

A REVIEW OF THE HINODE AND IRIS CONTRIBUTIONS TO UNDERSTANDING MAGNETIC RECONNECTION AND PROSPECTS FOR THE FUTURE

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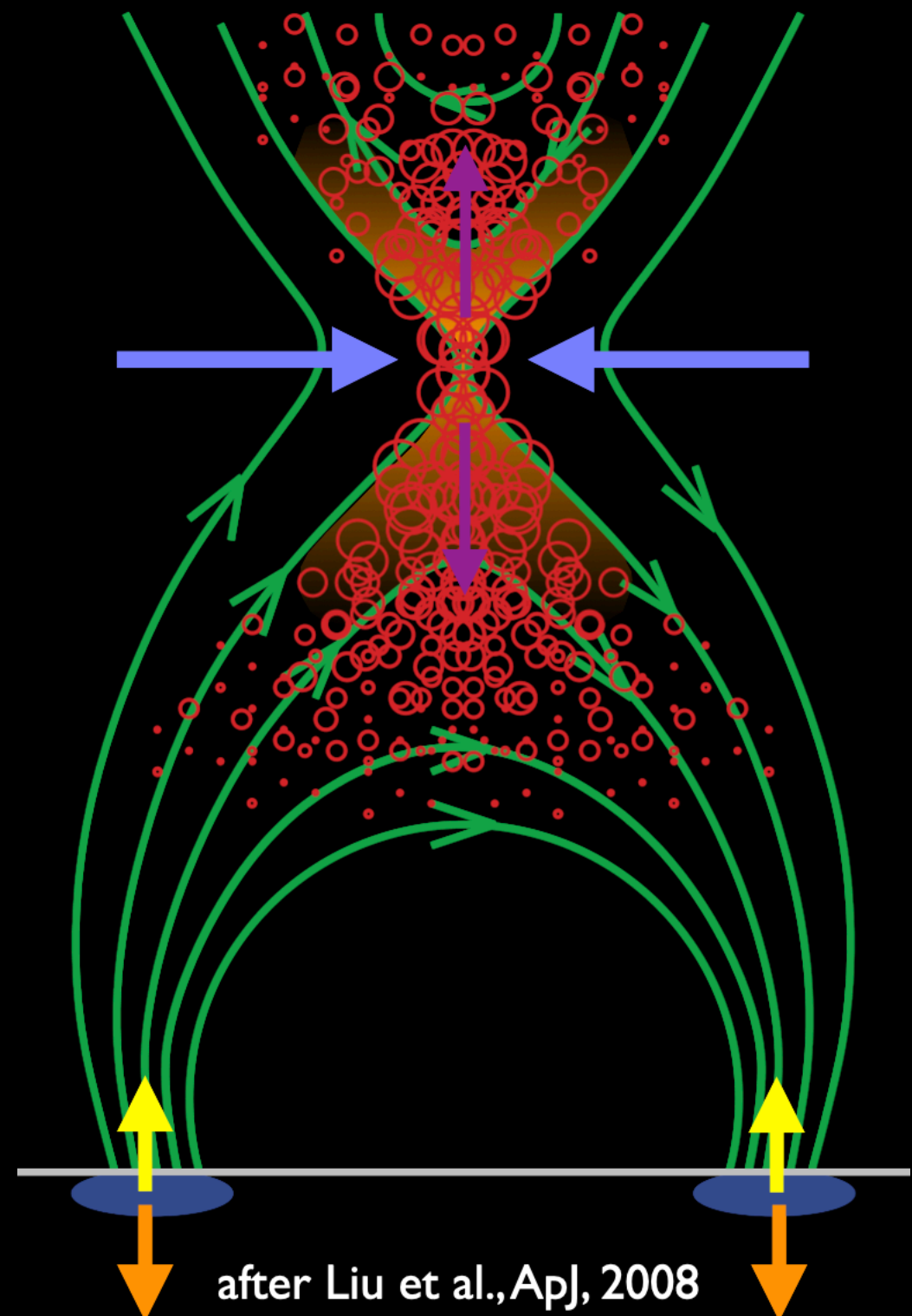
OUTLINE

- Brief introduction to flare reconnection
- EIS, XRT, IRIS observations of the plasma sheet region
- IRIS observations of flare ribbons
- Future prospects

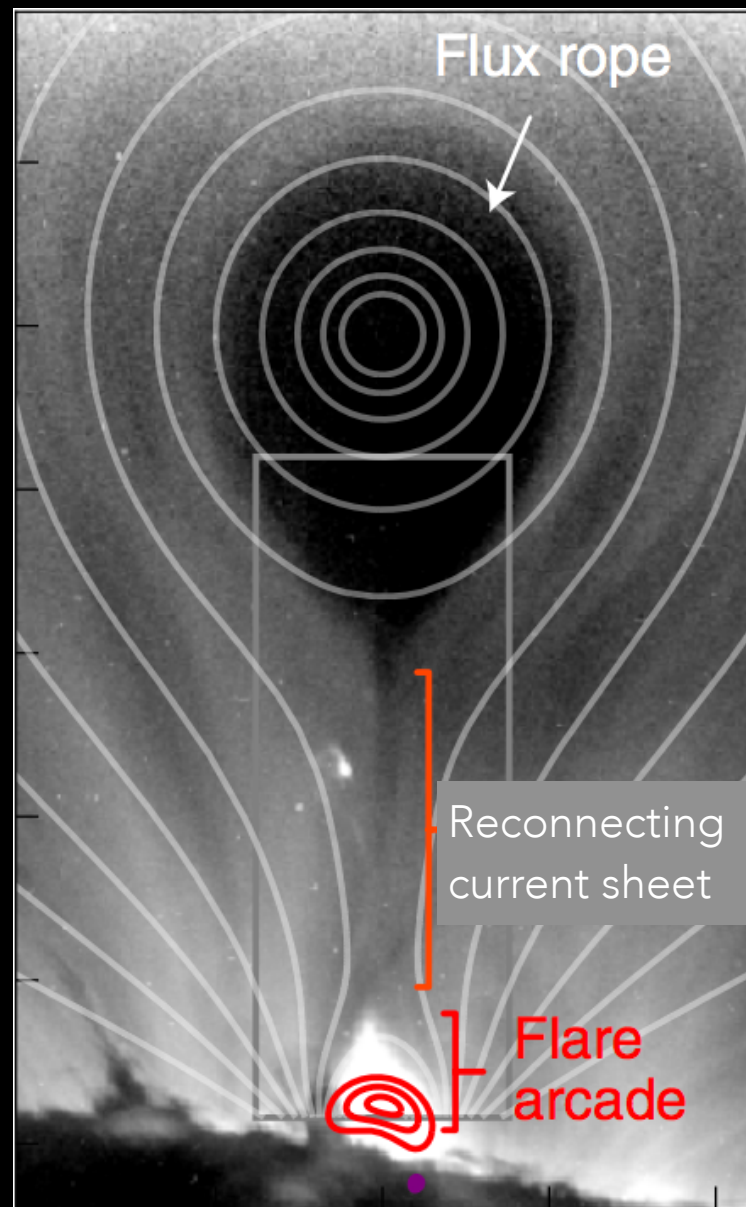
PHYSICAL OBSERVABLES OF RECONNECTION

- High temperature plasma near reconnection site
- Accelerated particles
- Flows and turbulence near reconnection site
- Termination shocks
- Energy deposited in to the chromosphere (flare ribbons)

