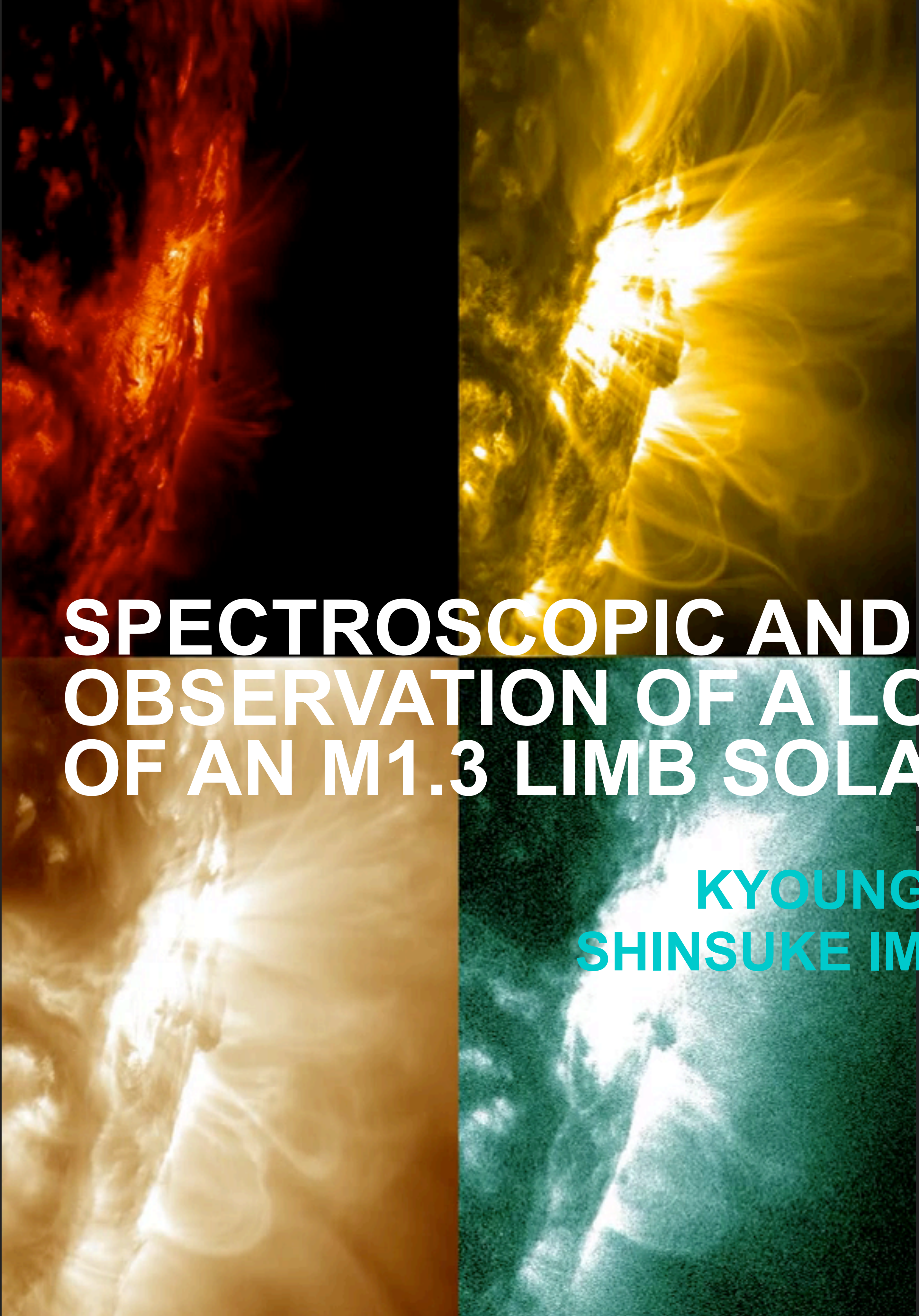

ISEST 2017

SPECTROSCOPIC AND STEREOSCOPIC OBSERVATION OF A LOOP-TOP SOURCE OF AN M1.3 LIMB SOLAR FLARE

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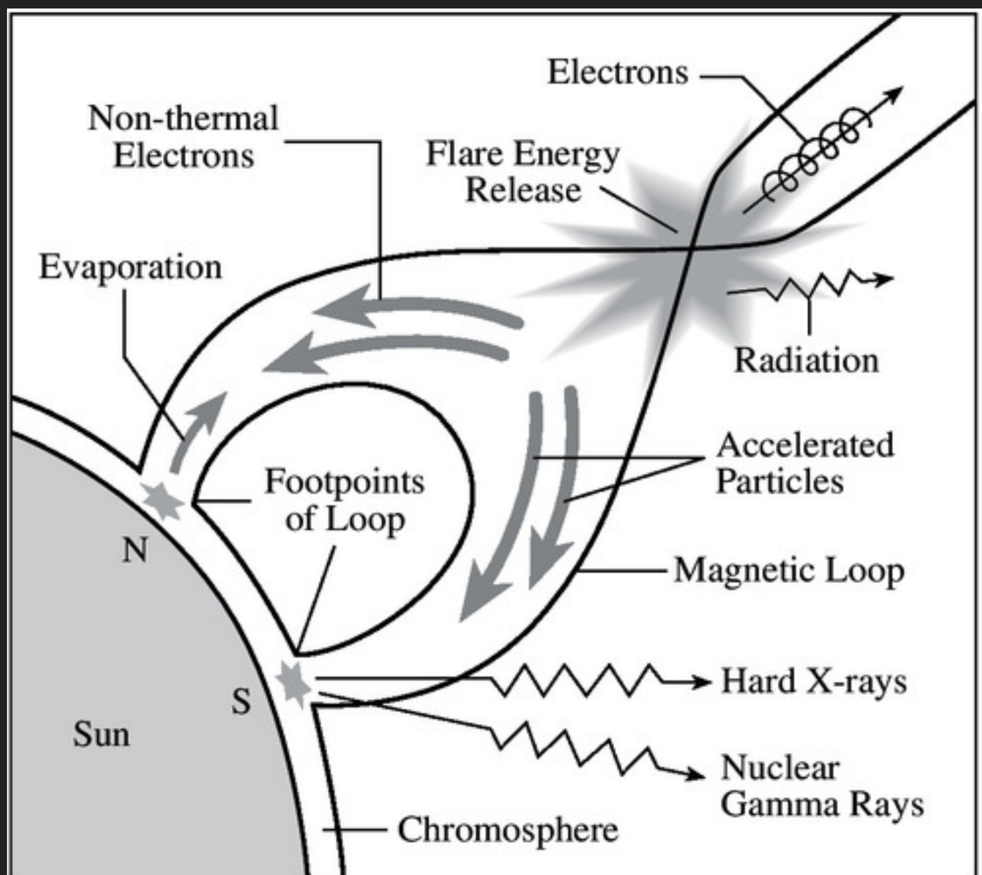
[3]National Defense Academy

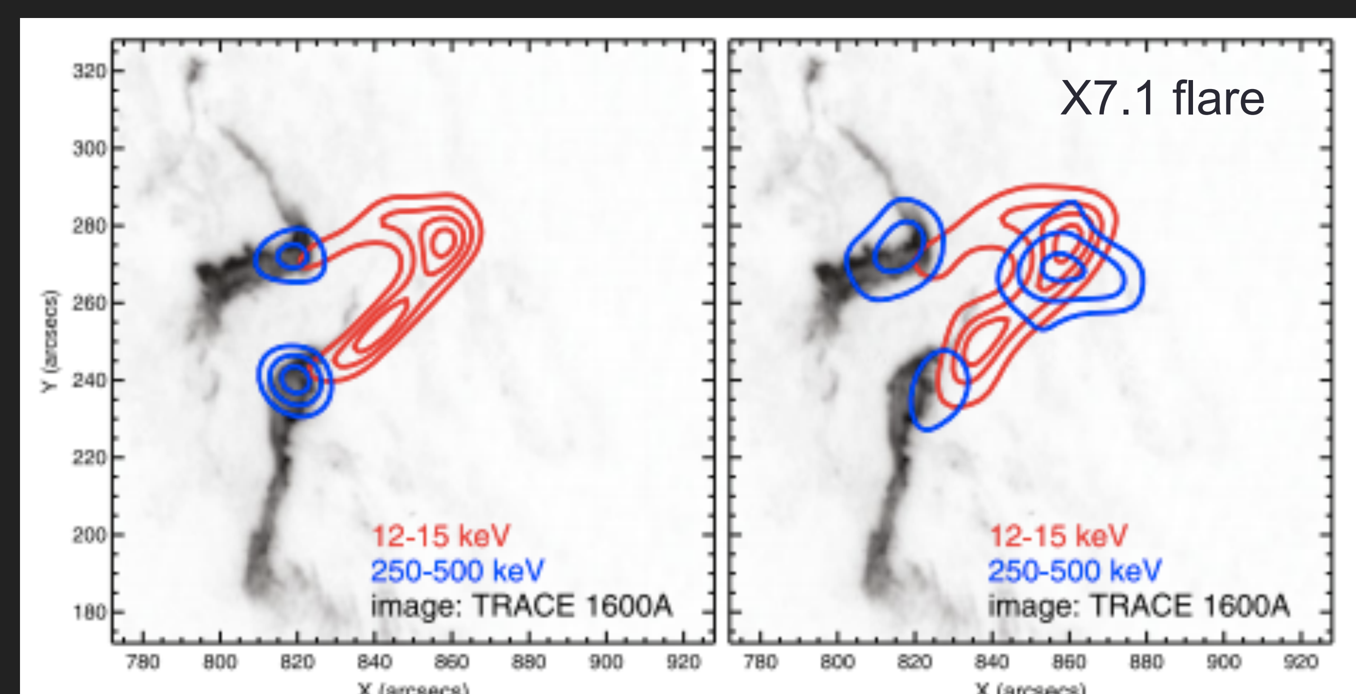
FLARE - OBSERVATION & MODEL

Solar flare model



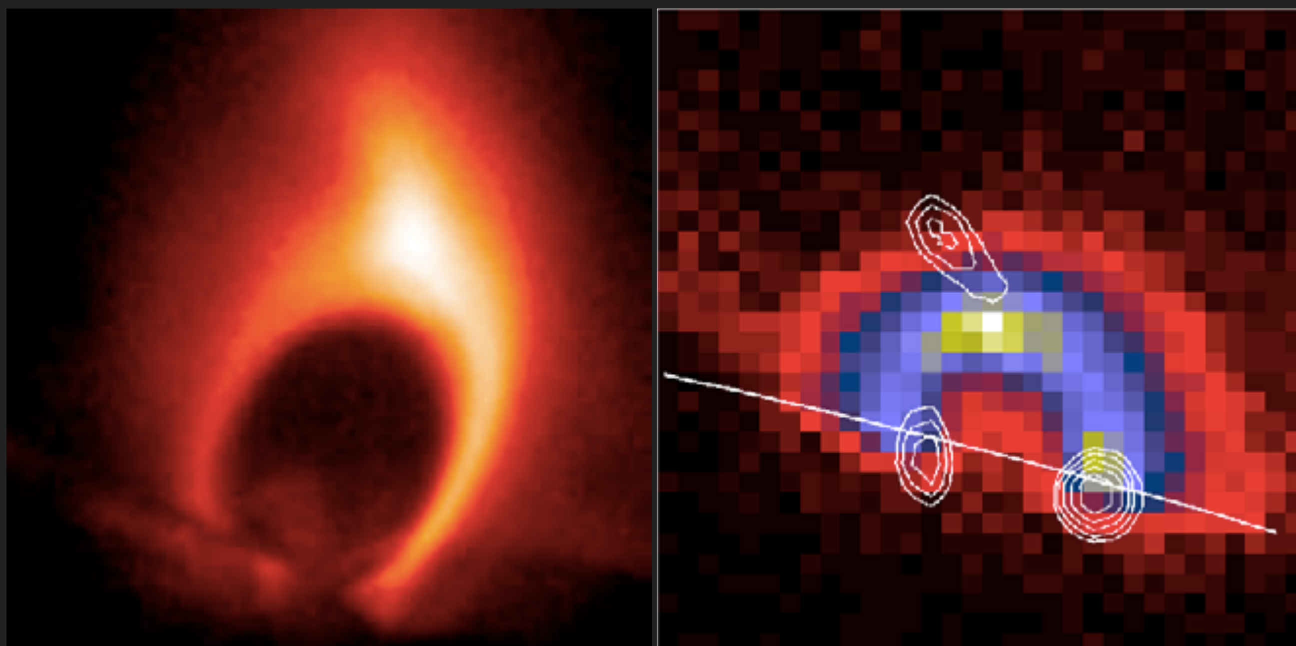
- Magnetic reconnection at the higher corona
- Energetic particles are accelerated at the reconnection site
  - Particles precipitates along the magnetic loop (radio emission) and hit the chromosphere footpoints (Hard X-ray emission, Hα emission and flare ribbon)
  - Heated chromospheric plasma evaporates into the corona (soft X-ray emission, post flare loop arcade)
- Evaporation flows
  - From the spectroscopic observation, evaporation flows are observed by Doppler velocity measurements

- **Sometimes, strong flares produce white light continuum enhancement, white light flare (WLF).**
- **White light flares and HXR emissions are well correlated** in spatially and temporally (Neidig 1989; Hudson et al. 1992; Krucker et al. 2015).



