

Spatially Resolved Measurements of Turbulence in the Flare Reconnection Region

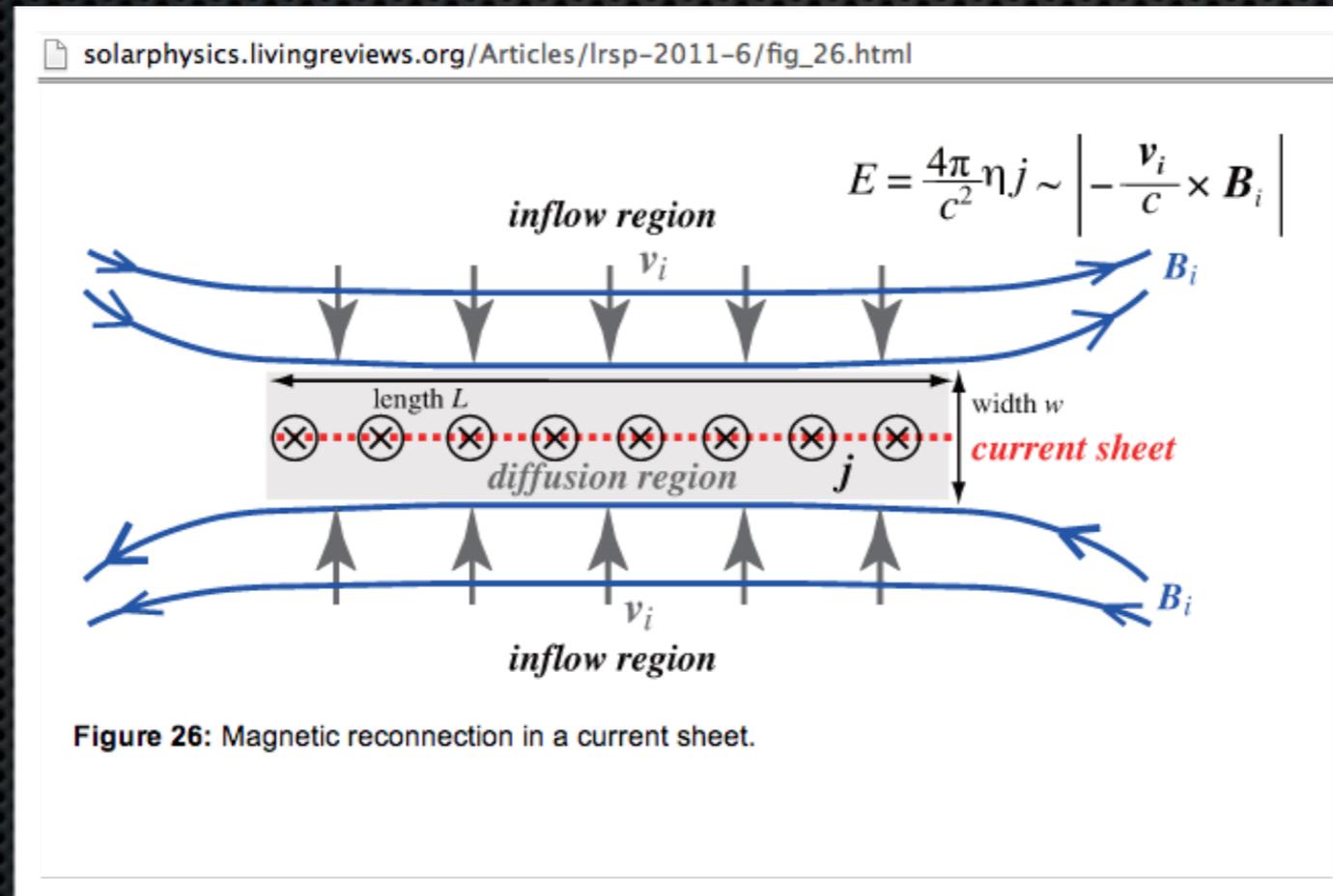
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Harry Warren², Michael Freed¹

¹Montana State University

²Naval Research Lab

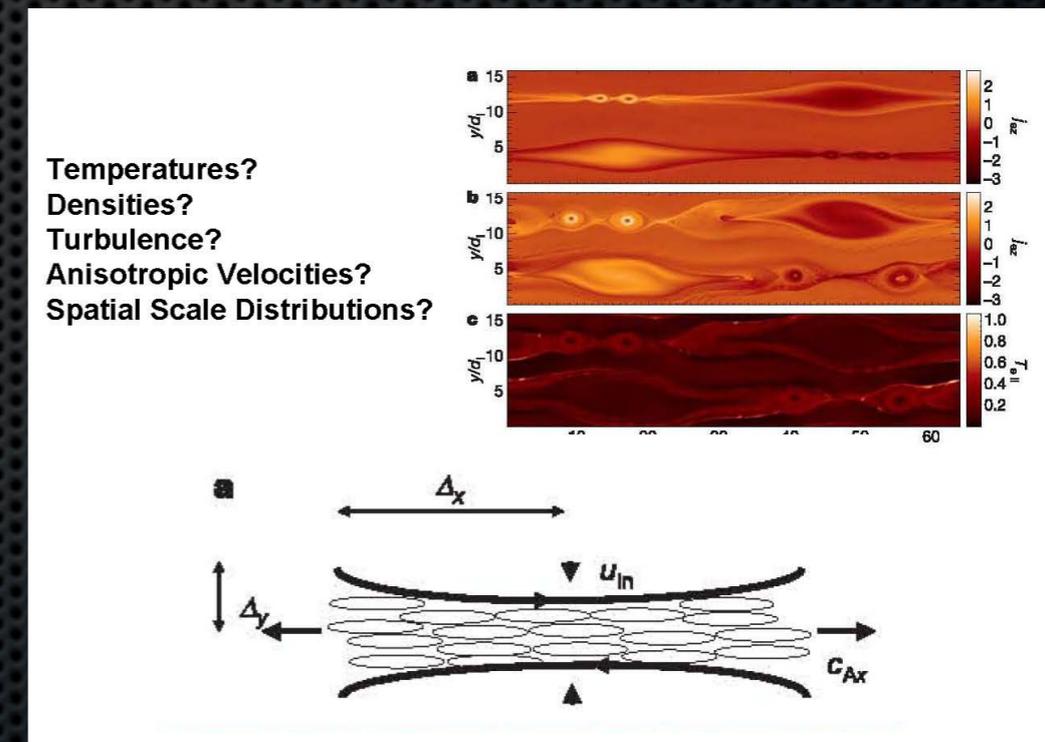
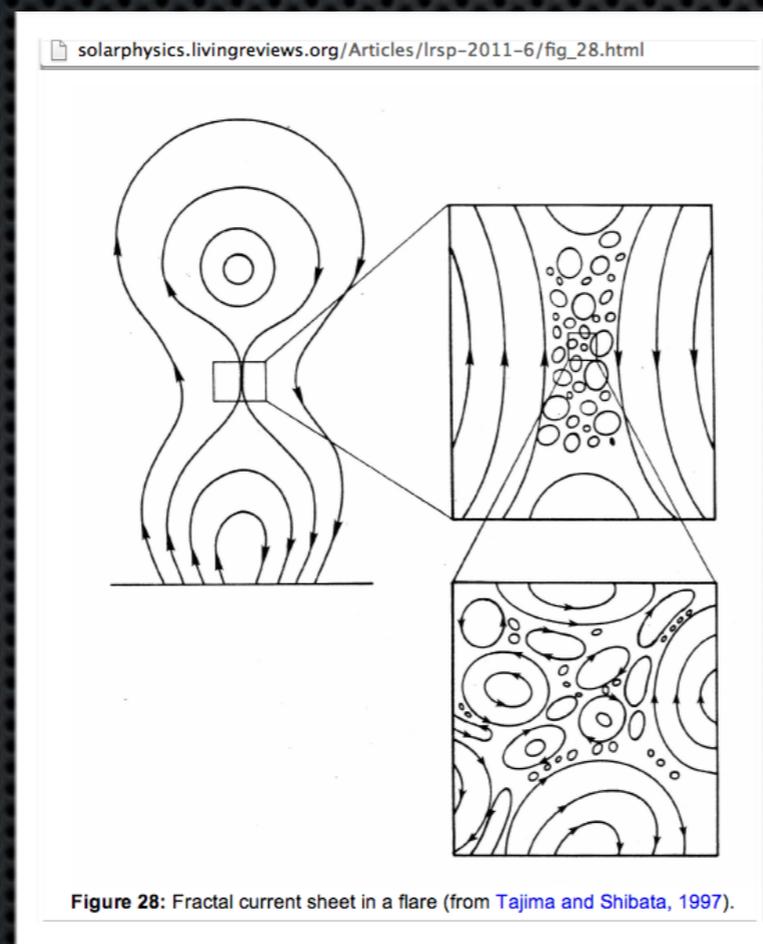
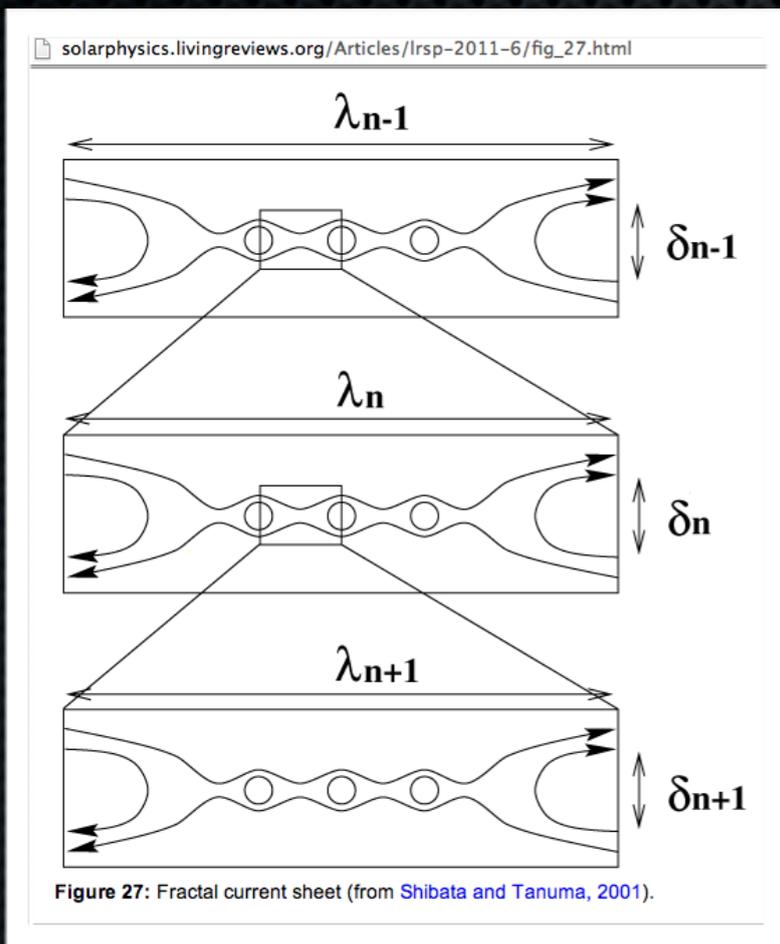
Reconnection happens

- But needs small length scales, and locally enhanced resistivity, to achieve useful speeds/timescales