Graphic from K. Reeves talk about reconnection, Hinode 9 meeting

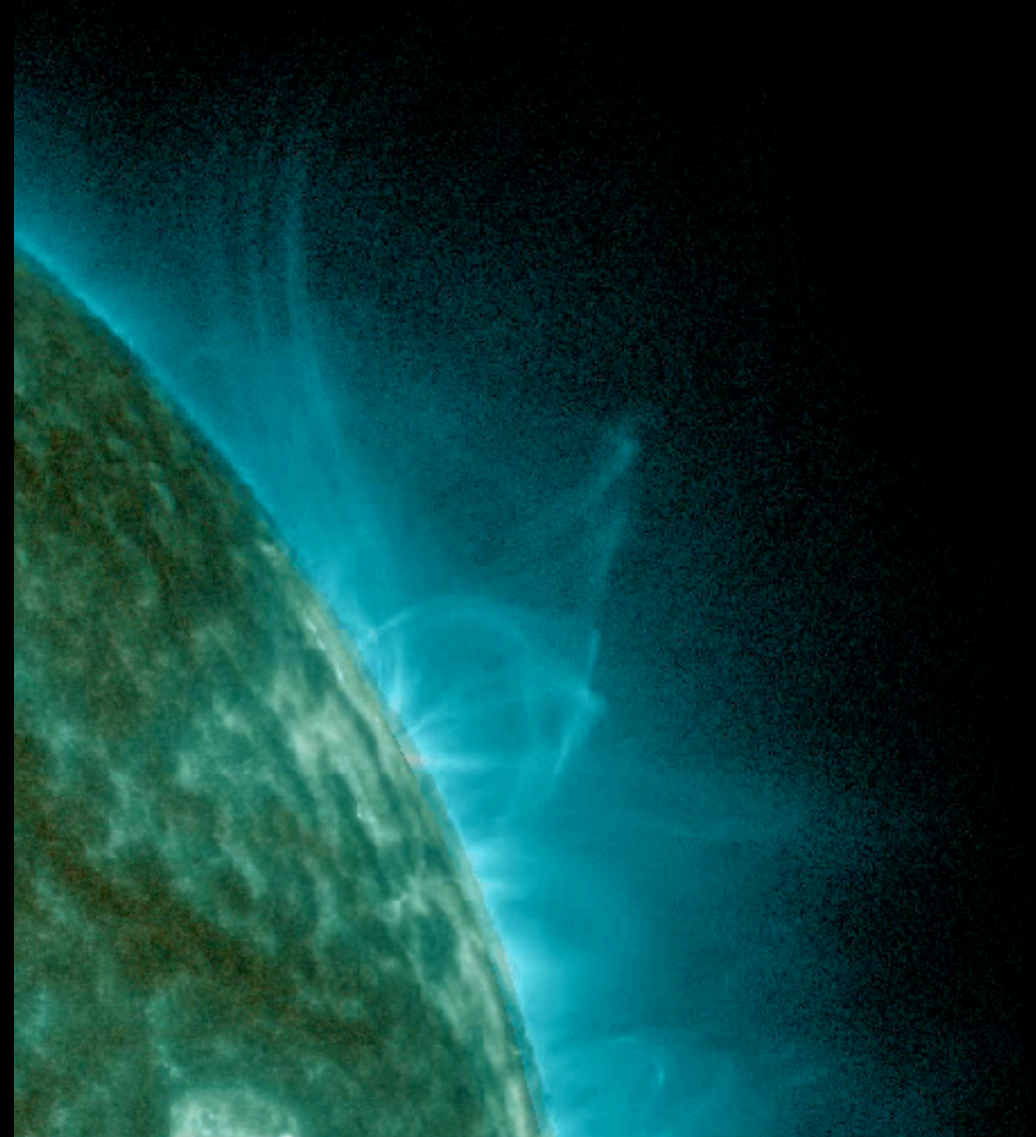


RECONNECTION IN THREE DIMENSIONS



Chen, B. et al., NatAs, 2021

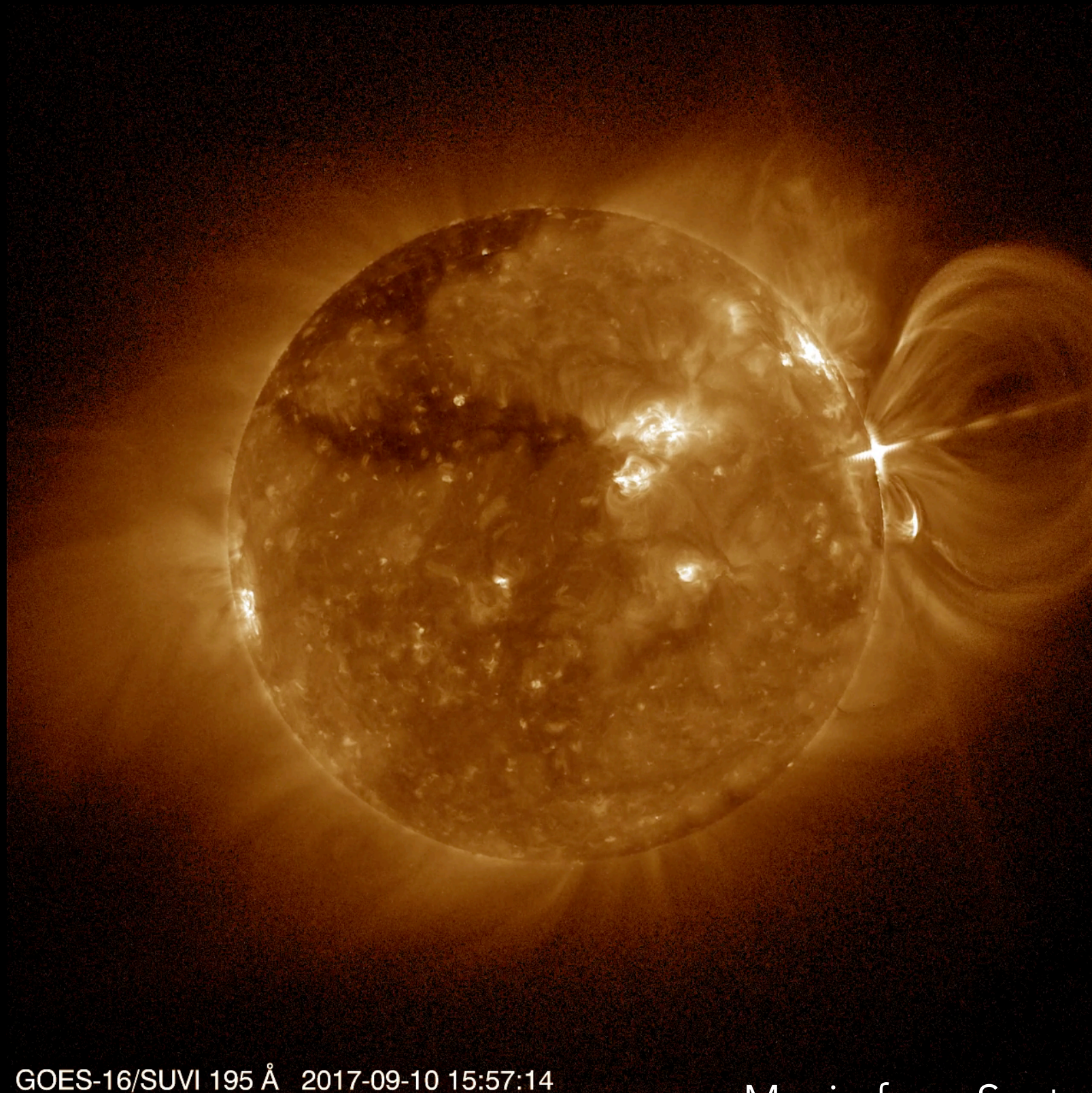
rotate
perpendicular



AIA 131 - 2011/10/22 - 10:00:33Z
AIA 1600 - 2011/10/22 - 10:00:41Z
AIA 304 - 2011/10/22 - 10:00:08Z

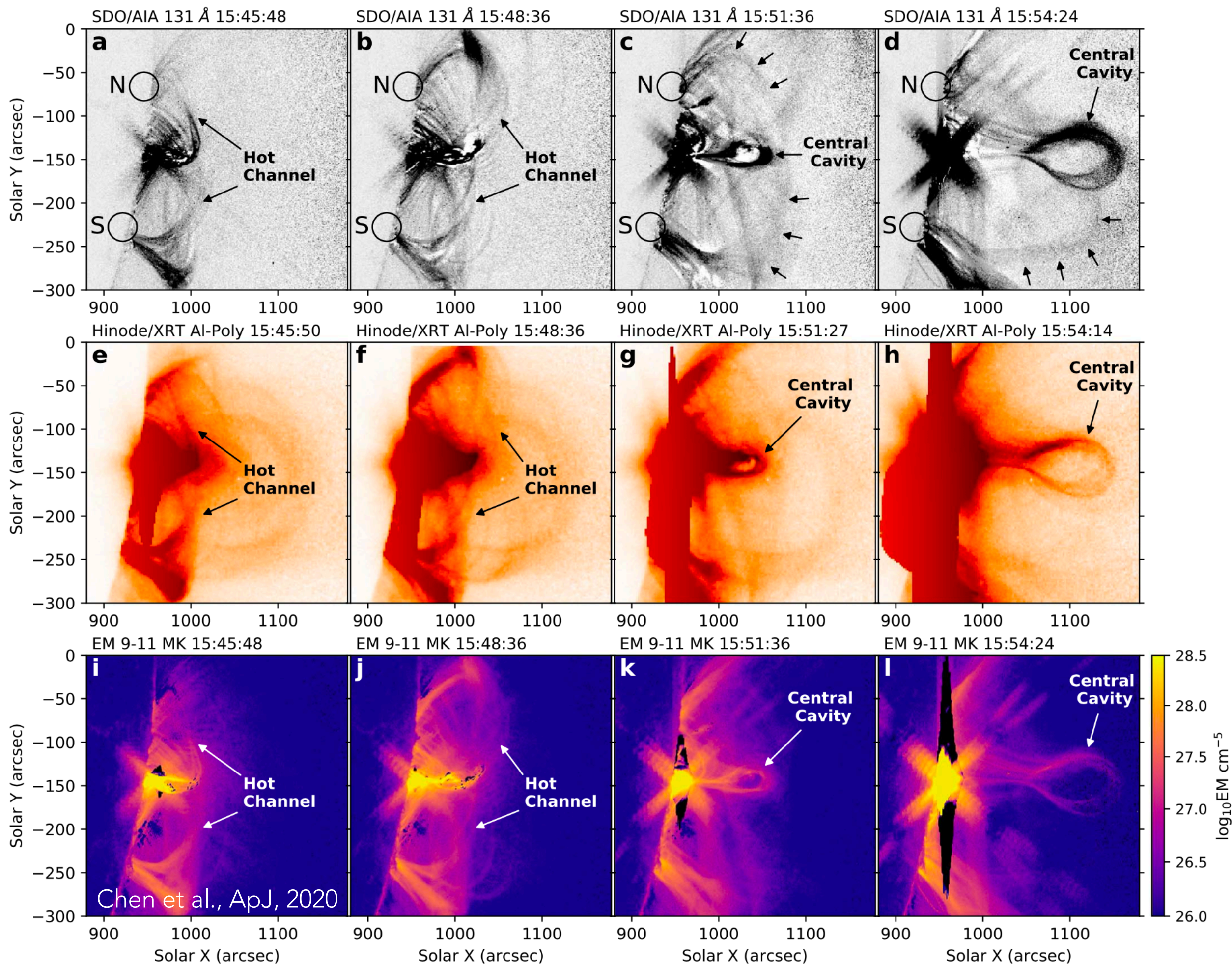
Movie courtesy of David McKenzie

SEPTEMBER 10, 2017 X8.2 FLARE

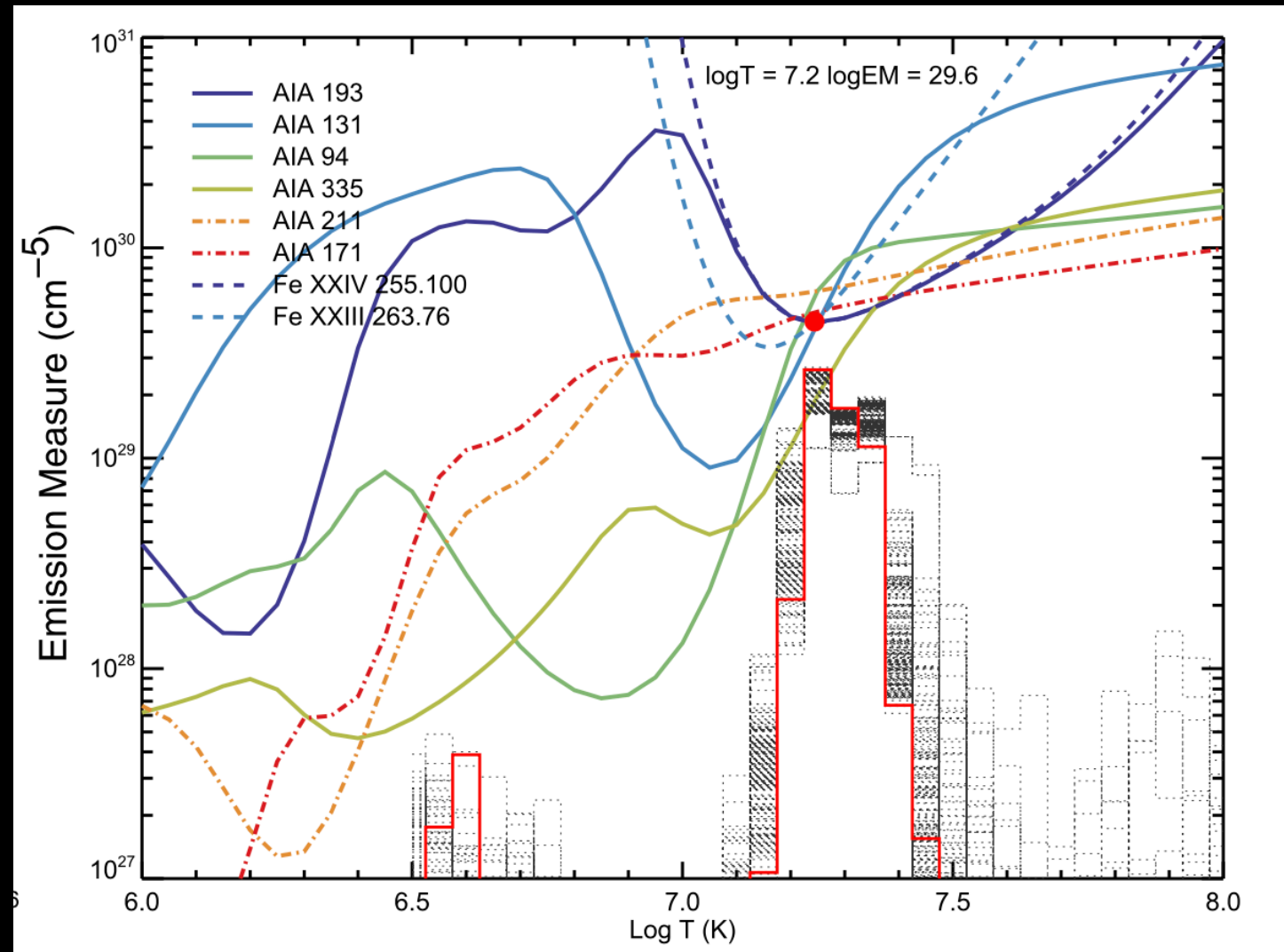
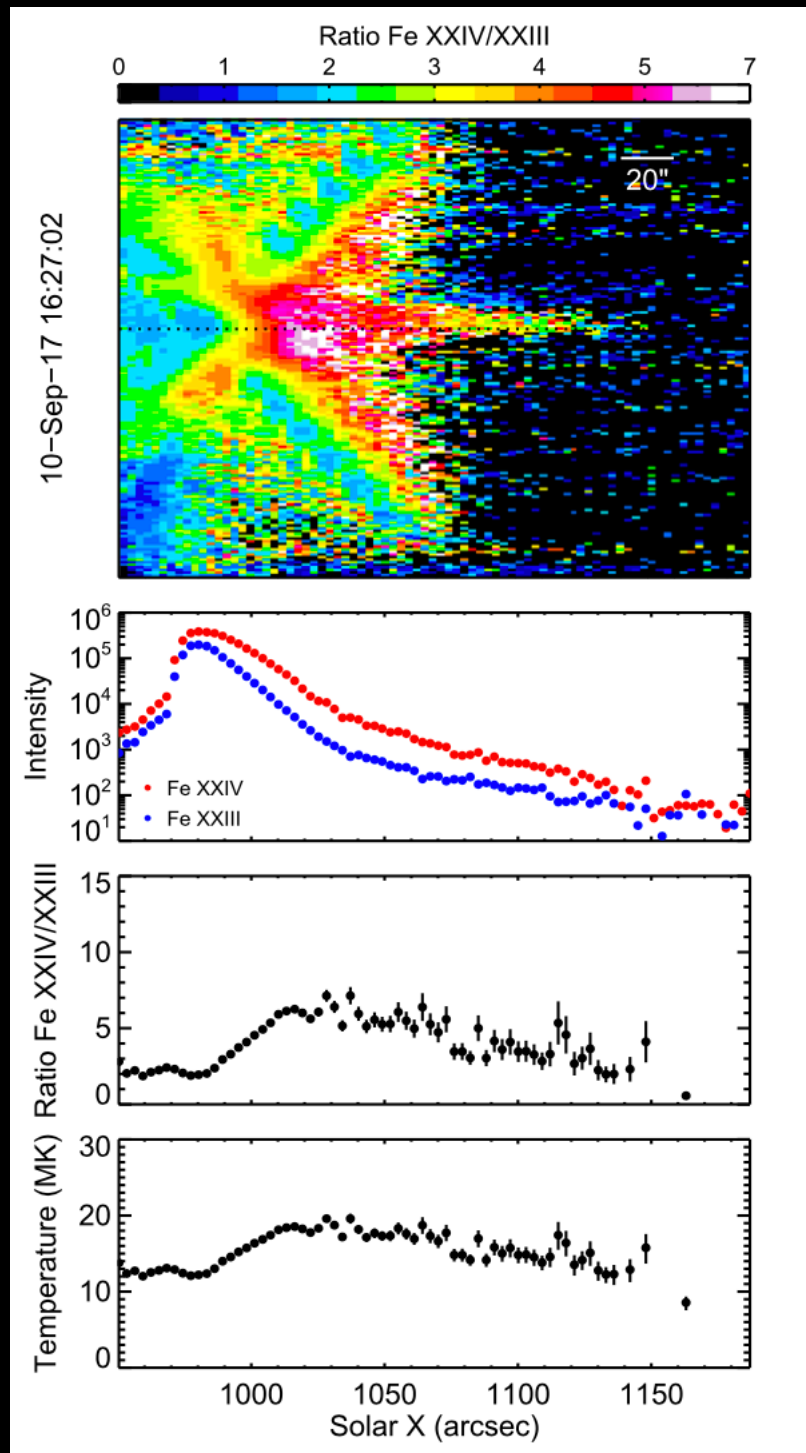


GOES-16/SUVI 195 Å 2017-09-10 15:57:14

Movie from Seaton et al., ApJL, 2018

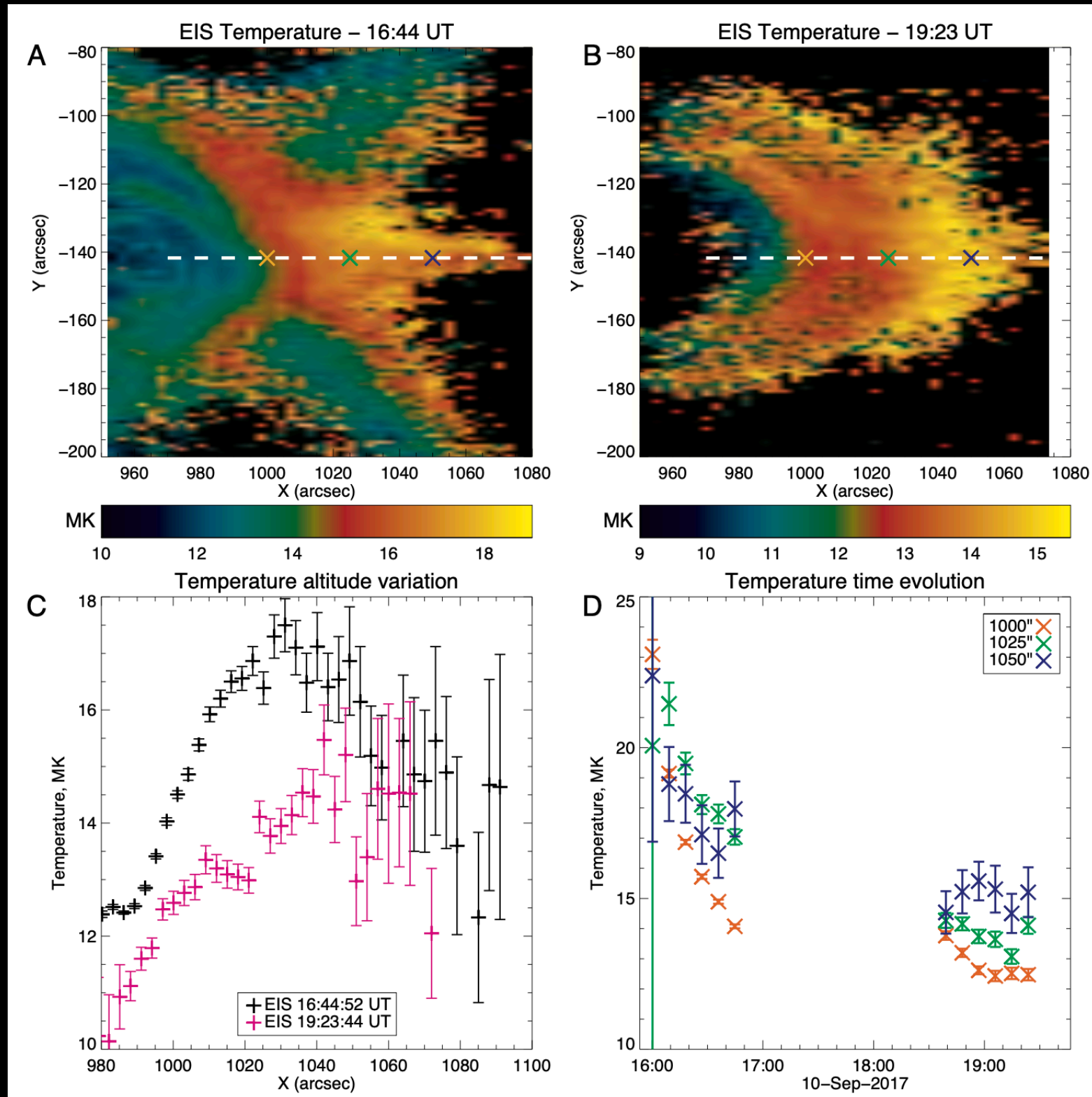


EVIDENCE FOR DIRECT HEATING IN THE CURRENT SHEET

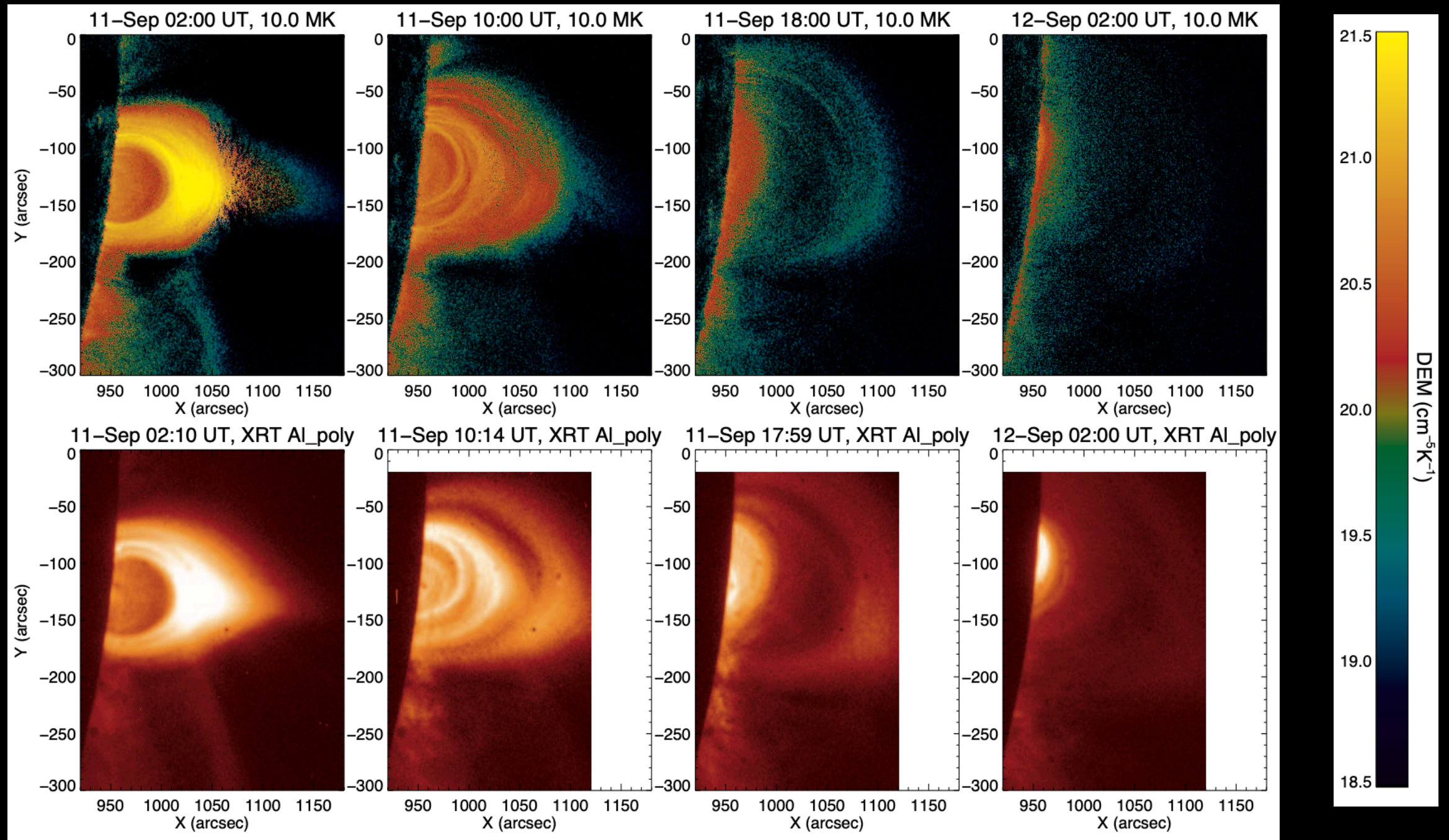


Assumption of coronal abundances makes the EM loci curves meet at around the same temperature.

