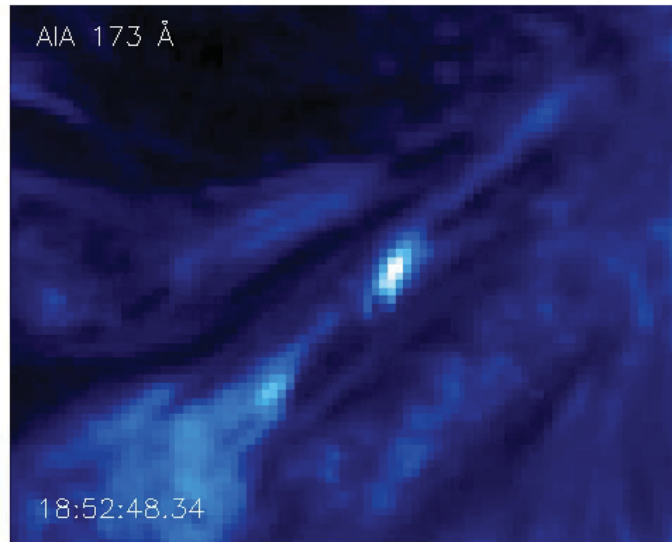
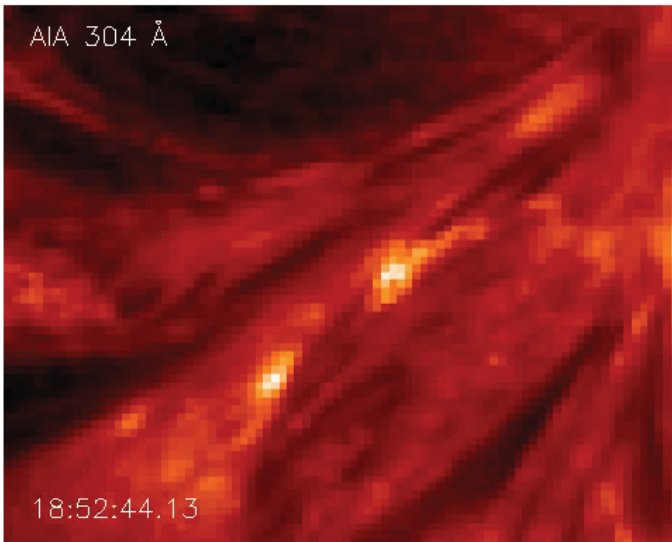
- Magnetic field braiding has been suggested as an energy storage mechanism in the solar corona.
- Hi-C observed braided magnetic field.

b HMI Magnetic Field Region 1



*Cirtain et al, 2013, Nature*

# Component Reconnection



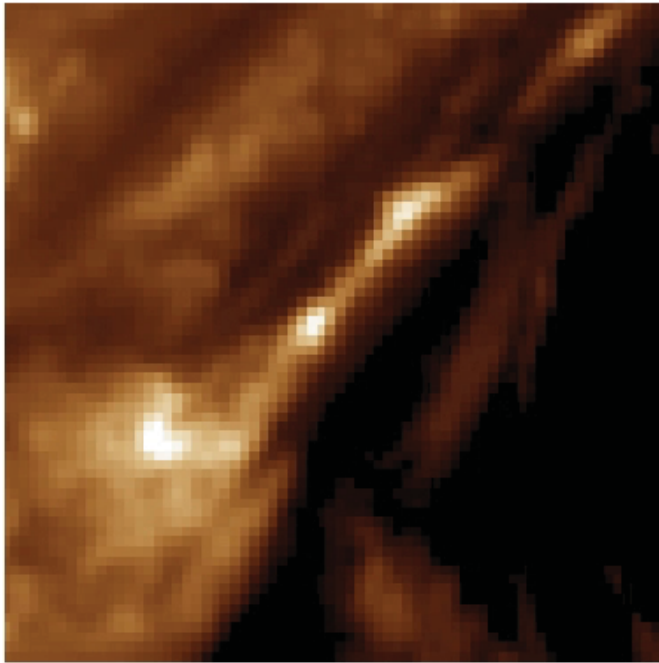
Shortly after the Hi-C flight, a small flare was observed at the field line crossing.

Velocities along strands measured to be  $\sim 150$  km/s.

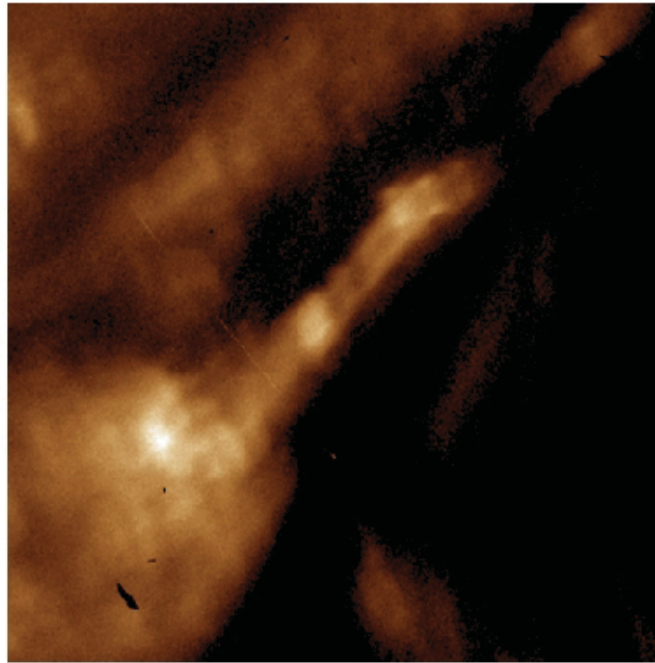
*Cirtain et al, 2013, Nature*

# Component Reconnection

AIA 193 Å : 11-Jul-12 18:52:07.840



Hi-C 193 Å : 11-Jul-12 18:52:07.840

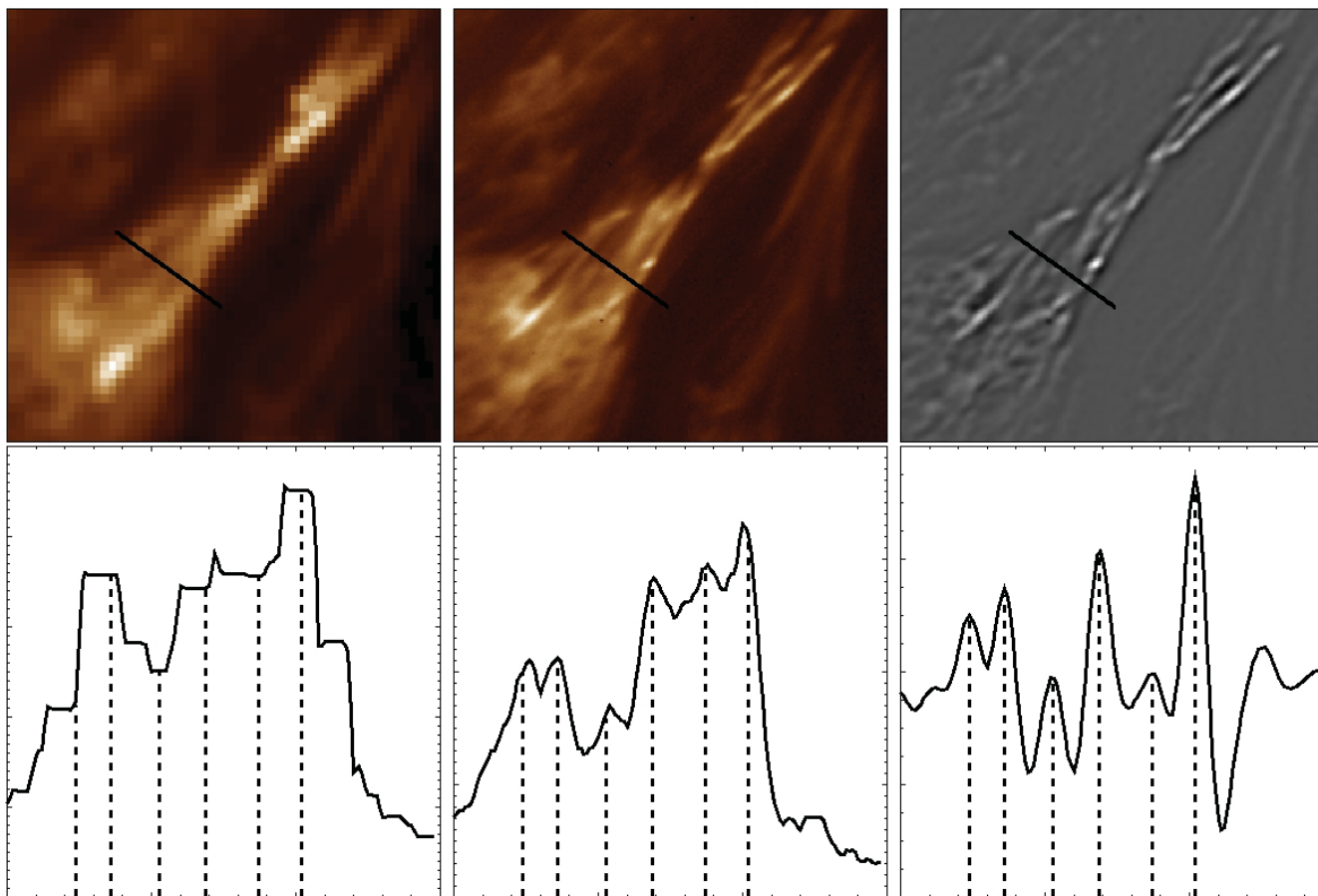


Hi-C 193 Å : Running Difference



Velocities along structure estimated to be 150 km/s.

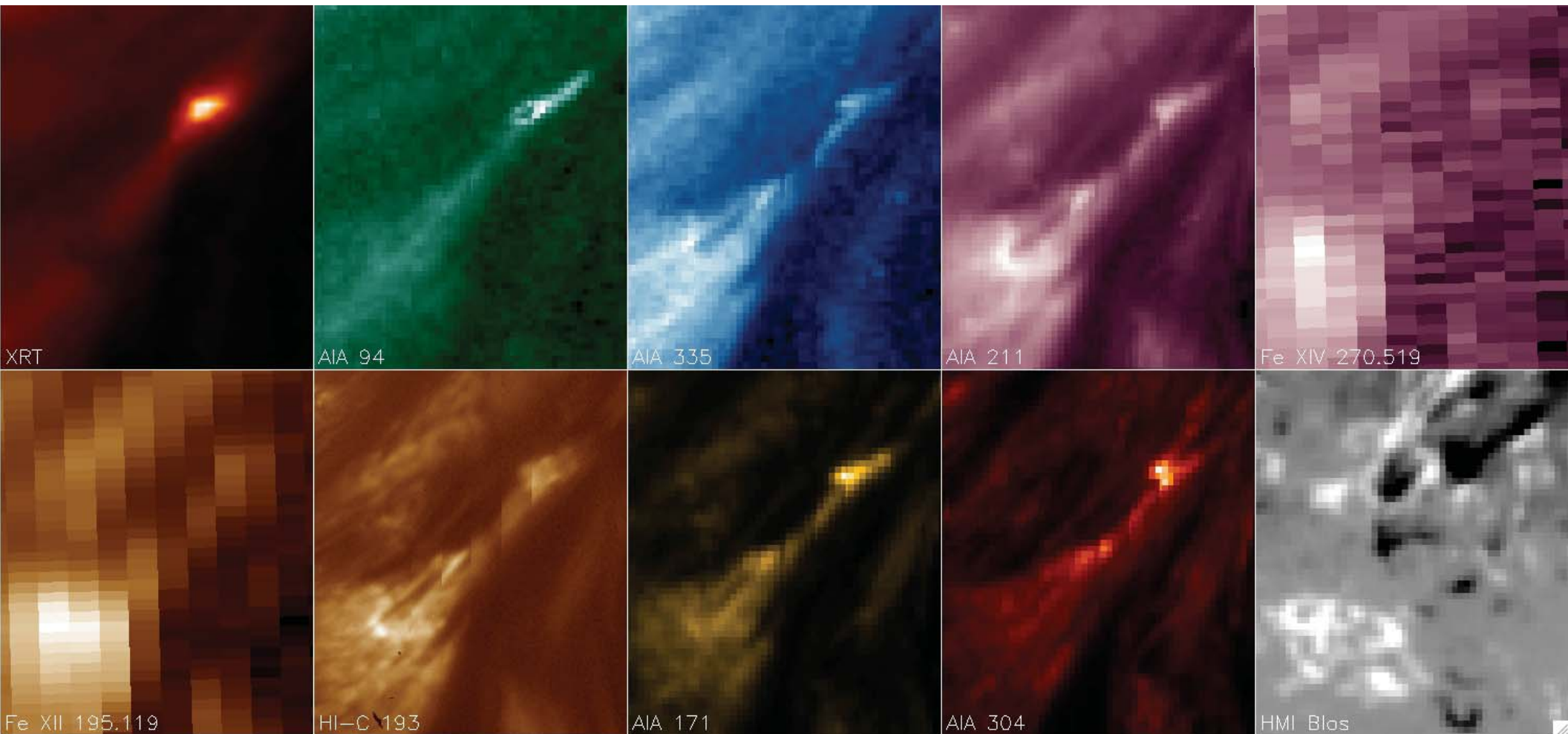
# Component Reconnection



- Cuts across the braided loop show that the loop is composed of at least 6 strands.