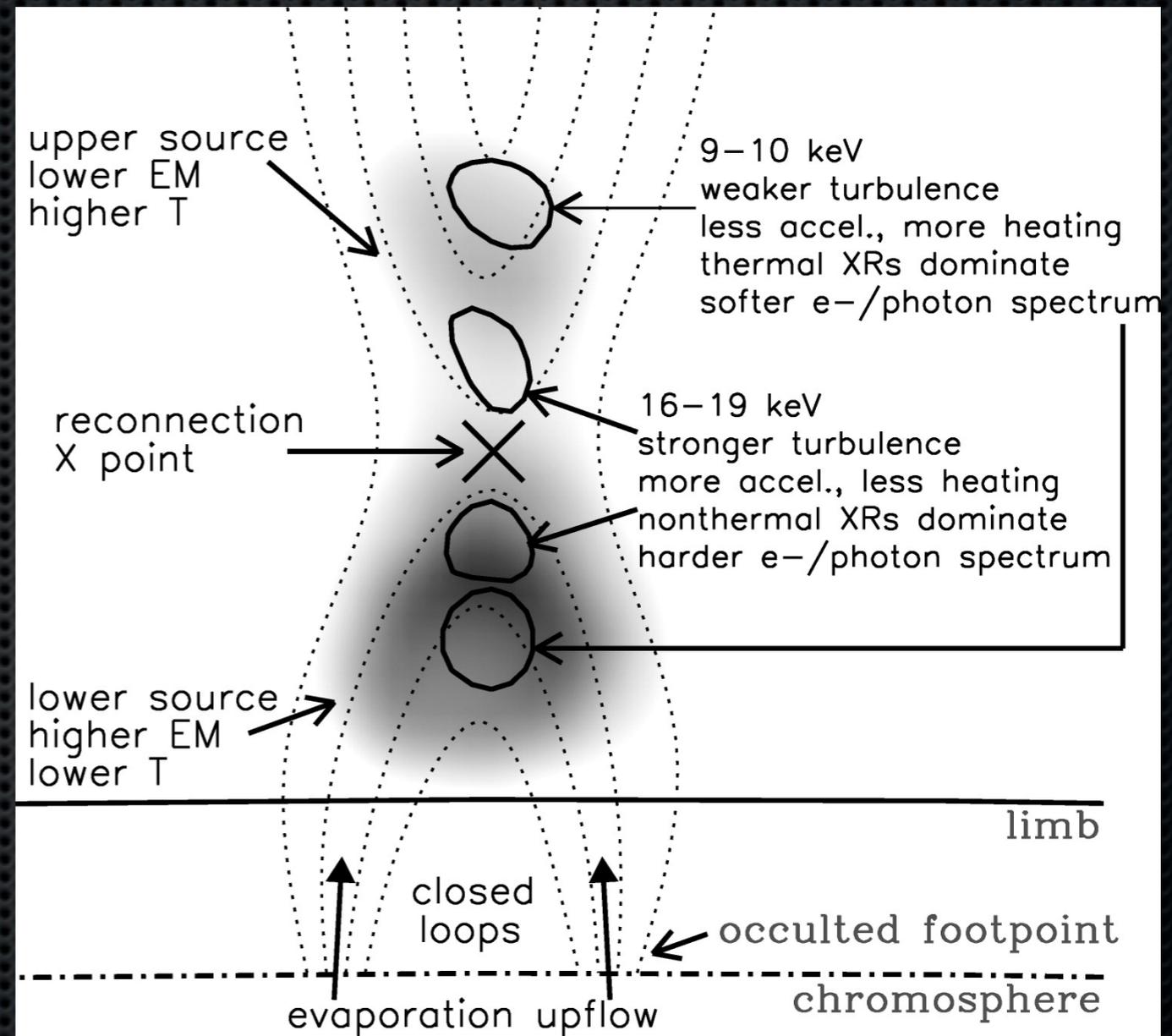
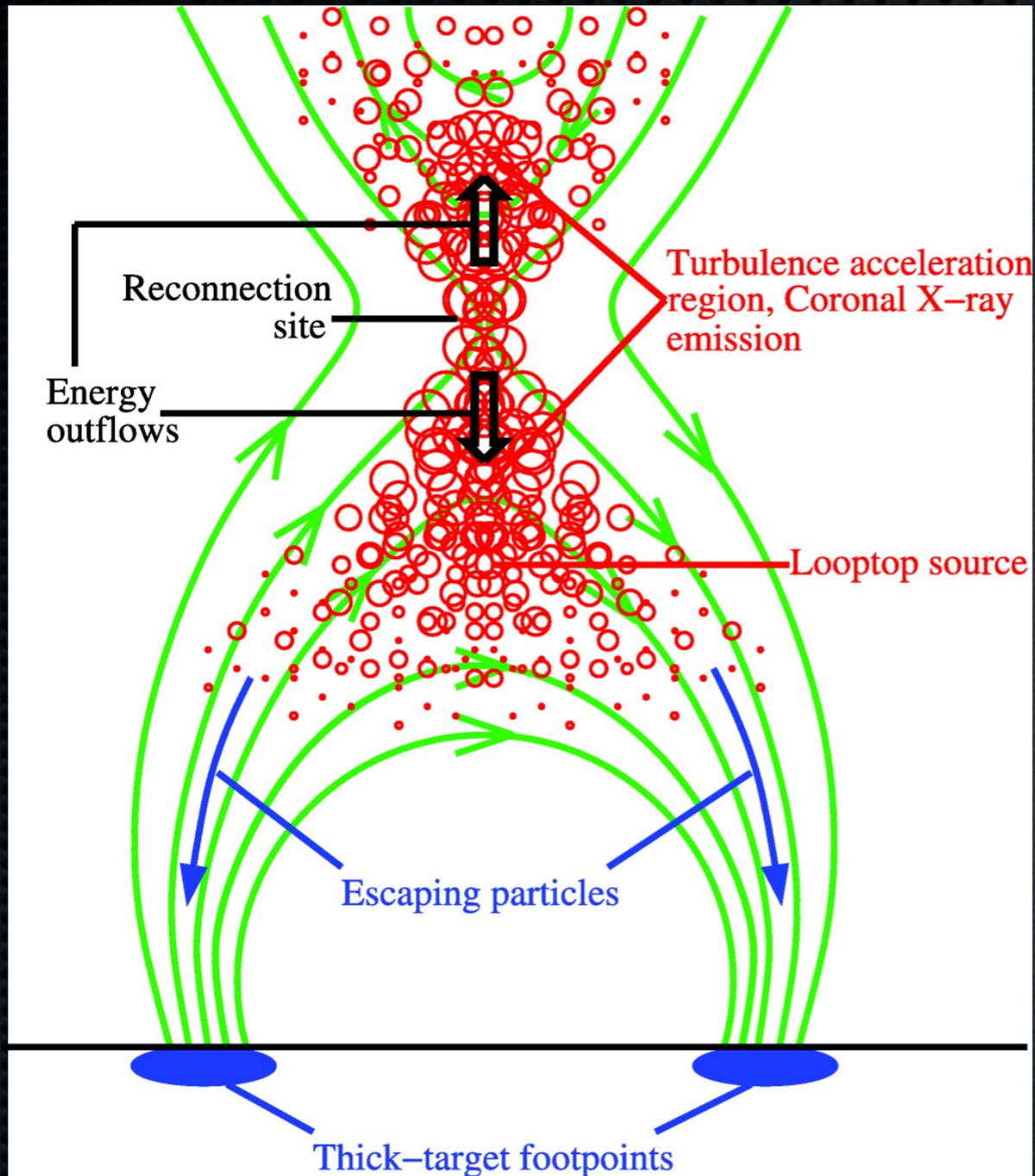


Reconnection happens

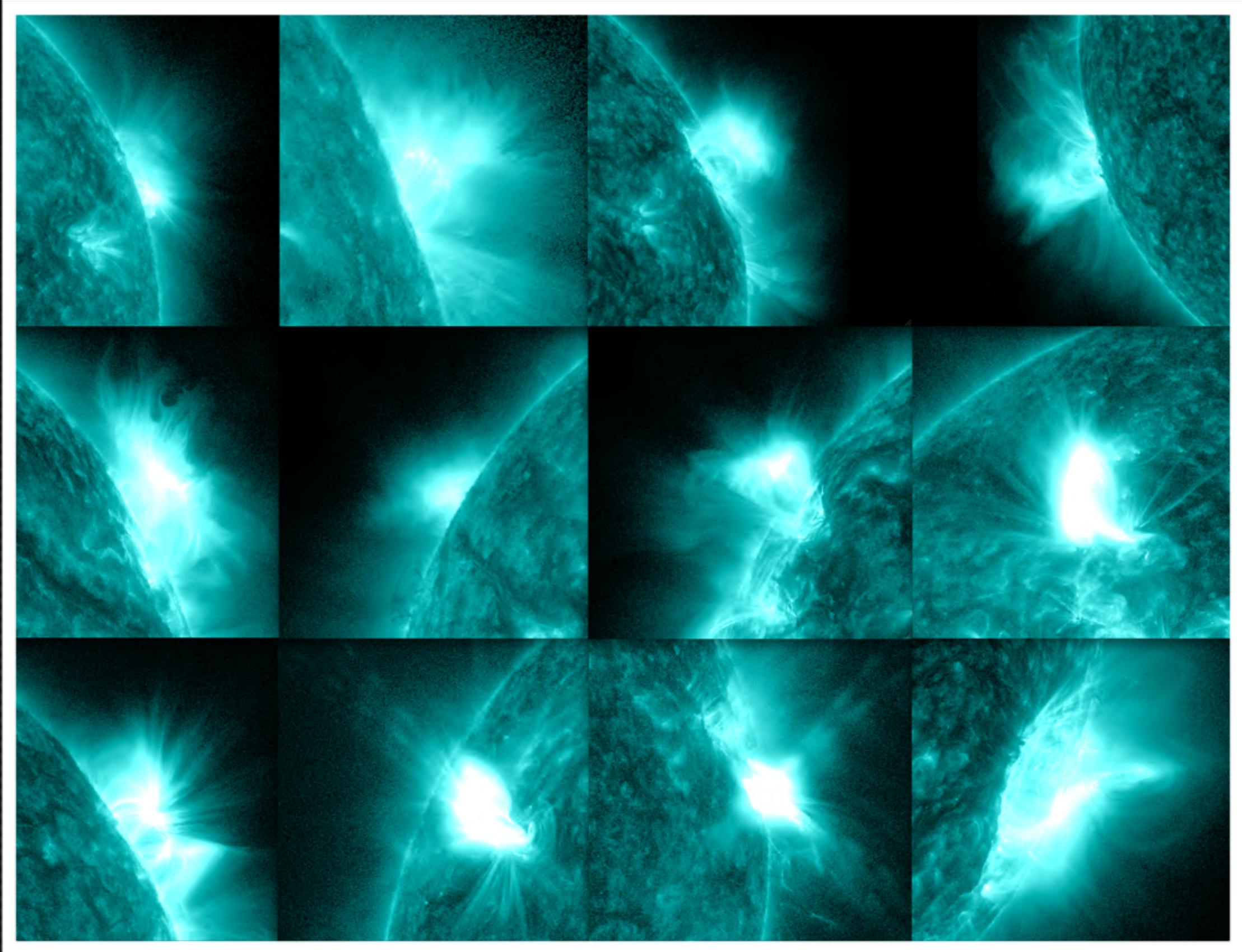
- But needs small length scales, and locally enhanced resistivity, to achieve useful speeds/timescales



Drake et al. Nature, 443, 553 (2006)



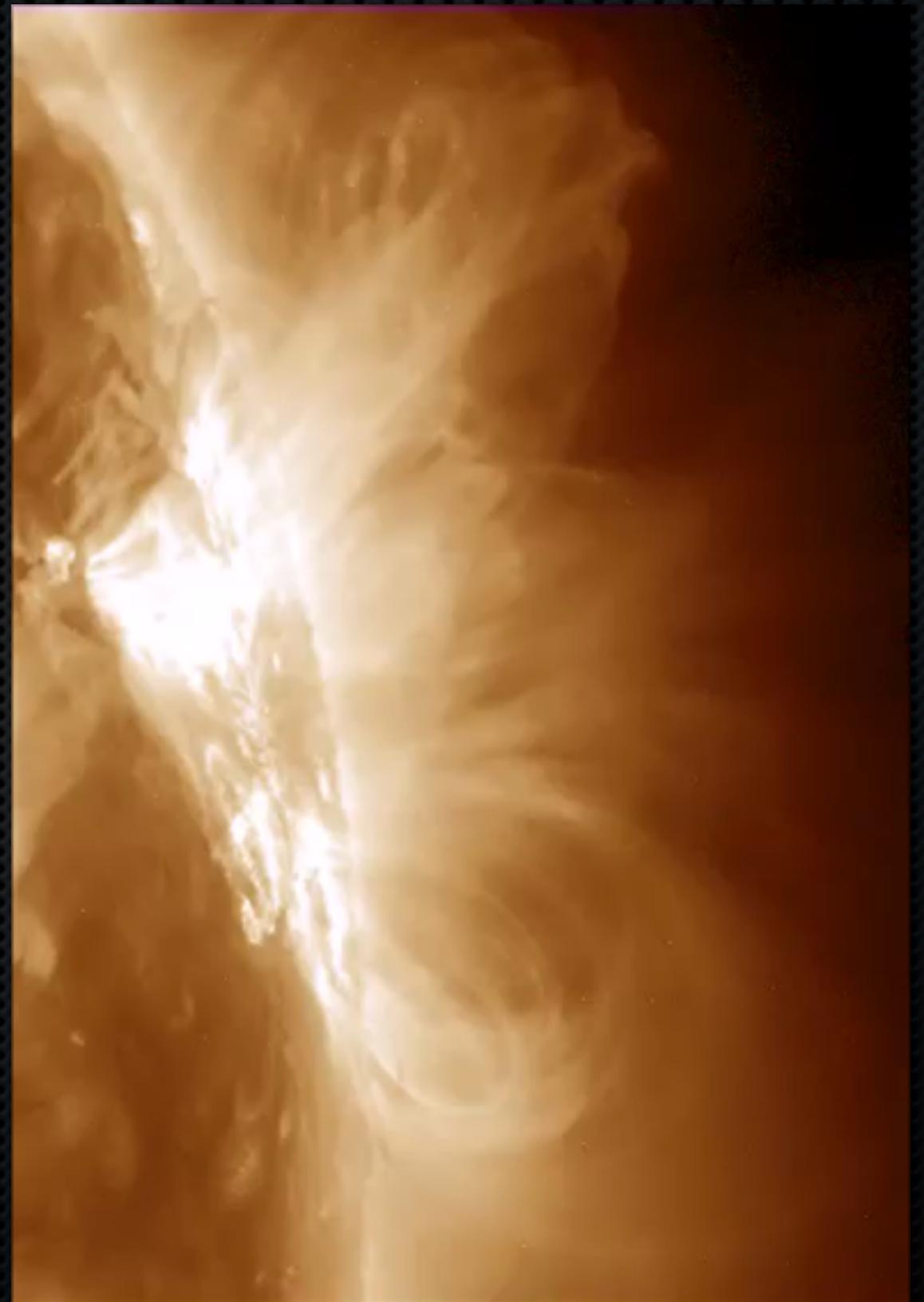
Liu et al. ApJ, 676, 704 (2008)