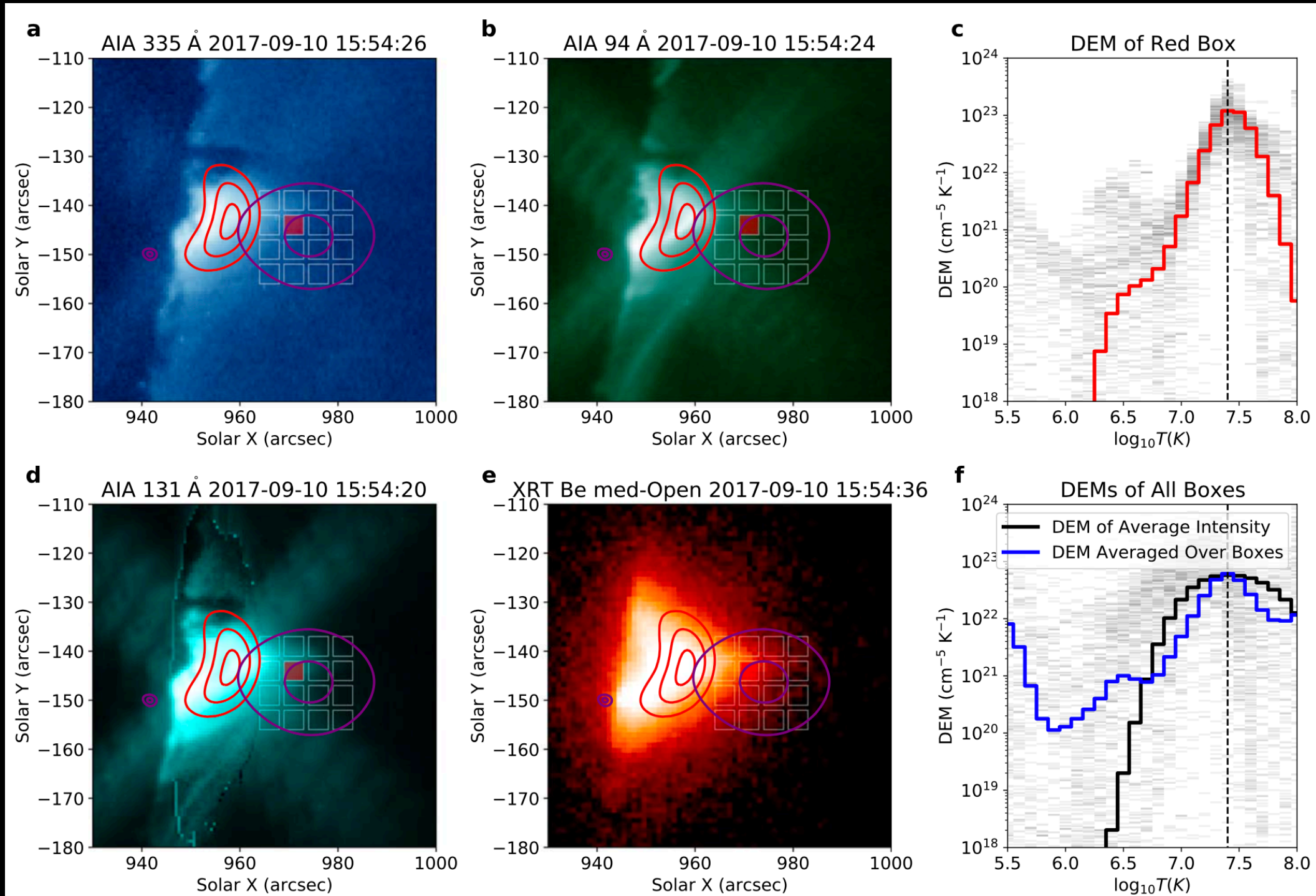
HIGH CURRENT SHEET TEMPERATURES ARE LONG-LASTING



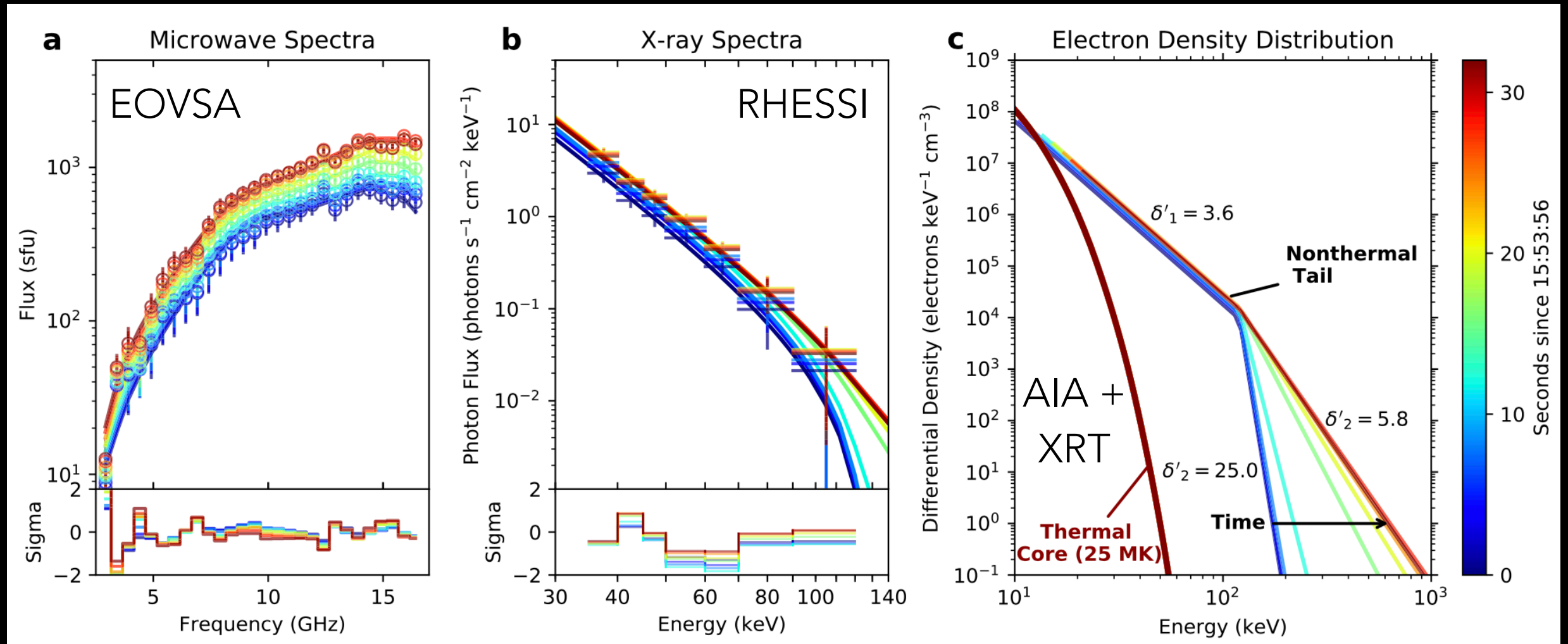
HIGH CURRENT SHEET TEMPERATURES ARE LONG-LASTING



TEMPERATURE OF THE ABOVE THE LOOP-TOP (ALT) SOURCE

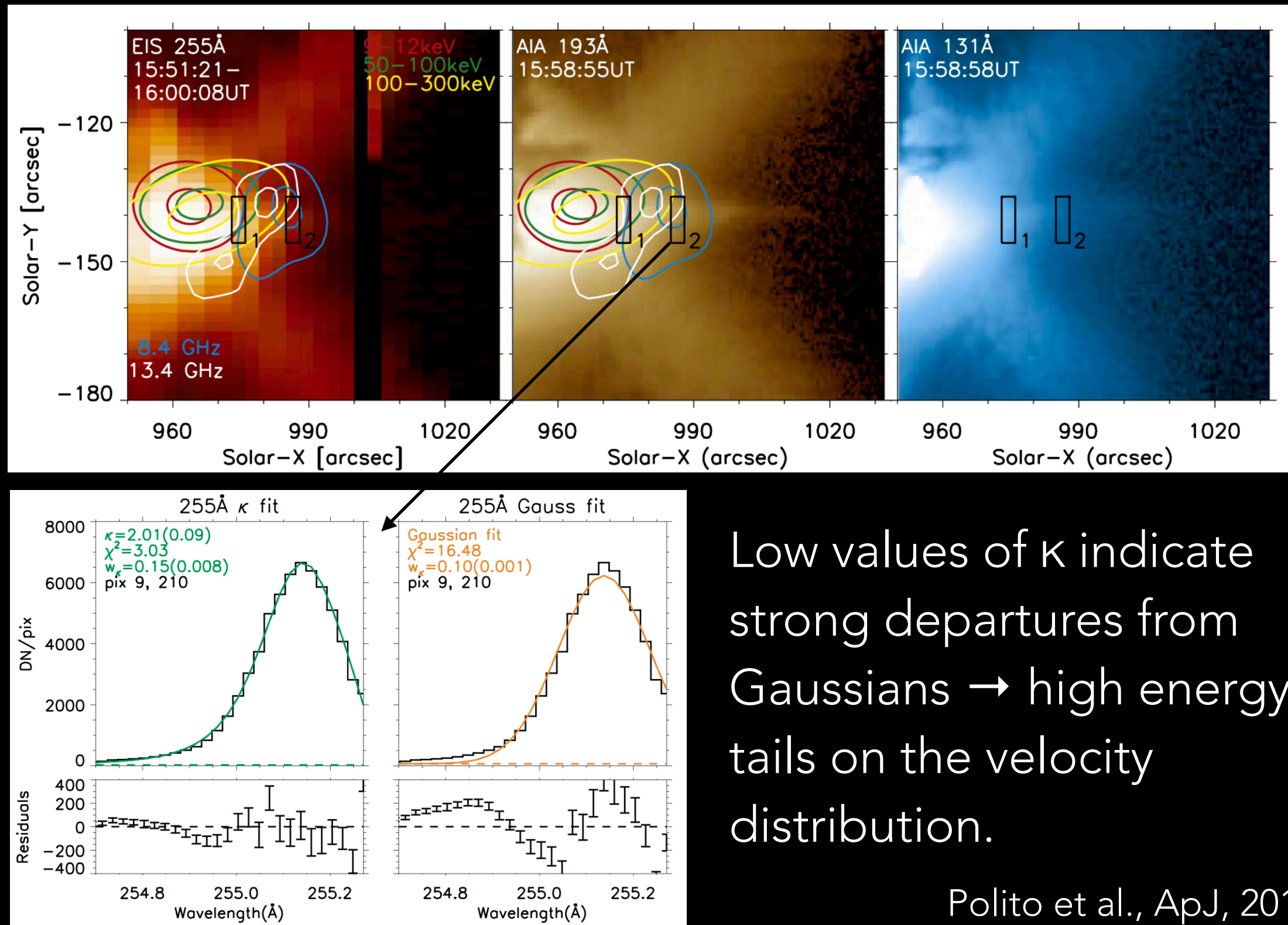


EVIDENCE FOR ALT SOURCE AS PRIMARY SITE FOR ONGOING ACCELERATION



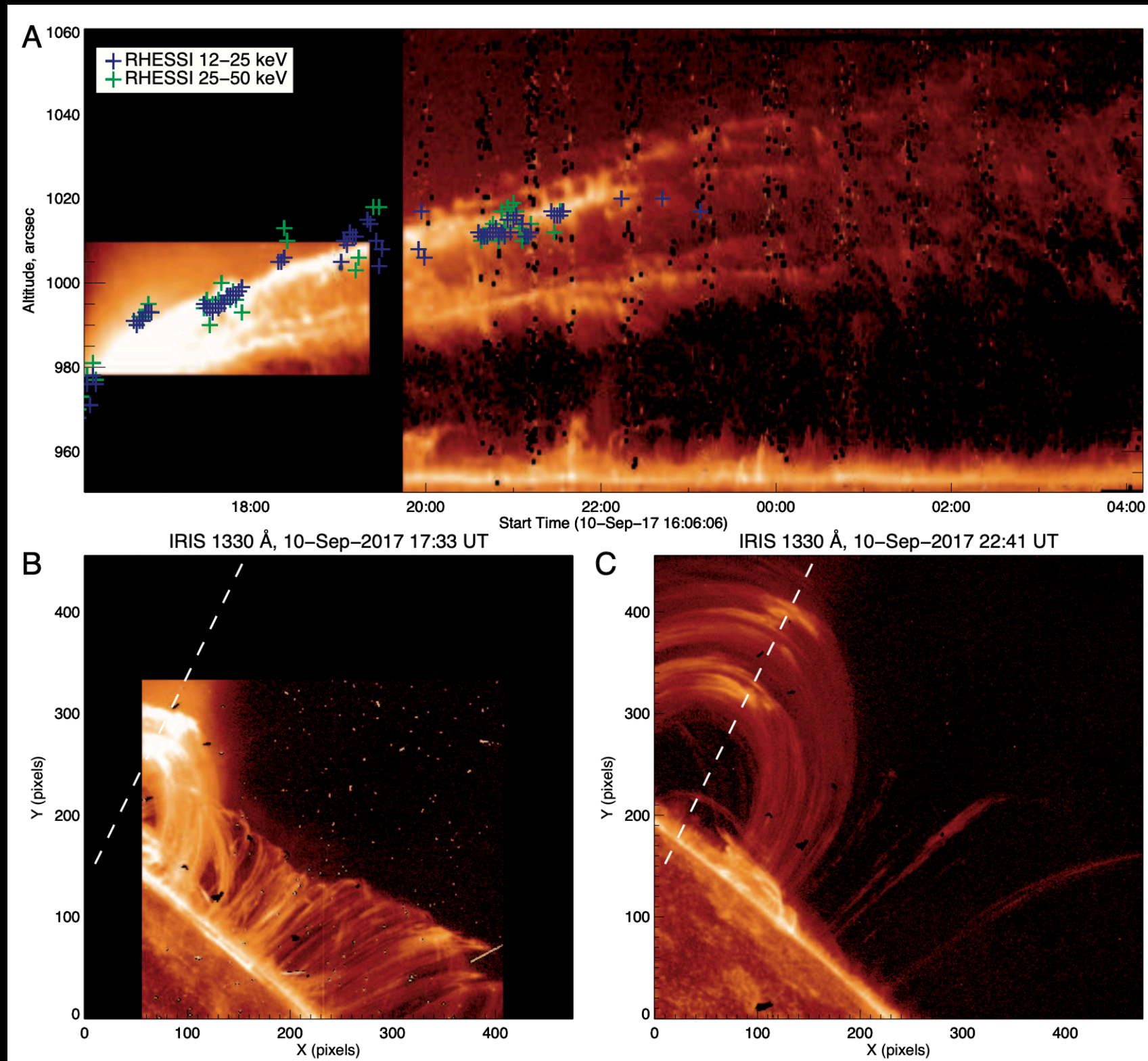
Electron distribution above the break energy rapidly hardens as a function of time

EVIDENCE FOR ALT SOURCE AS PRIMARY SITE FOR ONGOING ACCELERATION



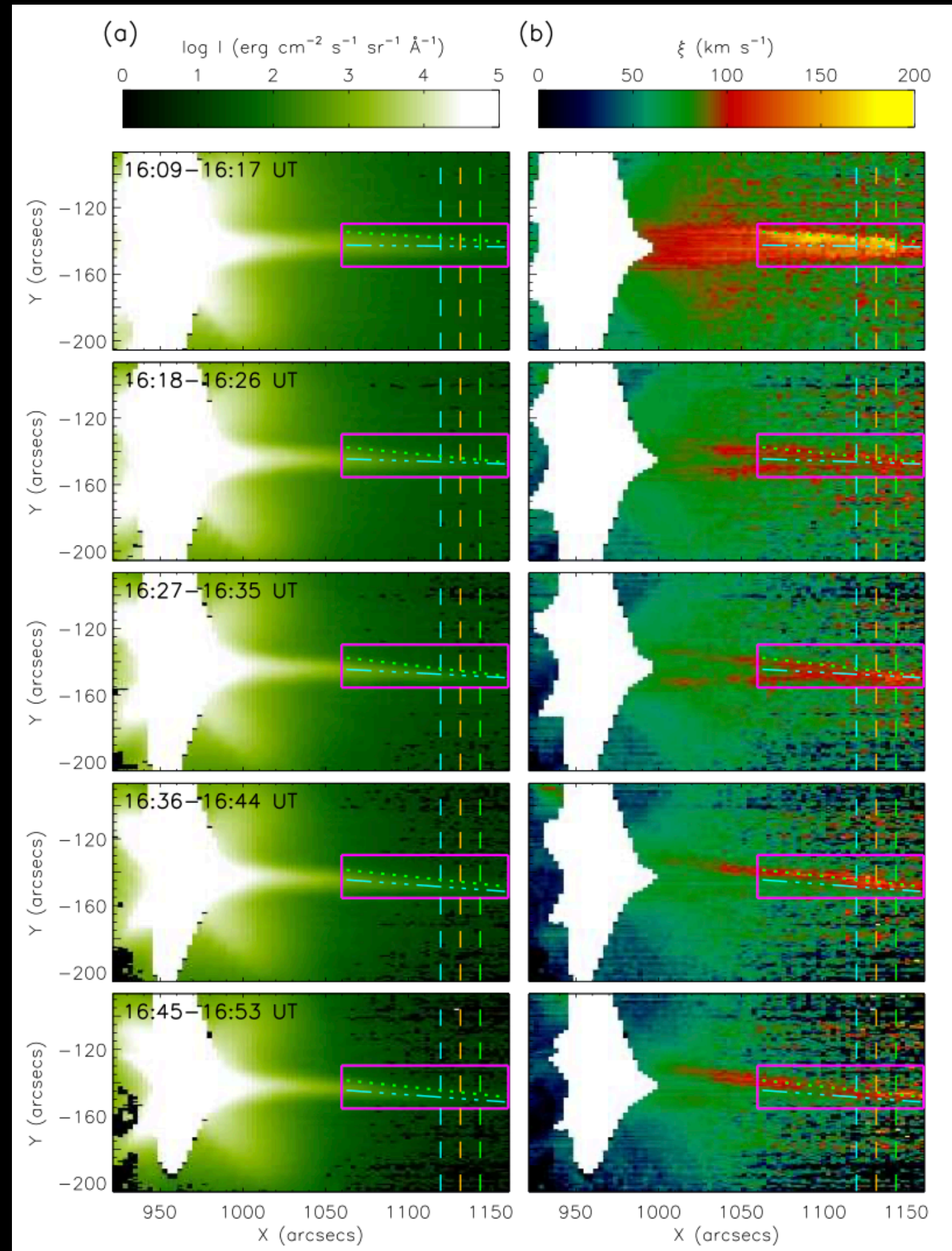
Low values of κ indicate strong departures from Gaussians $\rightarrow$ high energy tails on the velocity distribution.