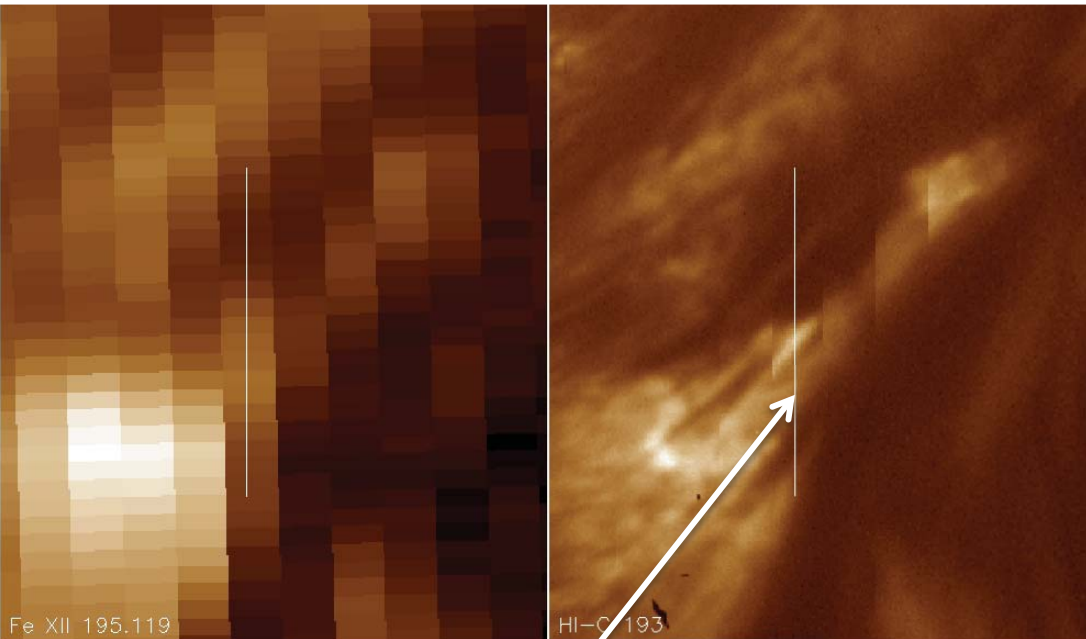
# Component Reconnection

← time





# Component Reconnection

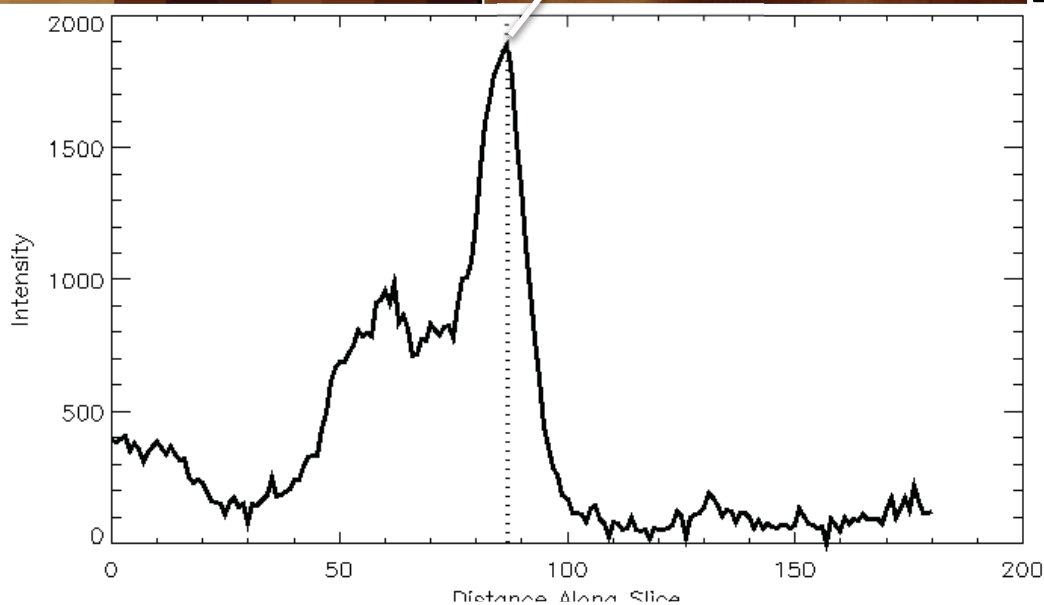


From EIS, we determine:

- Temperature = 1.8 MK
- Densities =  $0.5-7 \times 10^{10} \text{ cm}^{-3}$

From Hi-C, we determine:

- radius of structure = 435 km.



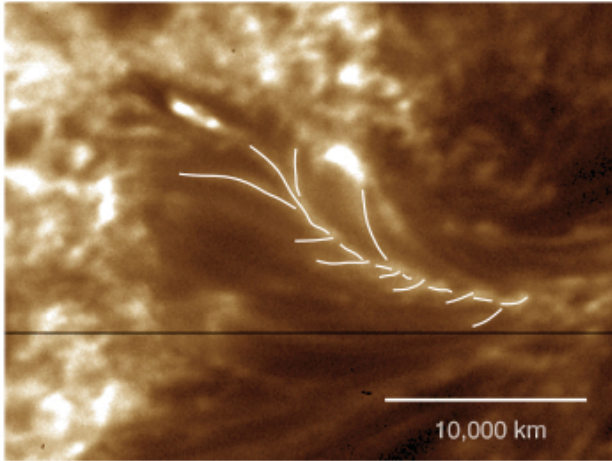
To obtain observed Hi-C intensity, we need:

$$\text{Density} = 1.15 \times 10^{10} \text{ cm}^{-3}$$

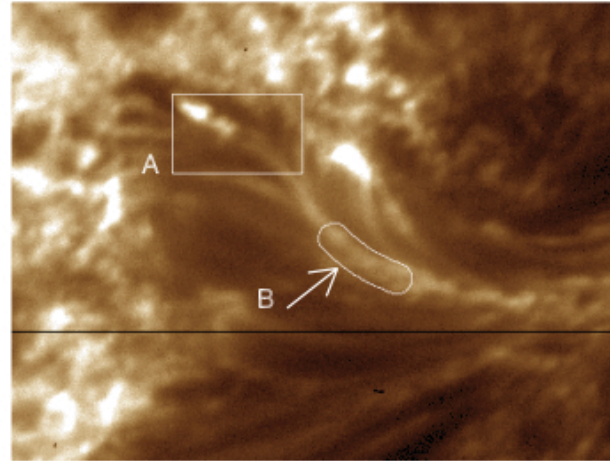
**Because this is in the range of densities determined from EIS, we conclude the substructure is likely resolved.**

# Braided Loop

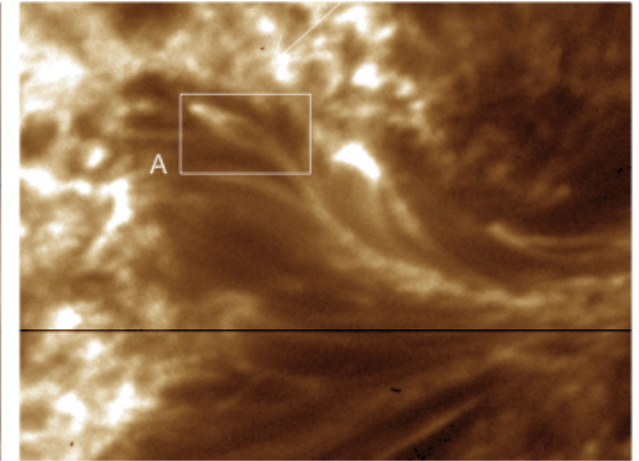
**a** Hi-C 193-Å: 18:53:28



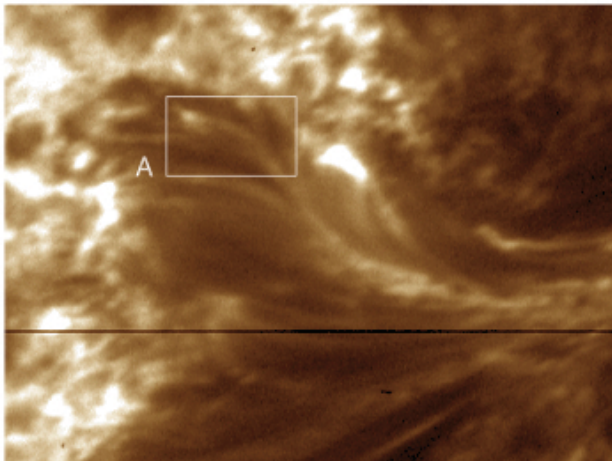
**b** Hi-C 193-Å: 18:53:45



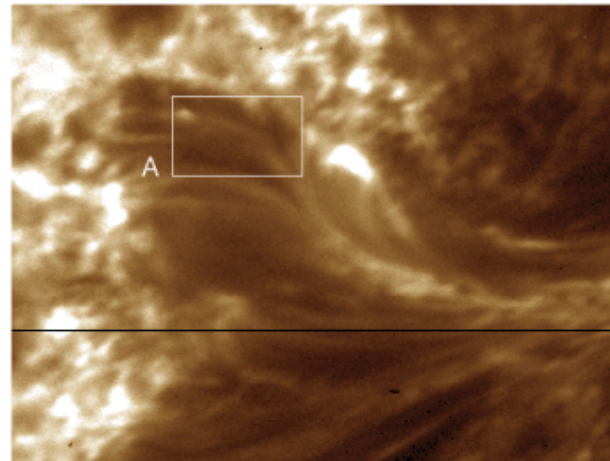
**c** Hi-C 193-Å: 18:54:13



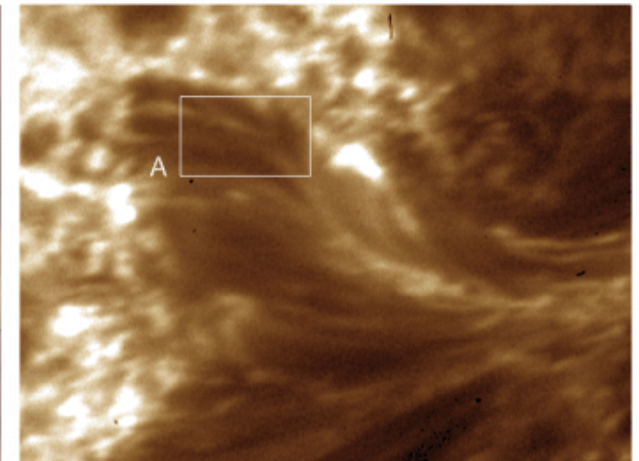
**d** Hi-C 193-Å: 18:54:41



**e** Hi-C 193-Å: 18:55:08



**f** Hi-C 193-Å: 18:55:36

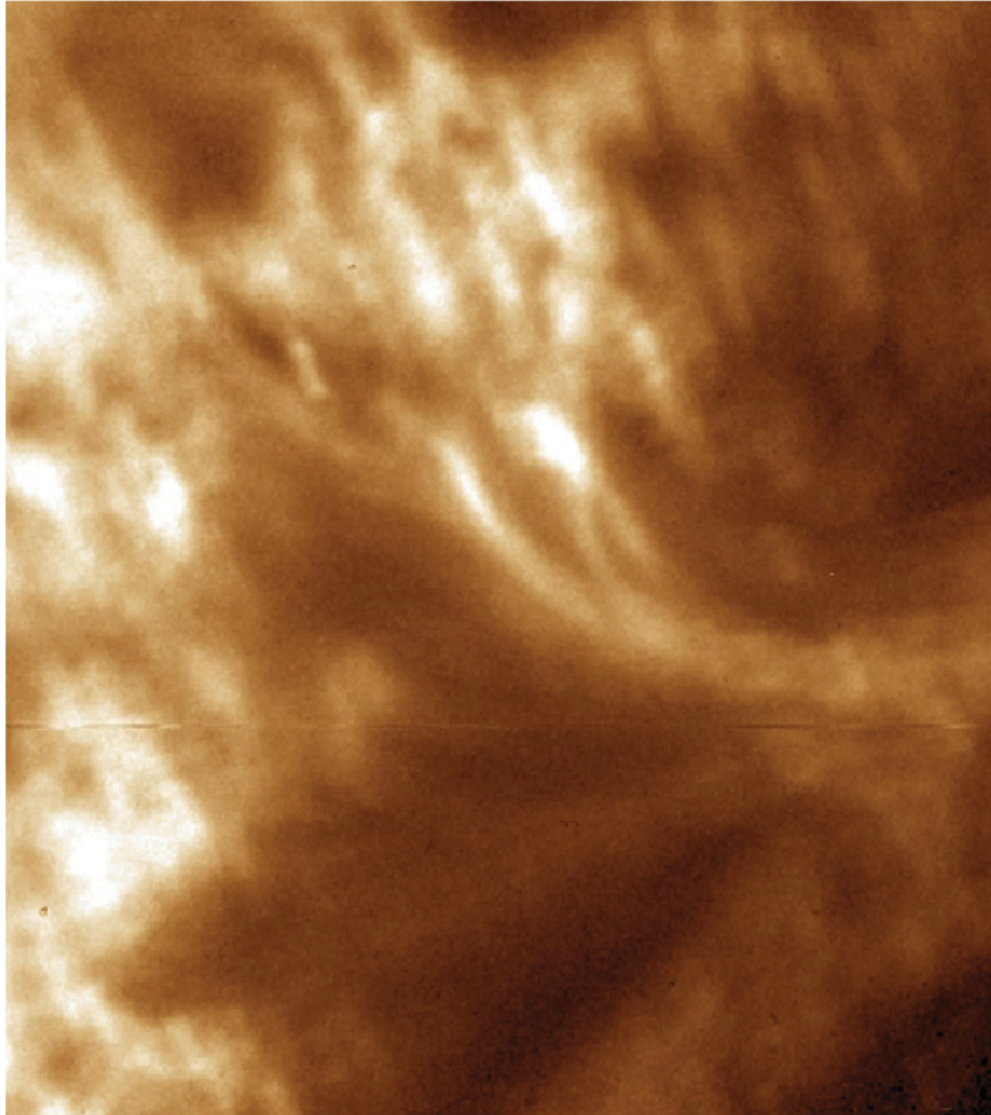


Multiple strands join into this structure. It appears to unwind during Hi-C observations.