Krucker et al. (2008)

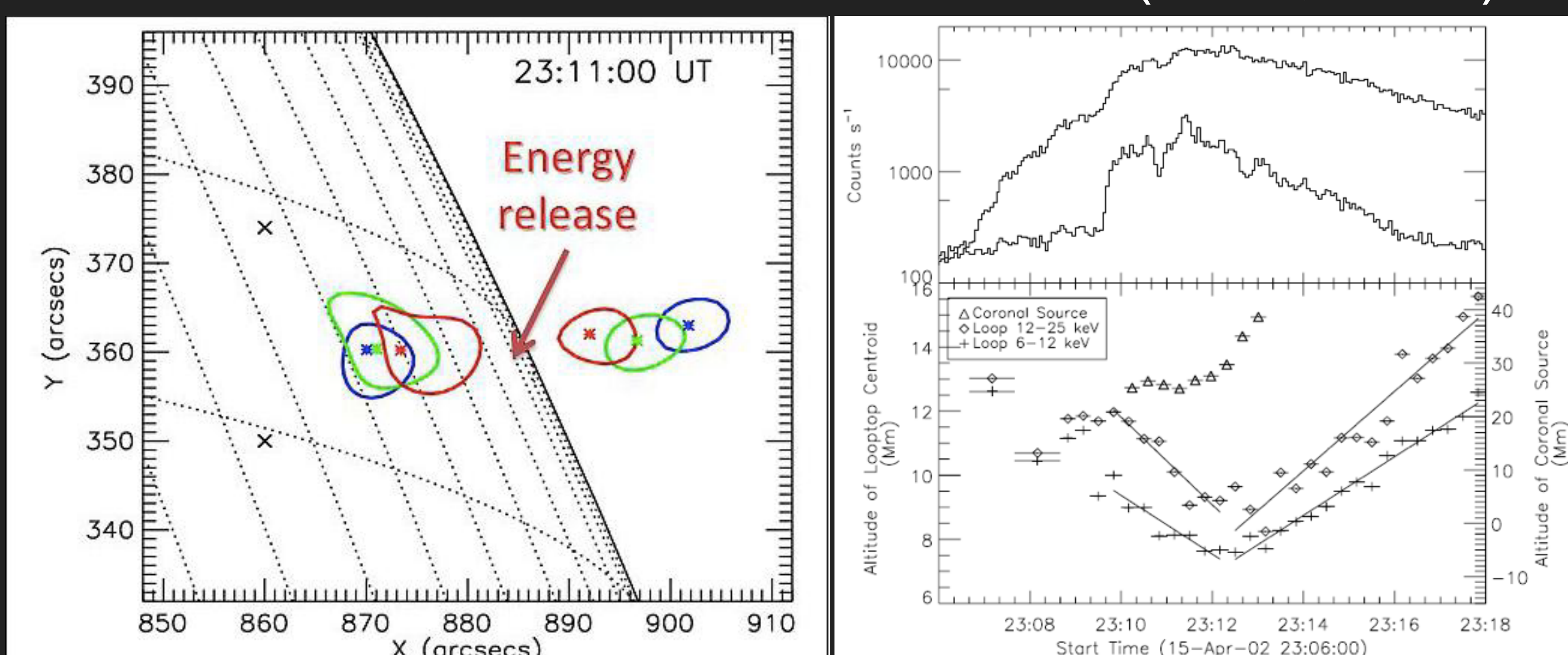
ABOVE THE LOOP TOP SOURCE

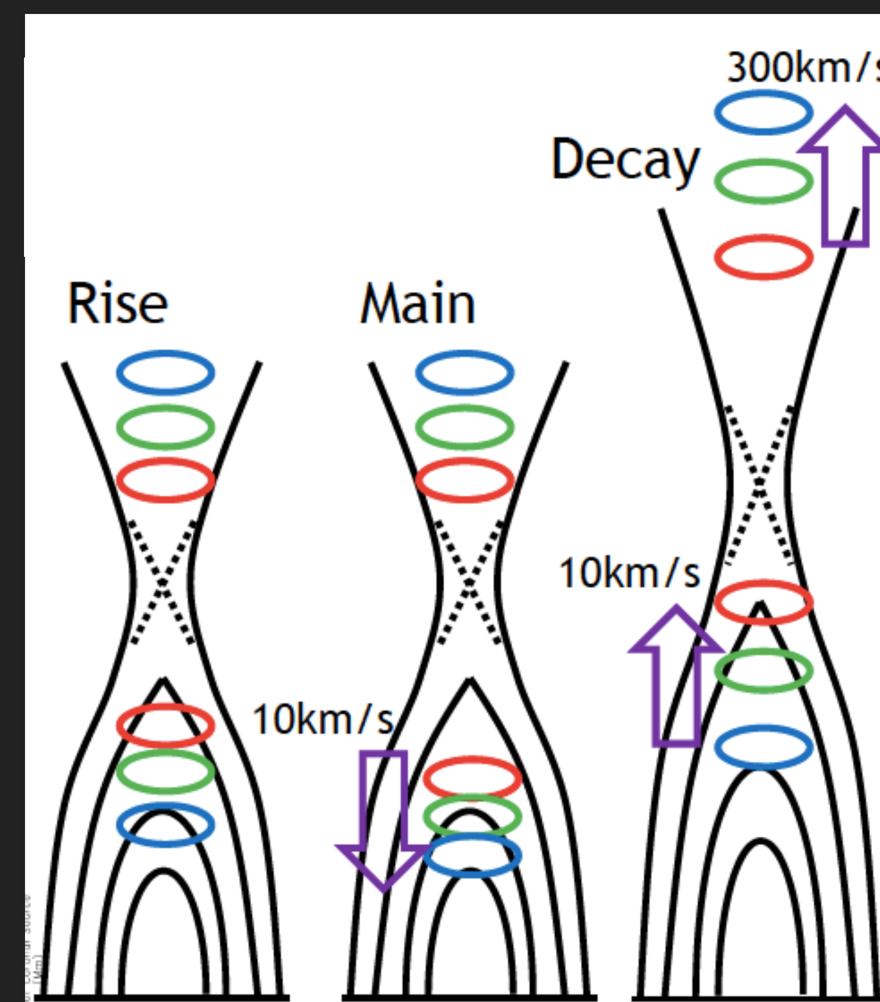


Masuda et al. (1994)

- Soft X-ray cusp-shape loop with HXR above the loop-top source
- Trace specific loop motion, or peak loop changes with time

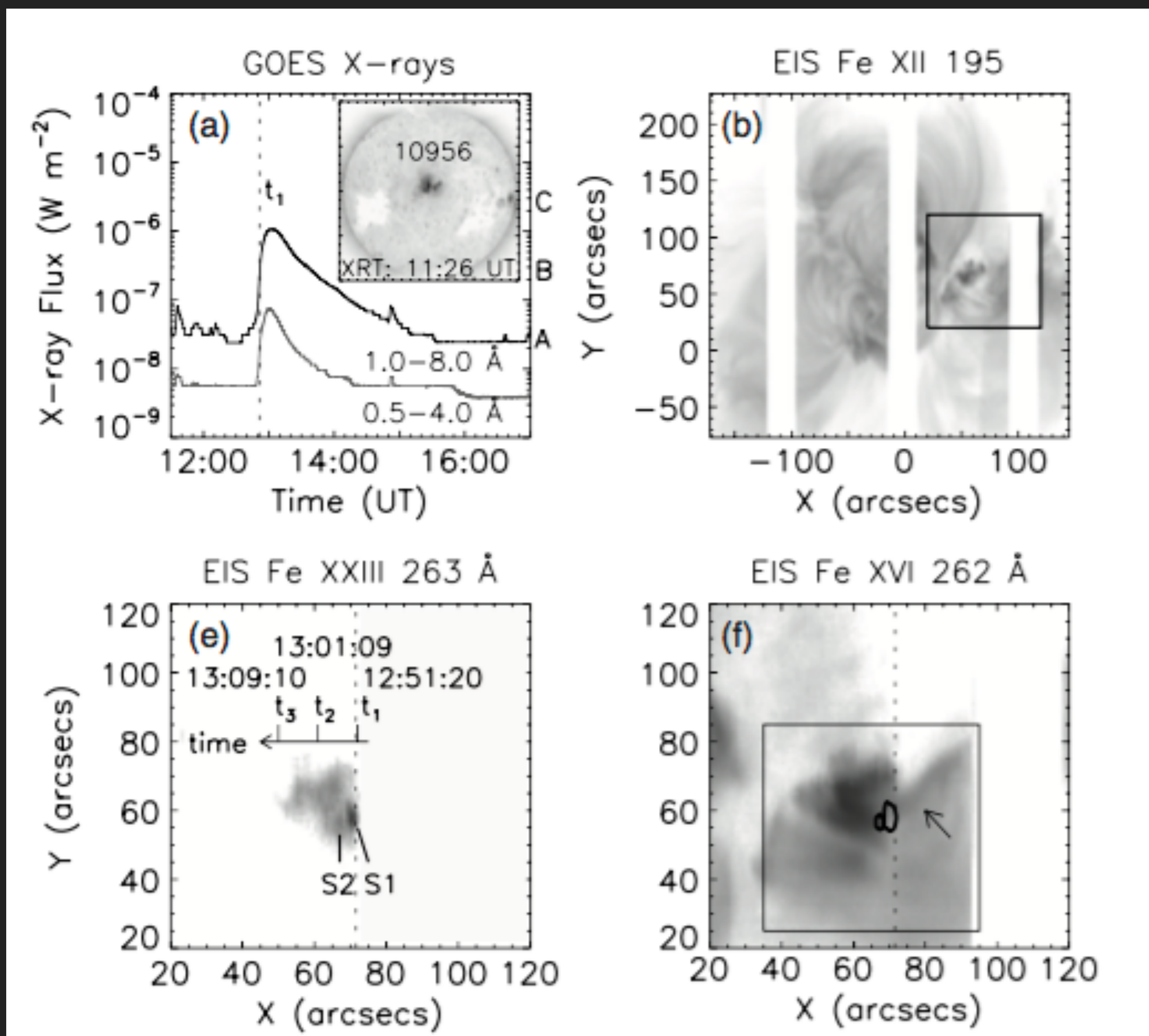
Sui et al. (2003, 2004)