PARTICLE ACCELERATION CONTINUES LATE INTO THE FLARE

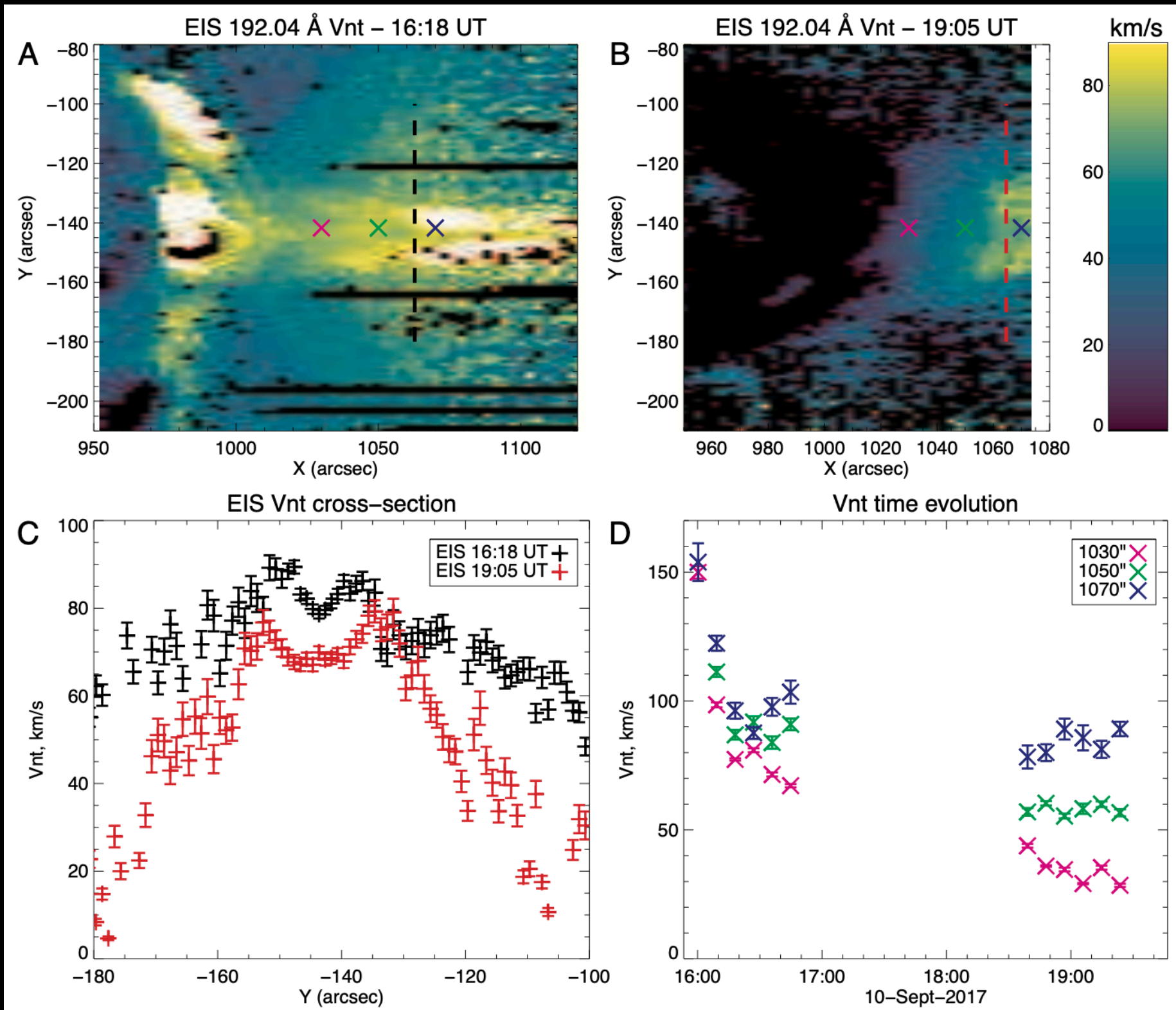


HIGH NON-THERMAL VELOCITY IN THE PLASMA SHEET

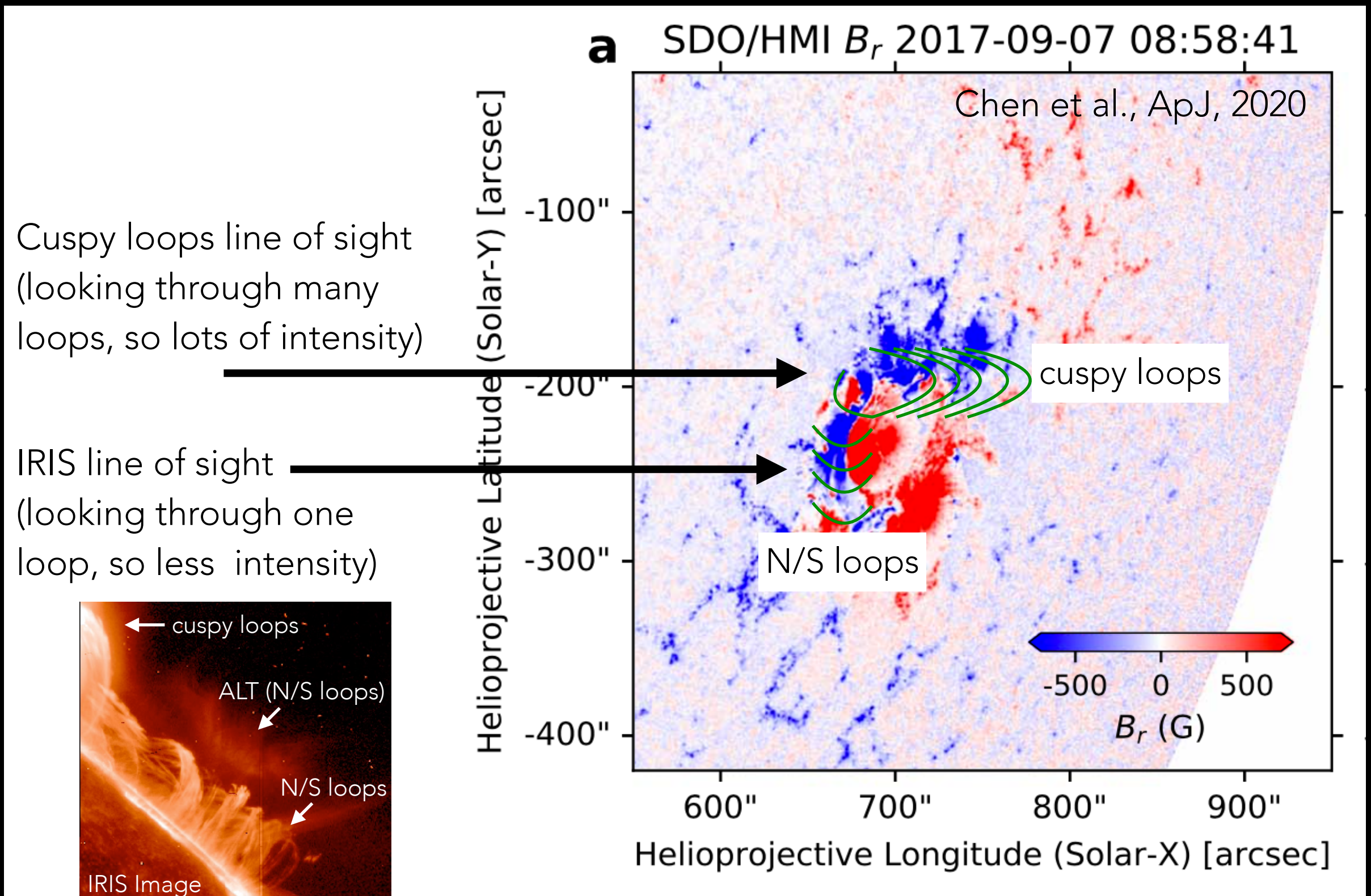
- Non-thermal velocity increases with height in the plasma sheet
- Indicative of turbulence or instabilities



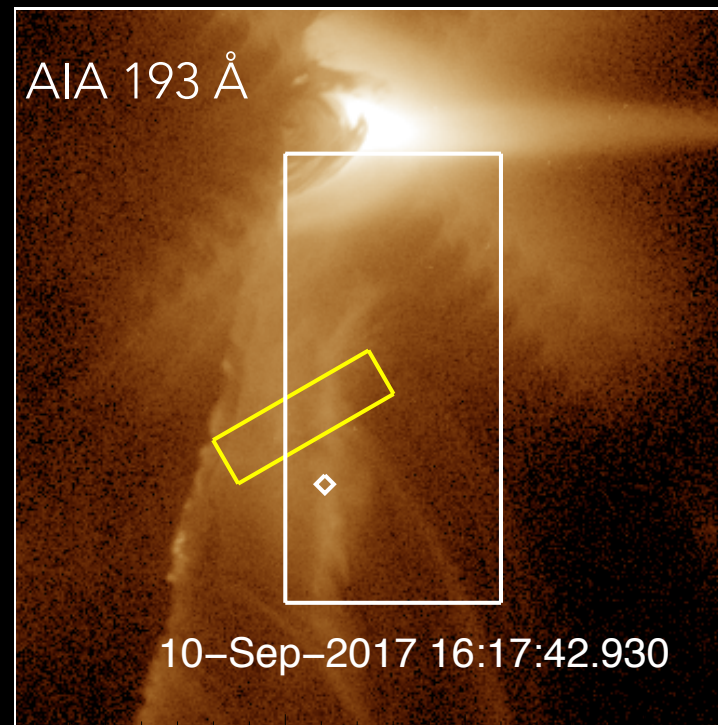
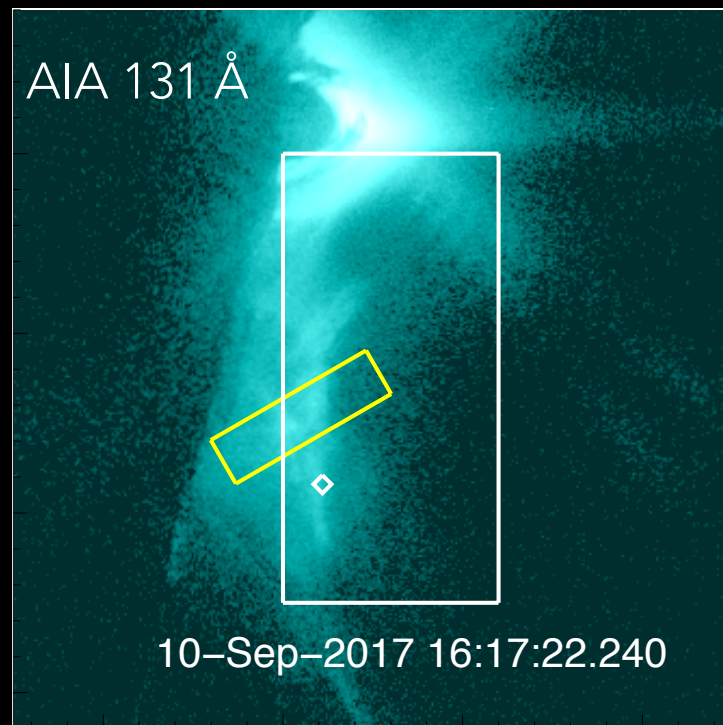
HIGH NON-THERMAL VELOCITY IN THE LATE PHASE