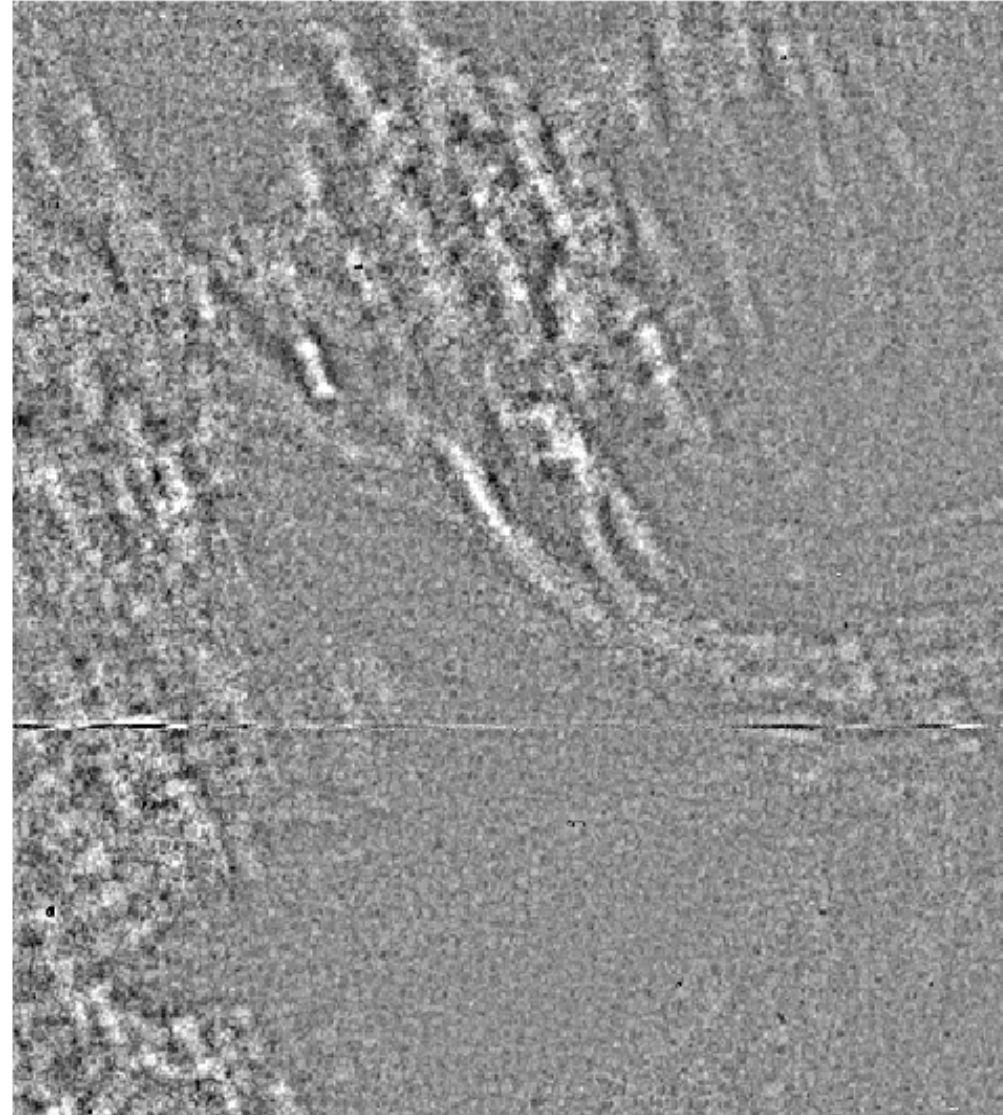
*Cirtain et al, 2013, Nature*

# Braided Loop

a Hi-C 193-Å 18:52:49

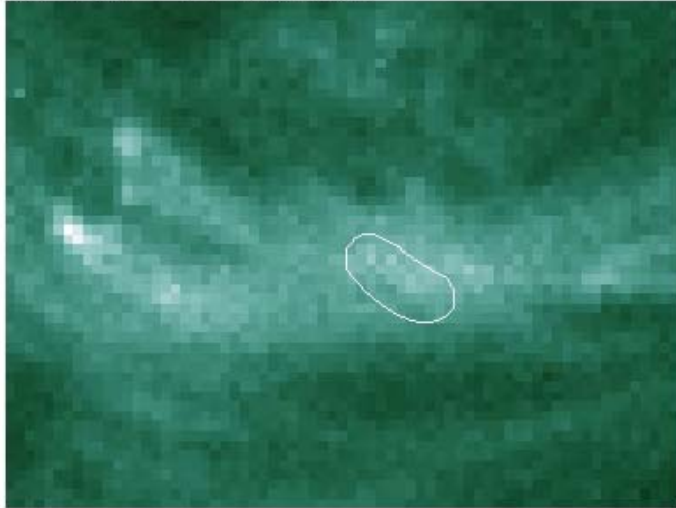


b Hi-C Unsharp Mask

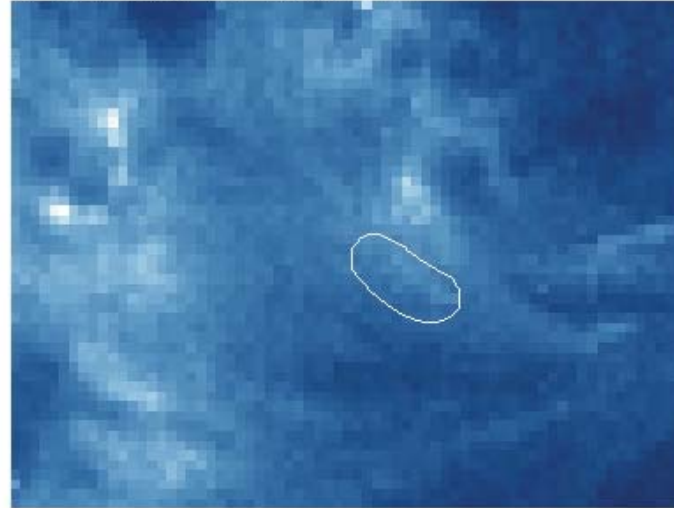


# Braided Loop

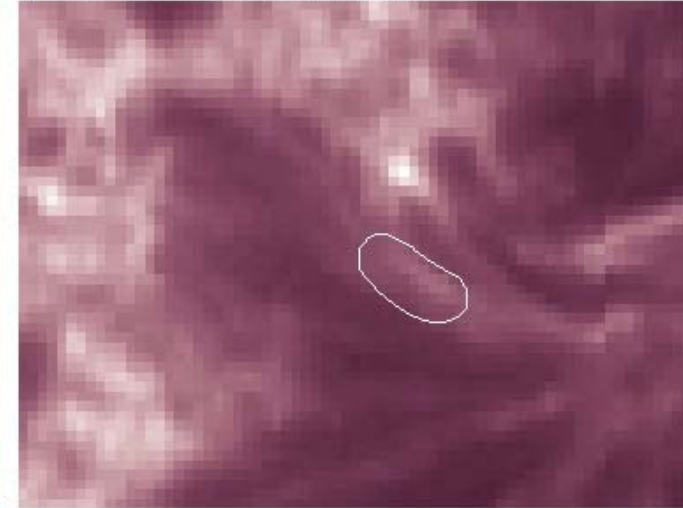
a AIA 94-Å 18:00:01



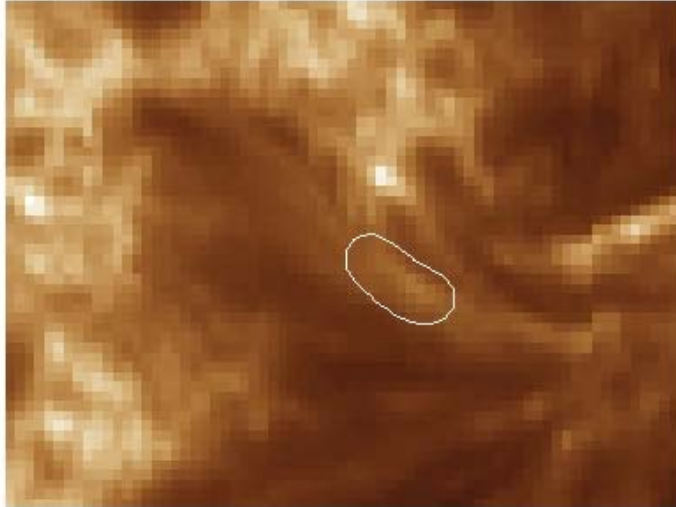
b AIA 335-Å 18:00:02



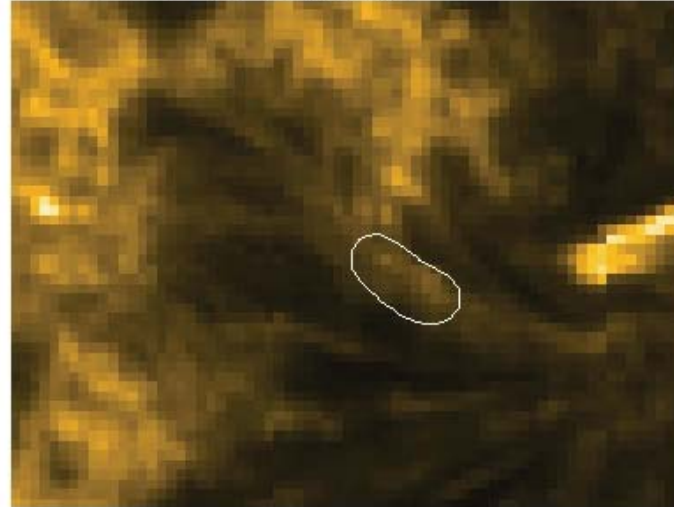
c AIA 211-Å 17:59:59



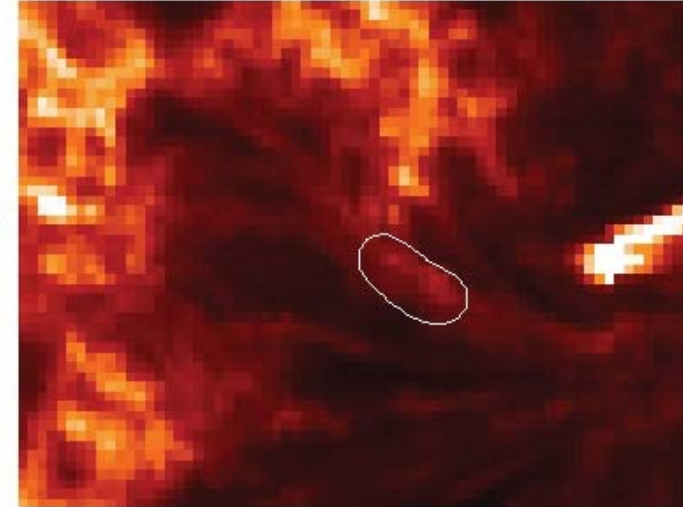
d AIA 193-Å 18:00:06



e AIA 171-Å 17:59:59



f AIA 304-Å 18:00:07



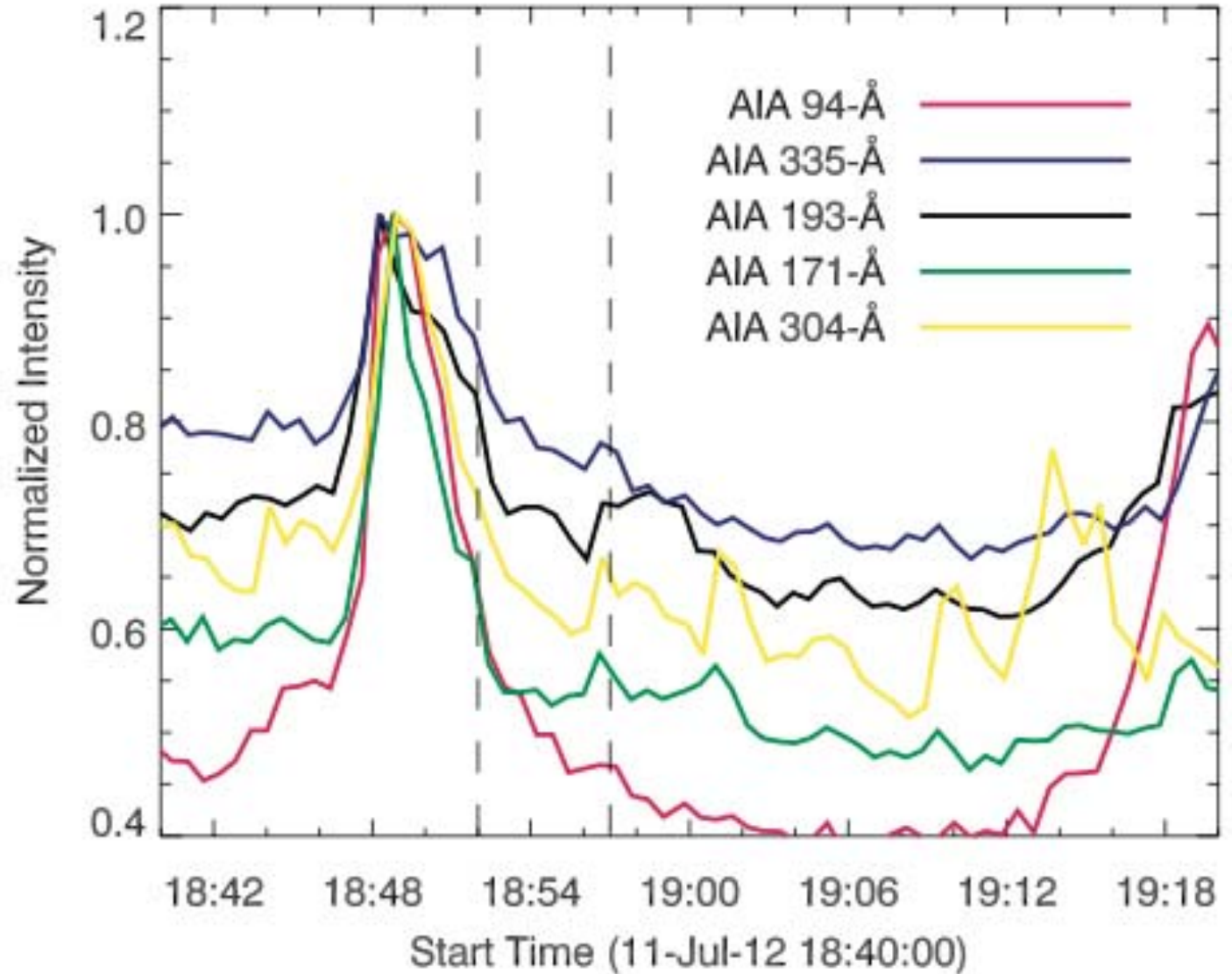
Loop involved in heating event prior to Hi-C flight.