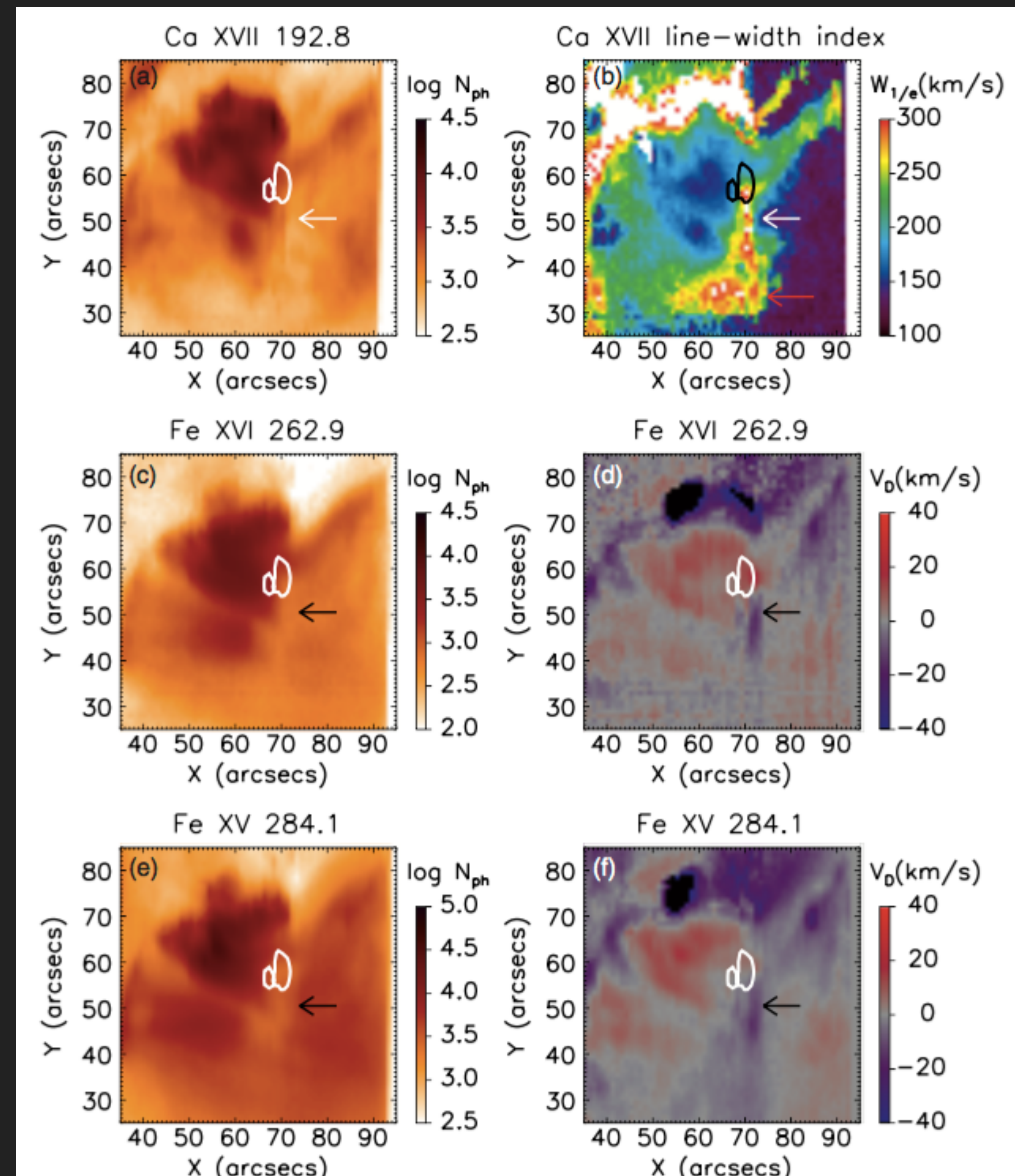




LOOP-TOP SOURCE REGION - RECONNECTION OUTFLOW

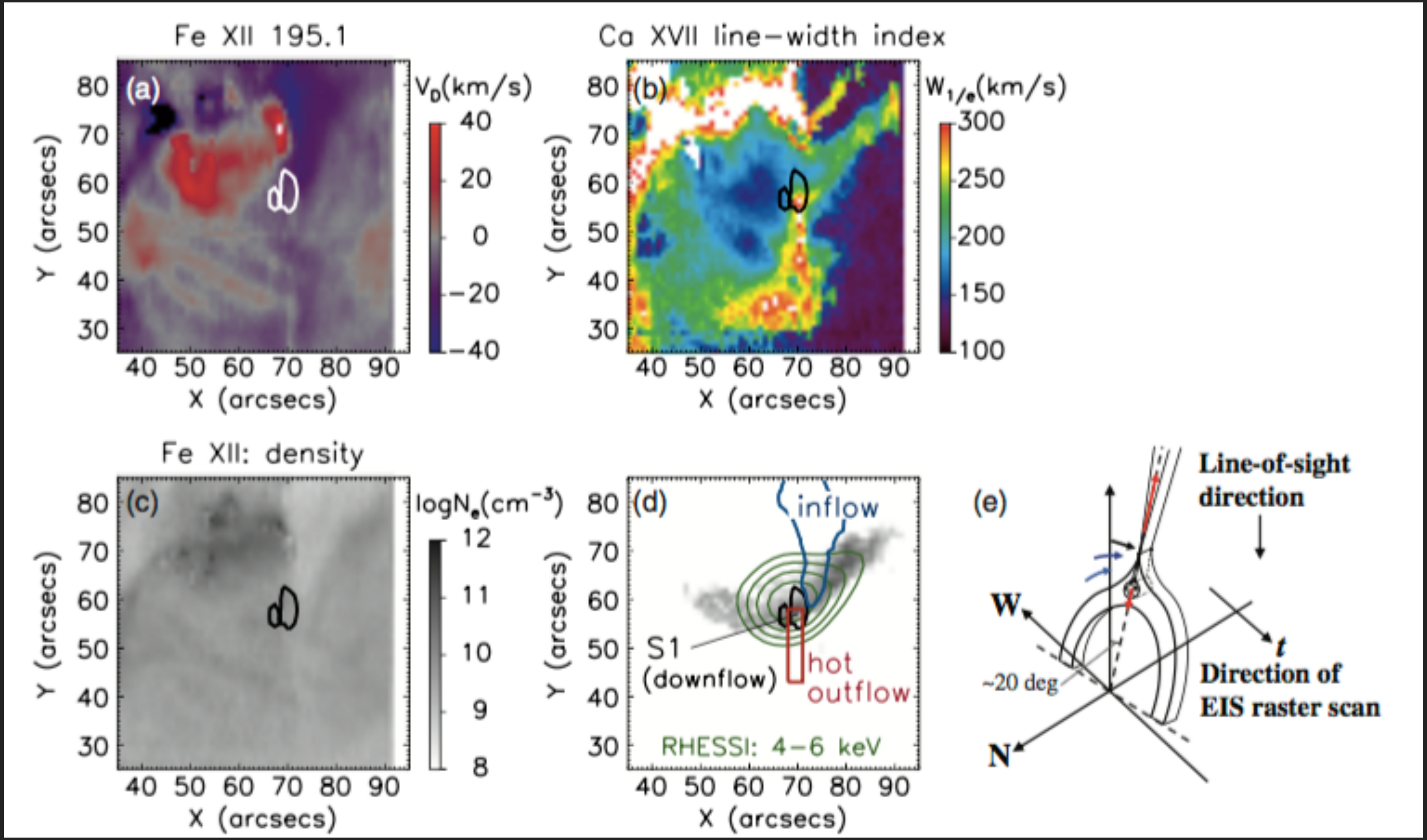
Hara et al. 2011





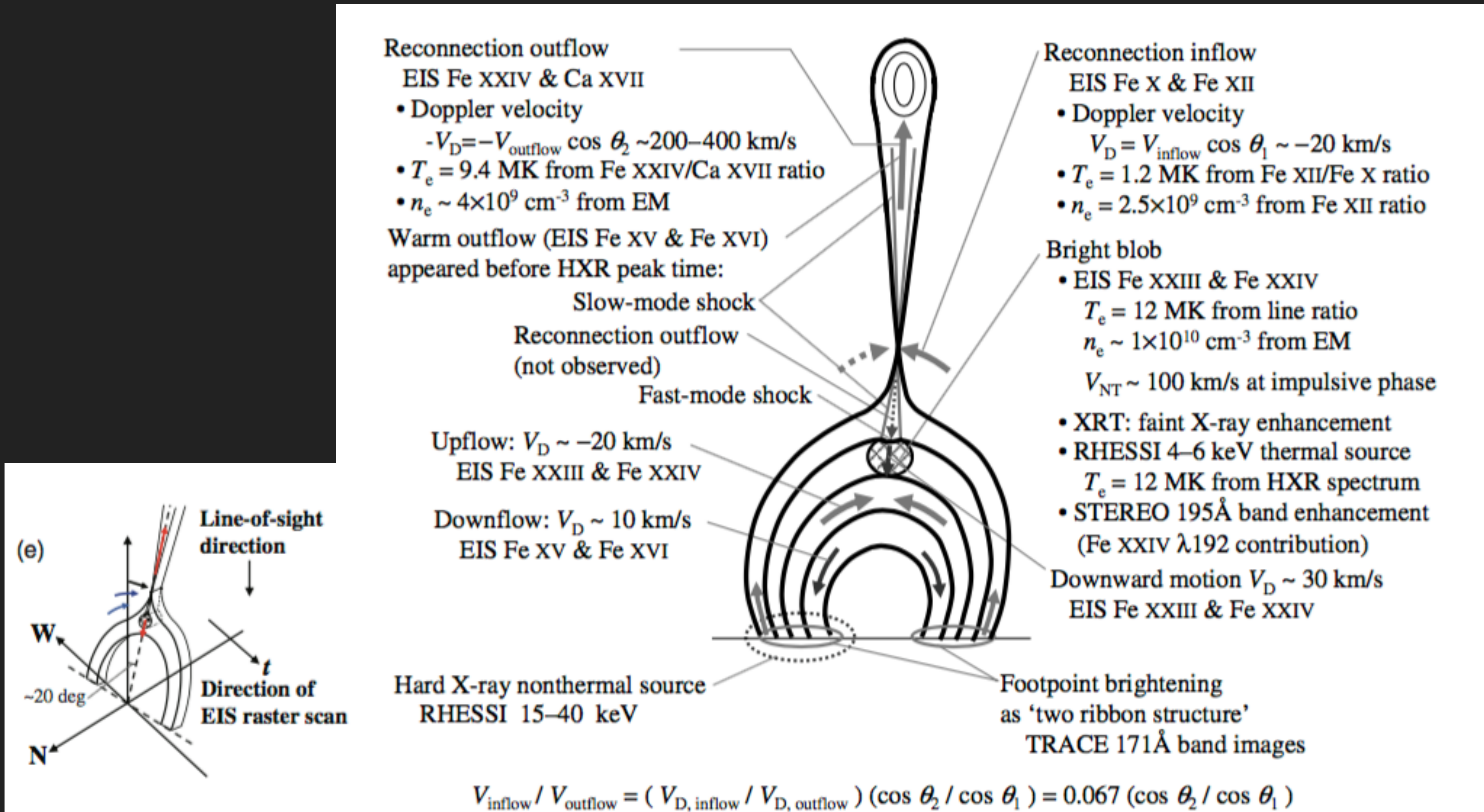
LOOP-TOP SOURCE REGION - RECONNECTION OUTFLOW