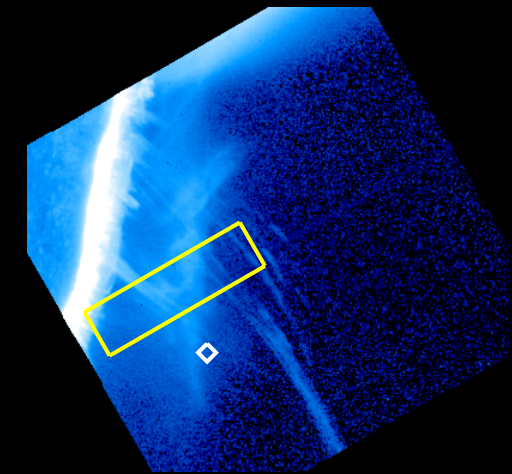
INTERESTING FLARE GEOMETRY



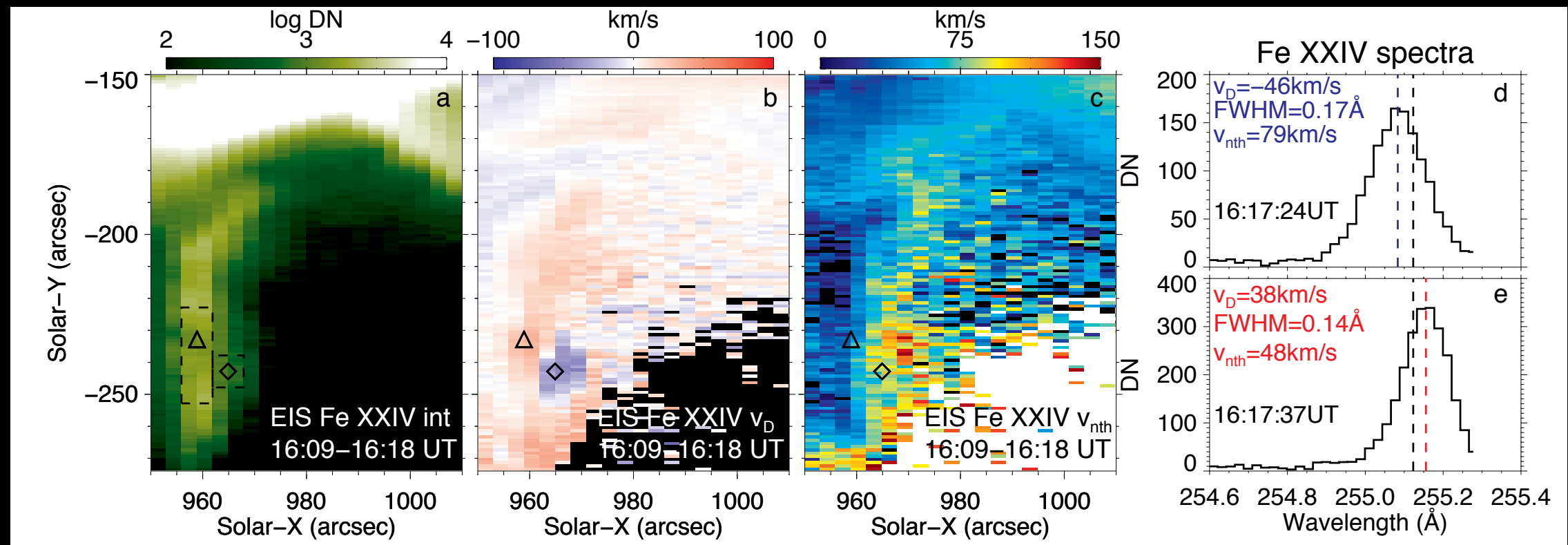
Hinode/EIS Spectroscopy: Fe XXIV



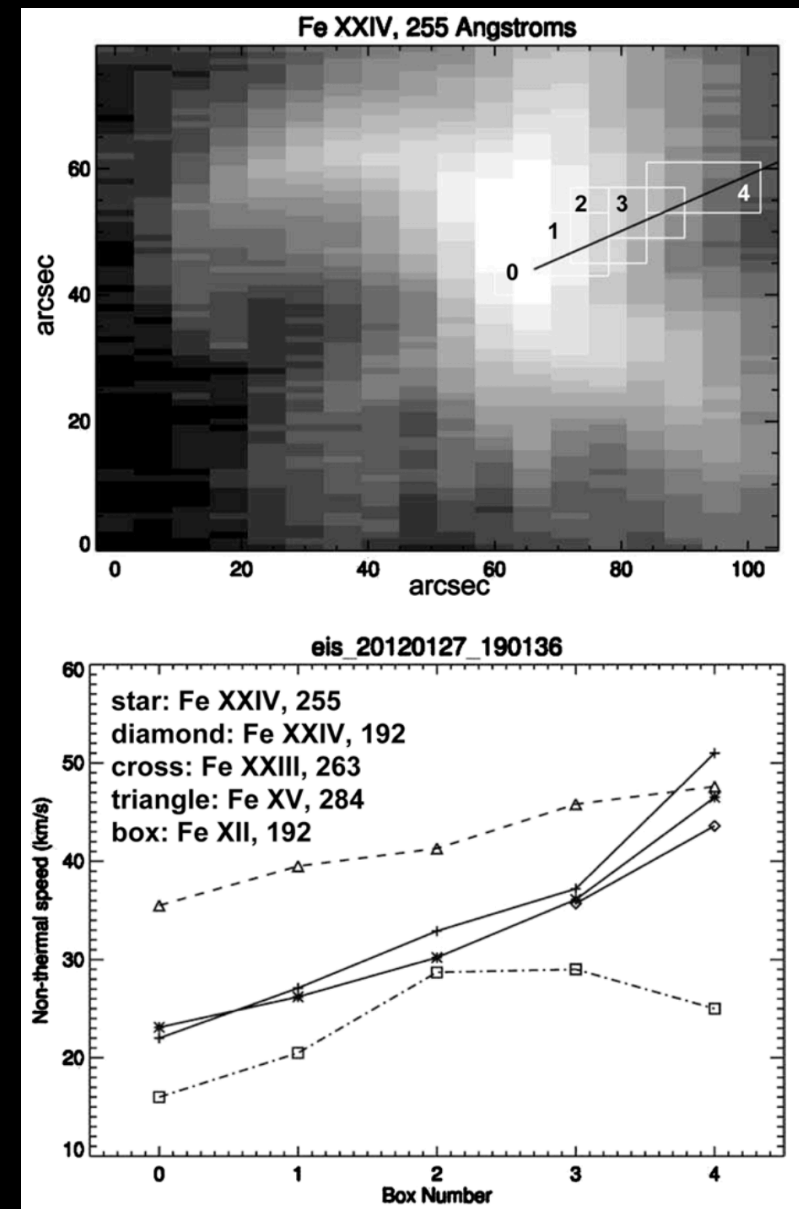
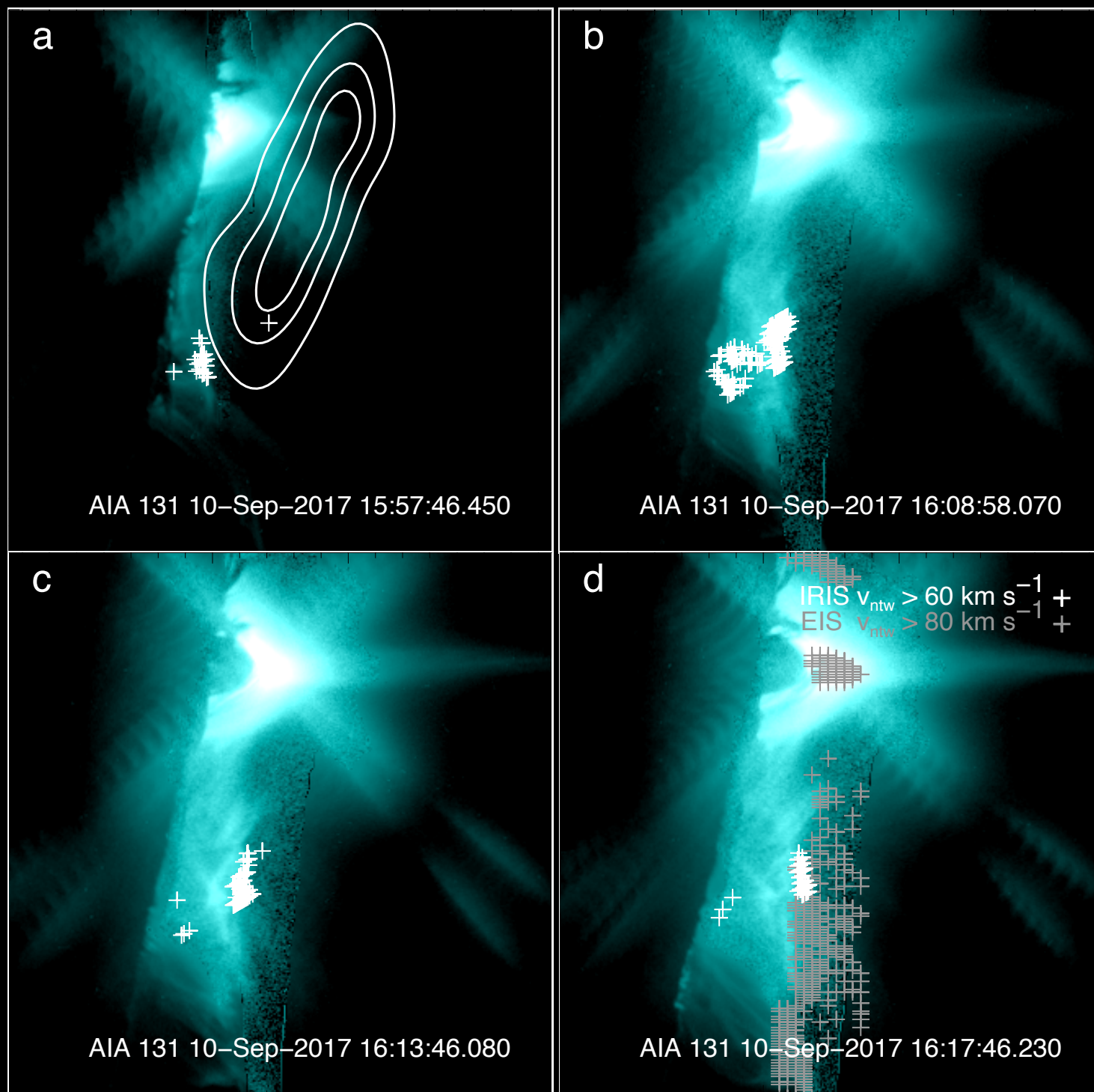
IRIS 1330 Å



Reeves et al., ApJ, 2020

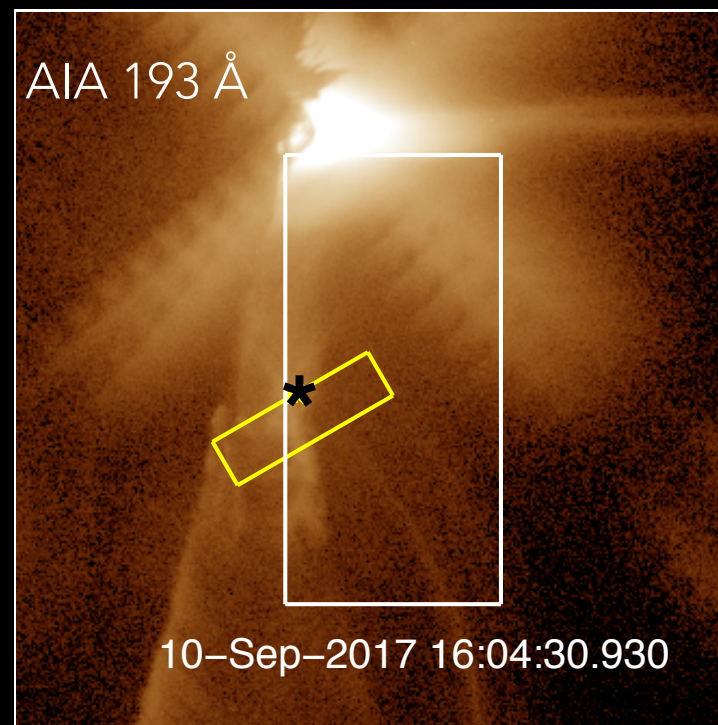
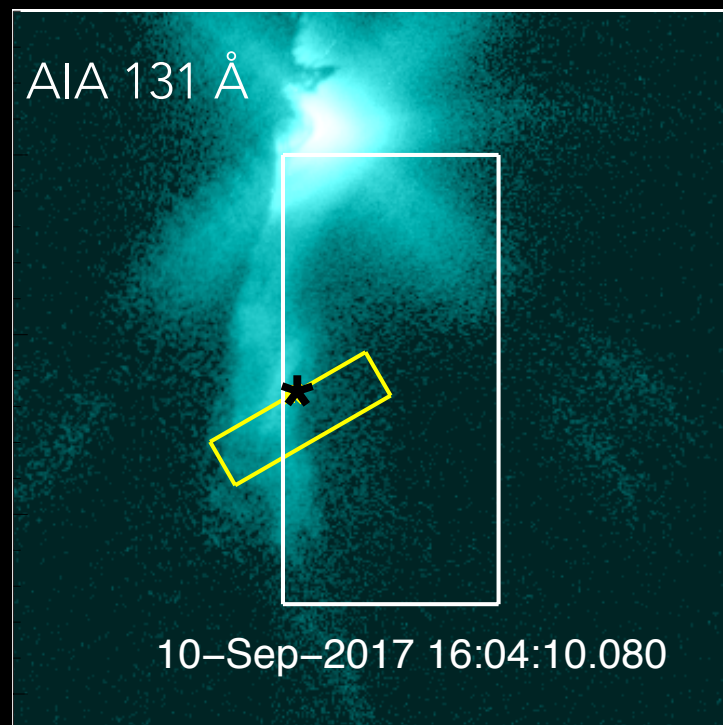


NONTHERMAL BROADENING UBIQUITOUS AT LOOP TOPS

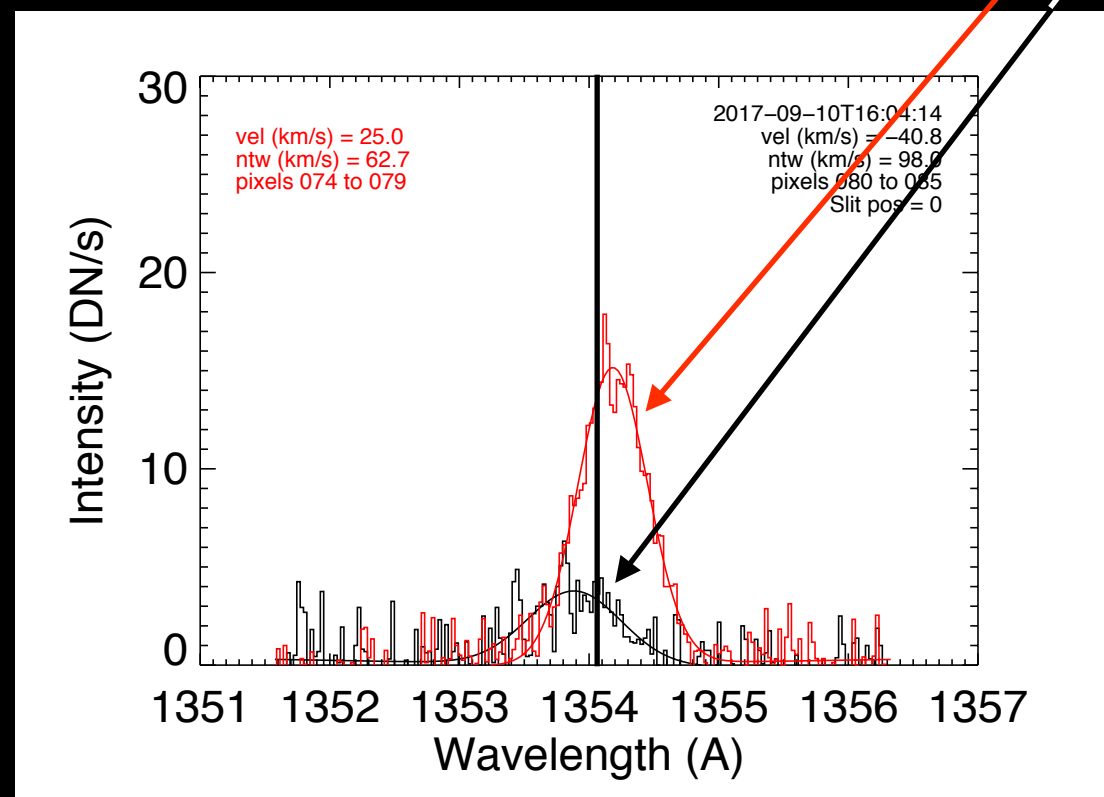
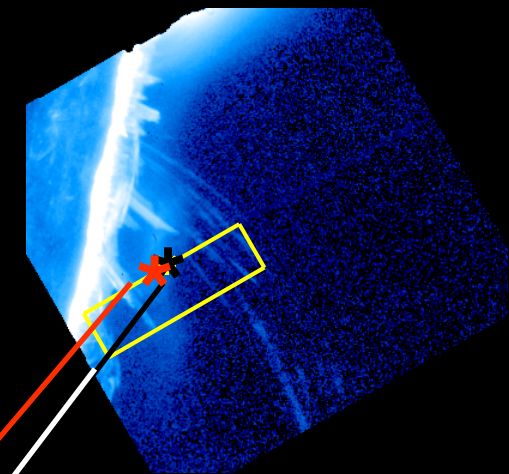