# Braided Loop

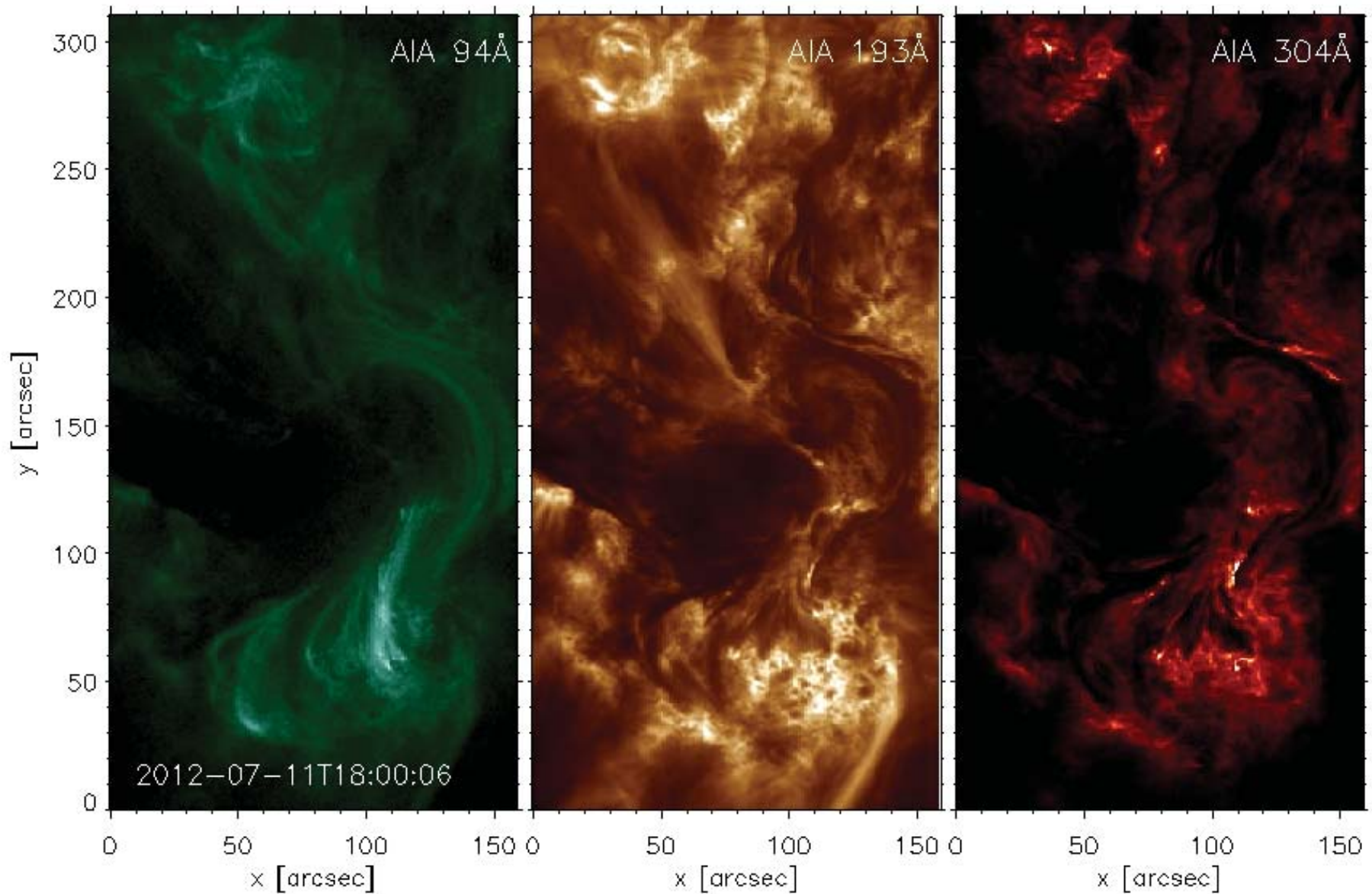
Hi-C observed the loop in decline after heating event.

$$B_{\phi} \sim 100G$$
$$V \sim 10^{11} \text{ km}^3$$
$$(B_{\phi})^2 V / 8\pi = 10^{29} \text{ ergs}$$

Note: From EIS and AIA data an estimate of the radiated power loss is  $\sim 10^{26} \text{ ergs sec}^{-1}$



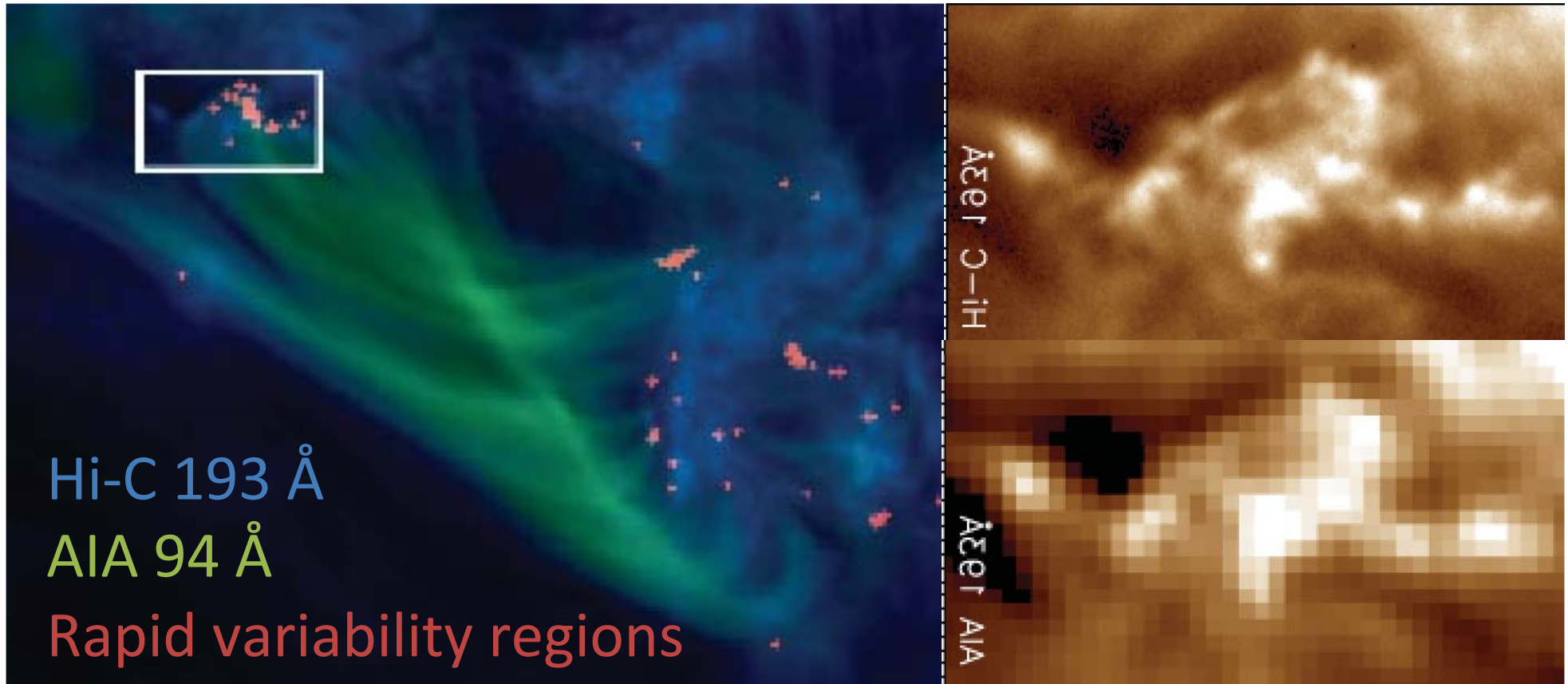
# Dynamic Moss



- Hi-C observed a location of highly dynamic moss.

*Testa, DePontieu, et al., ApJ, 770, L7 (2013)*

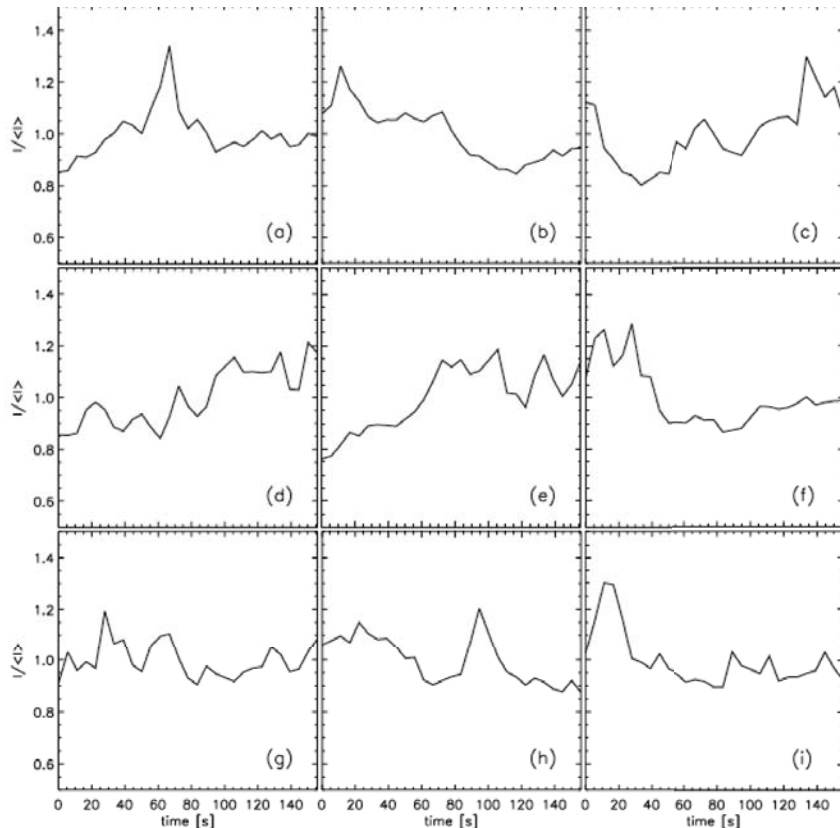
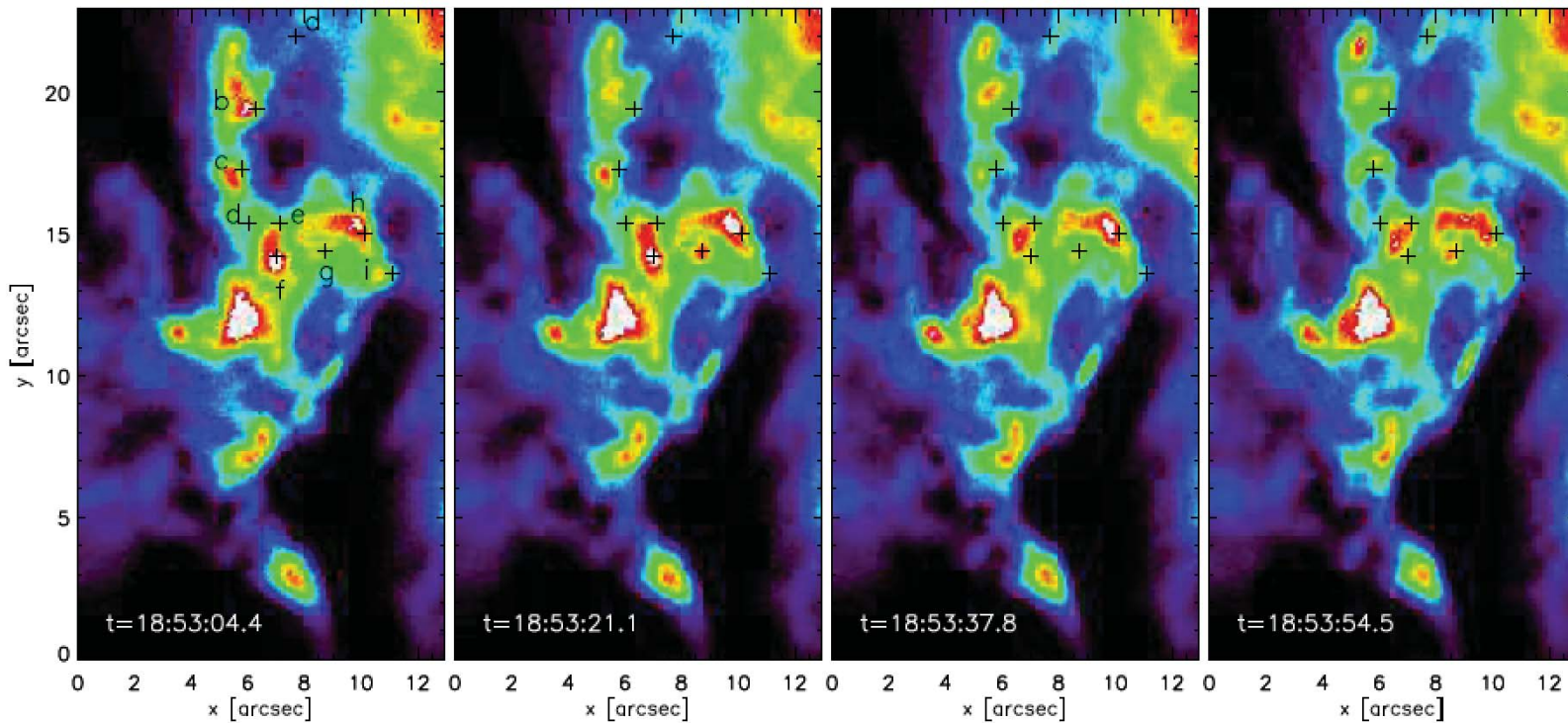
# Dynamic Moss



- Dynamic moss occurs at footpoint of high temperature loops.

*Testa, DePontieu, et al., ApJ, 770, L7 (2013)*

# Dynamic Moss



- Events as short as 15 s with increase in intensity on the order of 20-30%.
- Suggestive of footpoint response to coronal reconnection.



# Summary

- For the first time in the corona, Hi-C revealed magnetic braiding and component reconnection consistent with coronal heating.
- Hi-C shows evidence of reconnection and heating in several different regions and magnetic configurations with plasma being heated to  $0.3 - 8 \times 10^6$  K temperatures.
- Surprisingly, many of the first results highlight plasma at temperatures that are not at the peak of the response functions.

# Hi-C and you

- **All** Hi-C data is available via the VSO:

<http://sao.virtualsolar.org/VSO/DataProvider/MSFC/Hi-C/>

- Data analysis resources and IDL calibration software:

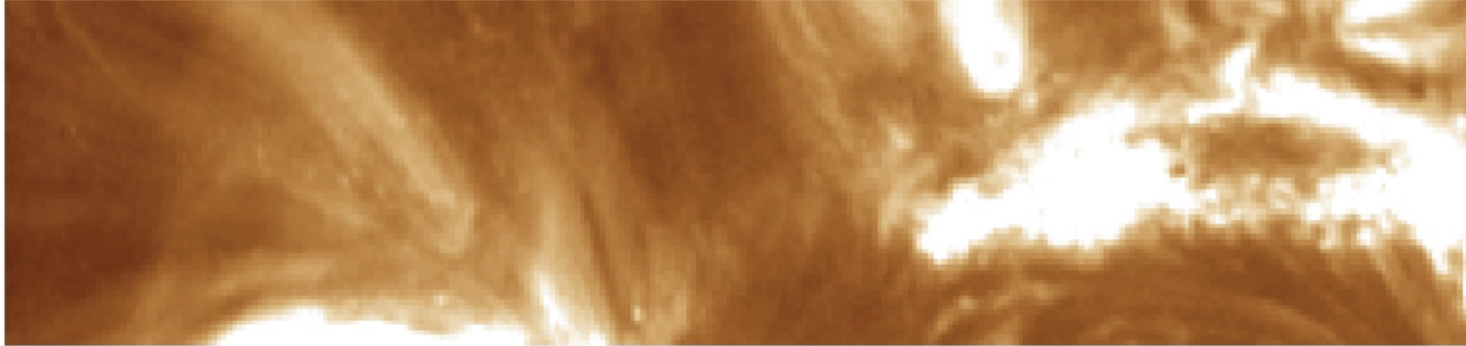
[http://hic.msfc.nasa.gov/data\\_analysis.html](http://hic.msfc.nasa.gov/data_analysis.html)

SAO and MSFC, along with our science and instrument partners, will submit a suborbital mission proposal for Hi-C. Passbands will be 17.4 and 30.4nm. Cadence will be increased from 5.4 sec to < 2sec.