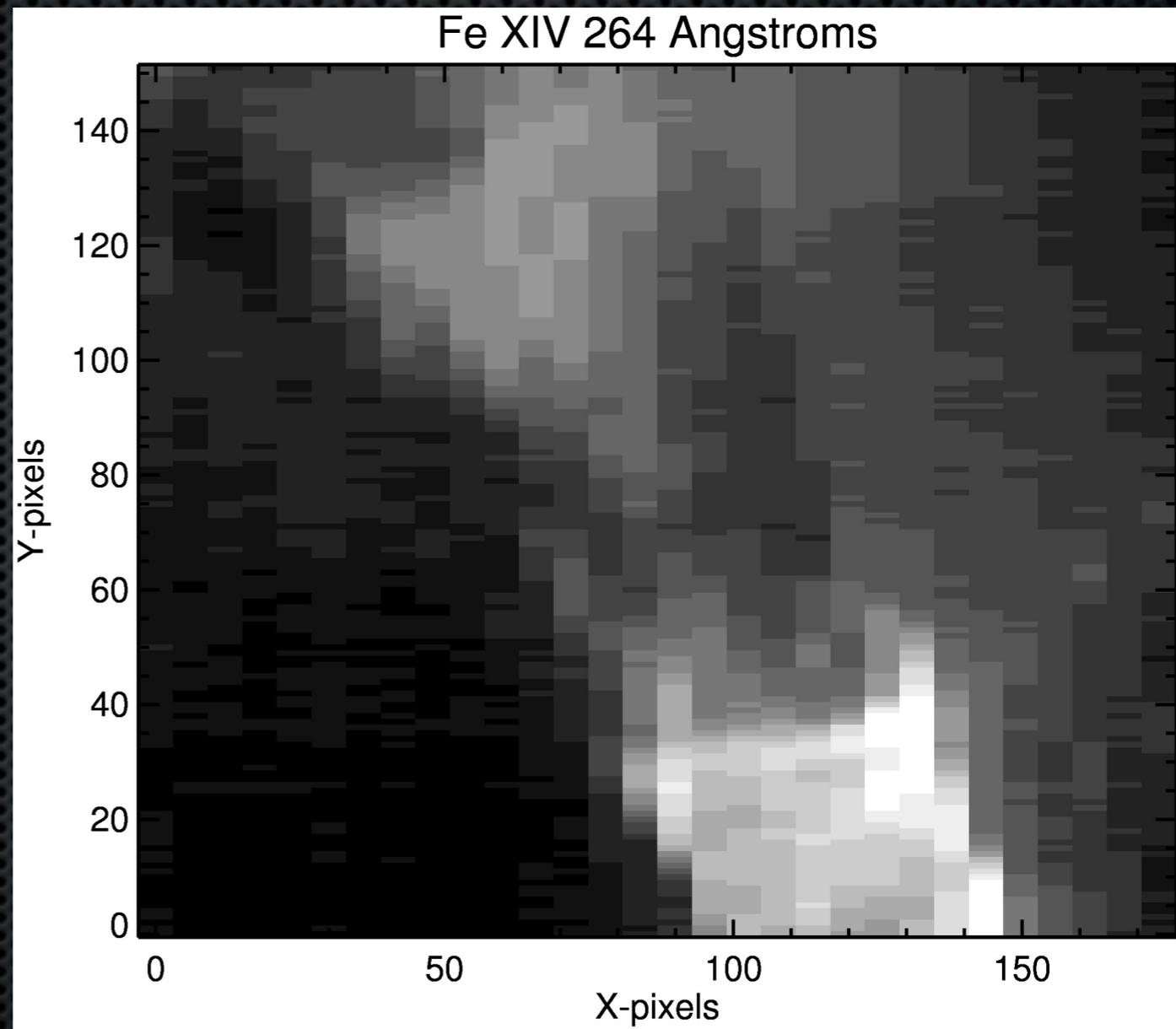
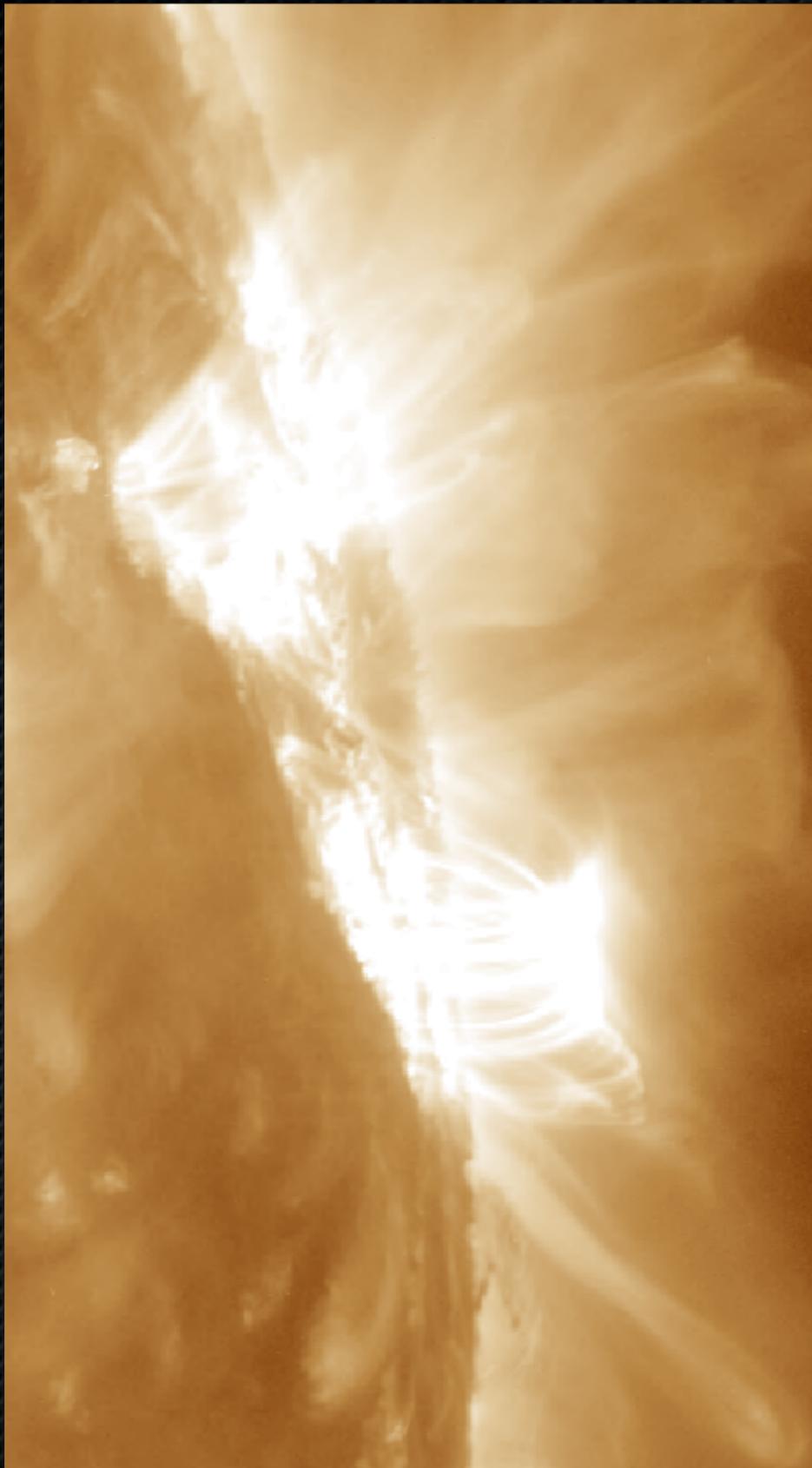
2012/05/17 Event

- ✦ GOES M5.1
- ✦ Complex motions, with eruptions, oscillations, and inflows
- ✦ This study focuses on the plasma sheet above the post-eruption arcade in the south.