Doschek et al., 2014

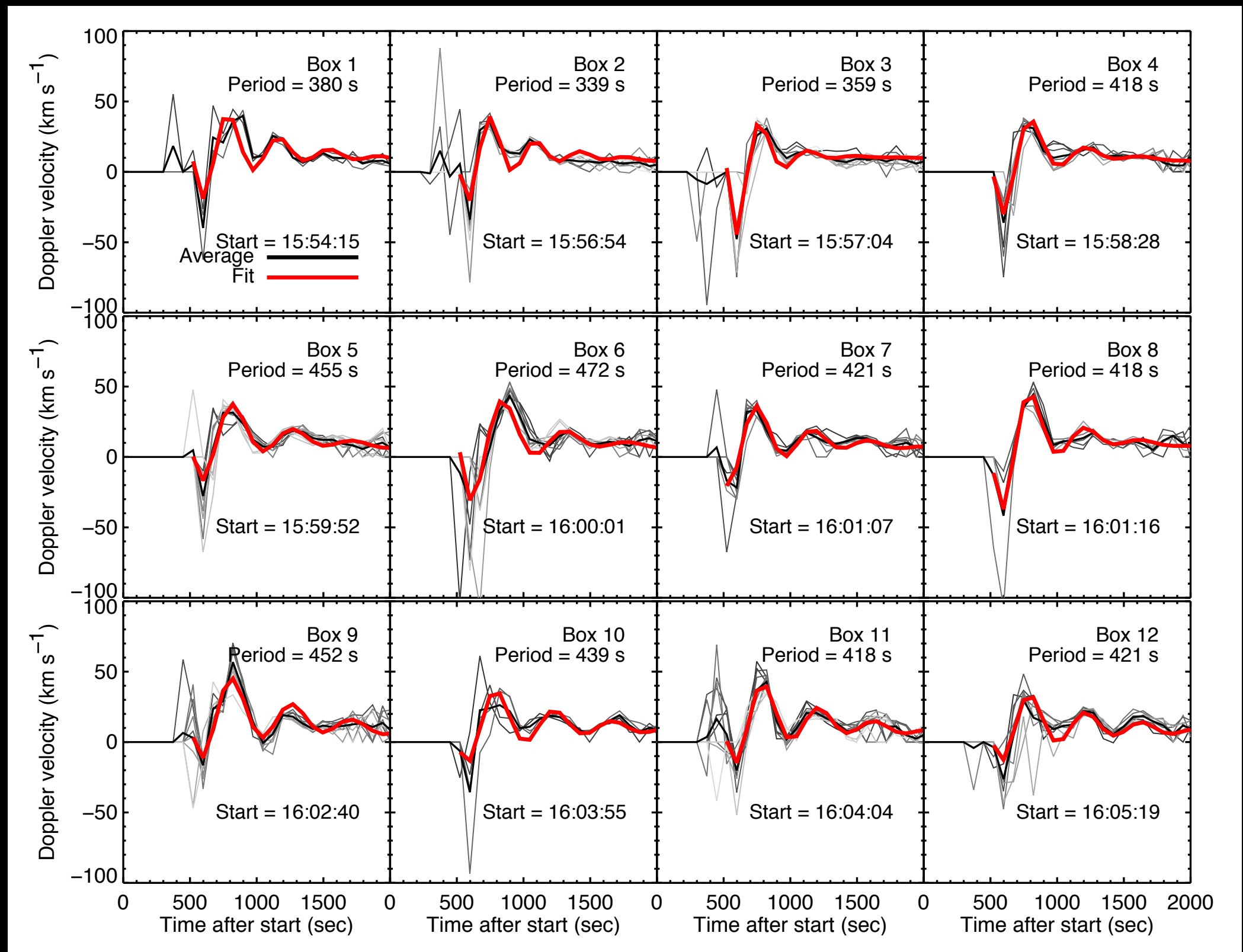
IRIS SPECTROSCOPY: FE XXI



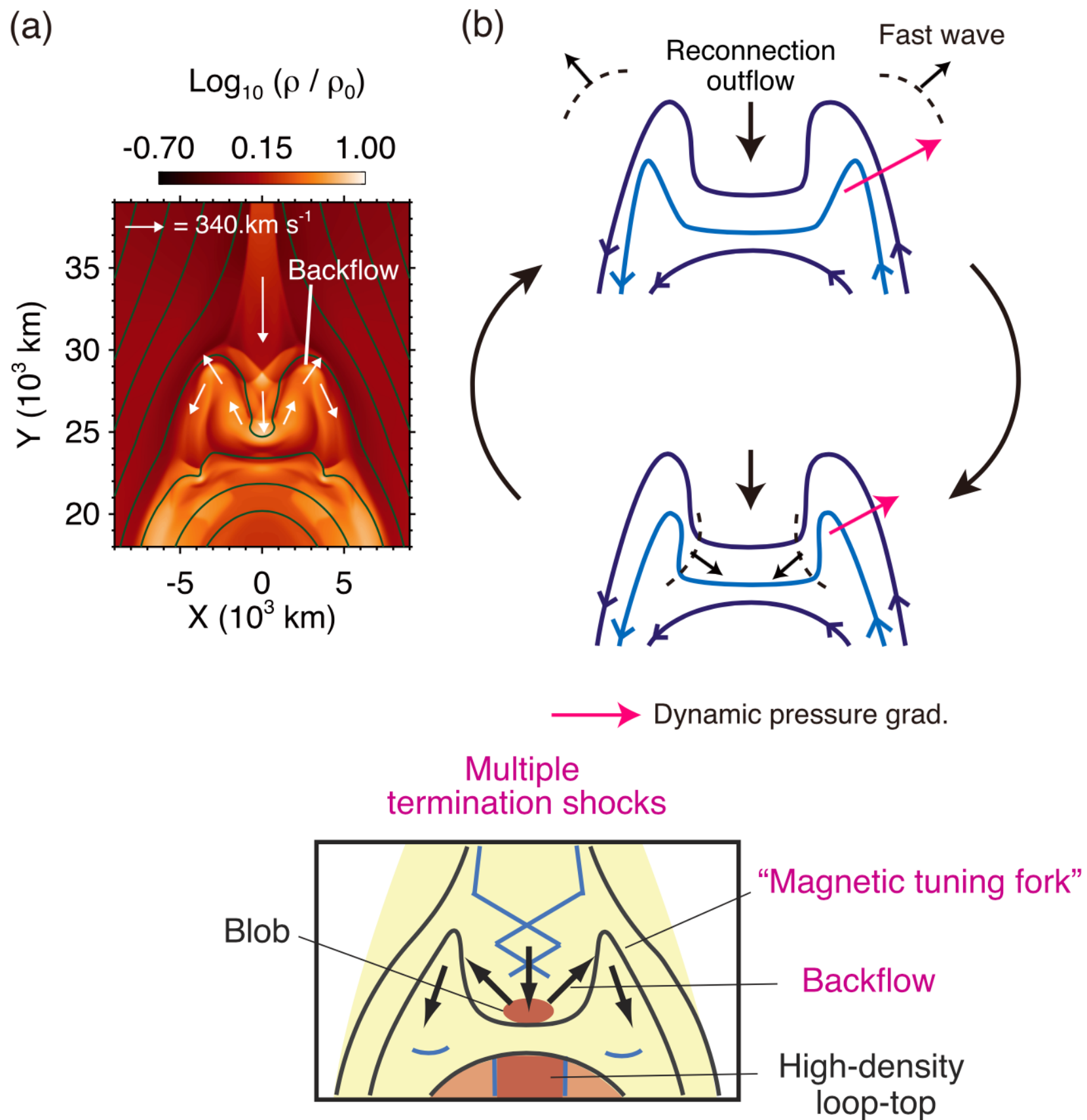
IRIS 1330 Å



DOPPLER SHIFTS OSCILLATE IN TIME



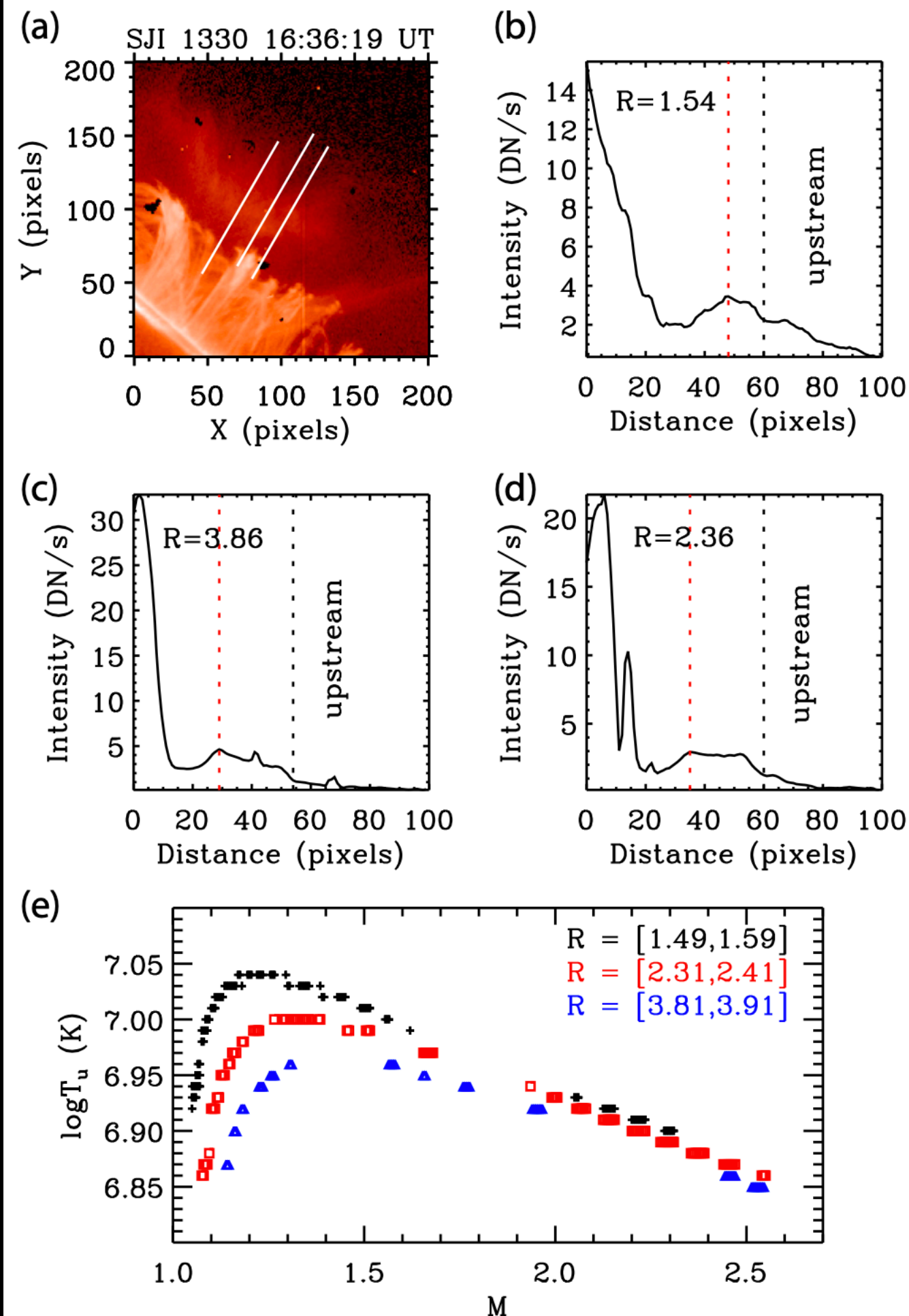
TAKASAO & SHIBATA (APJ 2016) MODEL



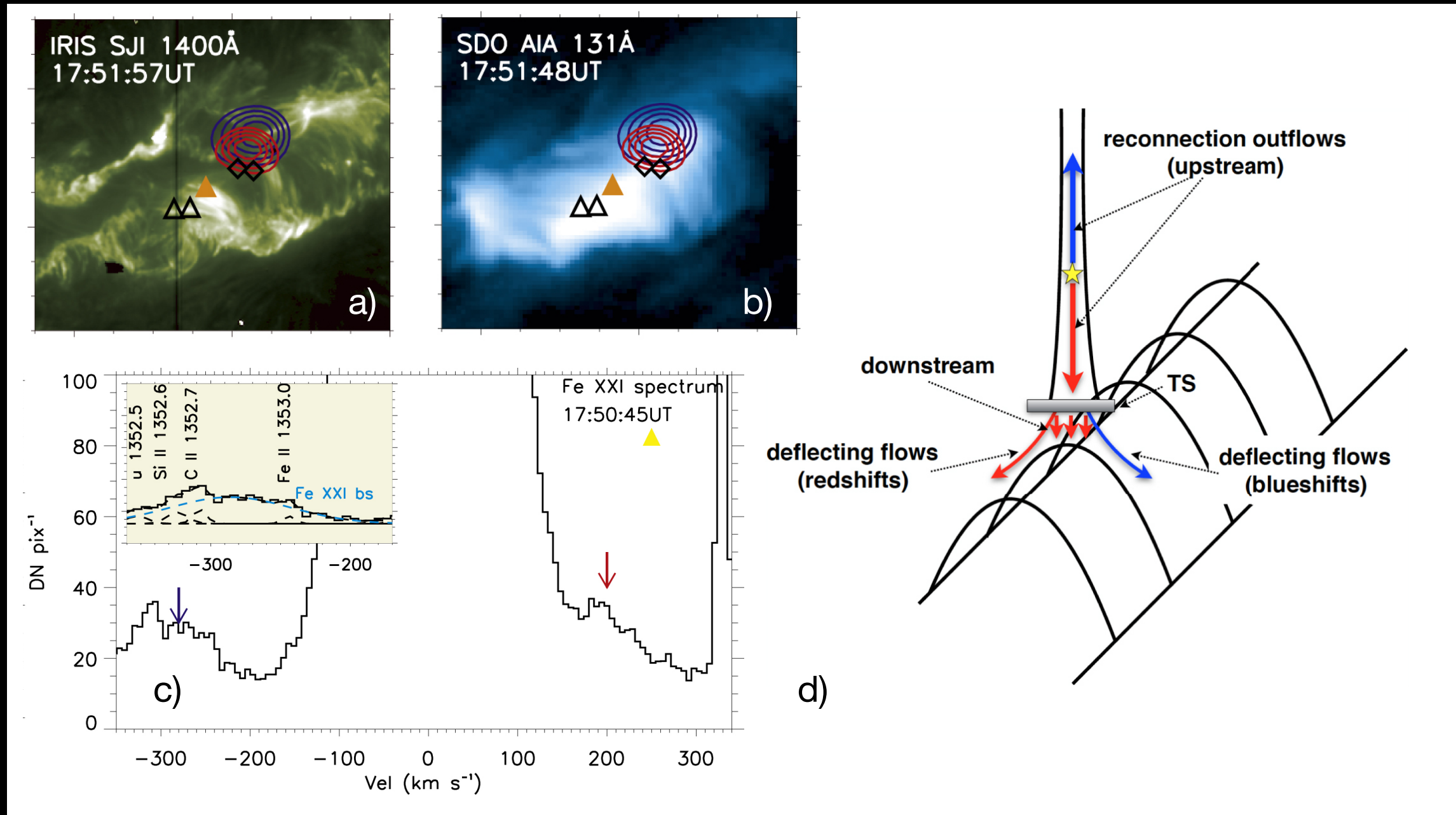
IRIS OBSERVATIONS OF THE "BLOB"

- Fe XXI source above loops could be due to compression of termination shock
- Ratios of upstream to downstream intensity indicate a Mach number of 1-2.5.

Cai et al., MNRAS, 2019
see also Cai et al., ApJ, 2021



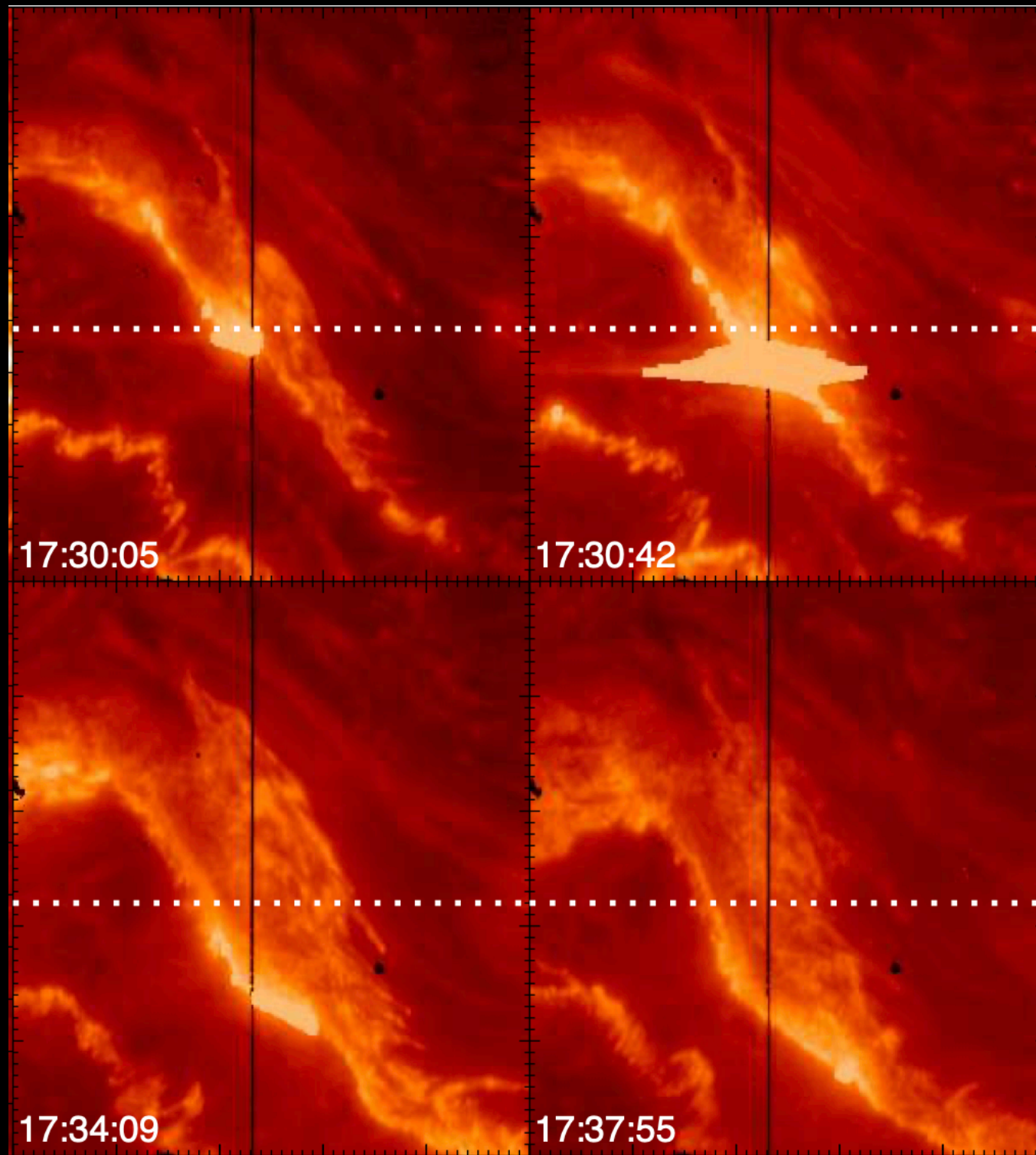
EVIDENCE FOR A TERMINATION SHOCK



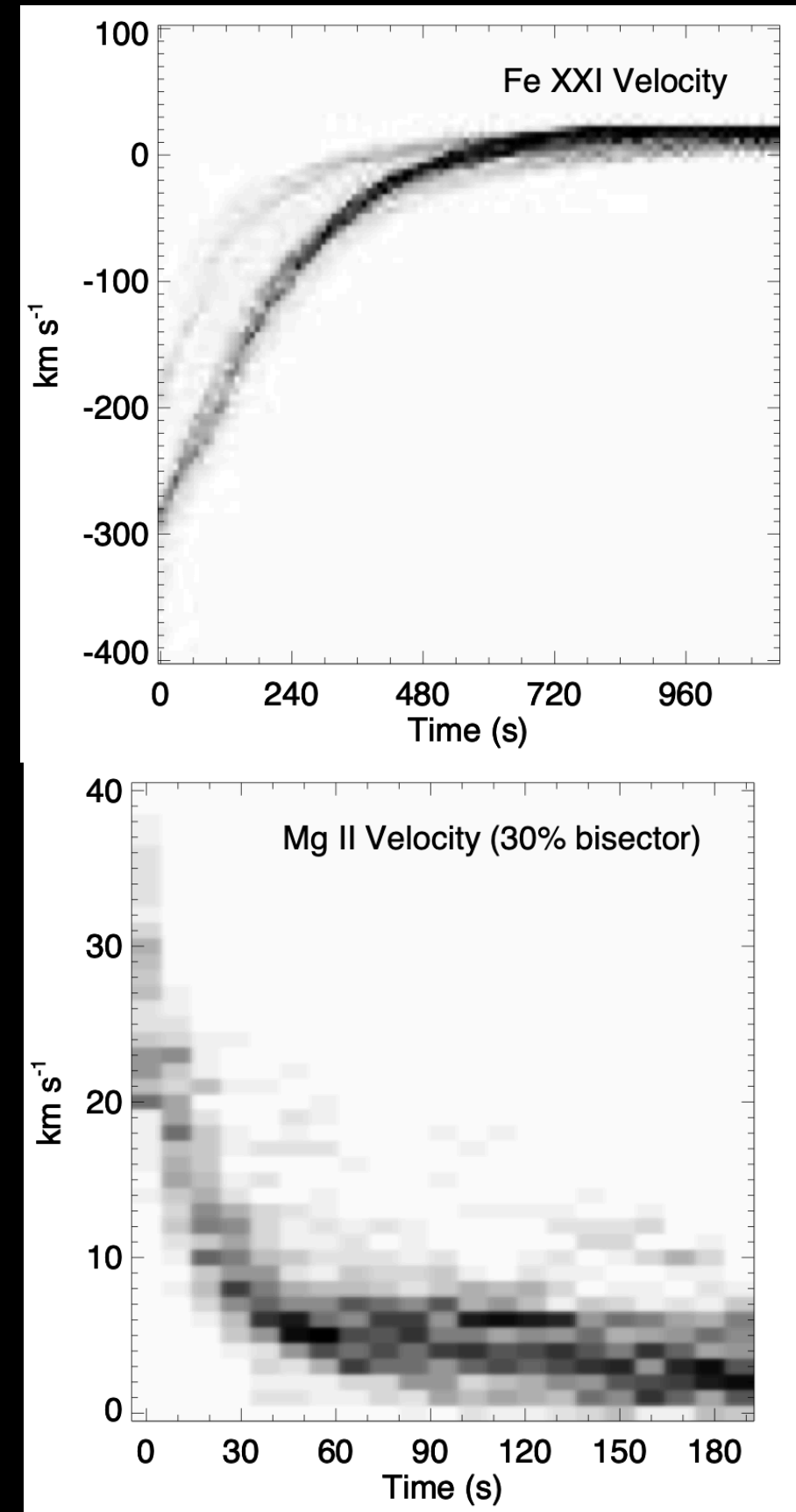
Polito et al., ApJ, 2018

(see also Hara et al. ApJ, 2011; Imada et al. ApJL, 2013)