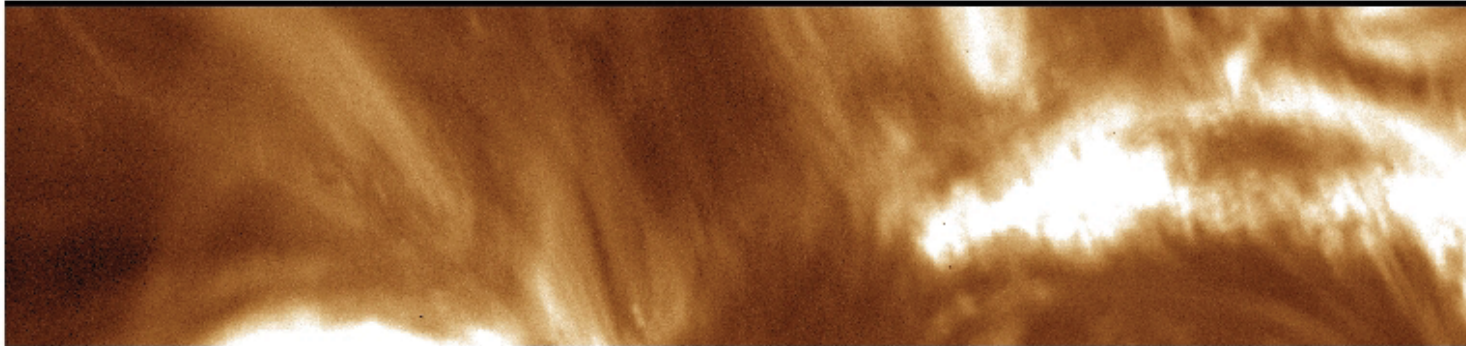
Camera electron noise (our largest source of noise in Hi-C I) will drop from 100+  $e^{-1}$ /pixel to < 10  $e^{-1}$ /pixel (AIA is about 25)

# “Dots”

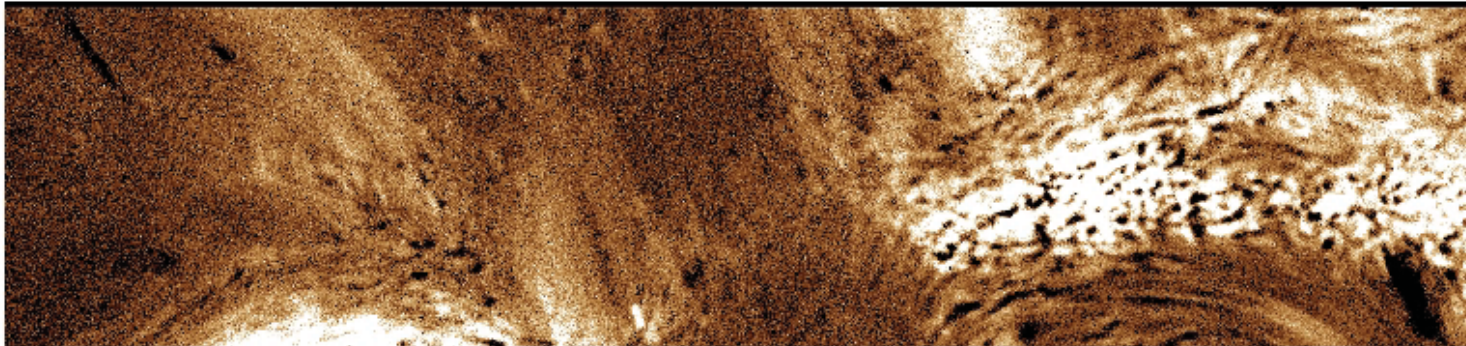
AIA 193 Å : 11-Jul-12 18:52:07.840



Hi-C 193 Å : 11-Jul-12 18:52:08.758



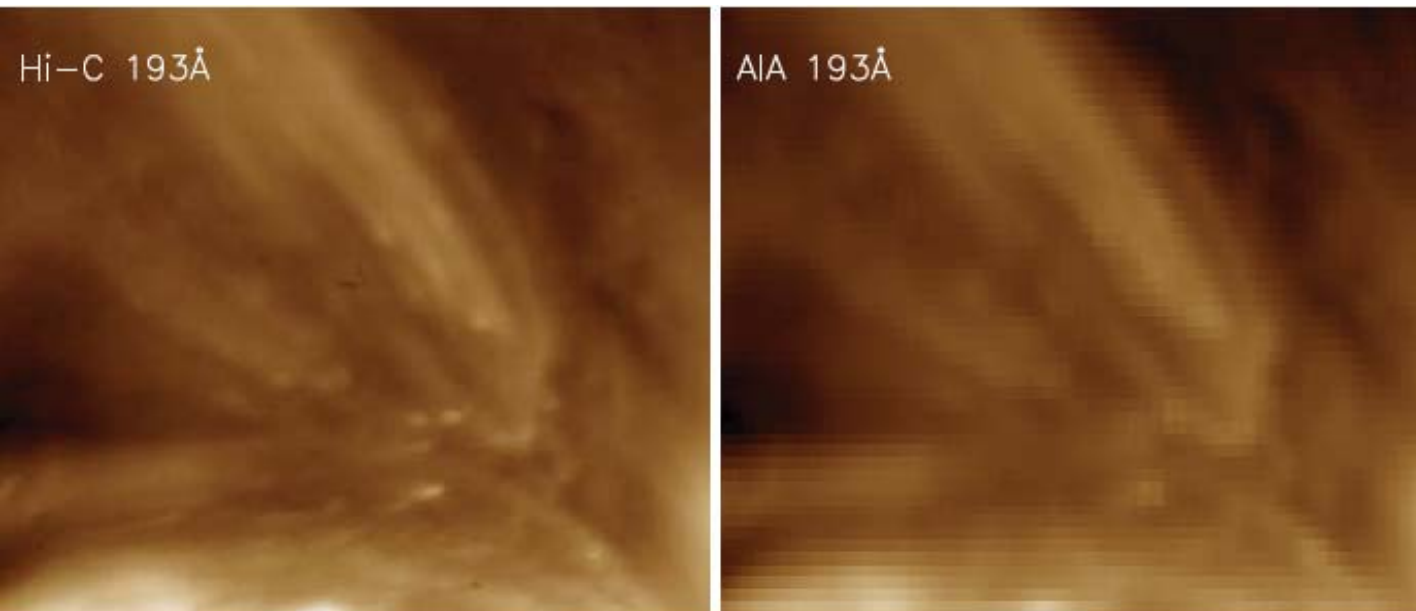
Enhanced Hi-C 193 Å : 11-Jul-12 18:52:08.758



“Dots” are small-scale, short-lived brightenings that occur at the periphery of the active region.

They may be associated with open fields.

# “Dots”



A filtering technique is used to determine locations of dots.

8 dots are identified in Hi-C data with this method.

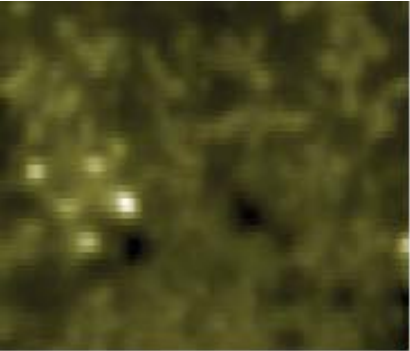
3 dots are found in AIA 193 data.

- EBD1
- EBD2
- EBD3
- EBD4
- EBD5
- EBD6
- EBD7
- EBD8



# “Dots”

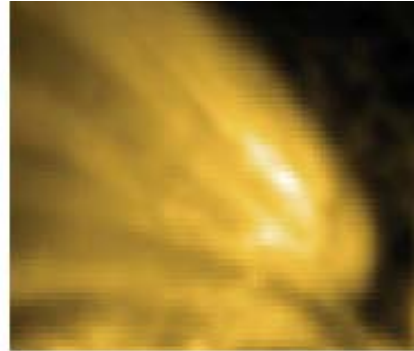
1600Å



304Å



171Å



211Å

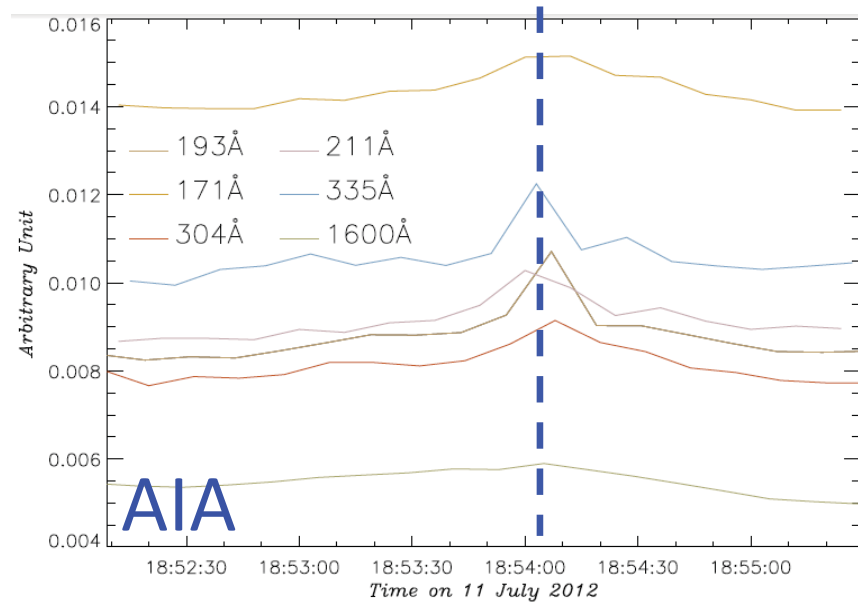
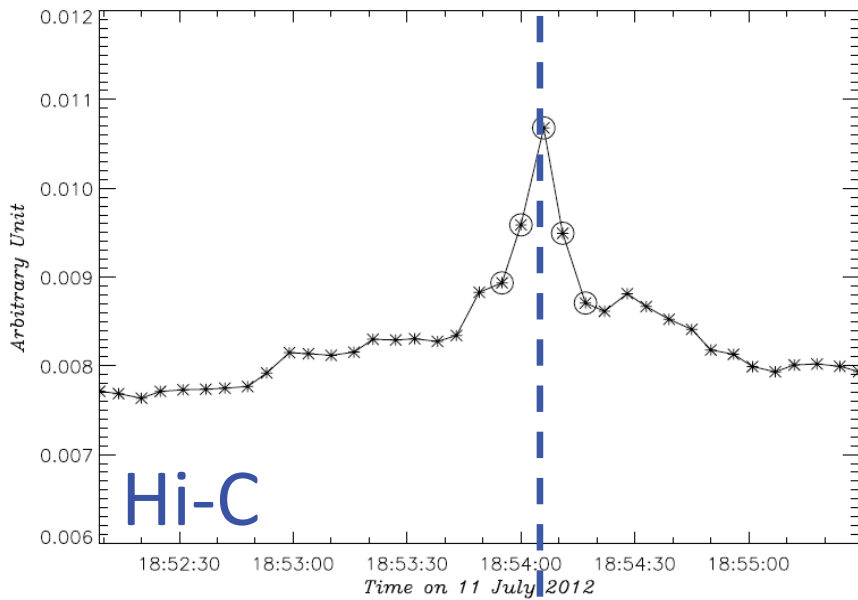


335Å



Some of these dots are observed in other AIA passbands.

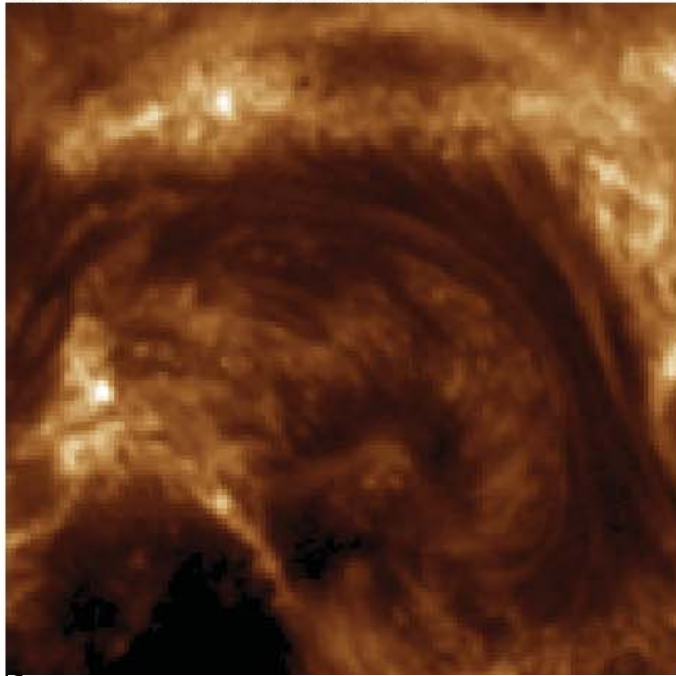
# “Dots”



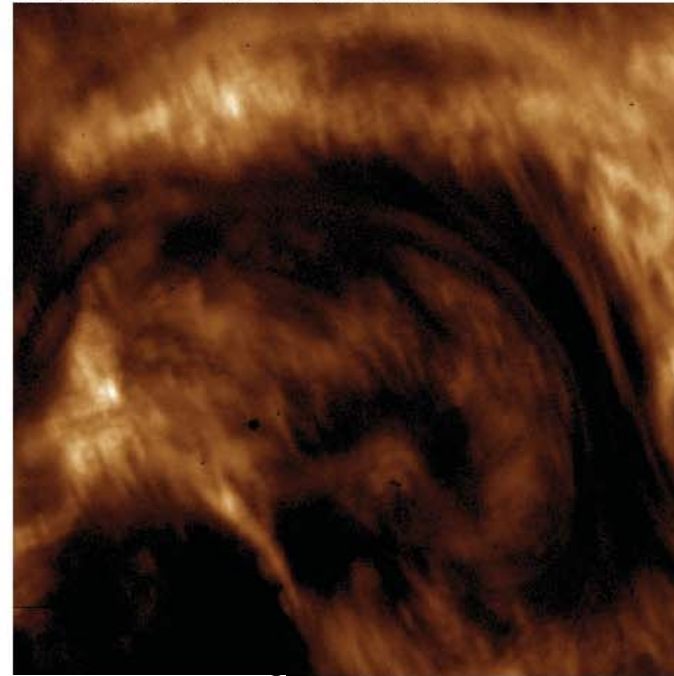
- Dots generally appear in only one AIA image, but several Hi-C images.
- Characteristic duration of 25s
- Characteristic length of 680 km ( $<1''$ )
- Not fully spatially or temporally resolved in SDO/AIA