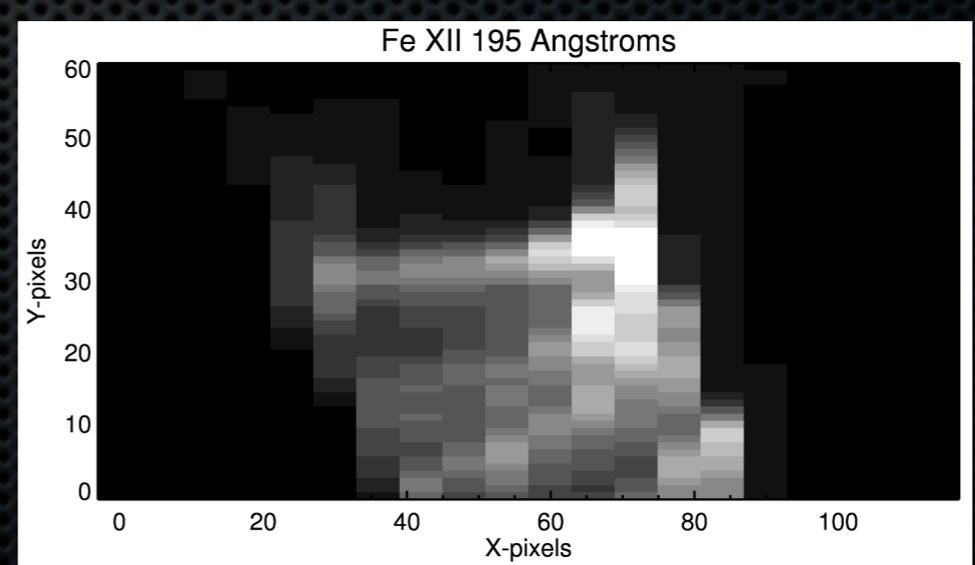
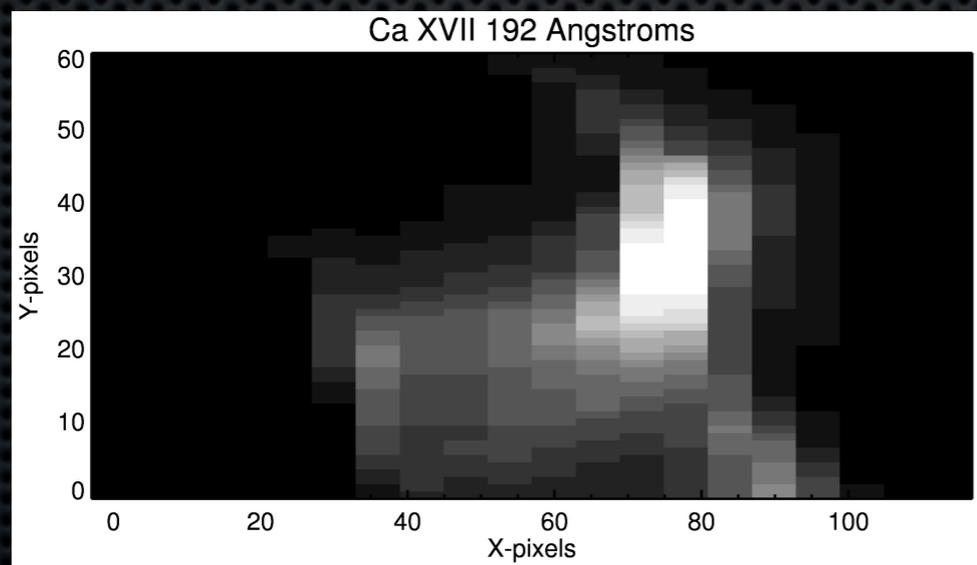
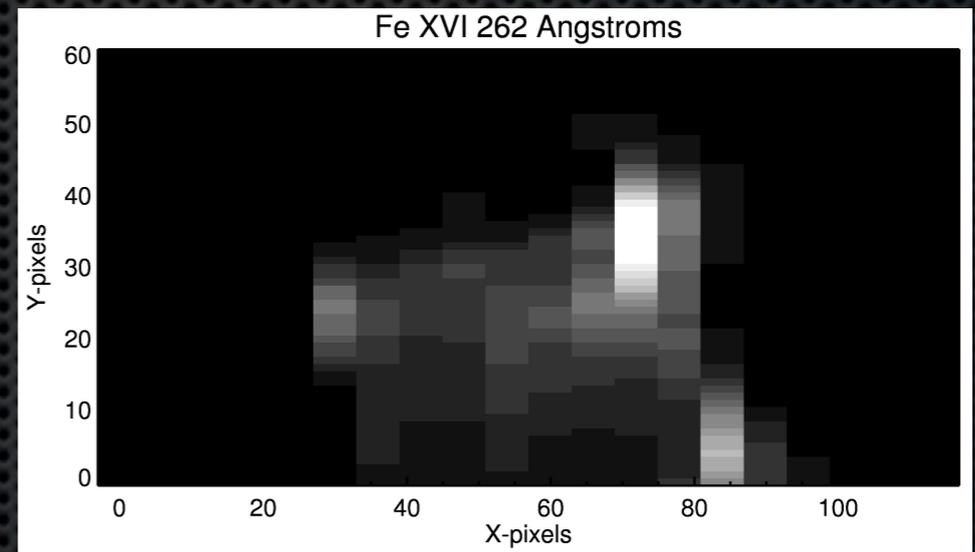
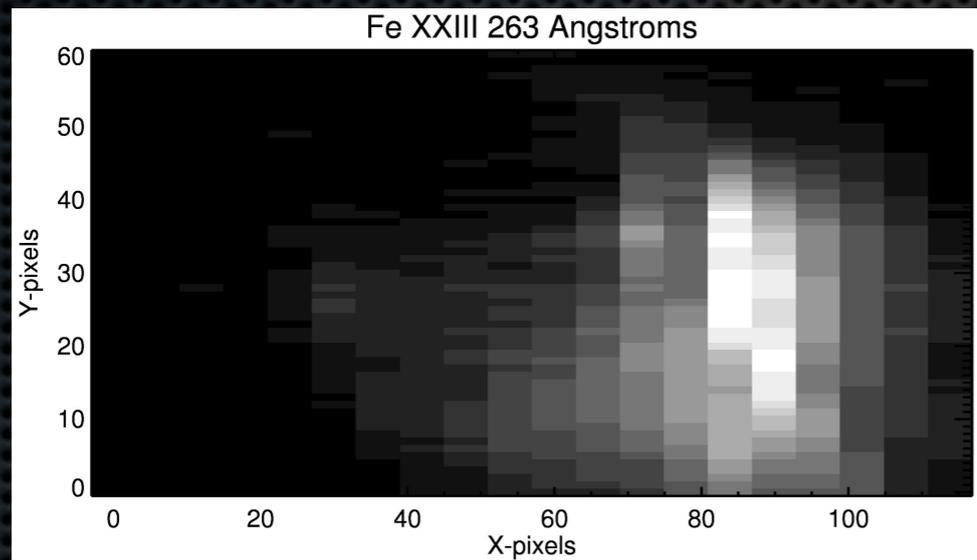
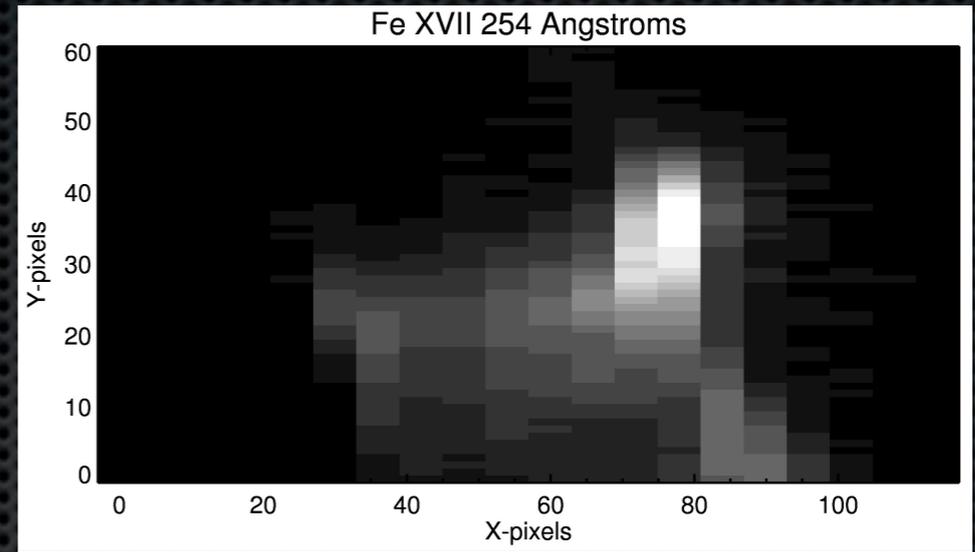
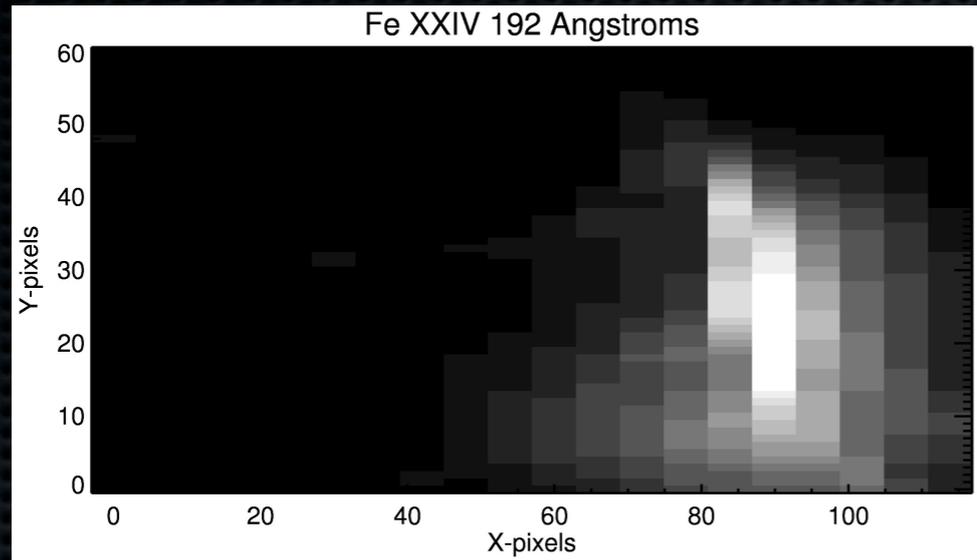
Movie file:
http://solar.physics.montana.edu/mckenzie/SADmovies/Explosive_Flare_20120517.mp4



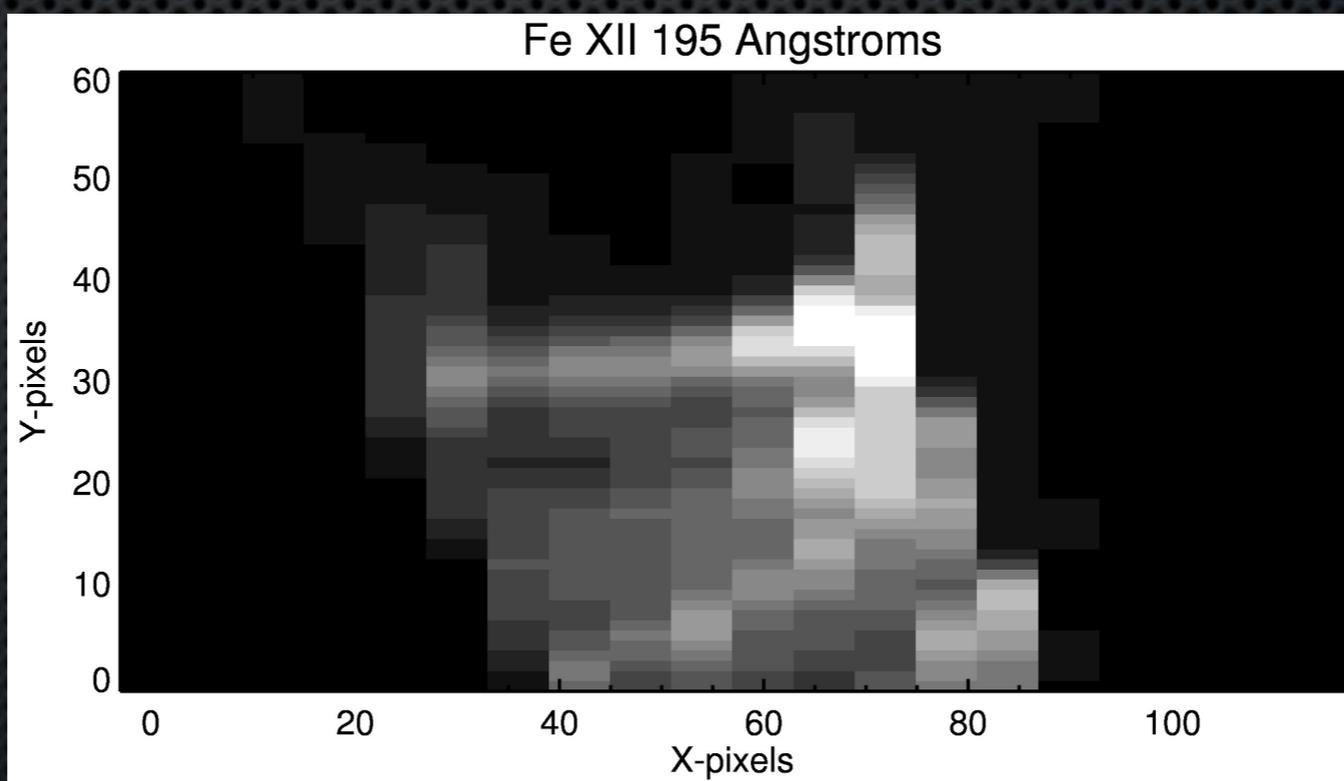
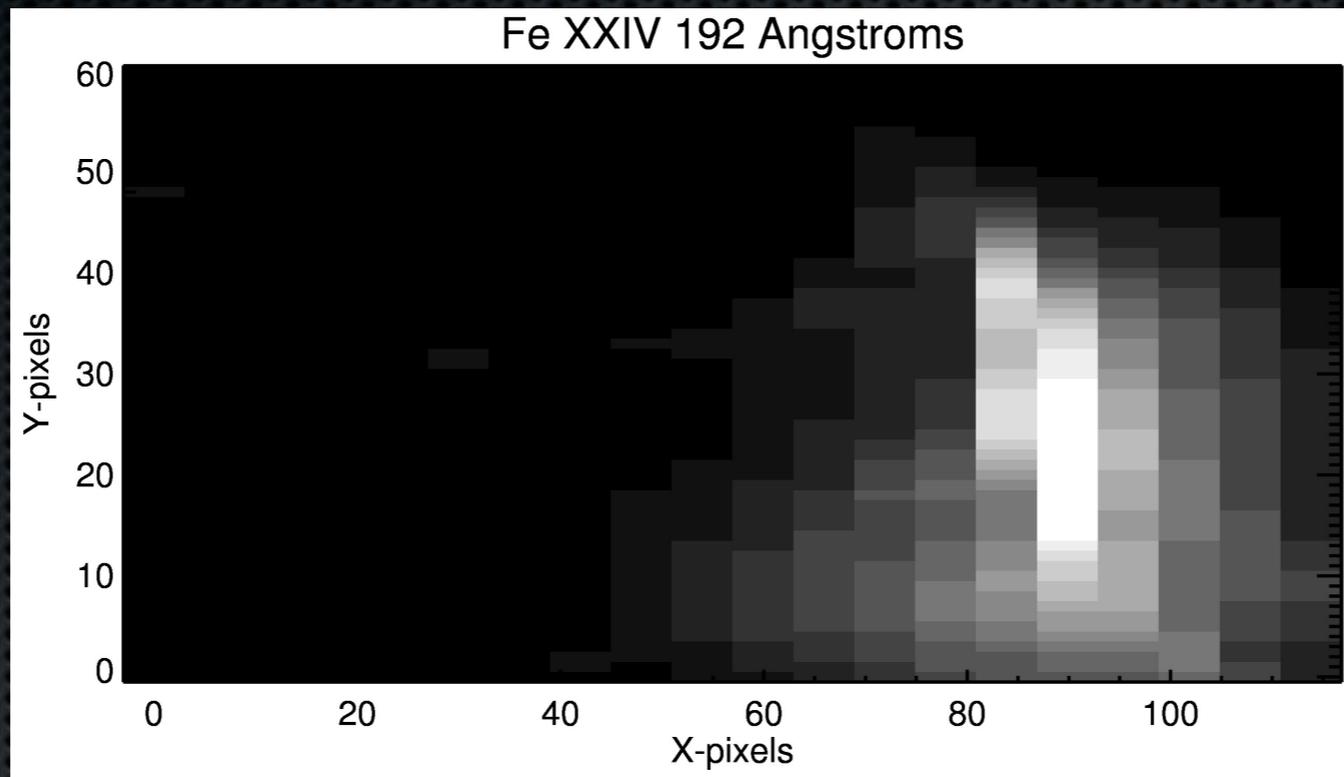
EIS and AIA