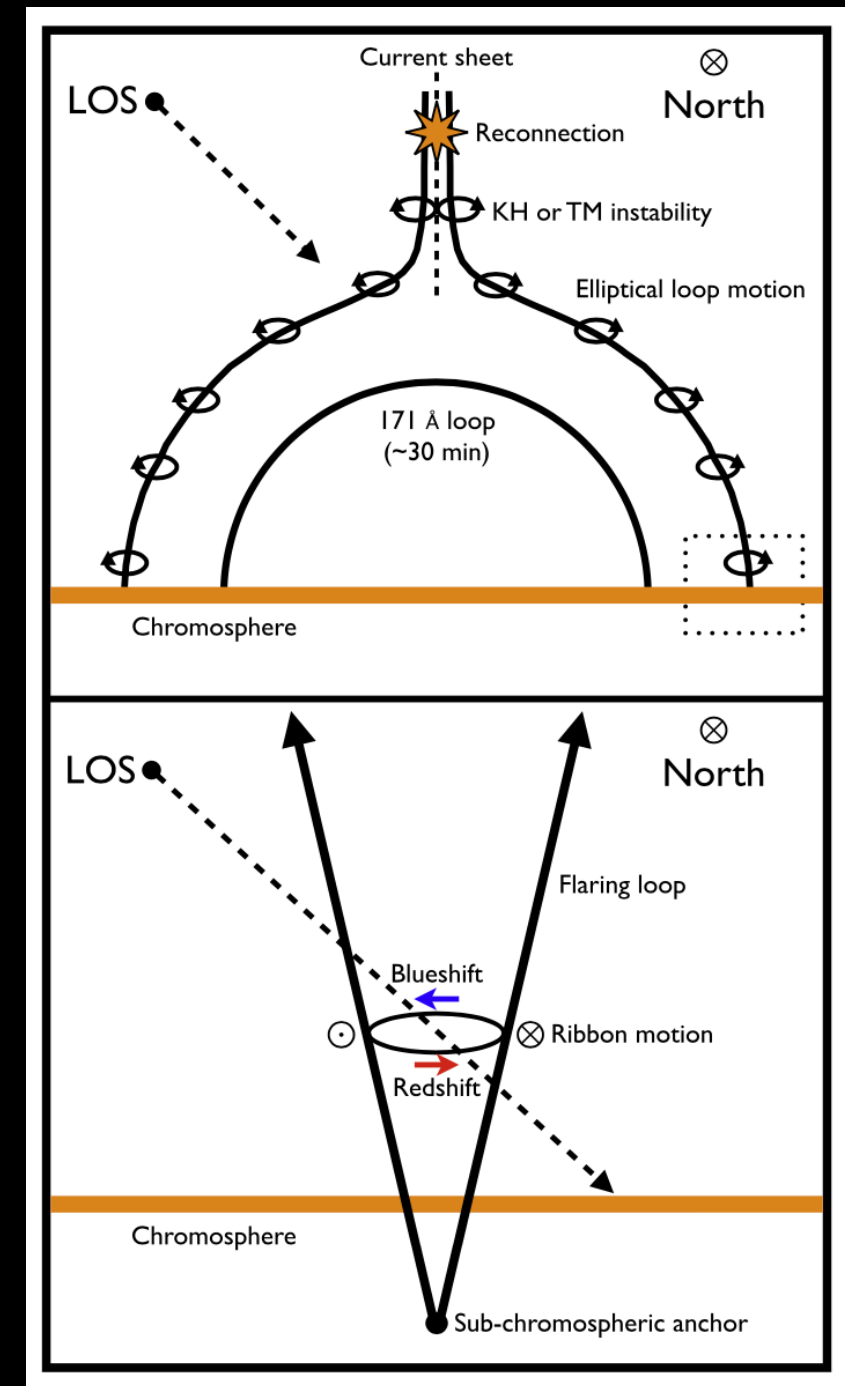
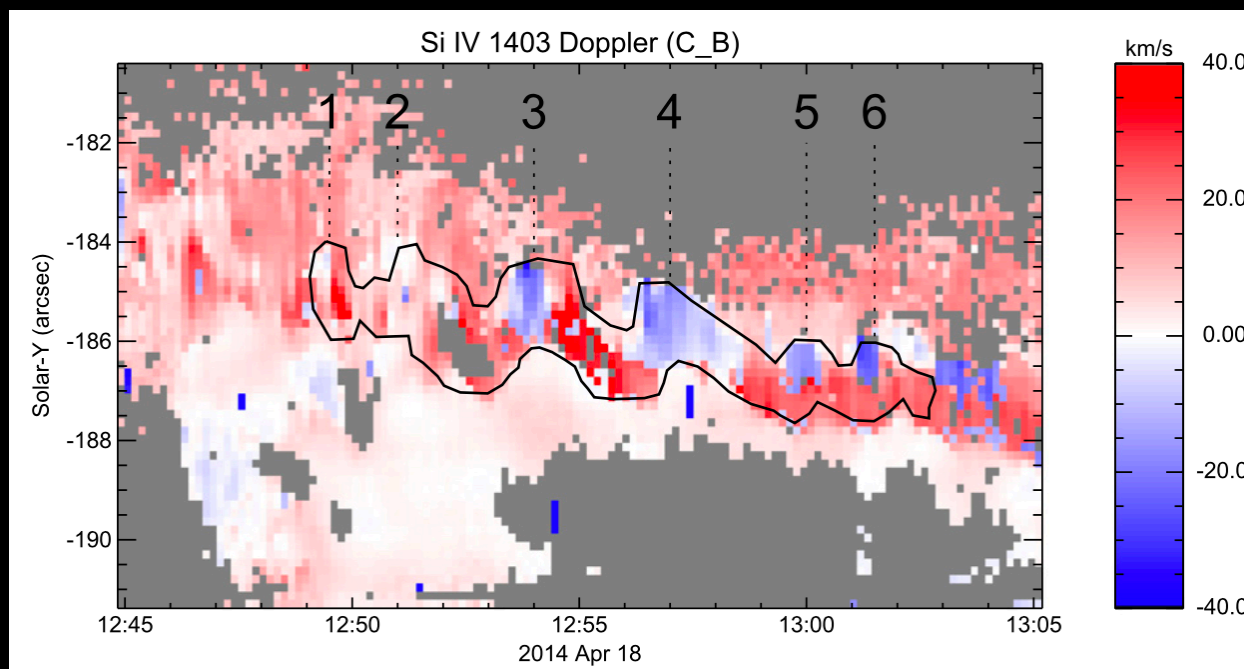
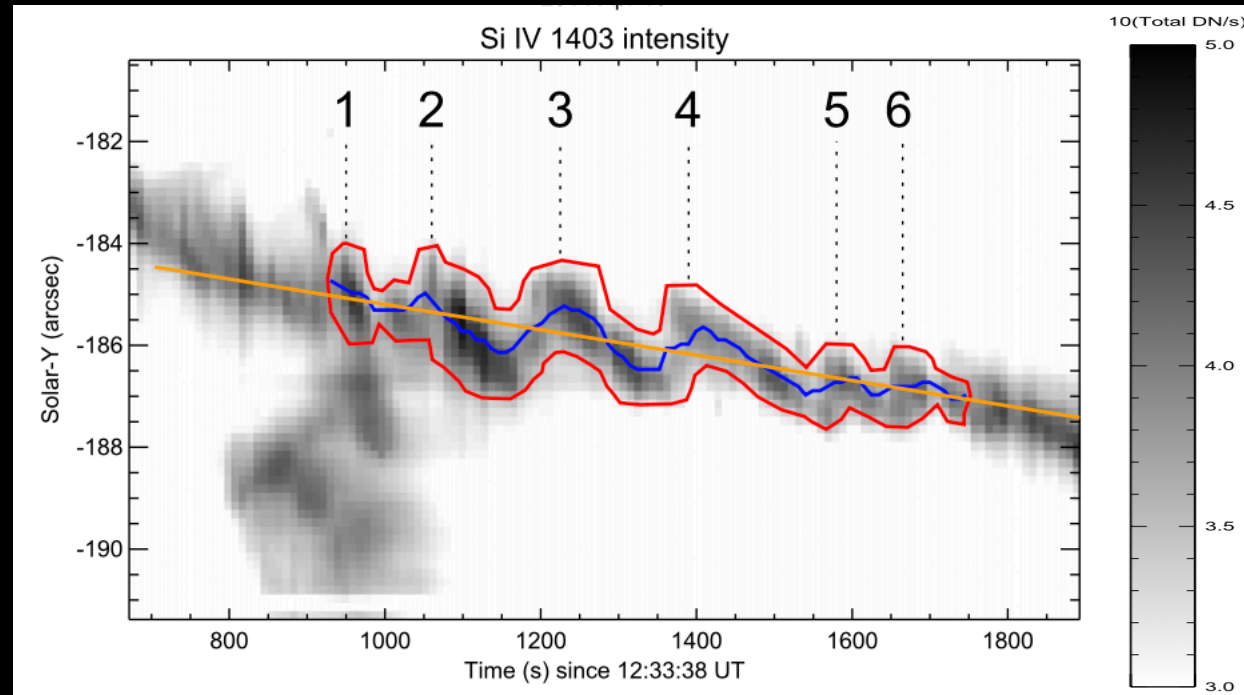
ENERGY DEPOSITED IN FLARE RIBBONS



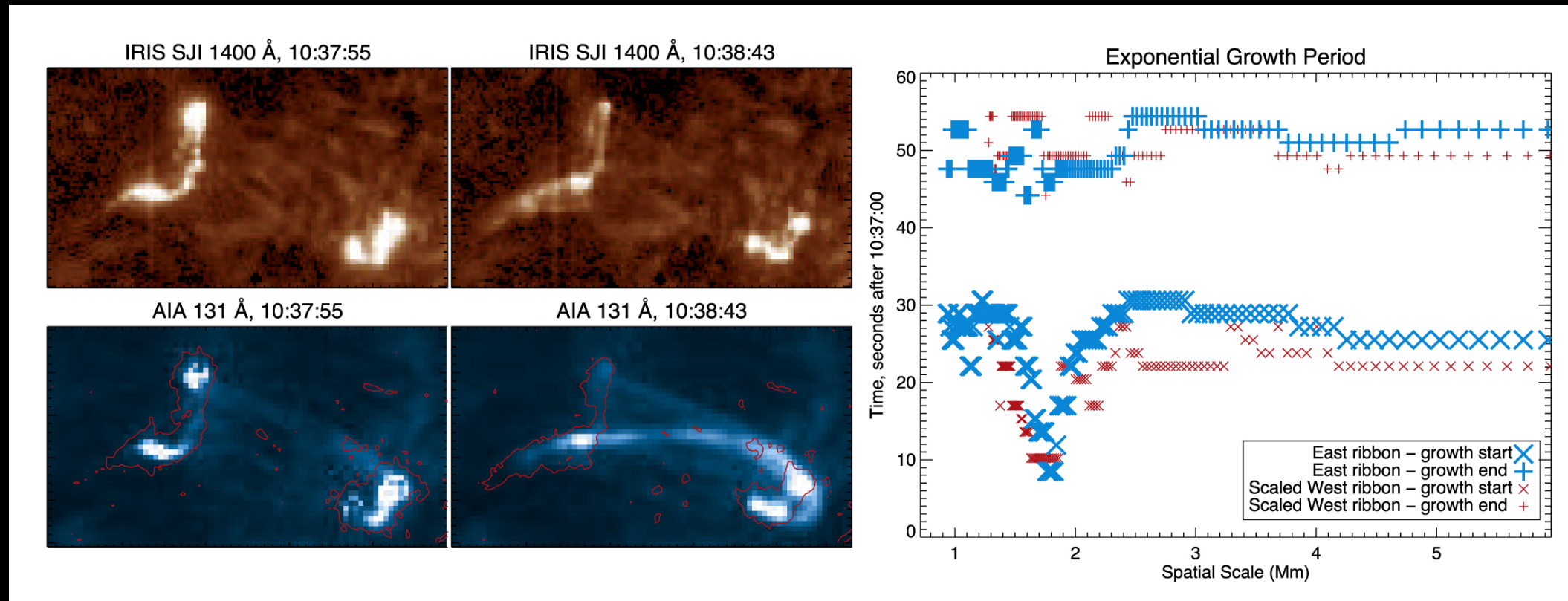
Graham & Cauzzi, ApJL, 2015



RECONNECTION IMPRINTED ON FLARE RIBBONS

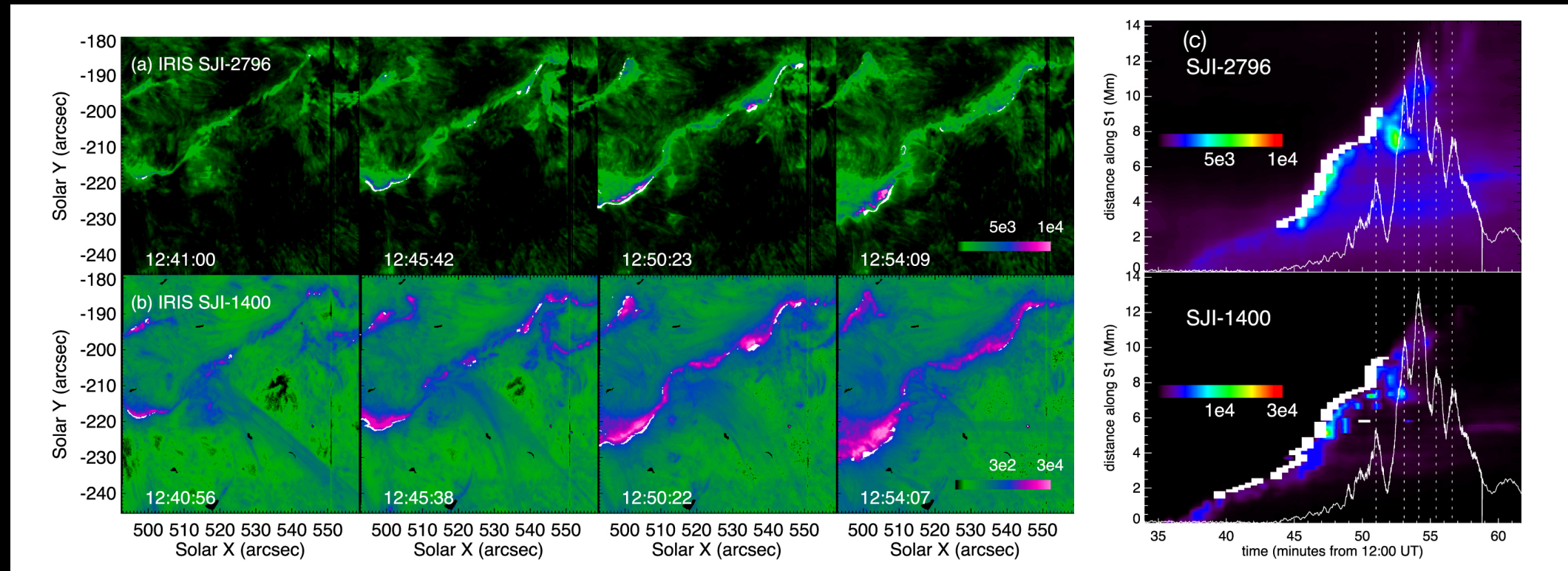


RECONNECTION IMPRINTED ON FLARE RIBBONS



- Growth of the intensity in flare ribbons at different spatial scales is exponential
- Growth starts at 1.75 Mm, then shorter and longer spatial scales follow
- Consistent with simultaneous coalescence and collapse of plasmoids in reconnection region