Hara et al. 2011



LOOP-TOP SOURCE REGION - SHOCK

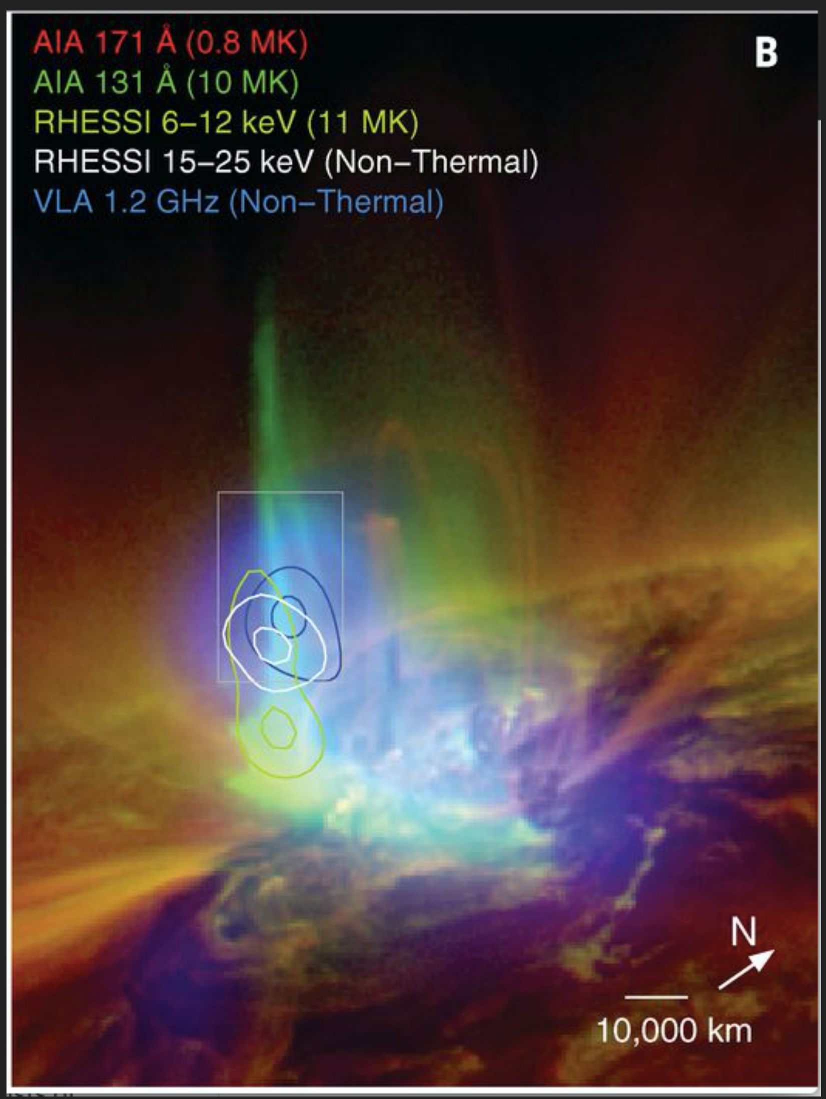
Hara et al. 2011

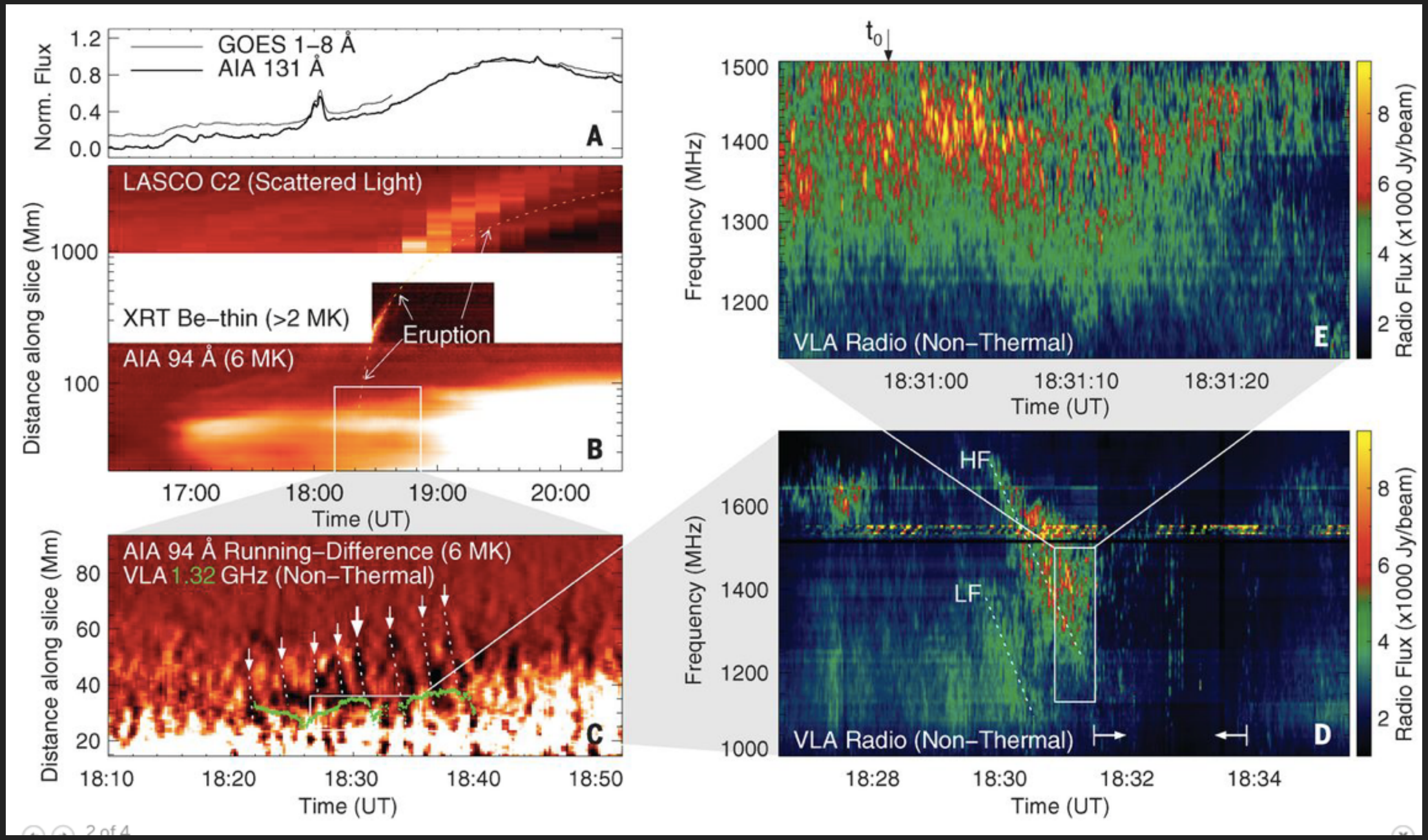


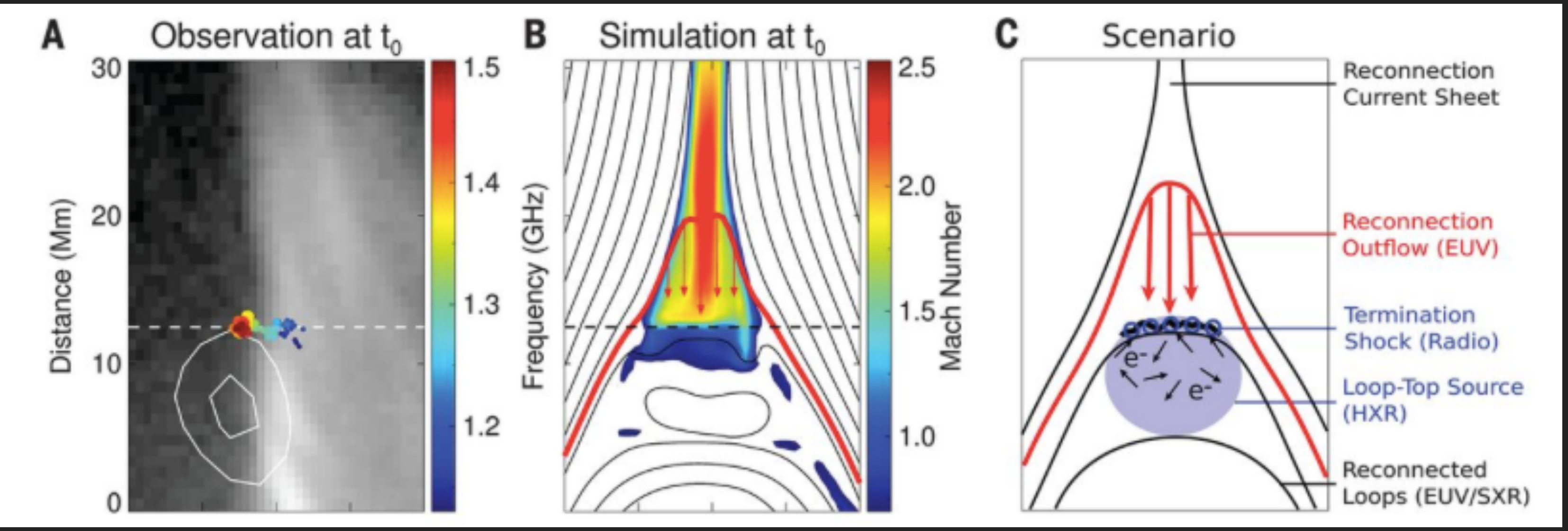
LOOP-TOP SOURCE REGION - SHOCK

Radio observation + HXR spectroscopy + EUV imaging + simulation

- Bin Chen et al. 2015







Particle acceleration and shock at the loop-top region

WHAT DO WE NEED FROM THE SPECTROSCOPIC OBSERVATIONS FOR UNDERSTANDING SOLAR FLARES?

- Magnetic reconnection region near the loop-top source
  - reconnection outflow & inflow
  - the presence of the slow-mode and fast-mode MHD shocks in the reconnection geometry
  - Particle accelerations in solar flares
  - Spectroscopic obs.:

    - Identification of the spectral line for hot plasma with low intensity due to the dynamic range or sensitivity

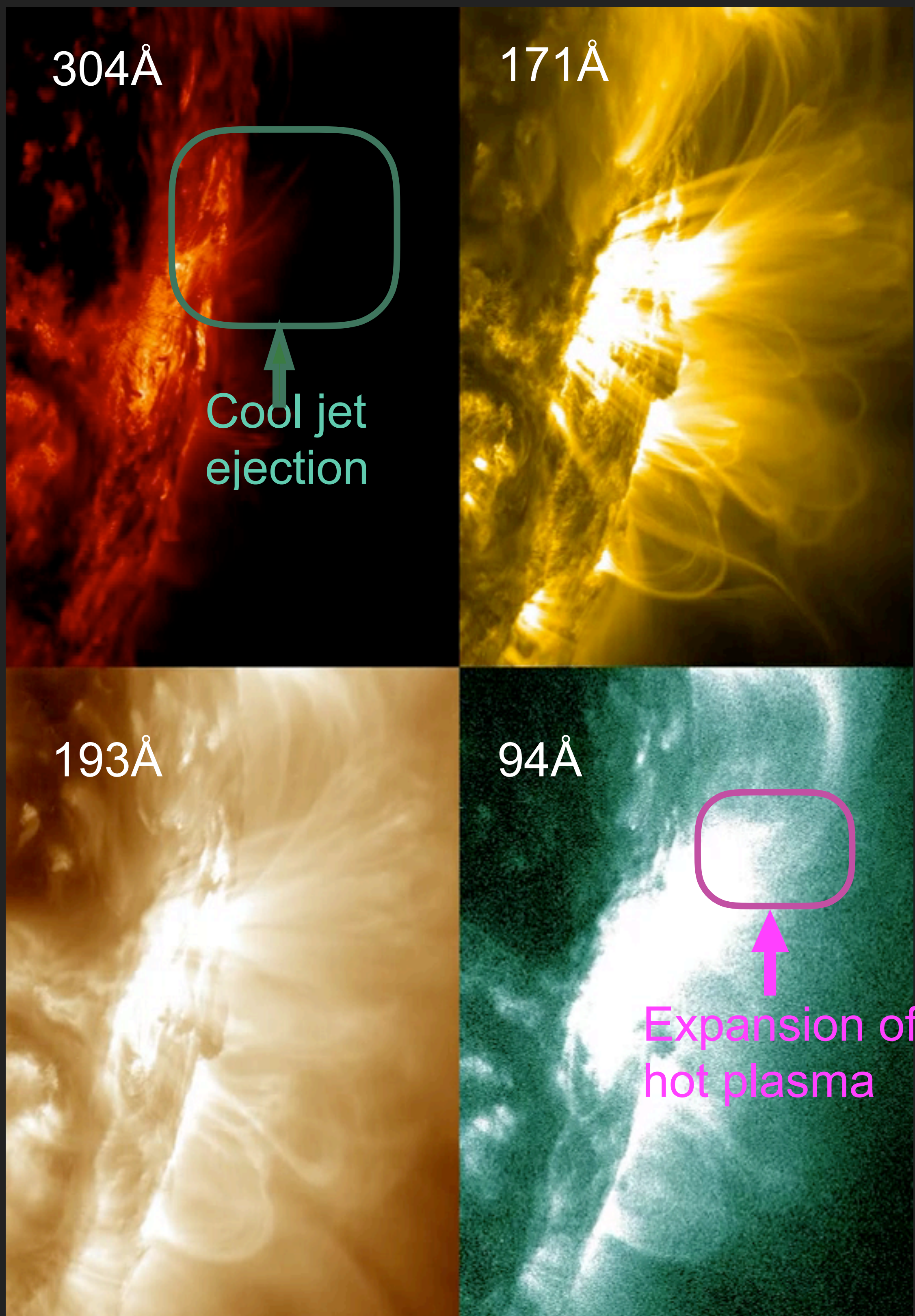
    - 3D velocity structure from the imaging (plane-of-sky velocity) & spectroscopic obs. (Doppler velocity)

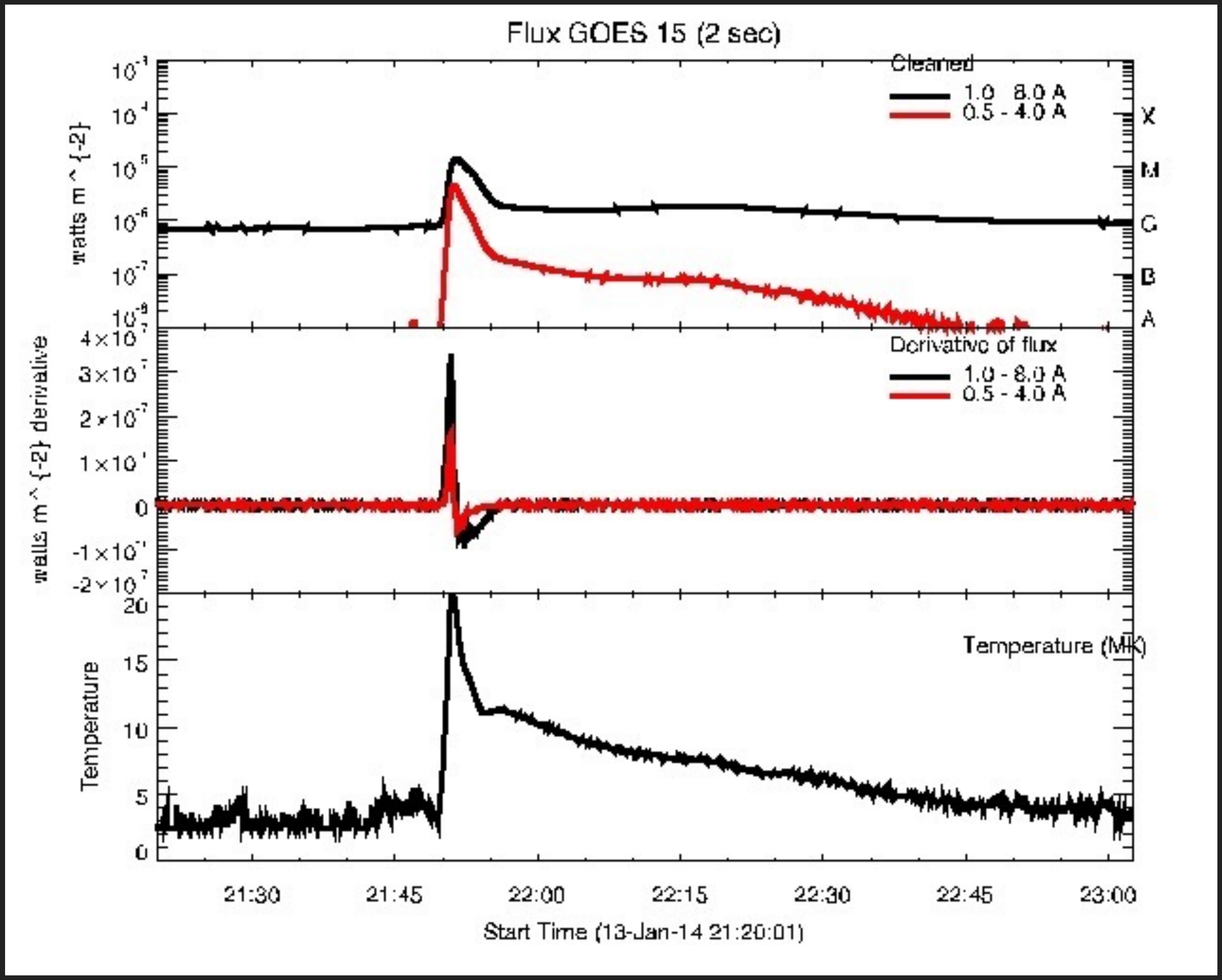
    - Excess line width (non-thermal velocity, turbulence, particle acceleration, multi-thermal structures)