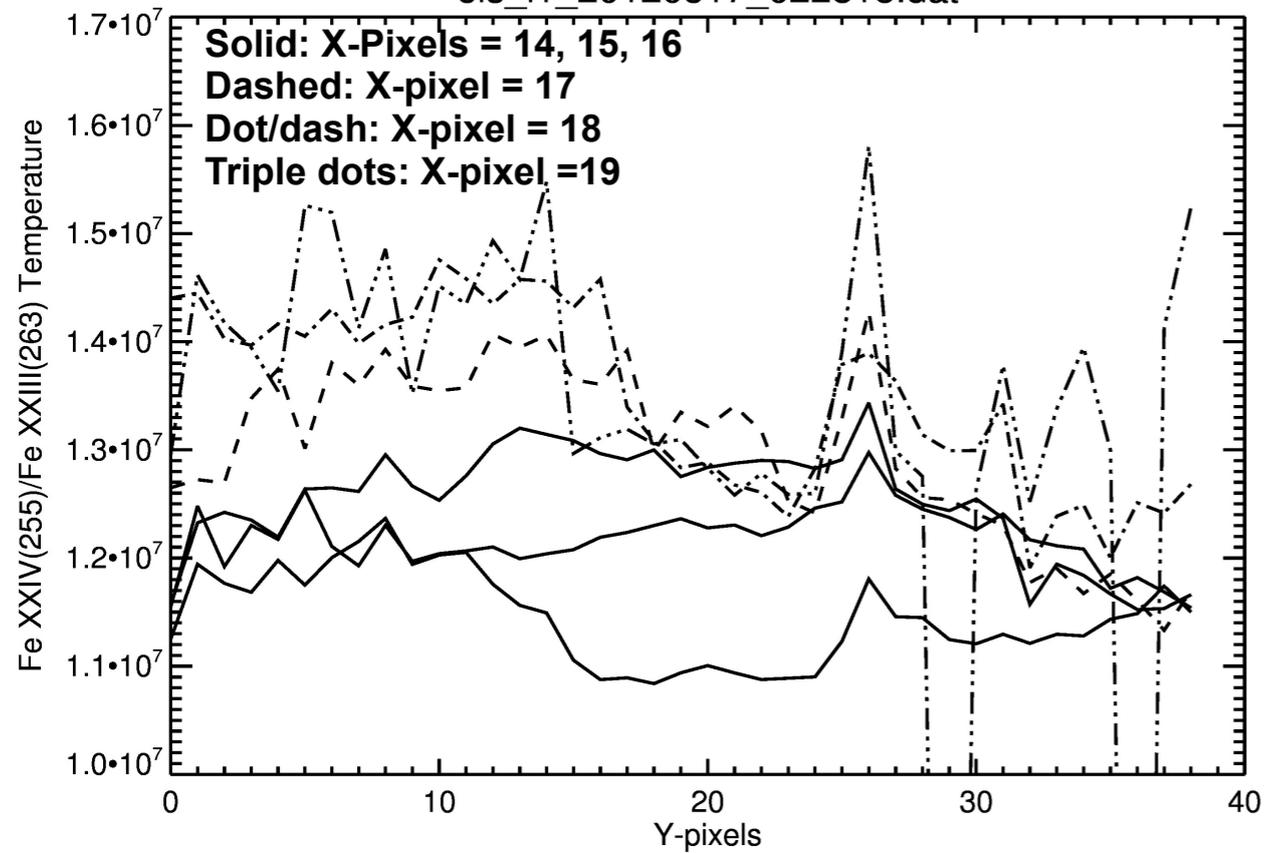
EIS rasters at range of temperature



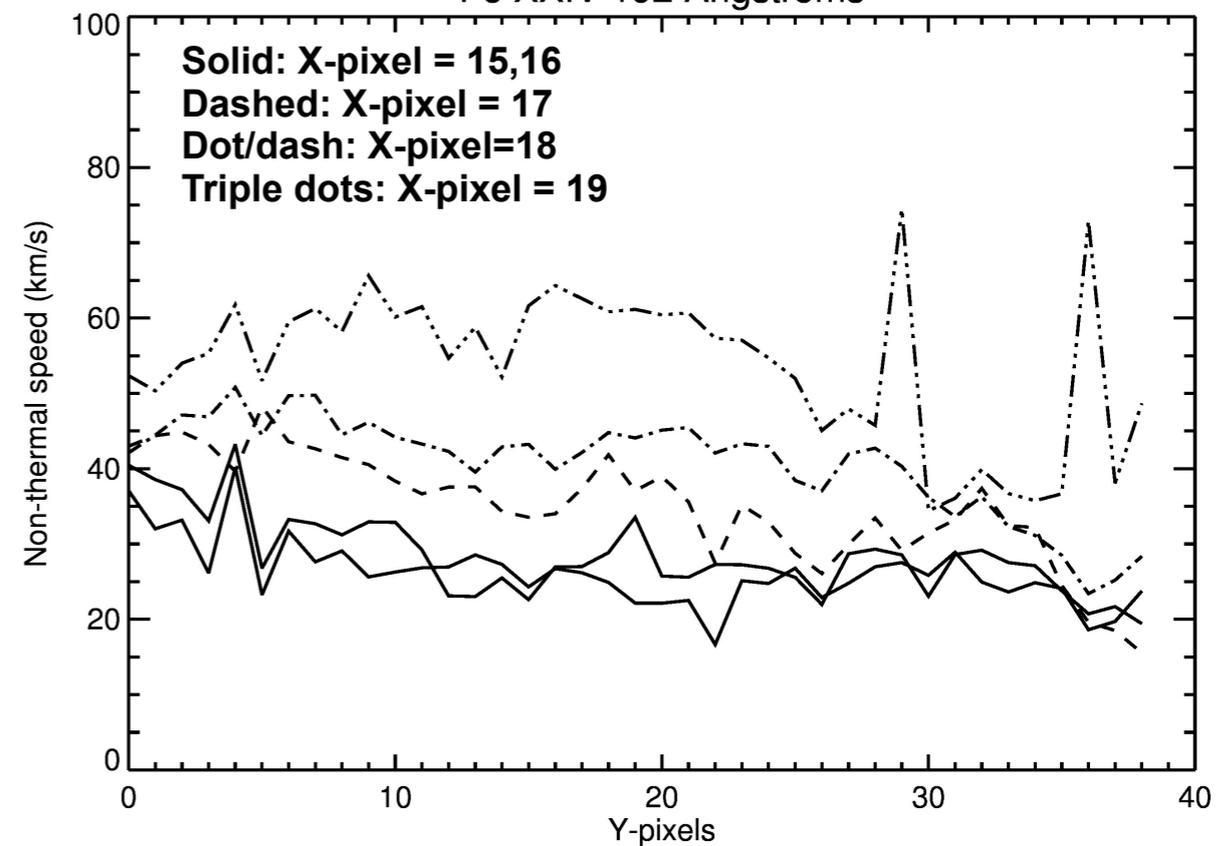
EIS rasters at range of temperature



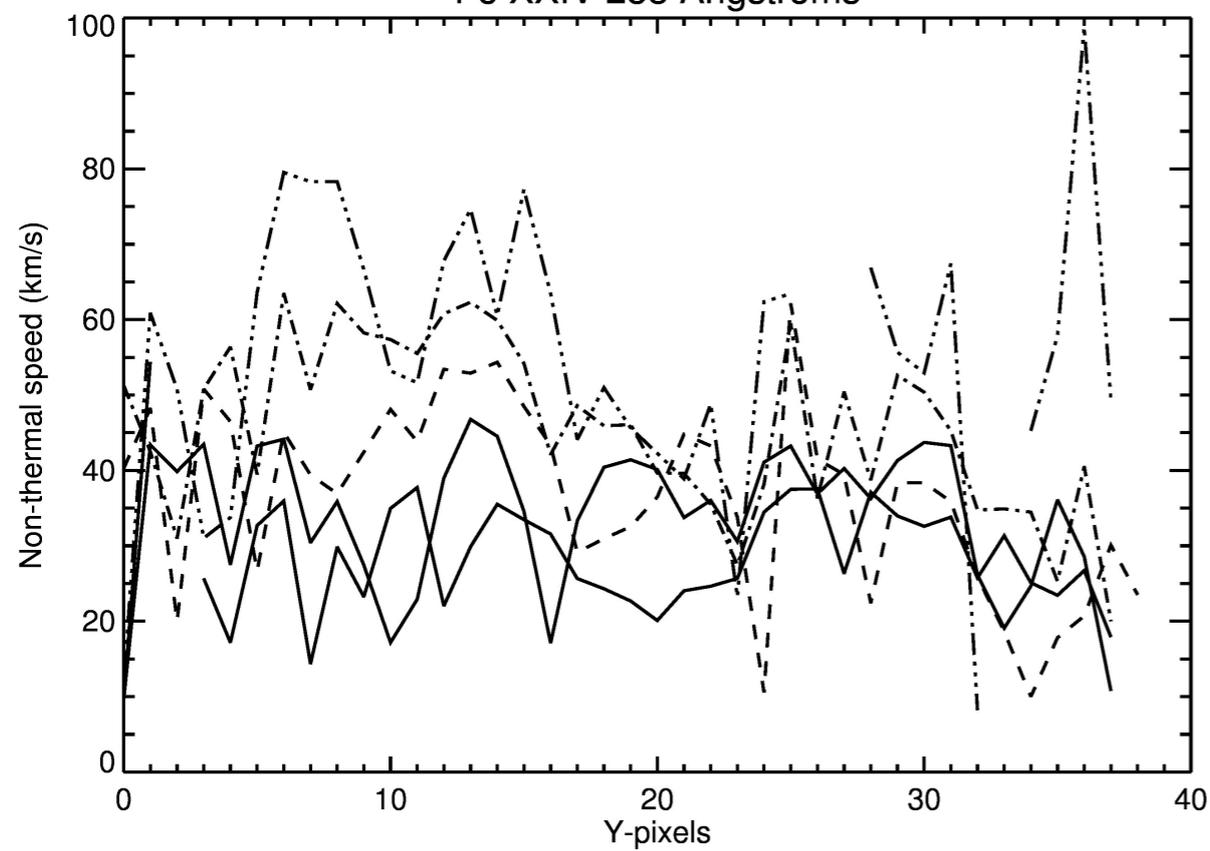
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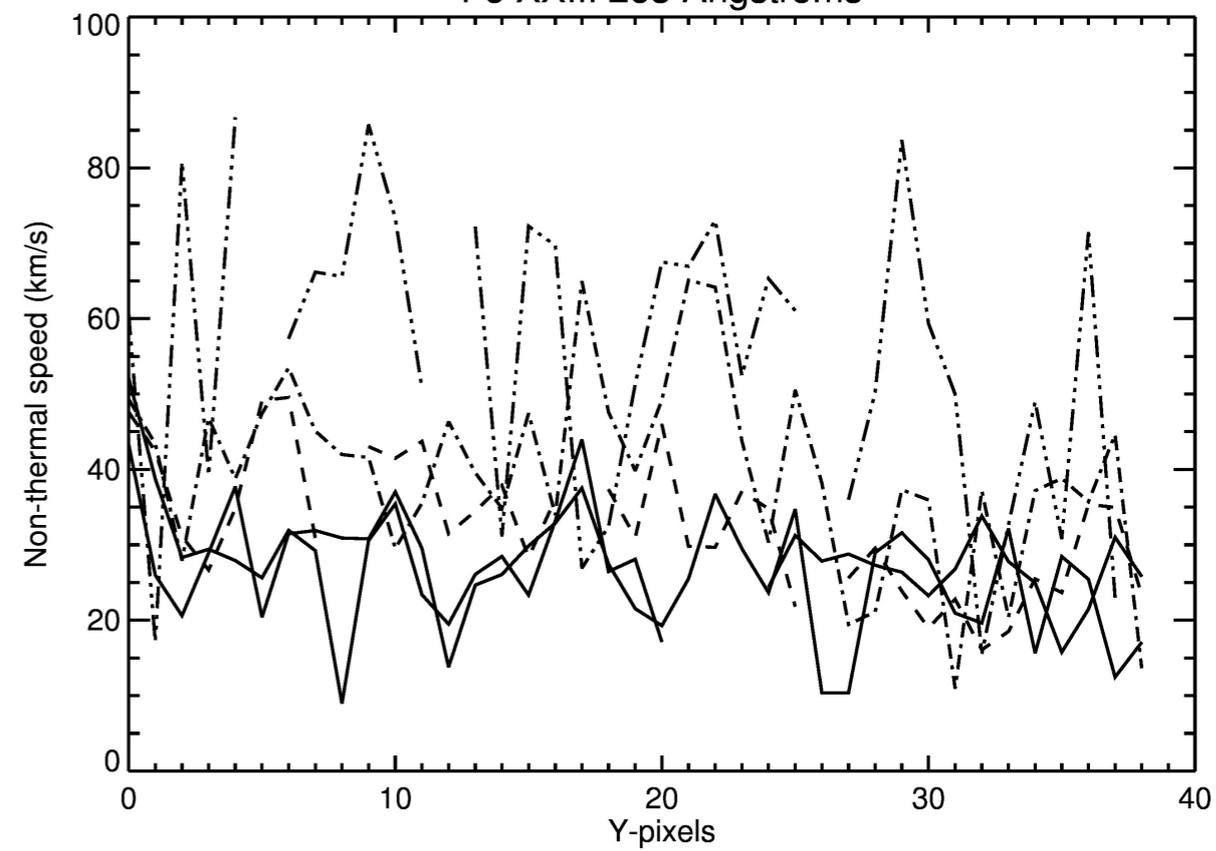
Fe XXIV 192 Angstroms



Fe XXIV 255 Angstroms



Fe XXIII 263 Angstroms



Non-thermal broadening velocities vary with height

Box 1:

Fe XXIV/Fe XXIII - 49 km/s;

Temperature = 13.6 MK

Fe XII - 28 km/s

Box 2:

Fe XXIV/Fe XXIII - 34 km/s;

Temperature = 12.7 MK

Fe XII - 33 km/s

Box 3:

Fe XXIV/Fe XXIII - 28 km/s;

Temperature = 11.8 MK

Fe XII - 35 km/s

Box 4:

Fe XXIV/Fe XXIII - 28 km/s;

Temperature = 11.4 MK

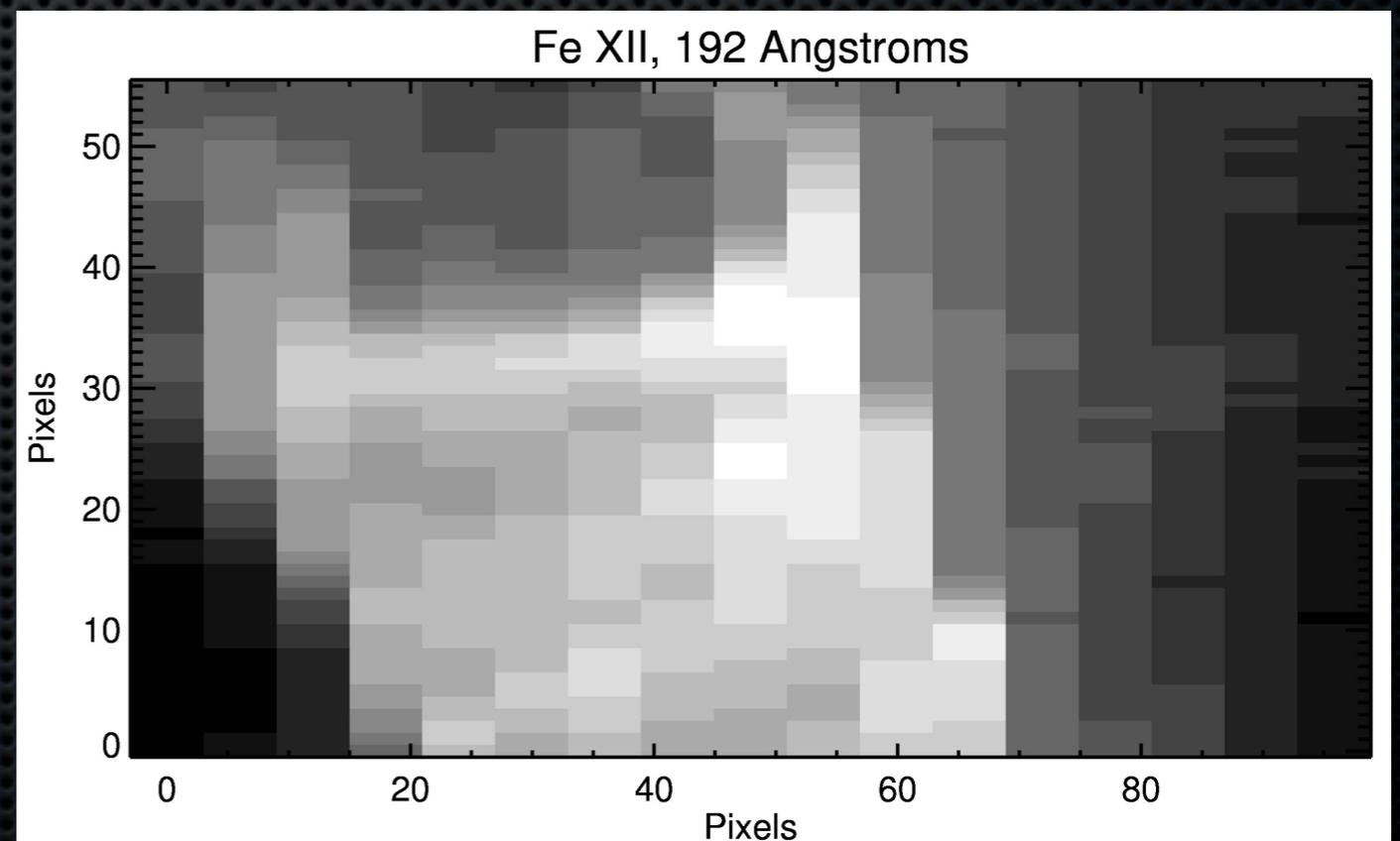
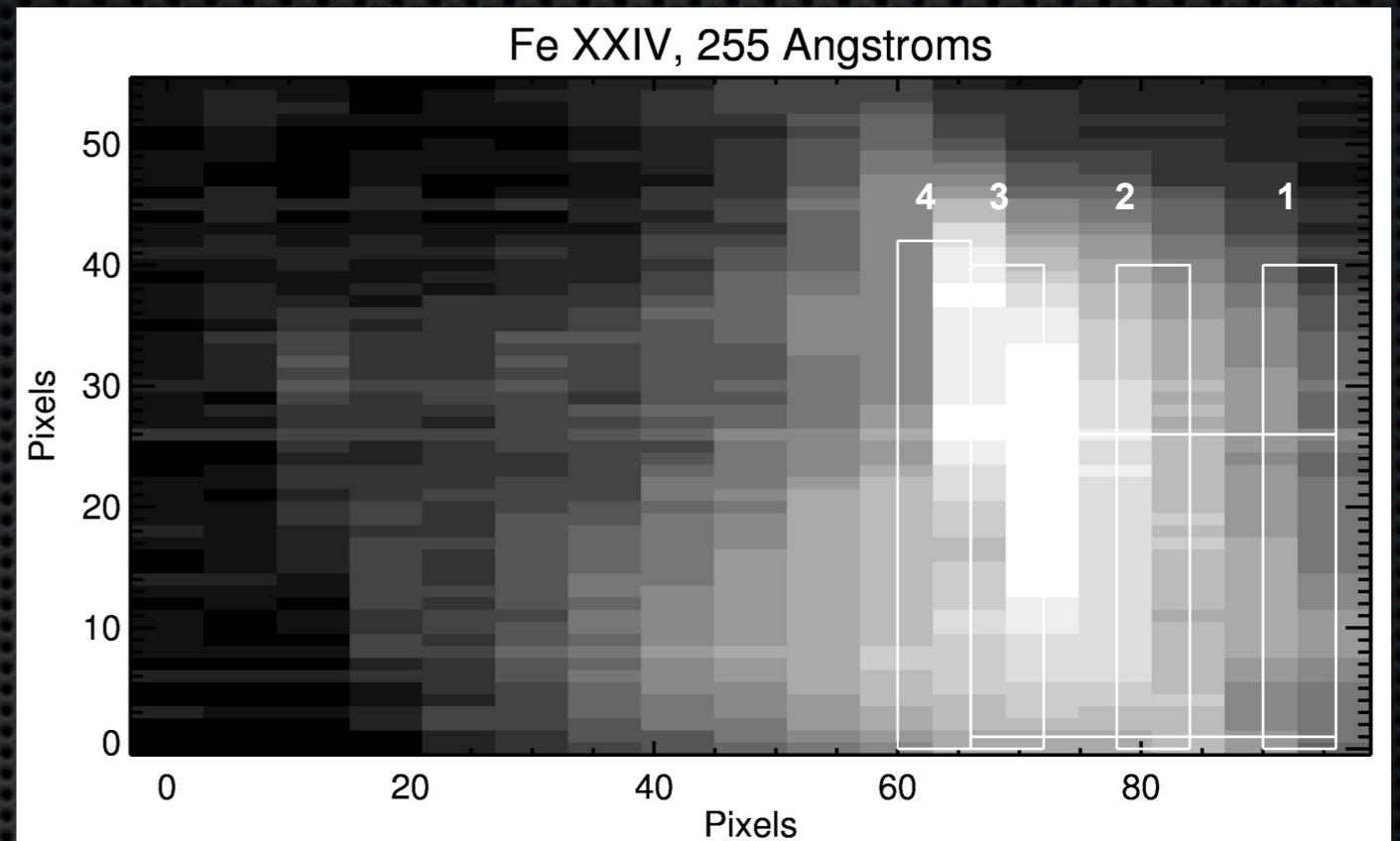
Fe XII - 41 km/s

Box 5:

Fe XXIV/Fe XXIII - 40 km/s;

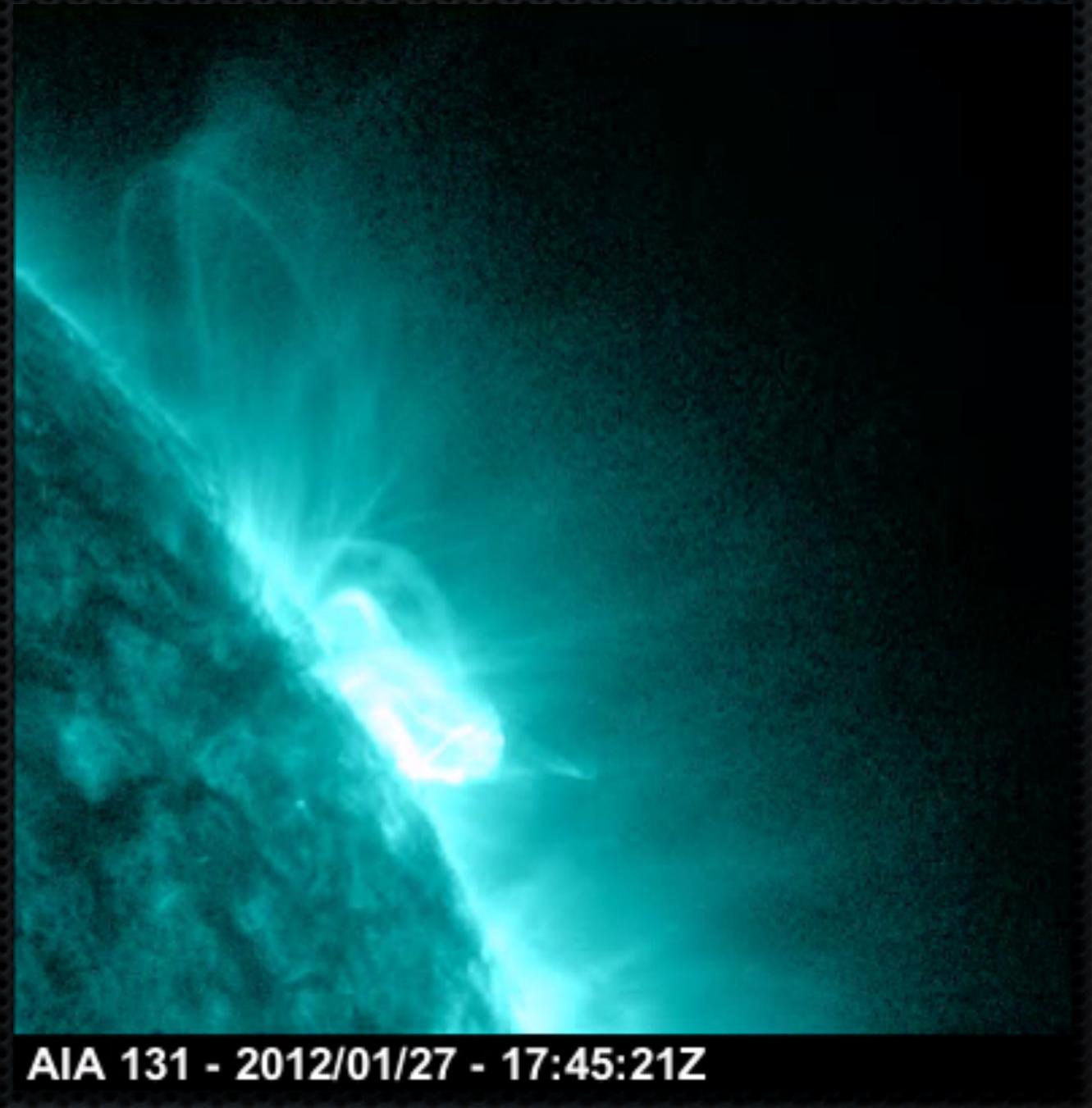
Temperature = 13 MK

Fe XII - 36 km/s



2012/01/27 Event

- ✦ GOES X1.7
- ✦ Similar orientation to the the 17-May event
- ✦ EIS non-thermal speeds are 35-50 km/s, along the line of sight.
- ✦ Images reveal motions in the plane of the sky. LCT allows us to capture and measure the velocity fields.