# Bi-directional Flows in Filaments

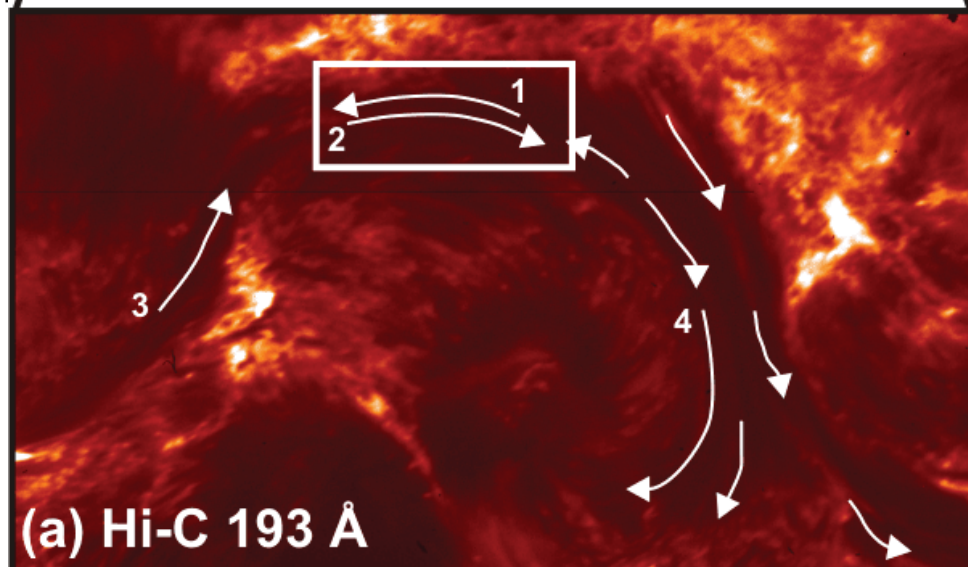
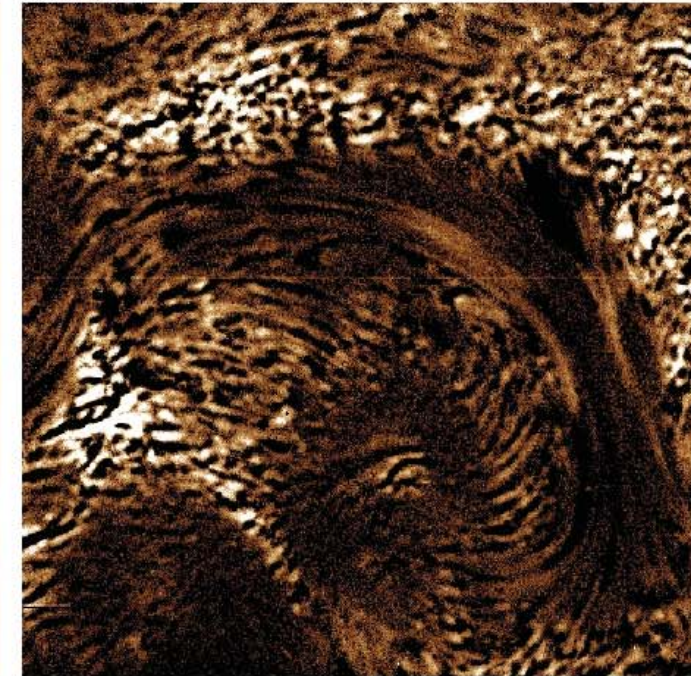
AIA 193 Å : 11-Jul-12 18:52:07.840



Hi-C 193 Å : 11-Jul-12 18:52:08.758



Enhanced Hi-C 193 Å : 11-Jul-12 18:52:08.758

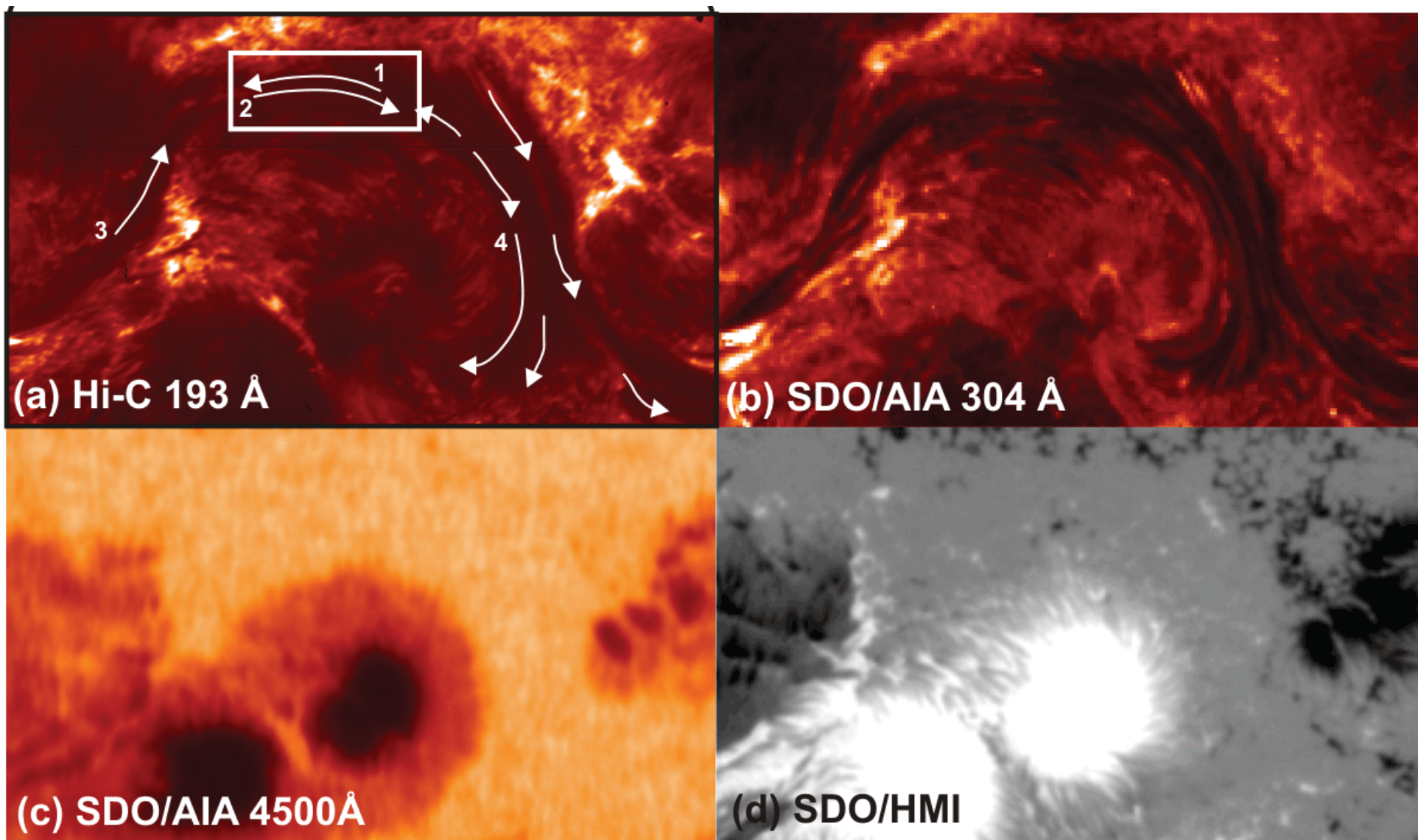


(a) Hi-C 193 Å

Hi-C observed bi-directional flows in a filament. This is the first observations of such flows in the EUV channel.

*Alexander, Walsh, in prep.*

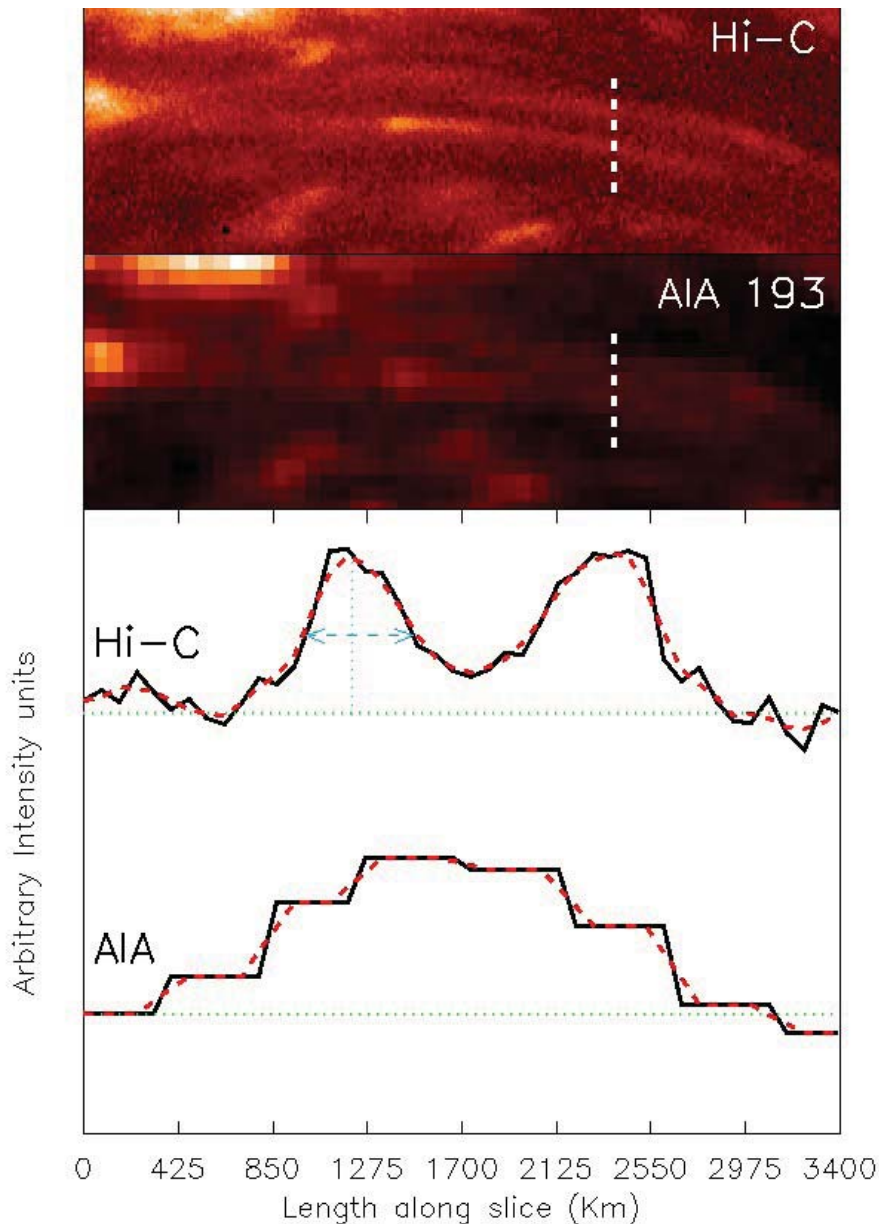
# Bi-directional Flows in Filaments



*Alexander, Walsh, in prep.*



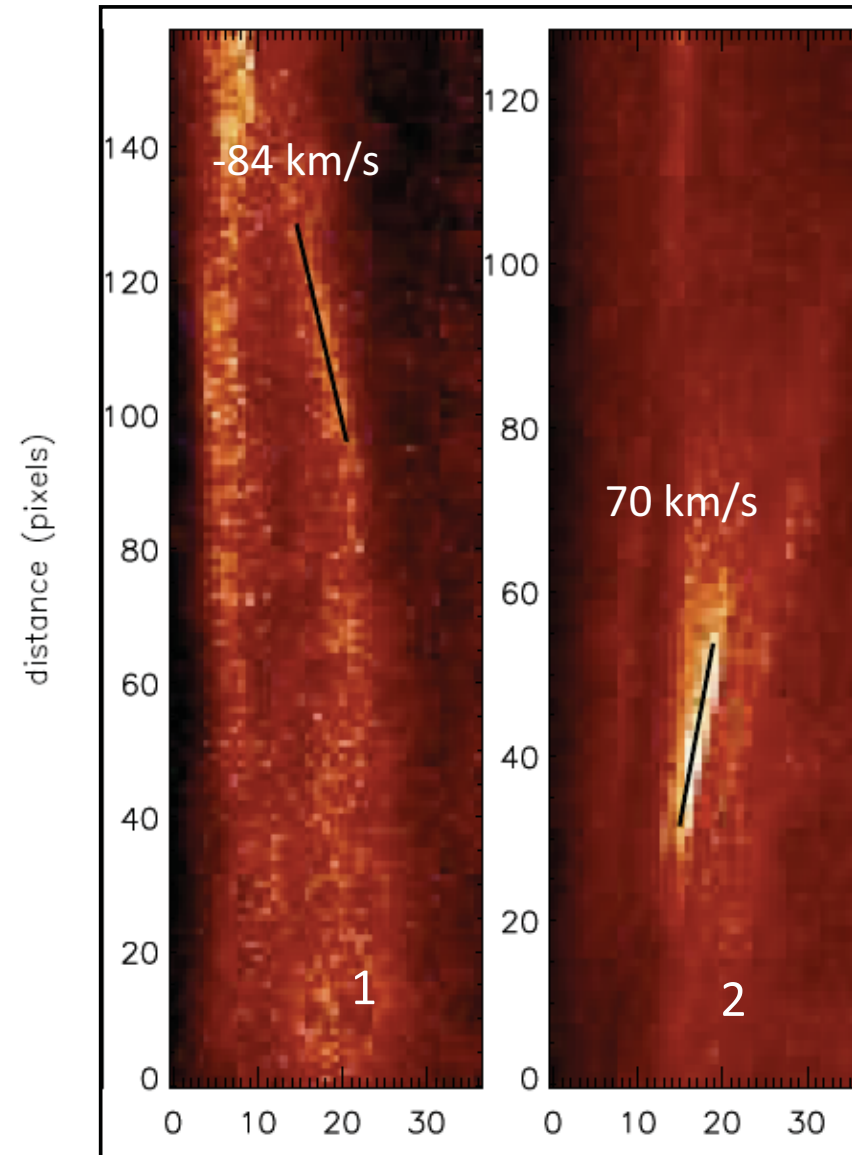
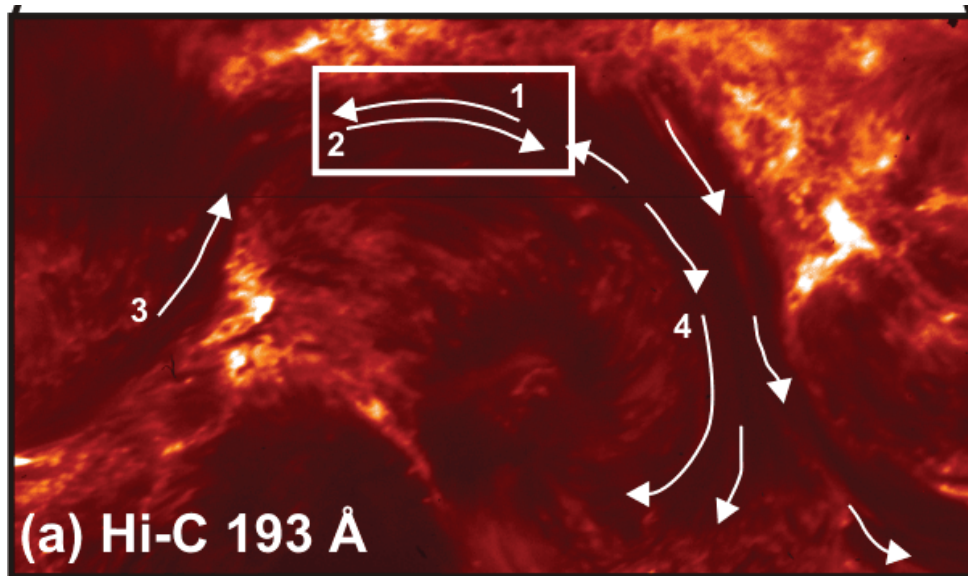
# Bi-directional Flows in Filaments



- Hi-C resolves two structures roughly 0.8'' wide
- AIA sees only a single structure.