    - Density & temperature structure at the shock region

OBSERVATION

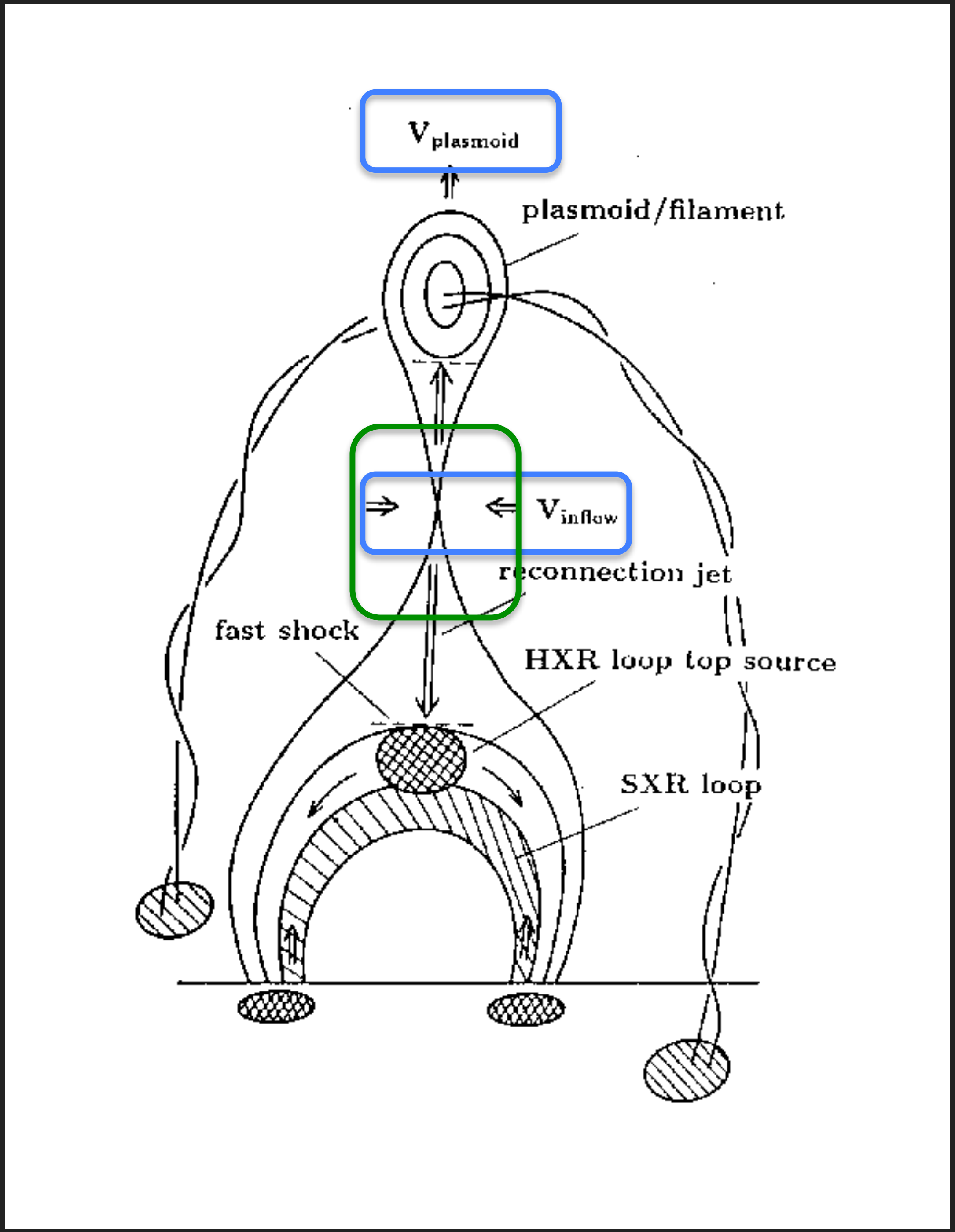
M1.3 LIMB FLARE





- M1.3 flare at 2014 Jan 13 21:47 UT
- Limb flare
- Observations
  - SDO/AIA: High temporal resolution multi-wavelength image
  - Hinode/EIS: Spectroscopy
  - STEREO/EUVI-A: Sterepscopy

STANDARD FLARE MODEL

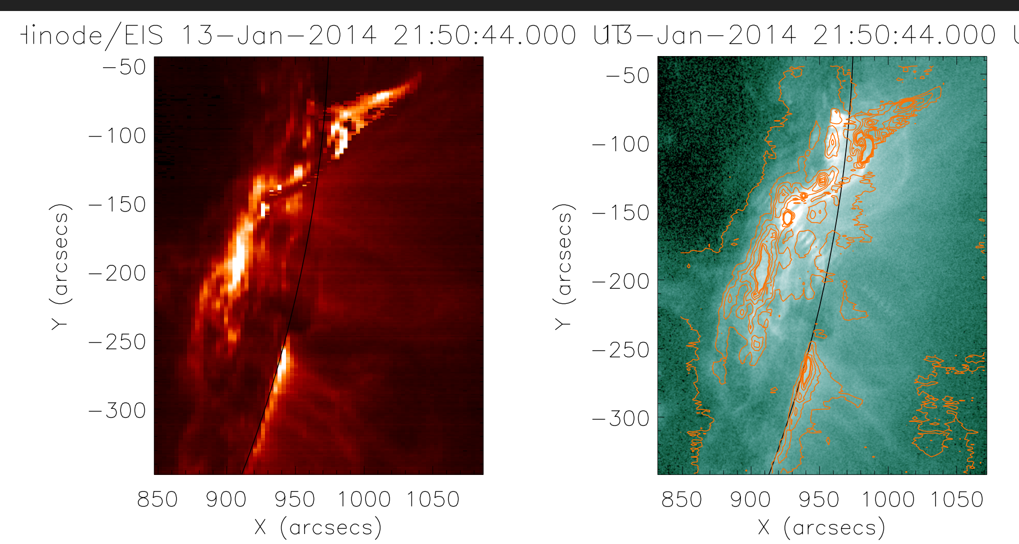


- By using the spectroscopic analysis (if we can observe the loop-top region at the limb)
  - Doppler velocity (line of sight velocity): detecting the flows at the loop to regions
  - Non-thermal velocity: detecting the turbulent motion related to the magnetic reconnection

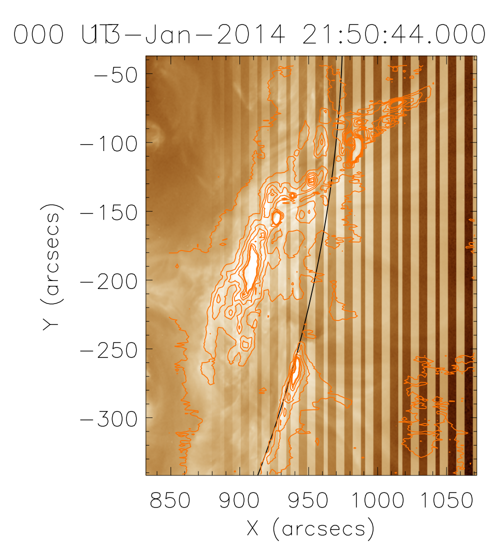
DE-CONVOLUTION OF THE HOT LOOP-TOP SOURCE (FE XXIV+FE XII) FROM THE HINODE/EIS SPECTRAL OBSERVATIONS

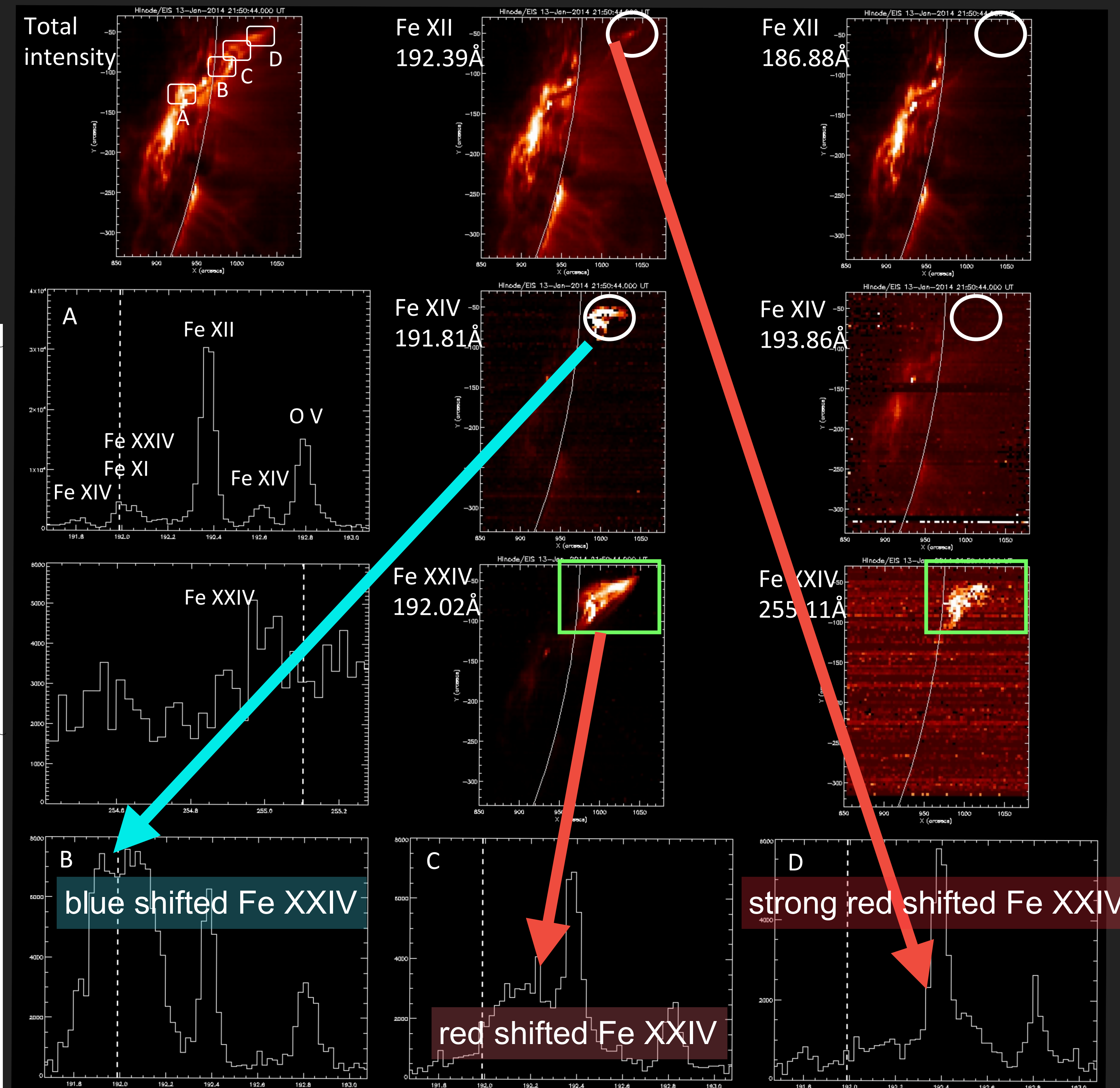
- EIS observation
  - Flare response 01
  - 6 Raster scan with 9 min cadence
  - 5 seconds exposure
  - 3x3 pixel binning

- Impulsive phase (21:50:44 - 21:59:39 UT)



- Top left: Fe XXIV 192.02 Å + Fe XII 192.39 Å
- Top right: AIA 94Å intensity scan raster image with EIS Fe XXIV 192.02Å intensity contour
- Bottom right: AIA 193Å intensity scan raster image with EIS Fe XXIV 192.02Å intensity contour