RECONNECTION IMPRINTED ON FLARE RIBBONS

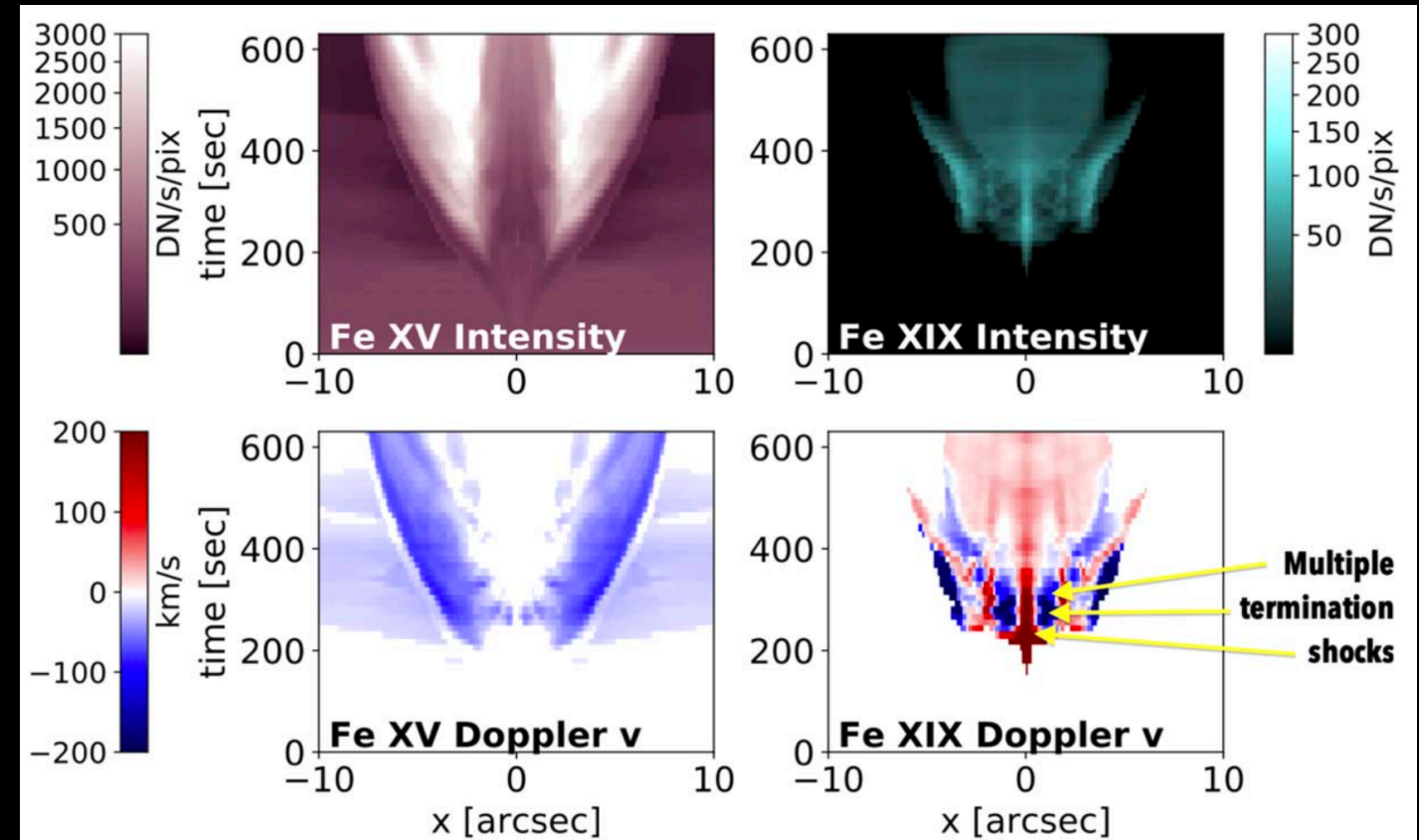
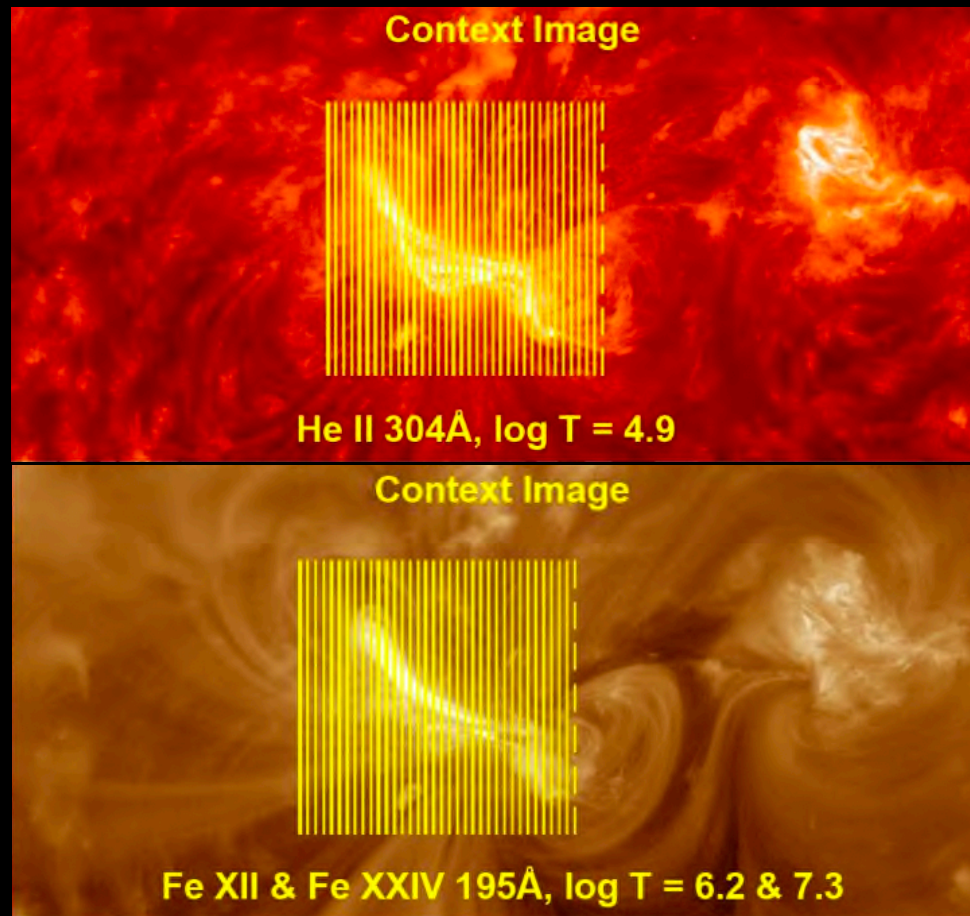


- Largest widths of the ribbon fronts and most intense bursts of UV emission are co-temporal and co-spatial with the HXR emission, indicating bursty reconnection.
- Burstiness may be caused by formation of magnetic islands in the current sheet

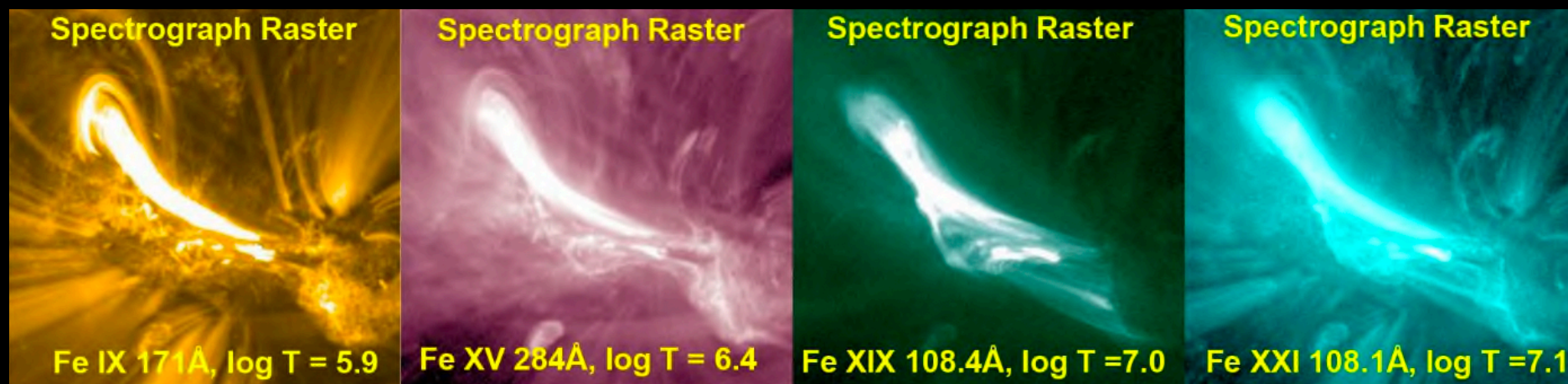
SUMMARY

- We have come a long way since Hinode 9!
 - Detailed observations of the plasma sheet, loop top region, and flare ribbons have provided new insights into the reconnection process
- Many of the new insights have come from detailed observations of the reconnection region in the September 10, 2017 flare, where both the EIS and IRIS slits were in good positions.
 - What if that happened more often???

MULTI-SLIT SOLAR EXPLORER (MUSE)

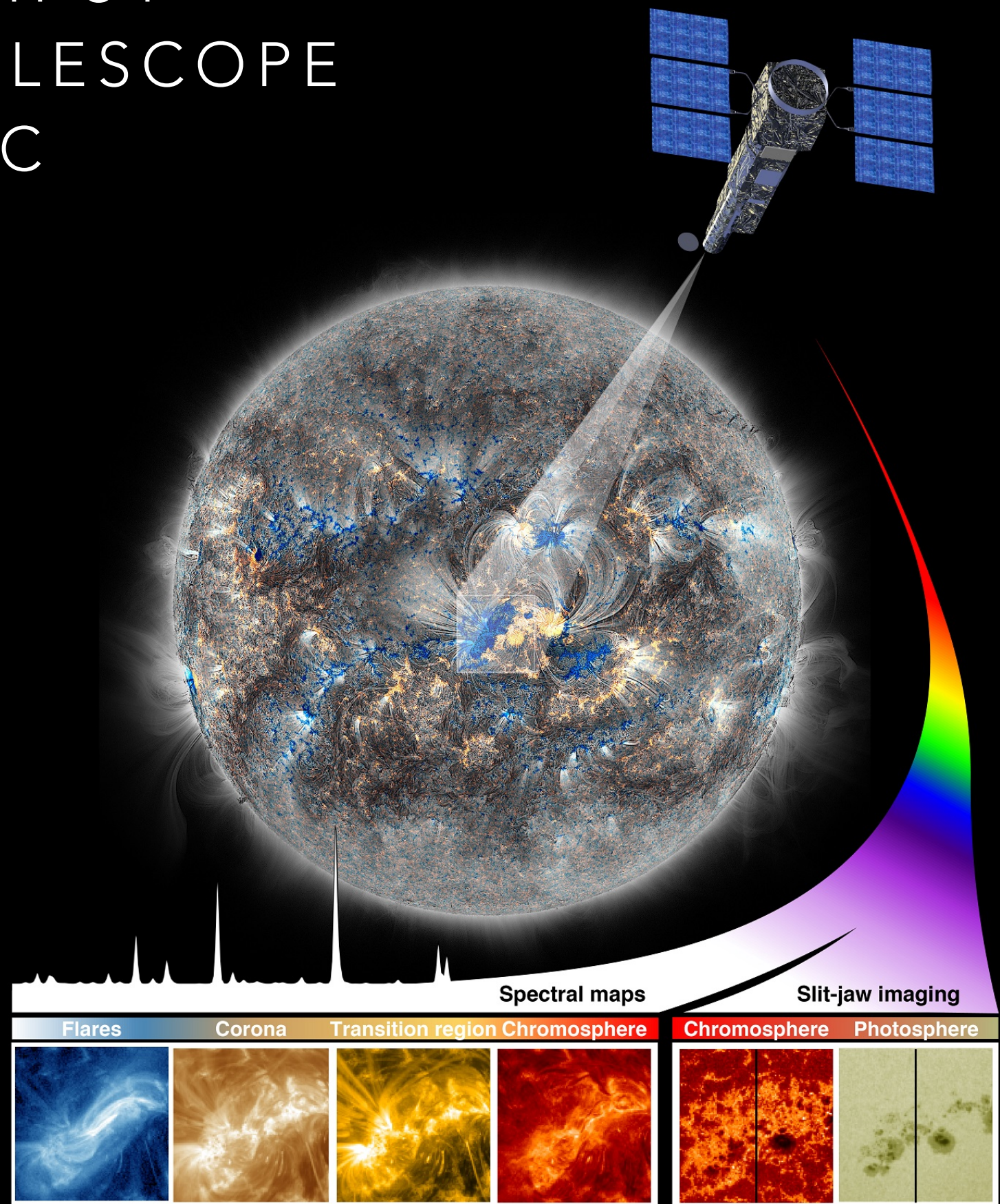


Cheung, M. et al., ApJ, 2022



EUV HIGH-THROUGHPUT SPECTROSCOPIC TELESCOPE (EUVST) ON SOLAR-C

- Spatial resolution seven times better than Hinode/EIS
- Temporal resolution < 1 s
- Wide temperature range
- Slit-jaw imaging



DANIEL K. INOUE SOLAR TELESCOPE

- Broad wavelength range covering the visible, near-infrared, and mid-infrared
- Spectroscopy, imaging, and polarimetry at high spatial and temporal resolution

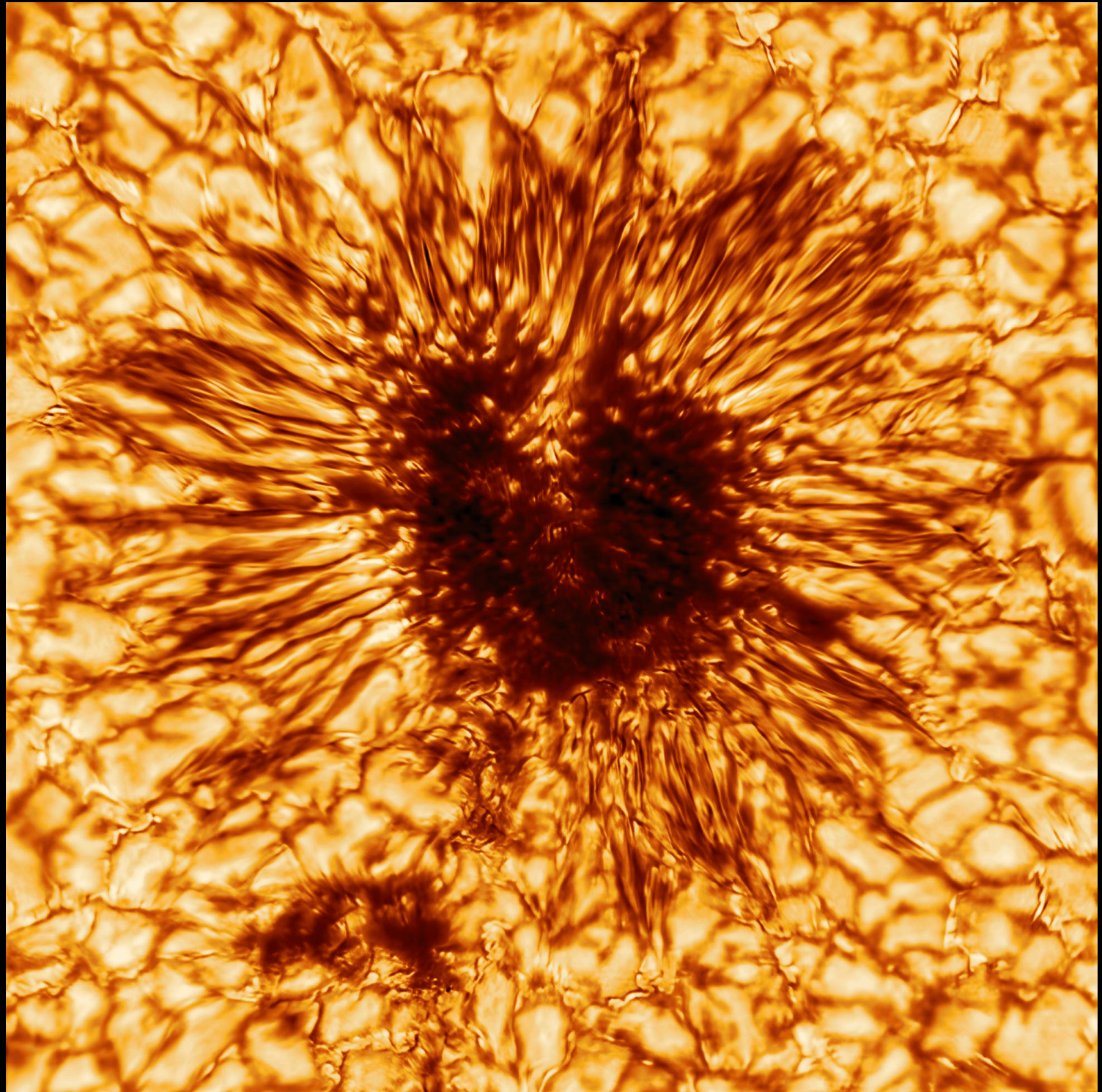




photo credit: Lorraine Lundquist

Thank You!