# Bi-directional Flows in Filaments

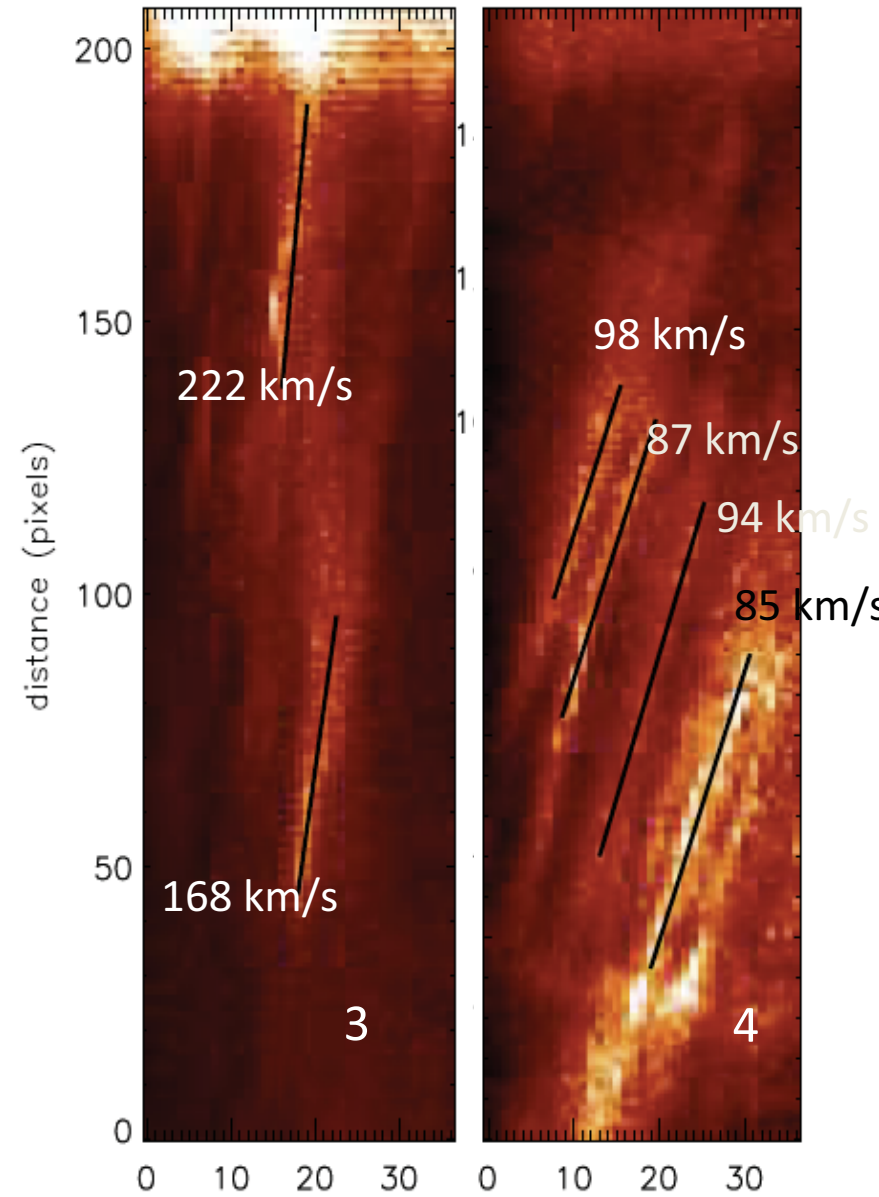
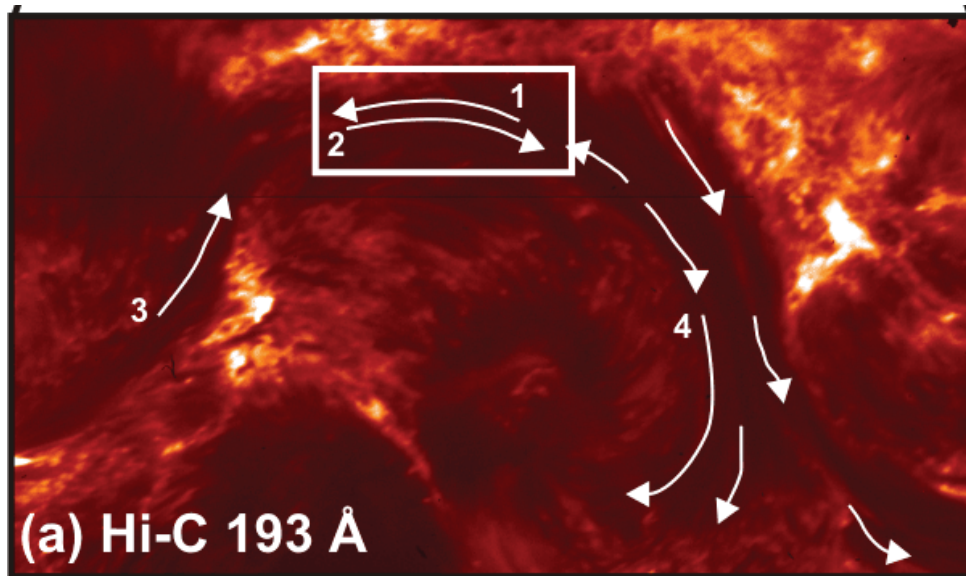
Velocities of Flows 1 and 2 are roughly equal and in opposite directions.



*Alexander, Walsh, in prep.*

# Bi-directional Flows in Filaments

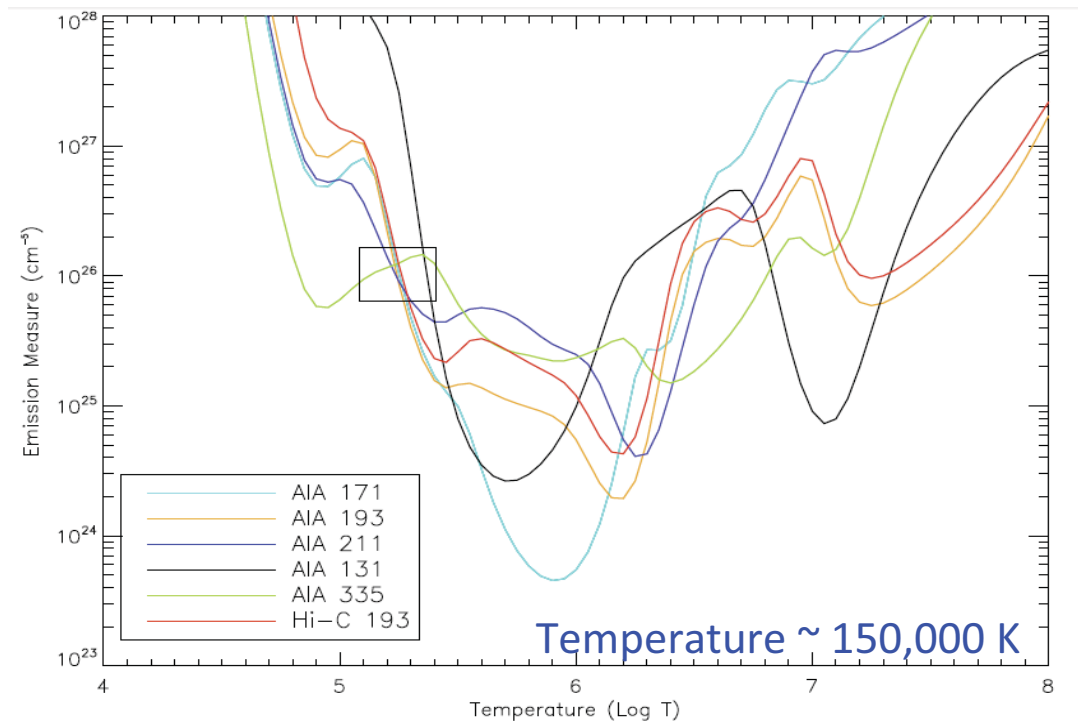
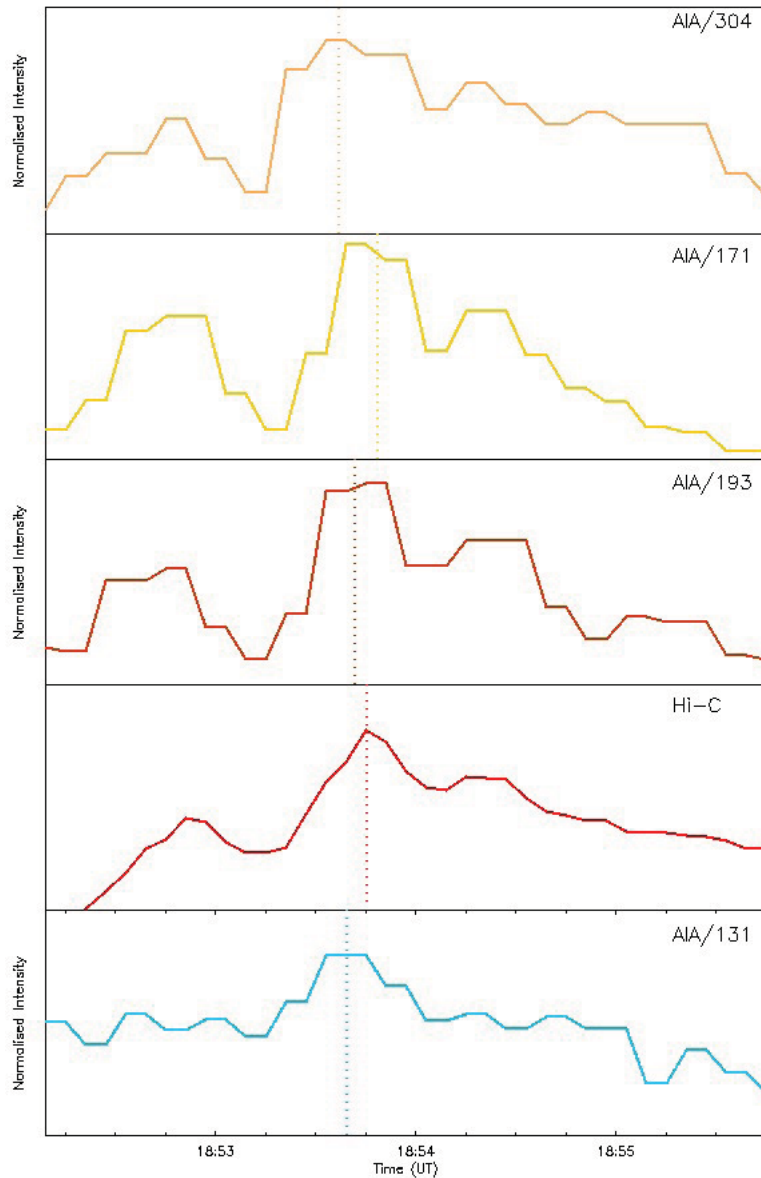
Velocities of Flows 3 is  $> 150$  km/s and Region 4 shows period flows of  $\sim 100$  km/s.



Alexander, Walsh, in prep.

# Bi-directional Flows in Filaments

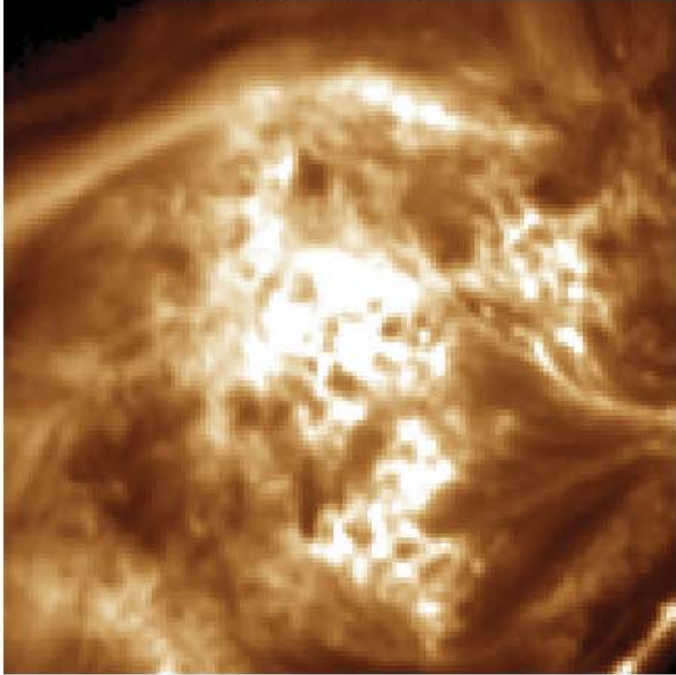
Light curves and EM Loci plots indicate the plasma is at an isothermal, cool temperature.