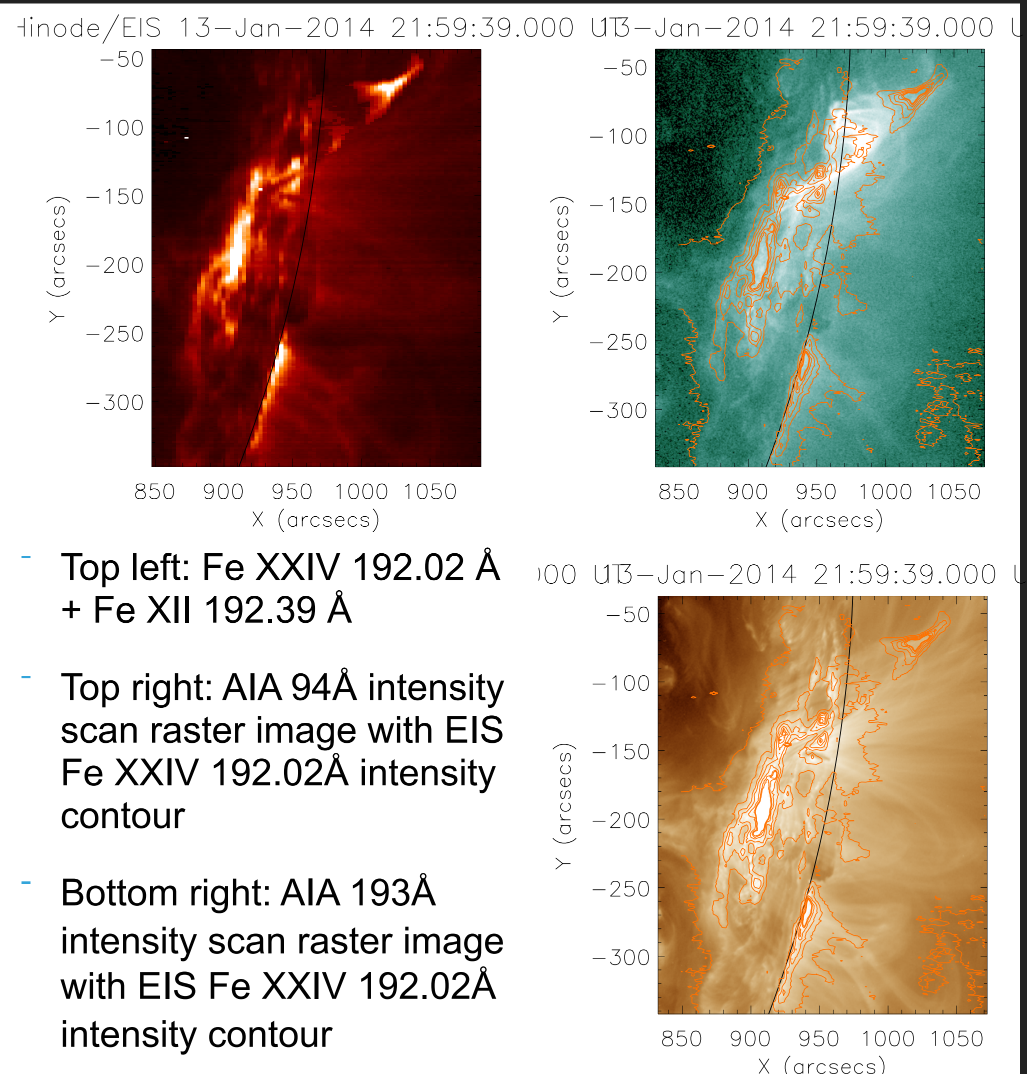


SPECTROSCOPIC ANALYSIS & RESULT

DE-CONVOLUTION OF THE HOT LOOP-TOP SOURCE (FE XXIV+FE XII) FROM THE HINODE/EIS SPECTRAL OBSERVATIONS

- EIS observation
  - Flare response 01
  - 6 Raster scan with 9 min cadence
  - 5 seconds exposure
  - 3x3 pixel binning

- Gradual phase (21:59:39 - 22:08:34 UT)



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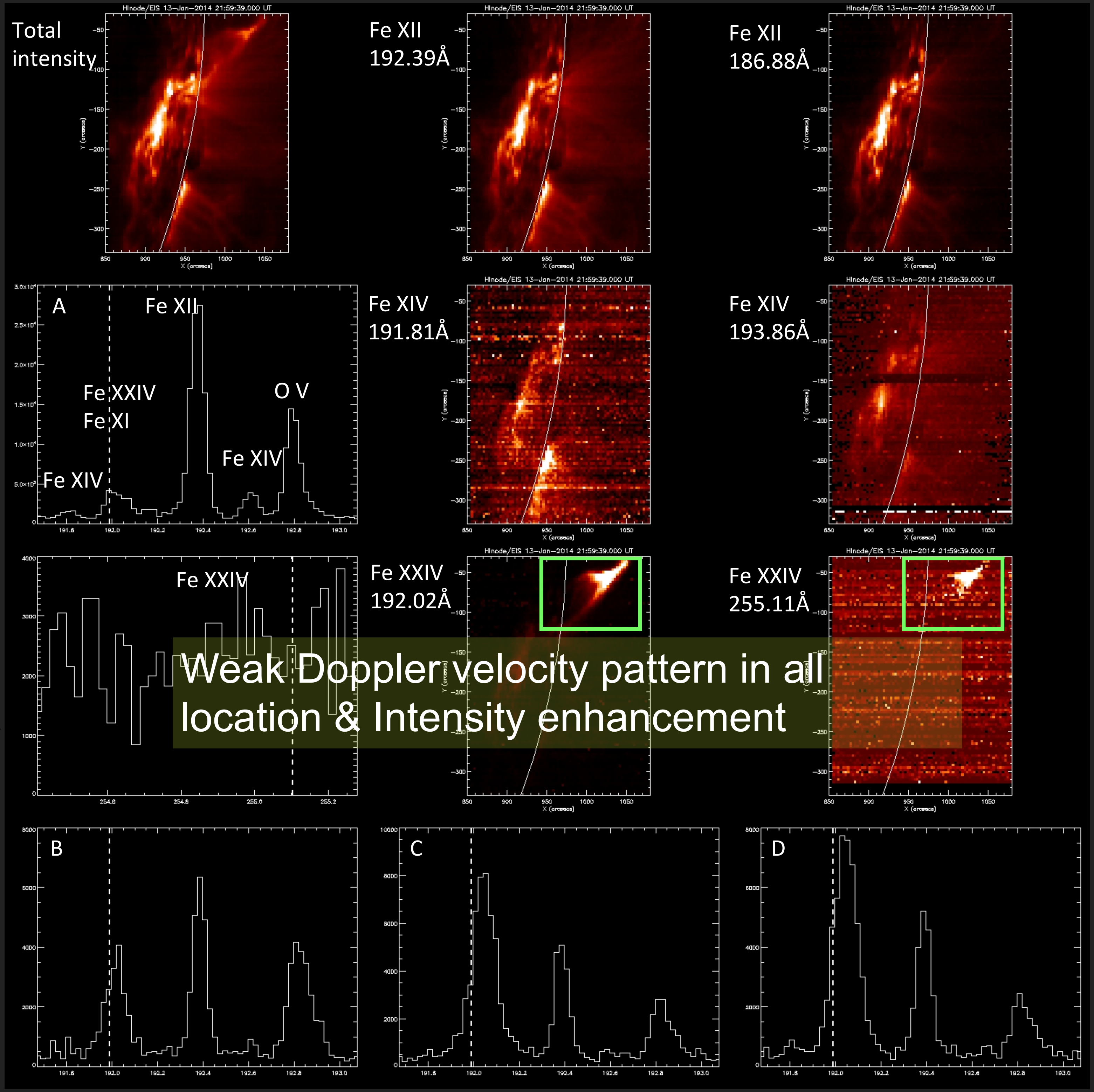
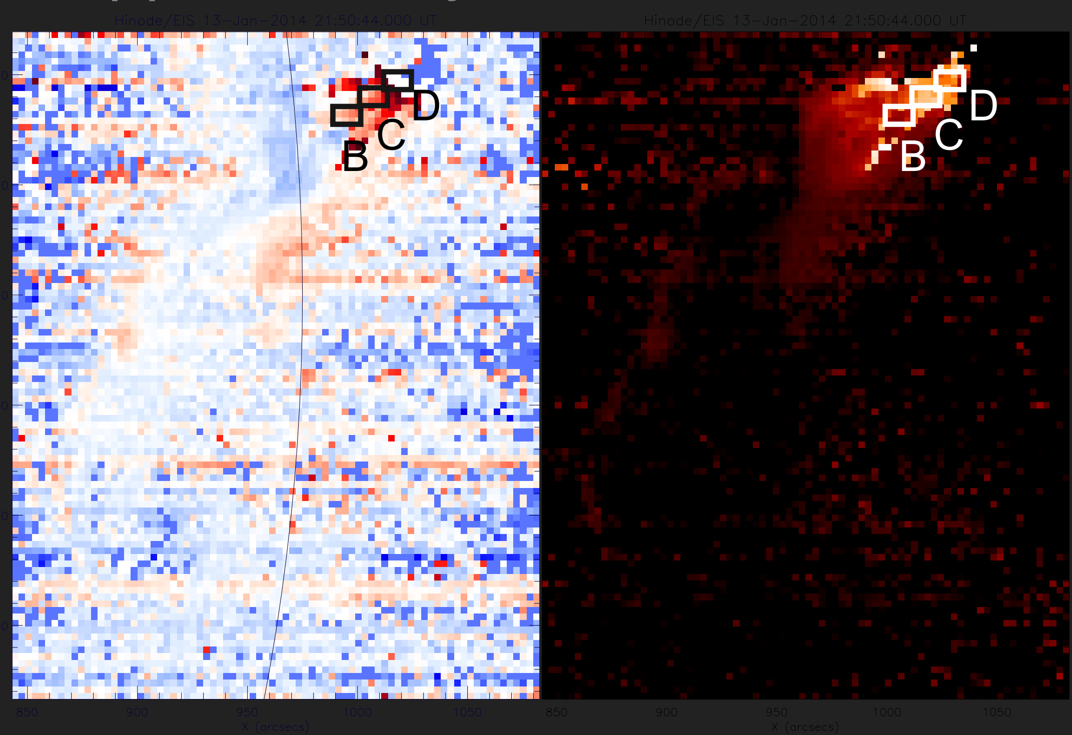


SPECTROSCOPIC ANALYSIS & RESULT

DOPPLER VELOCITY & NON-THERMAL VELOCITY DISTRIBUTIONS FOR THE HOT LOOP-TOP SOURCE

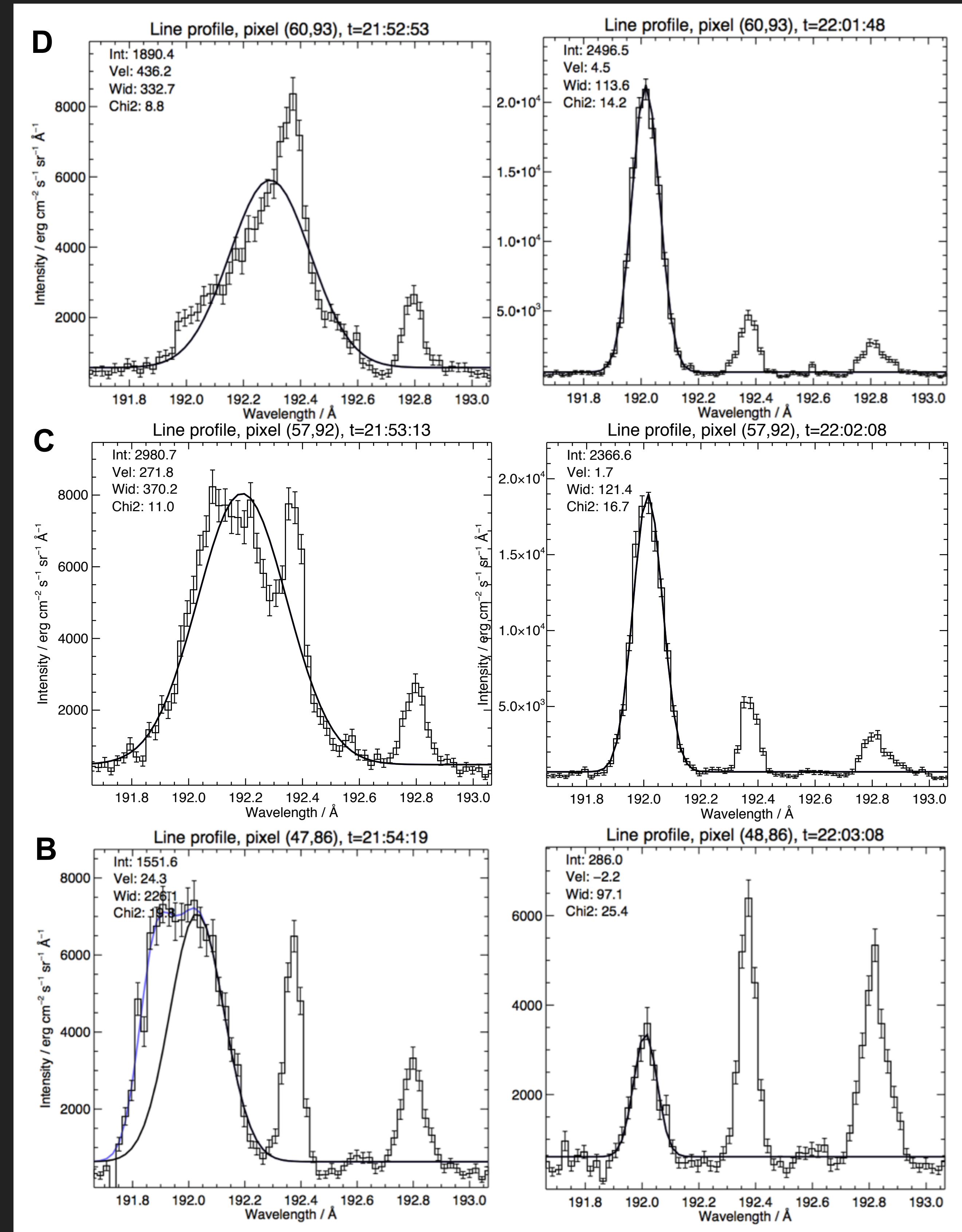
- Doppler velocity & Non-thermal velocity