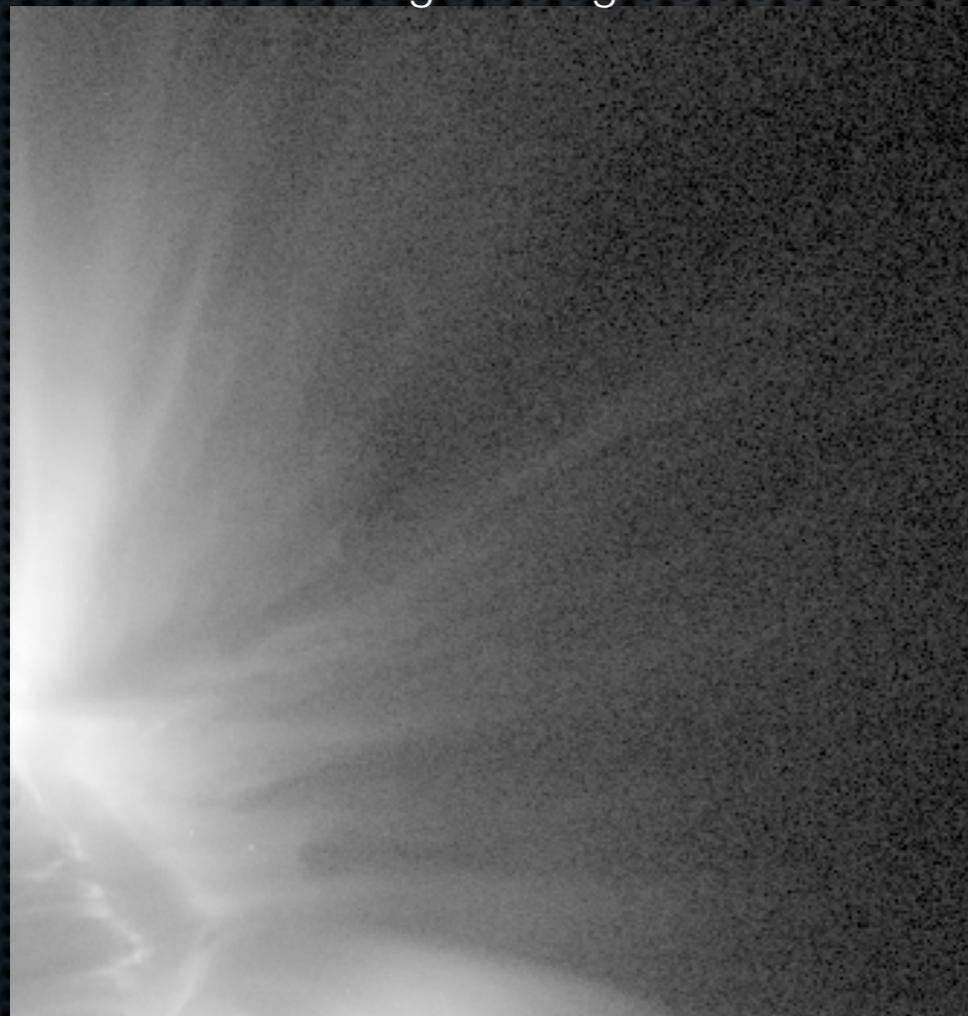
Movie file:

http://solar.physics.montana.edu/mckenzie/SADmovies/AIA_20120127_rawSADs.mp4

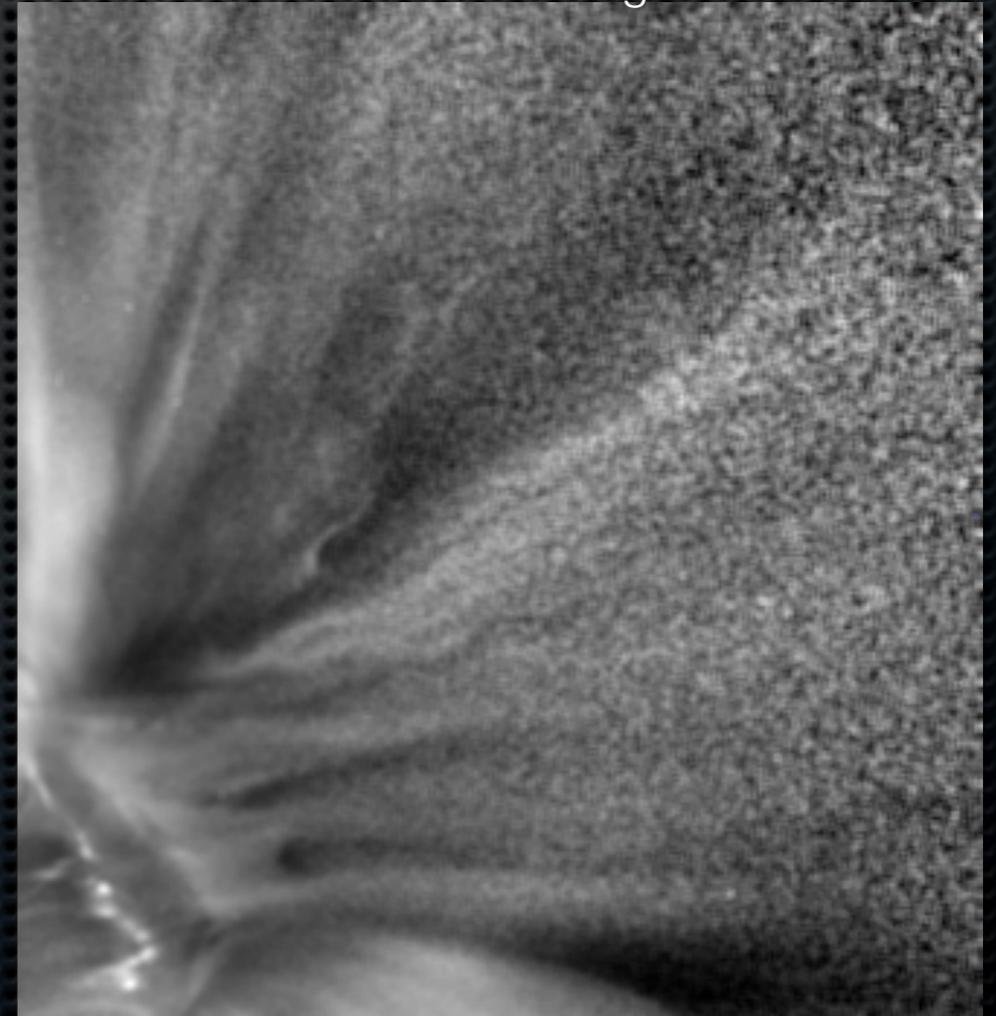
LCT Methodology

- ✦ Selected 645 images in 131 Å, from 19:00:21--23:29:58 UT. Cadence is 24s.
- ✦ Enhanced for contrast and to emphasize motions.