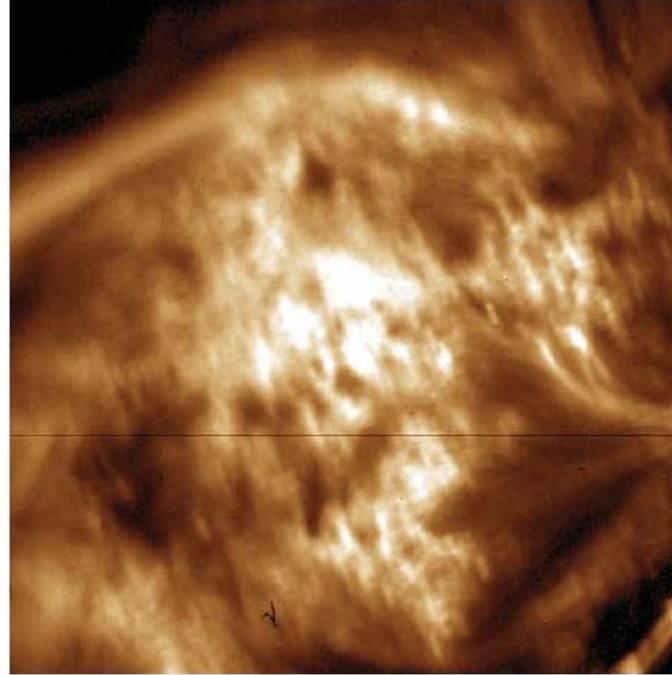
*Alexander, Walsh, in prep.*

# Spicules in Moss

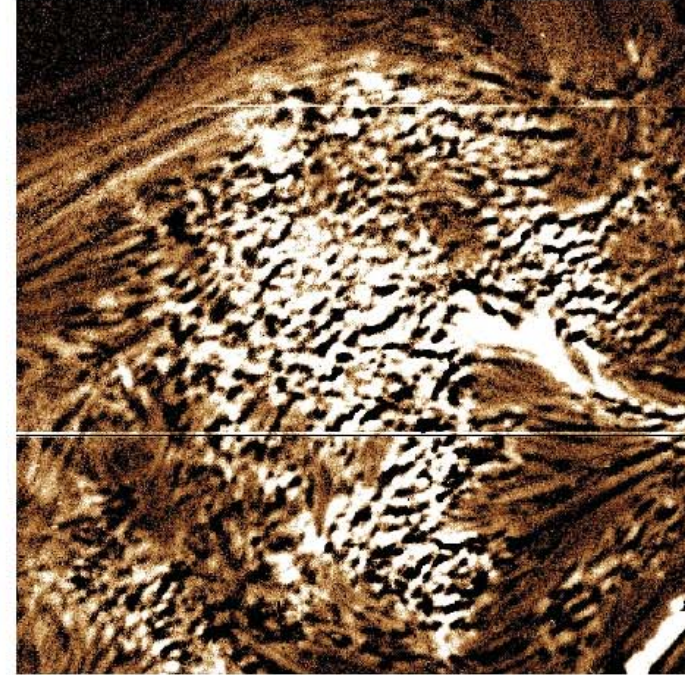
AIA 193 Å : 11-Jul-12 18:52:07.840



Hi-C 193 Å : 11-Jul-12 18:52:08.758



Enhanced Hi-C 193 Å : 11-Jul-12 18:52:08.758

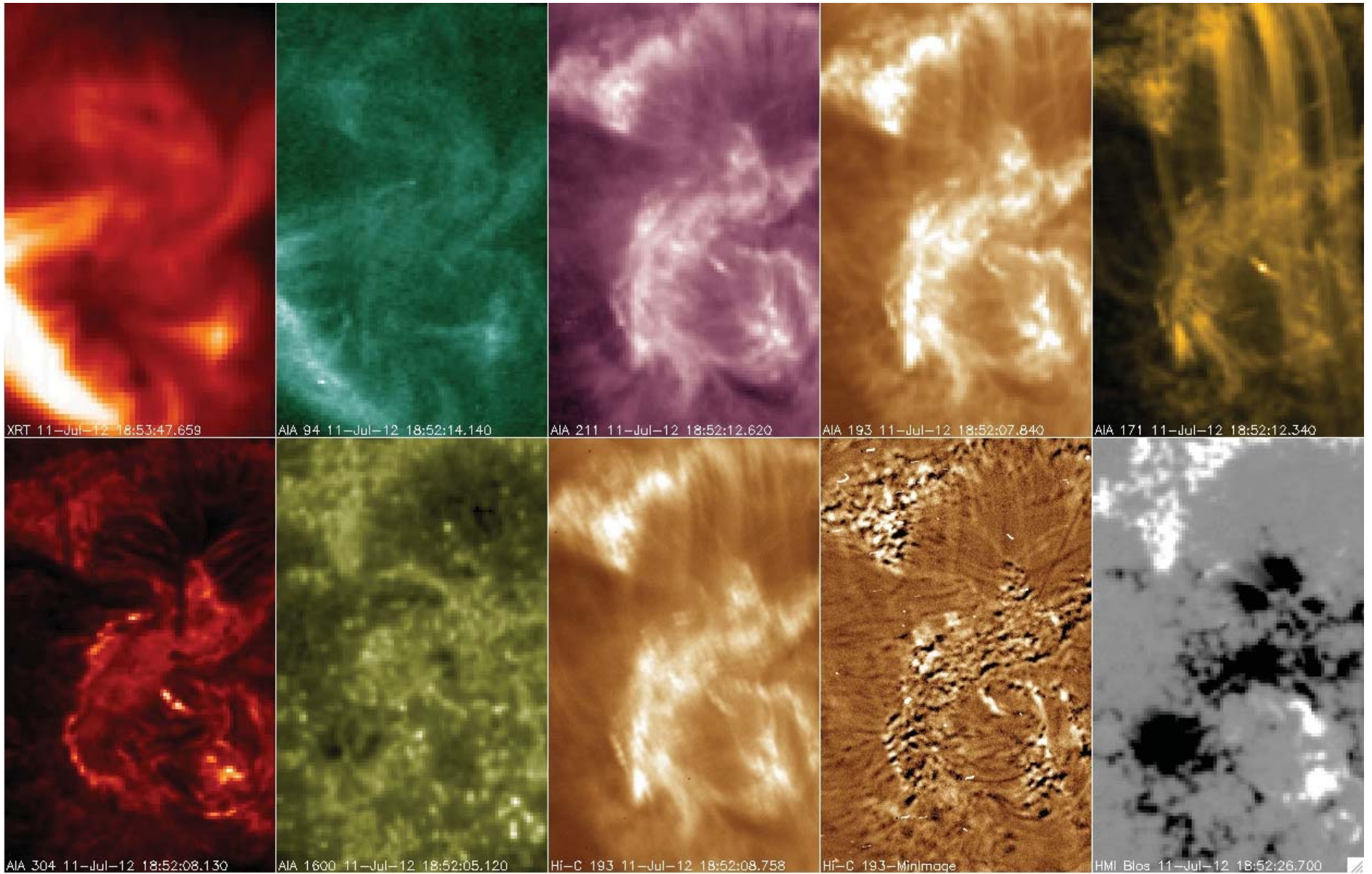


Hi-C reveals many short-lived absorption features in the moss. These features are likely spicules – dense plasma at chromospheric temperatures.

Currently studying the lifetime and evolutions of these features.

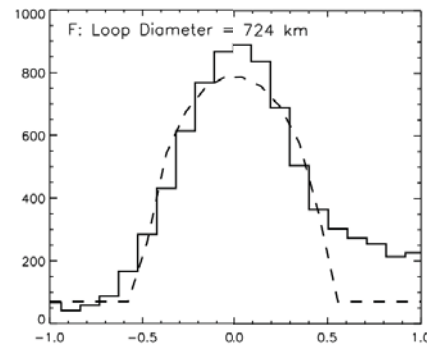
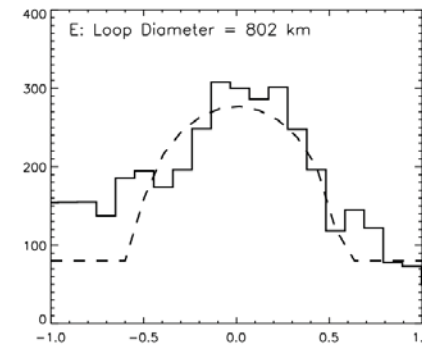
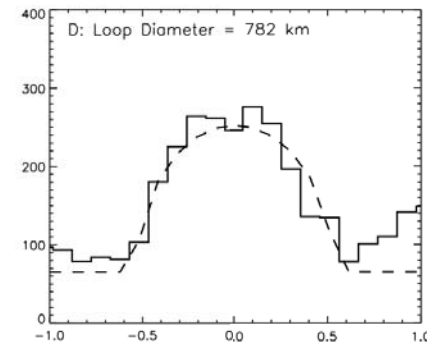
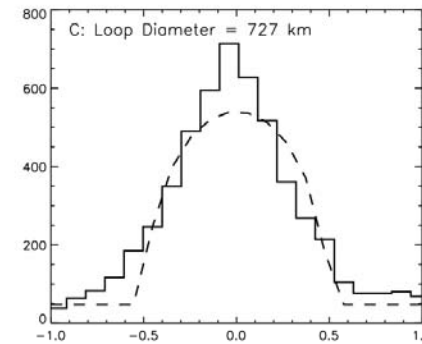
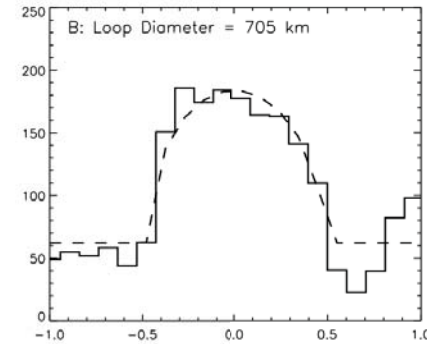
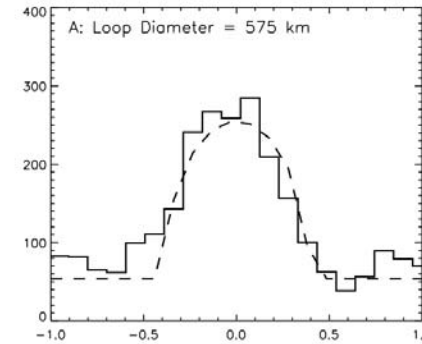
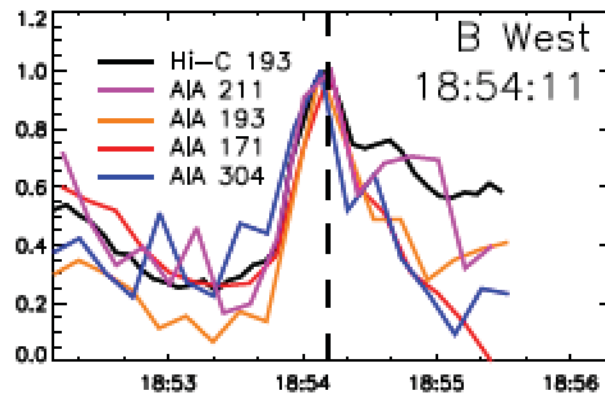
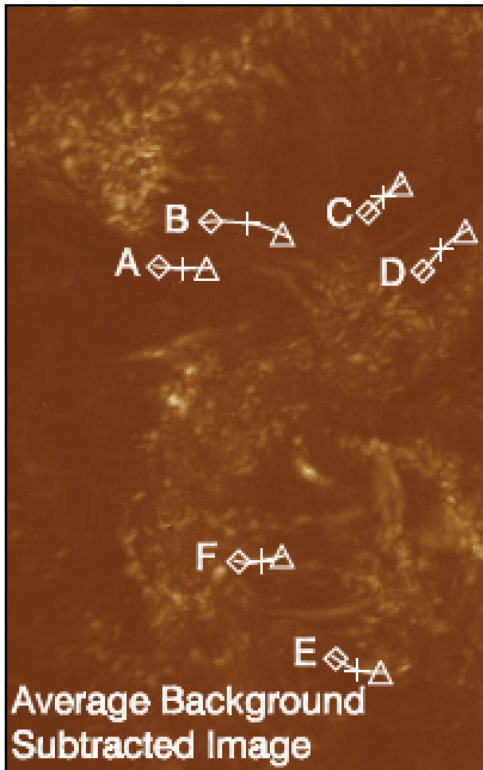
*Winebarger, in prep.*

# Flashing Loops



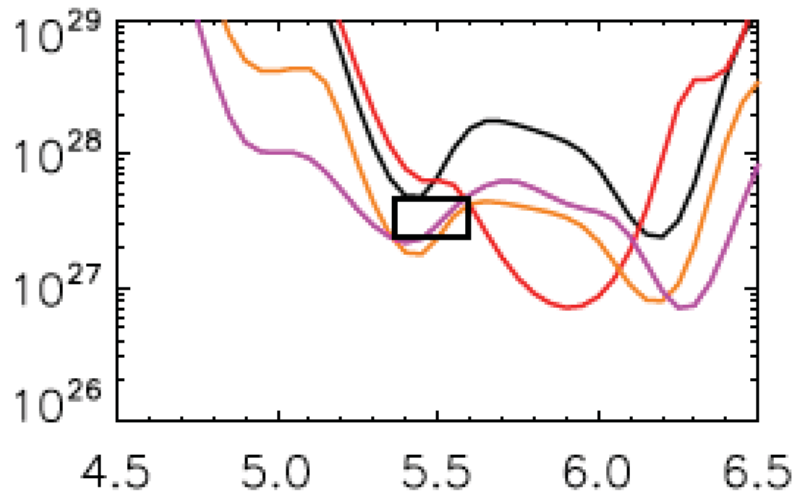
*Winebarger, Walsh, in prep.*

# Flashing Loops



- Six loops were identified.
- Diameter of loops 575-800 km
- Lifetime of loops < 60 s.

# Flashing Loops



Loop	Log T	Photospheric Log EM	$n_e$
A	$5.48 \pm 0.12$	$27.52 \pm 0.15$	$7.58\text{E}+09$
B	$5.47 \pm 0.13$	$27.61 \pm 0.13$	$7.62\text{E}+09$
C	$5.47 \pm 0.12$	$28.03 \pm 0.12$	$1.21\text{E}+10$
D	$5.47 \pm 0.12$	$27.74 \pm 0.12$	$8.34\text{E}+09$
E	$5.44 \pm 0.14$	$28.01 \pm 0.06$	$1.13\text{E}+10$
F	$5.44 \pm 0.14$	$28.27 \pm 0.06$	$1.60\text{E}+10$

- Because loops evolve identically in multiple AIA filters, we conclude the loops are isothermal.
- EM Loci analysis indicate a cool (300,000 K) temperature.
- Density estimates are  $7\text{-}10 \times 10^9 \text{ cm}^{-3}$ .



# Summary



- Hi-C obtained the highest spatial and temporal resolution observations ever taken in the solar corona.
- Hi-C reveals dynamics and structure at the limit of its temporal and spatial resolution.
- Hi-C observed ubiquitous fine-scale flows consistent with the local sound speed.