- De-convolution of the Fe XXIV line emission

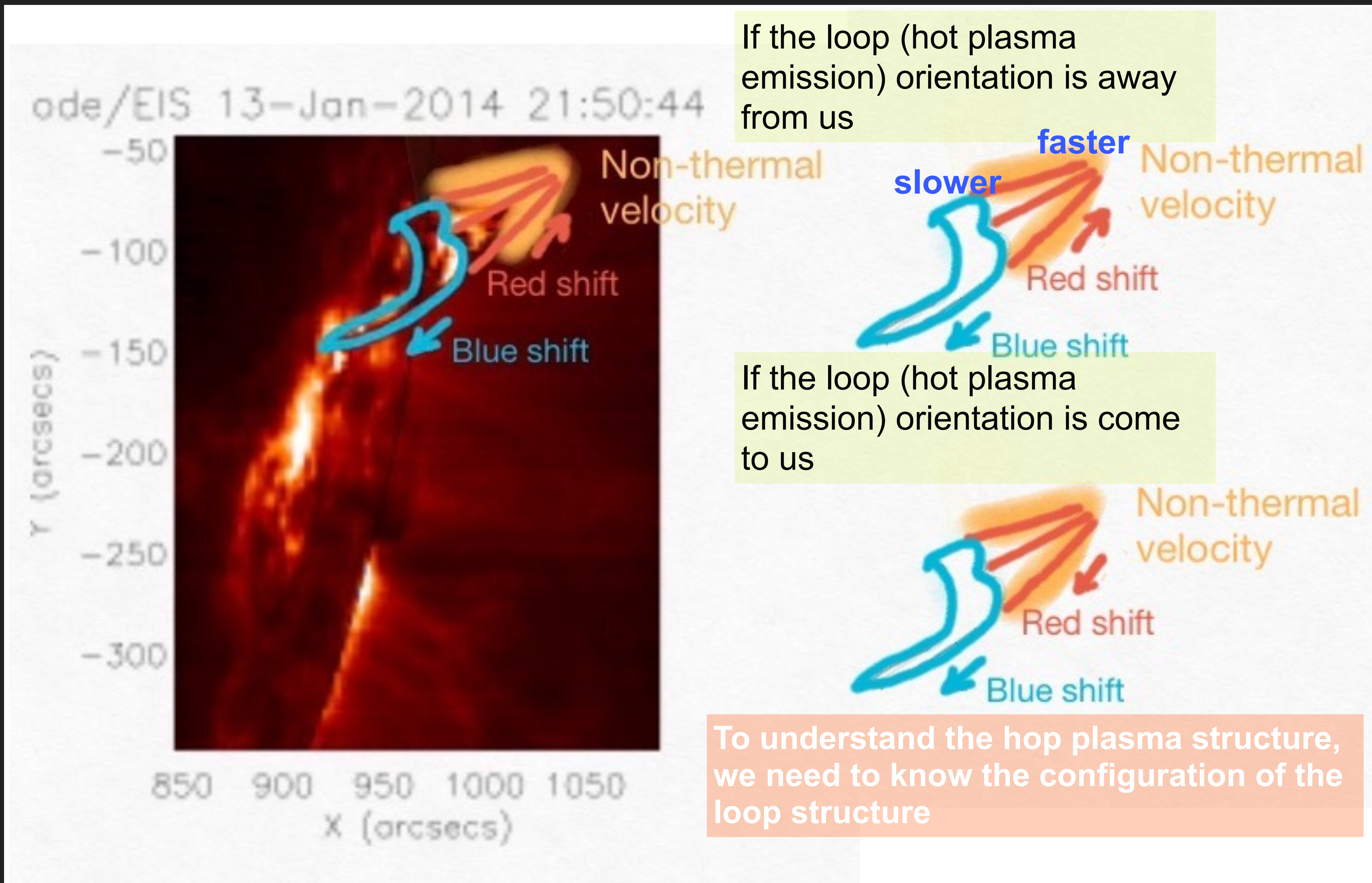
  - Top end of the cusp-shape (region D): strong red shift (>500km/s) and large line width from hot temperature plasma
  - Loop top cusp-shape region (region C): red shift (~250km/s)
  - Loop top (region B): bi-directional flow

    - Strong red shift (LOS velocity) at the limb: need to check the loop tilt angle
    - Large non-thermal velocity: turbulence motion?



STUDY II - SEARCHING A HIGH CORONAL RECONNECTION (LIMB)

THE STRUCTURE AND PLASMA DYNAMICS OF THE M1.3 LIMB FLARE ON 2014 JAN 13



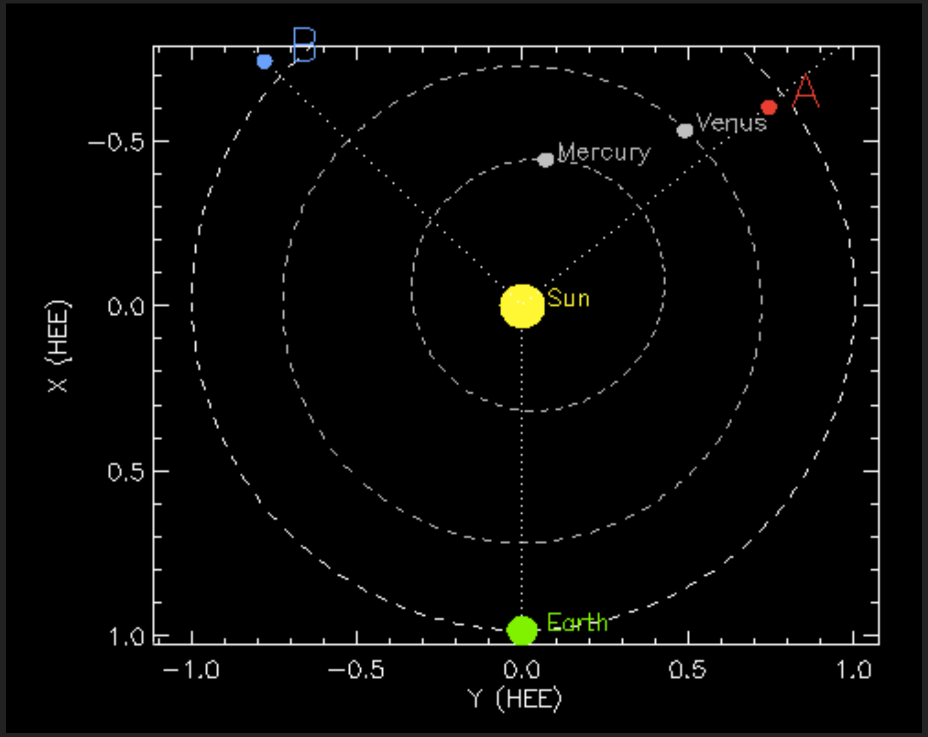
If the loop (hot plasma emission) orientation is away from us

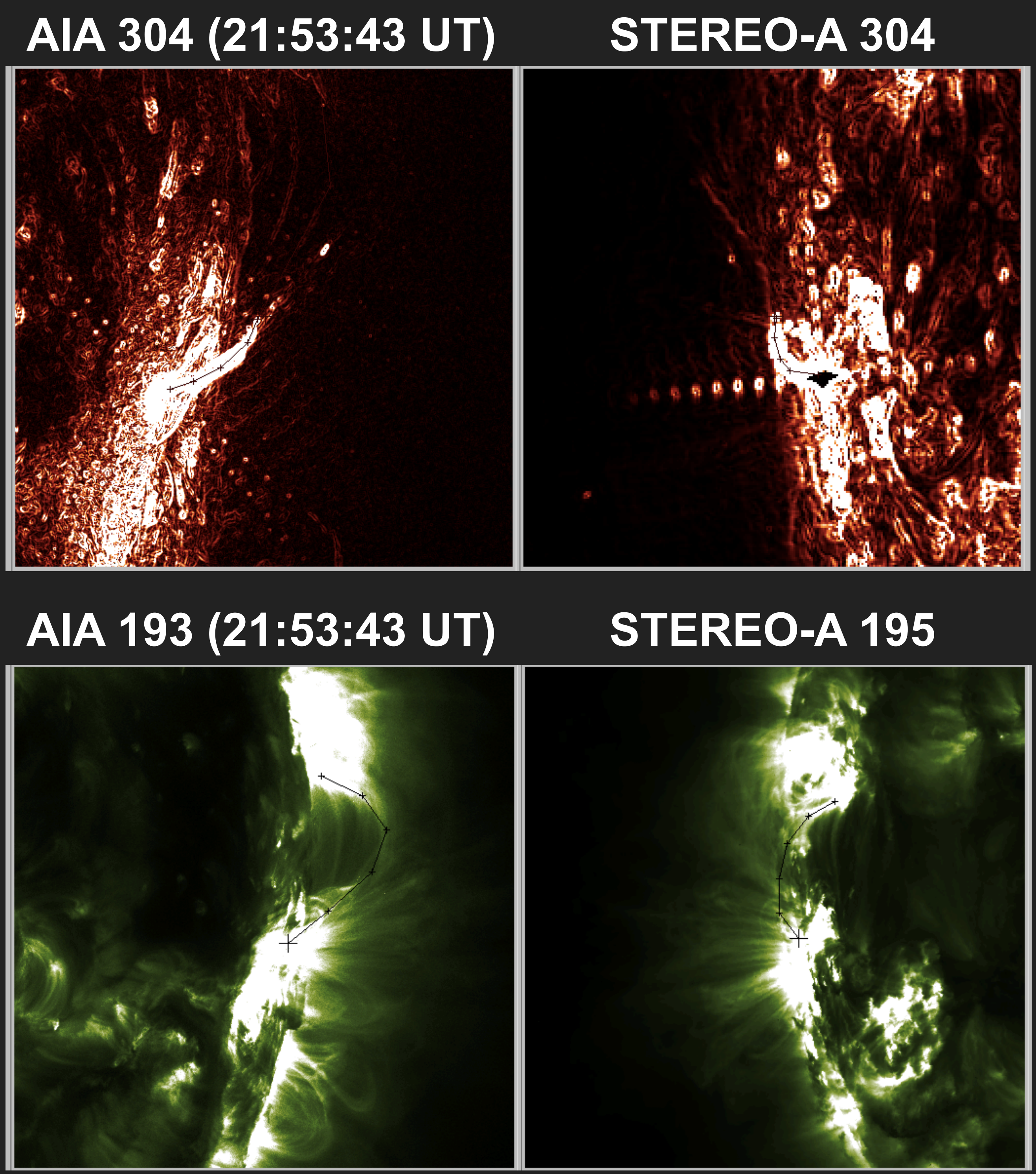
If the loop (hot plasma emission) orientation is come to us

To understand the hop plasma structure, we need to know the configuration of the loop structure