Original image
Original image

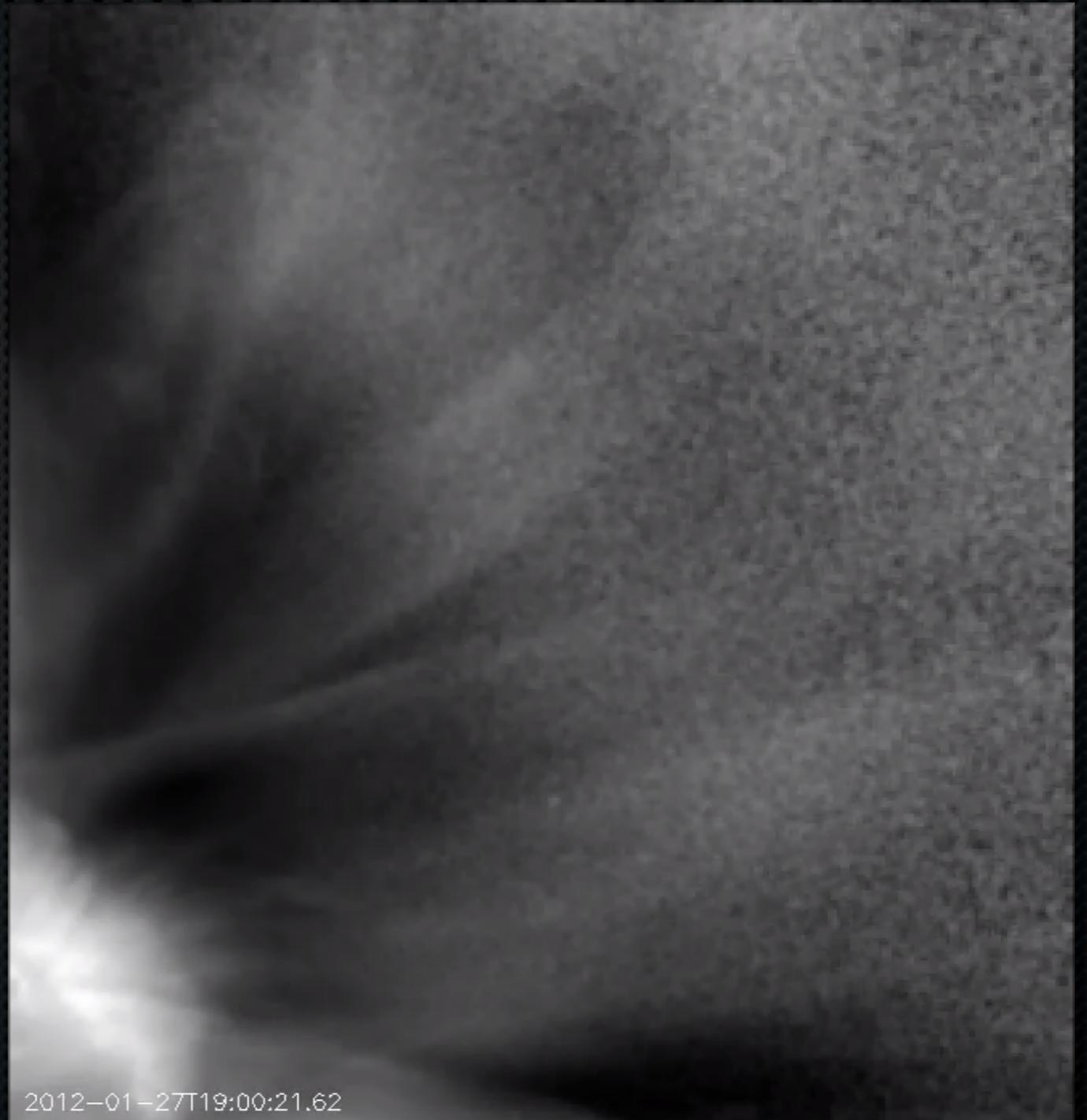


Enhanced image
Enhanced image



2012/01/27 Event

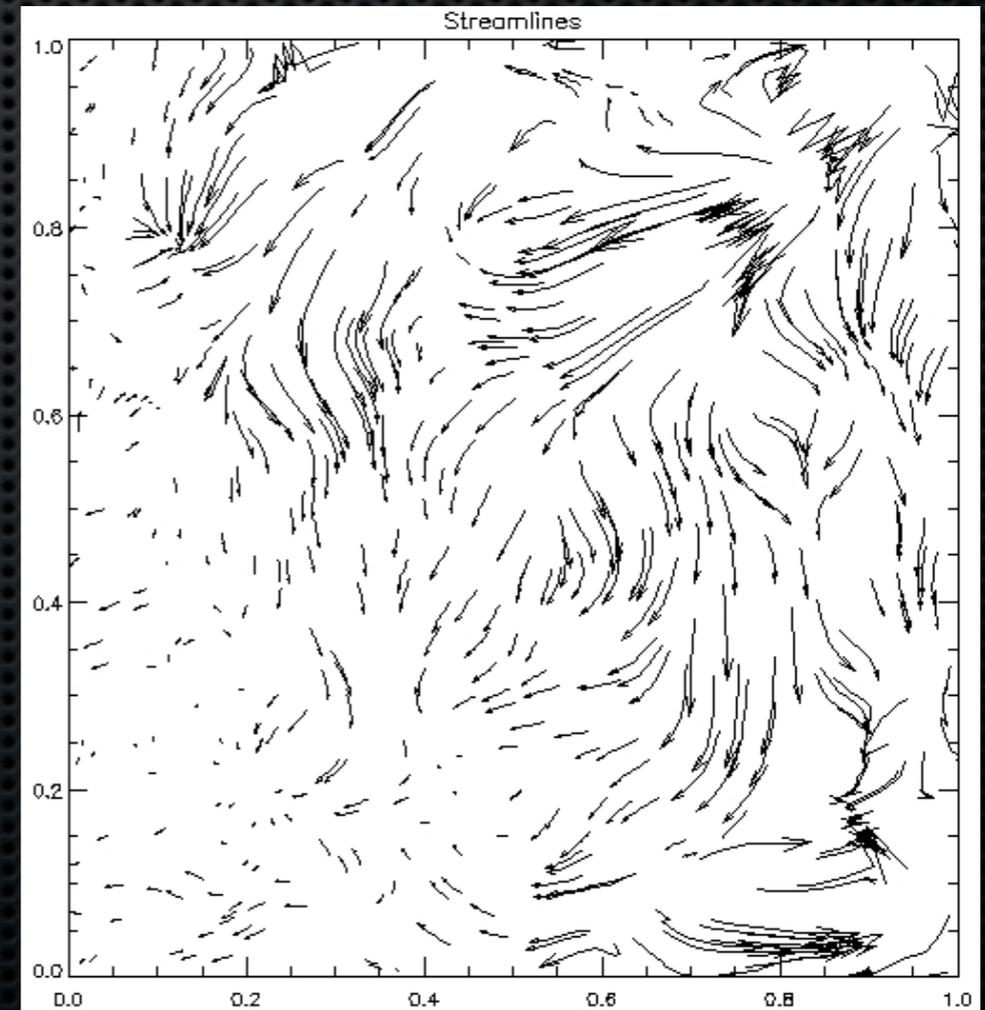
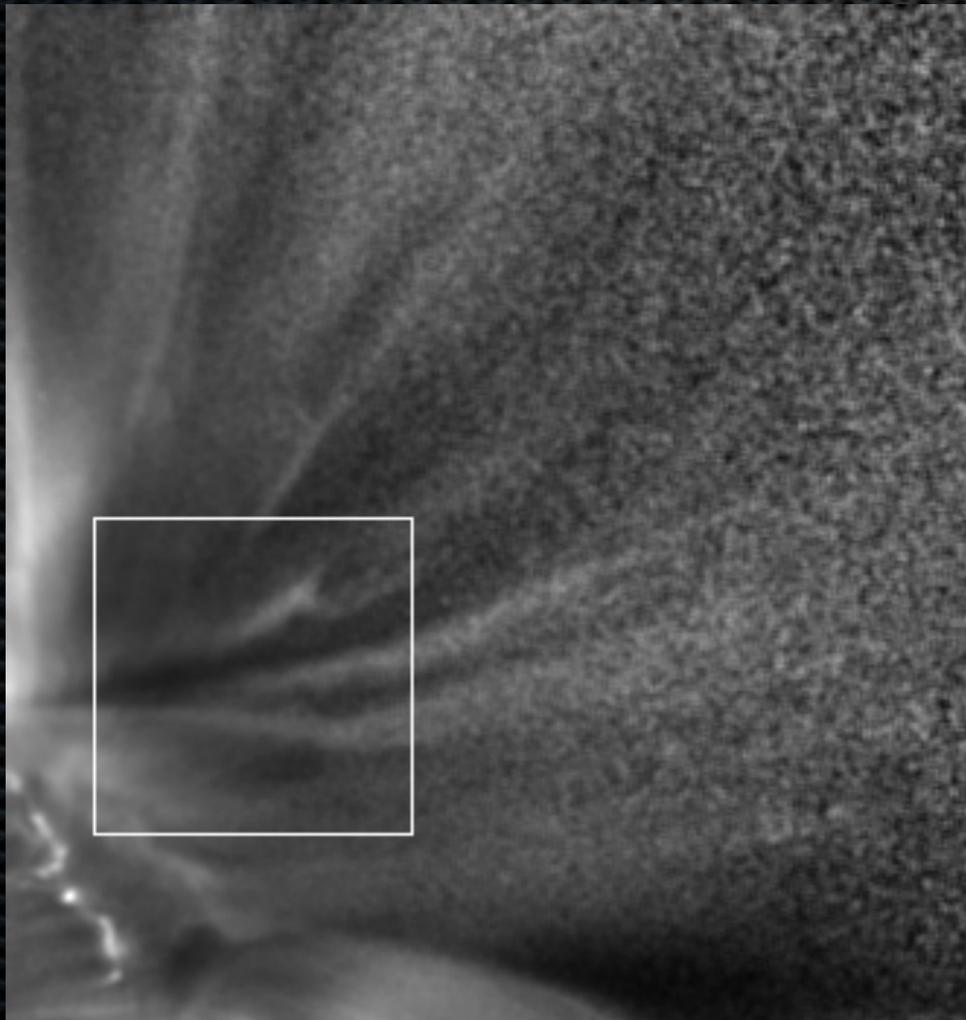
- ✦ Enhanced for contrast, to emphasize dynamics, and to reduce noise
- ✦ Local correlation tracking via FLCT on the 644 pairs of enhanced images (Fisher & Welsch 2008, ASPCS, vol. 383, p. 373)



Movie file:
http://solar.physics.montana.edu/mckenzie/SADmovies/AIA_20120127_SADs.mov

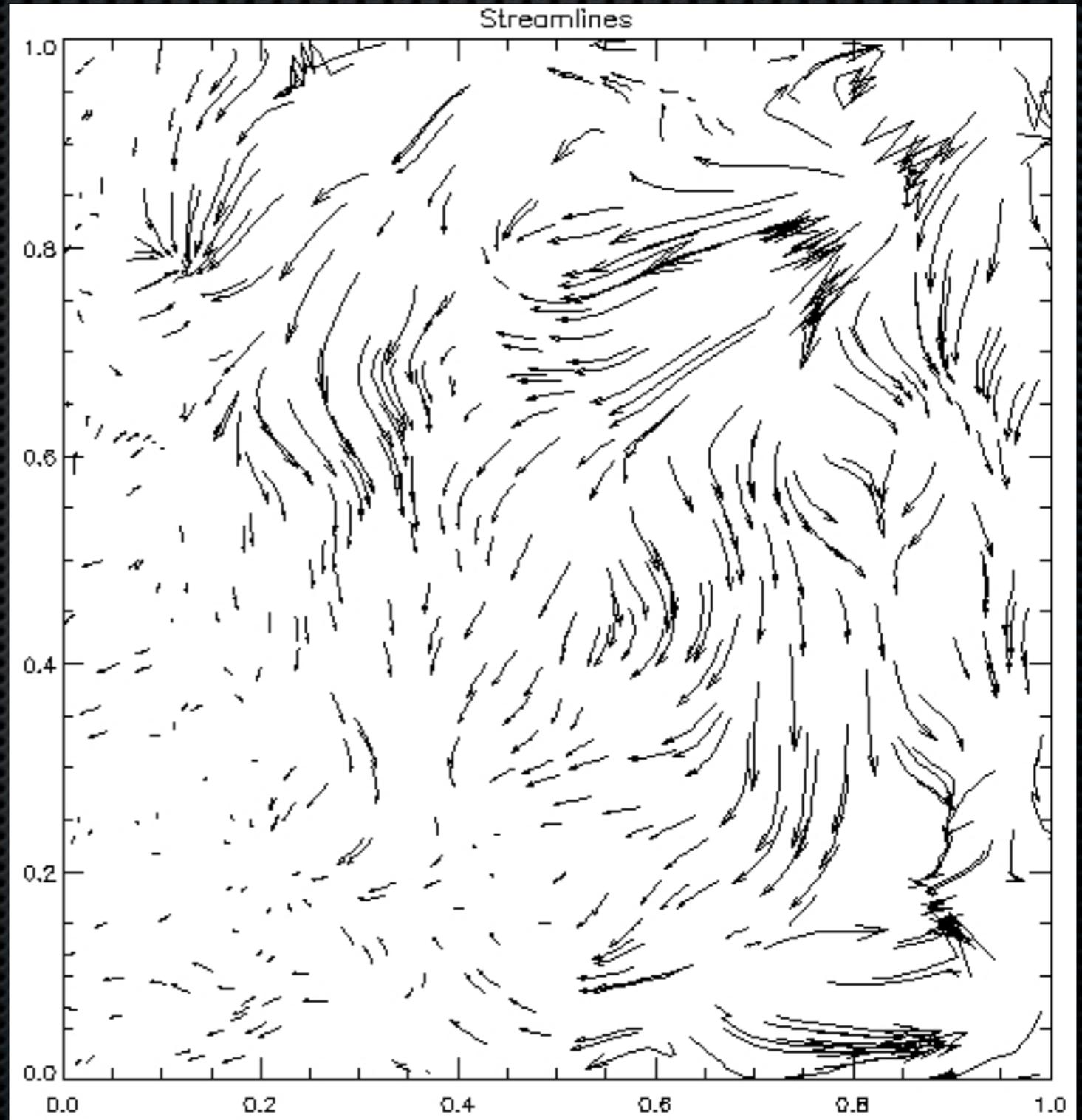
LCT Methodology

- ✦ Considering the whole field of view, median speed is 40 km/s.
- ✦ EIS nonthermal broadening speeds in this event are 35--50 km/s.
- ✦ Similarly, McKenzie (2013) found median speed of 38 km/s in the 2011/10/22 plasma sheet. Speeds for 2012/05/17 are slower.



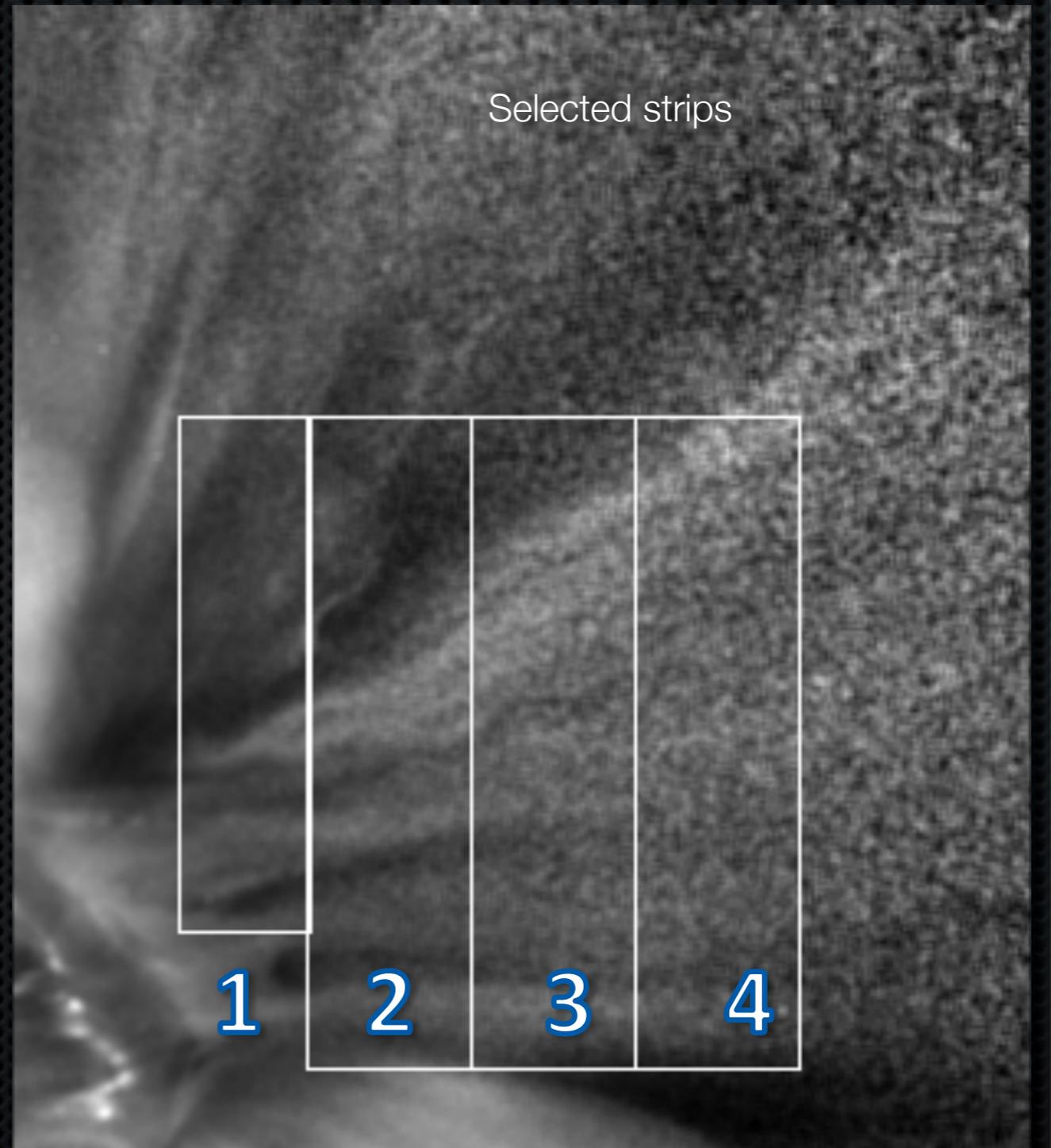
LCT Velocity Fields

- The velocity fields include time-varying shears & vortices, on a range of length scales.
- These velocity field characteristics are consistent with turbulence, at the same locations & same times as the EIS measurements.



2012/01/27 Event

- ✦ In selected strips of reduced field of view:
 - ✦ Strip 1: median = 13 km/s
 - ✦ Strip 2: median = 23 km/s
 - ✦ Strip 3: median = 47 km/s
 - ✦ Strip 4: median = 67 km/s
- ✦ EIS non-thermal speeds are 35-50 km/s
 - ✦ EIS data are from southern parts of Strips 1-2 only.



Conclusions

- ✦ Temperatures in the plasma sheet are 11~15 MK
- ✦ EIS & AIA both suggest velocities of 20-60 km/s in the plasma sheet. EIS = line-of-sight $|\underline{v}|$ for **four** flares. AIA = plane-of-sky \underline{v} for **three** flares.
- ✦ In both instruments, the velocities appear to increase with height.
- ✦ AIA directly observes the cascade from large length scales (CME-size) to sizes at the limit of resolution.
- ✦ Directly observed motions in AIA appear consistent with the non-thermal broadening in EIS. Supports interpretation as turbulence.
- ✦ With $\beta \geq 1$ (McKenzie 2013) this turbulence is important for generating small length scales and tangled magnetic fields needed for fast & prolonged reconnection.

Acknowledgements

- This work is supported by NASA Hinode and SDO, and Montana Space Grant Consortium