THE LOOP TILT ANGLE MEASURED FROM THE STEREOSCOPY USING THE STEREO/EUVI-A AND SDO/AIA

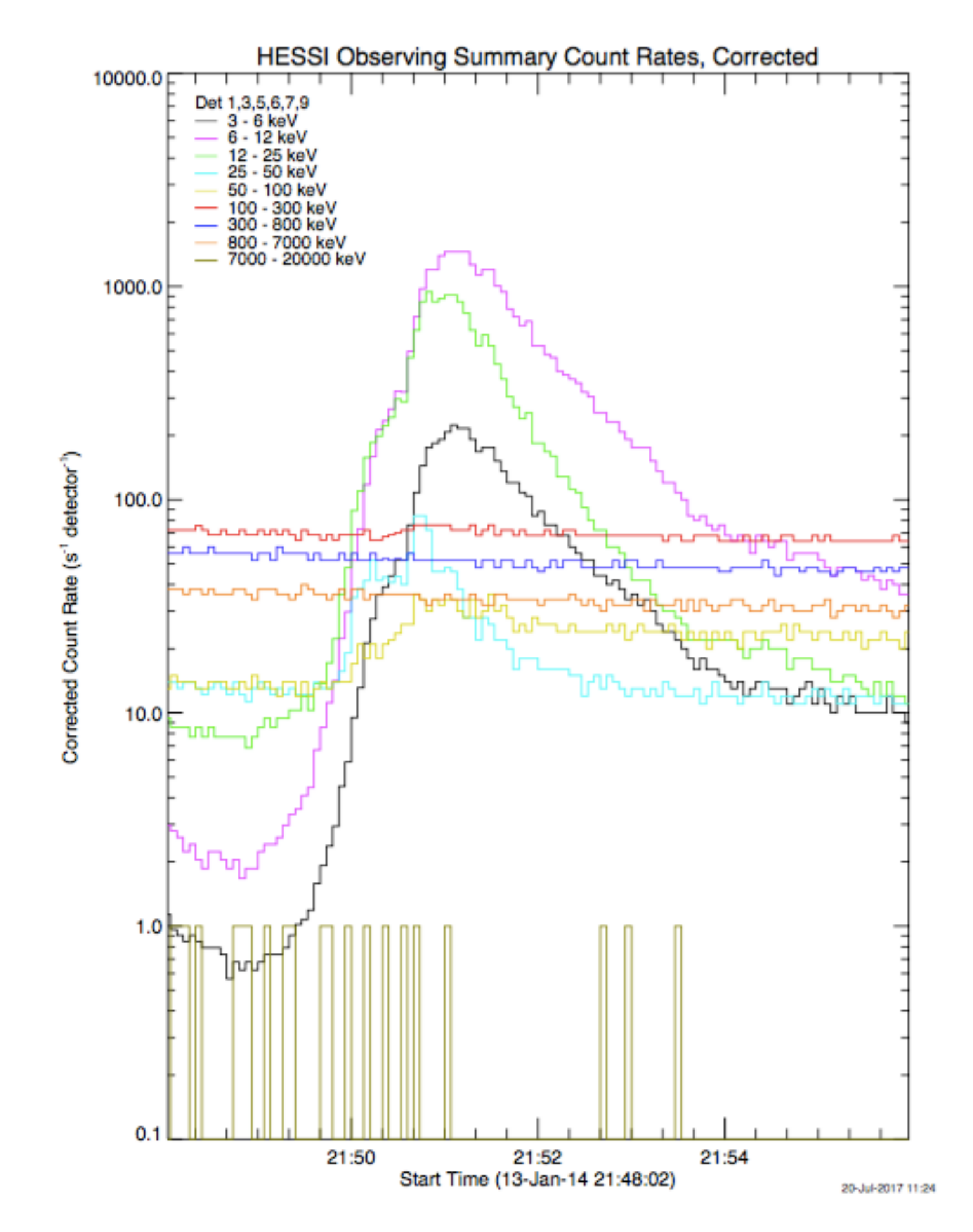
- SDO & STEREO orbits



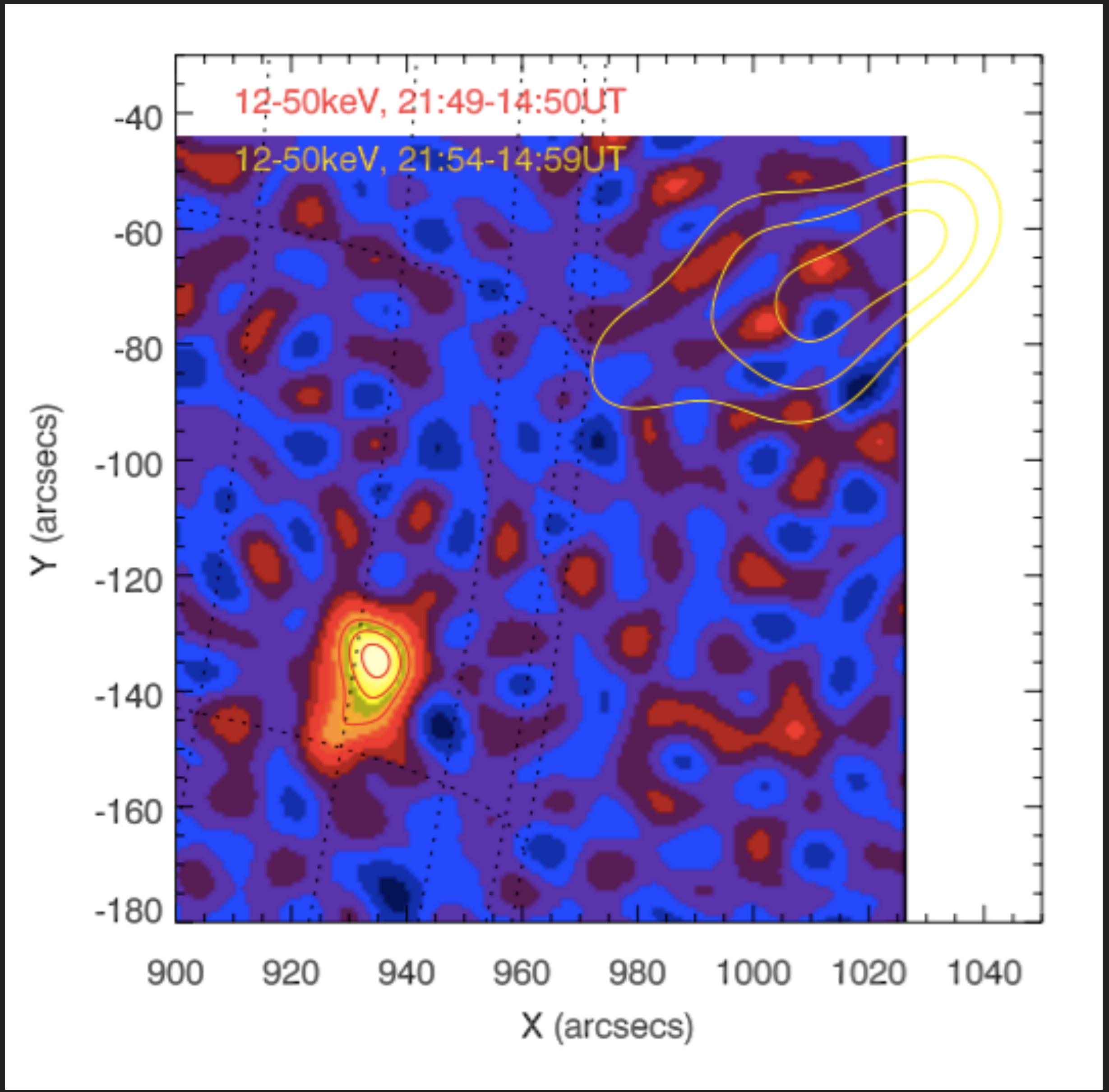


- Loop tilt angle from the cool jet position of two different spacecraft ~ 42.9 degree
  - Given any 3 points from two different spacecraft determine a plane
  - We can calculate the loop tilt angle between loop and solar equator computed by considering all possible combinations of 3 points of the available points along the loop.

HXR FROM RHESSI OBSERVATION



- HXR at the footprint region (21:49-21:50)
- SXR at the loop-top region (21:54-21:59)



SUMMARY

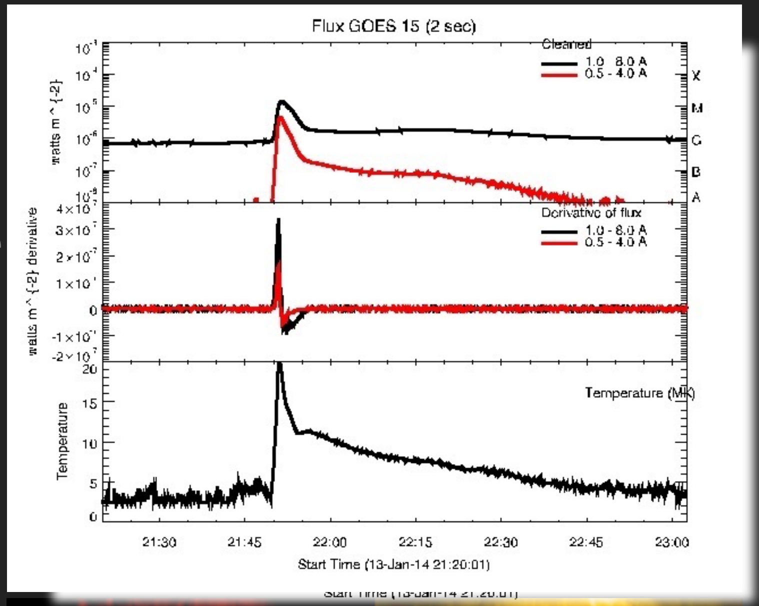
- We investigated the limb flare using the EUV imaging spectroscopy.
- The hot flaring loop-top region shows the strong red-shift and large line width broadening at the impulsive phase
- The strong red-shift imply the reconnection outflow (downflow) considering the loop geometry.
- The reconnection related to the flare may occurs above the loop

OVERVIEW OF AN LIMB FLARE (SPECTROSCOPY+STEREOSCOPY)

M1.3 LIMB FLARE OBSERVED BY SDO, HINODE, AND STEREO

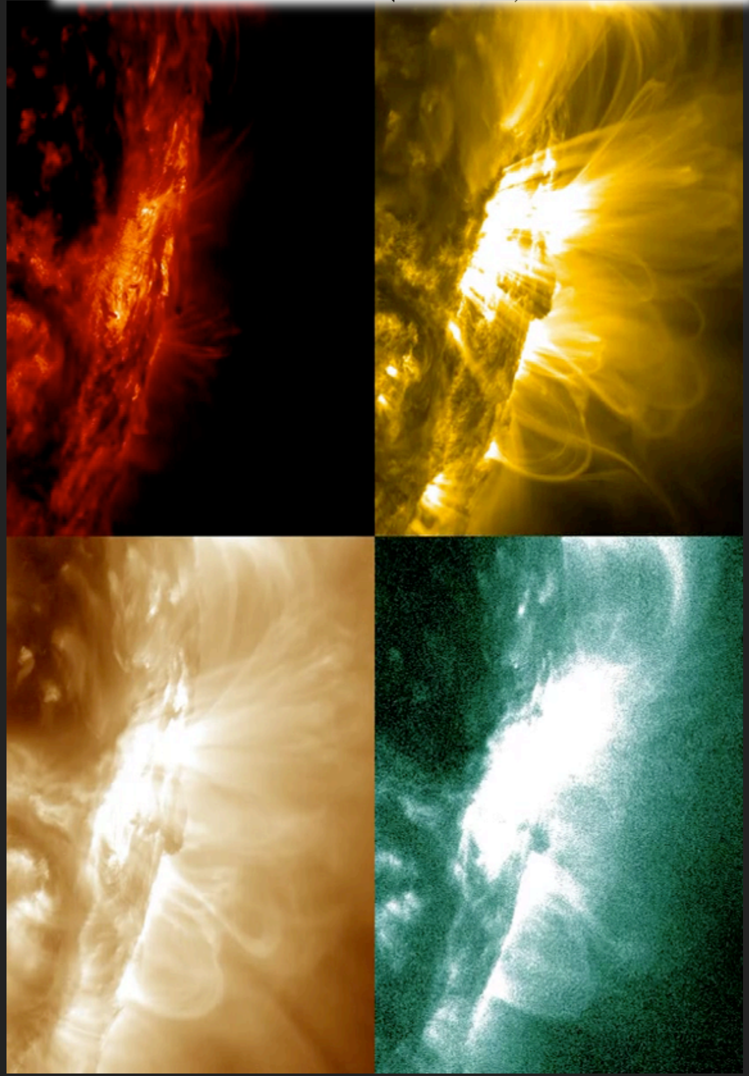
- GOES

Soft X-ray light curve



- AIA

Multi-channel EUV images



- **Spectroscopy**

- Hot loop-top source (Fe XXIV) with a strong red shift (>300 km/s) and large non-thermal velocity (>150 km/s) at the impulsive phase of the flare

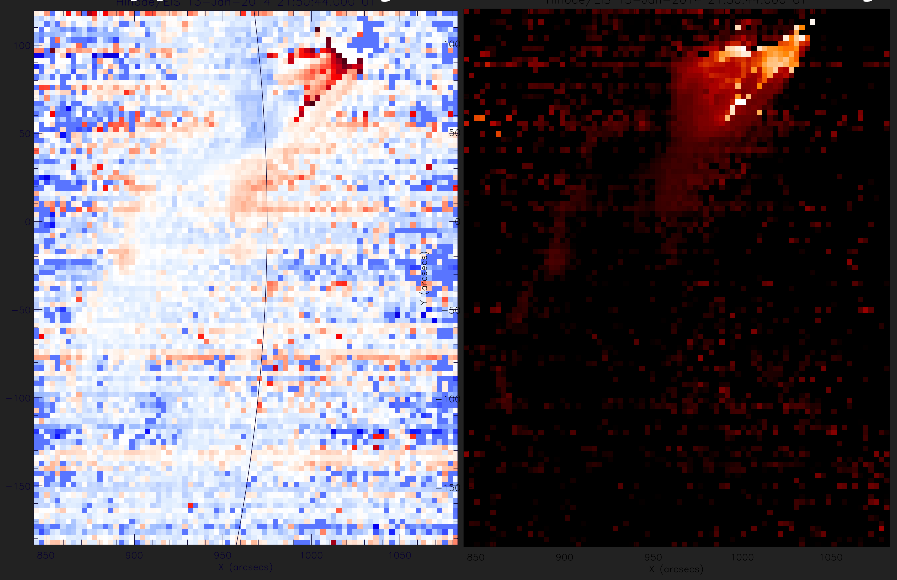
- **Stereoscopy**

- STEREO/EUVI A & SDO/AIA provide the angle of the loop structure even though it has large uncertainty. The stereoscopy gives the loop tilt angle of about 42.9 degree.

- **Summary of results**

- We found a strong outflows and turbulent motions at the above the loop-top source (cusp shape structure) during the impulsive phase of the flare.

Doppler velocity | Non-thermal velocity



AIA 304 (21:53:43 UT) | STEREO-A 304