Searching for Signs of Termination Shocks in Solar Flares

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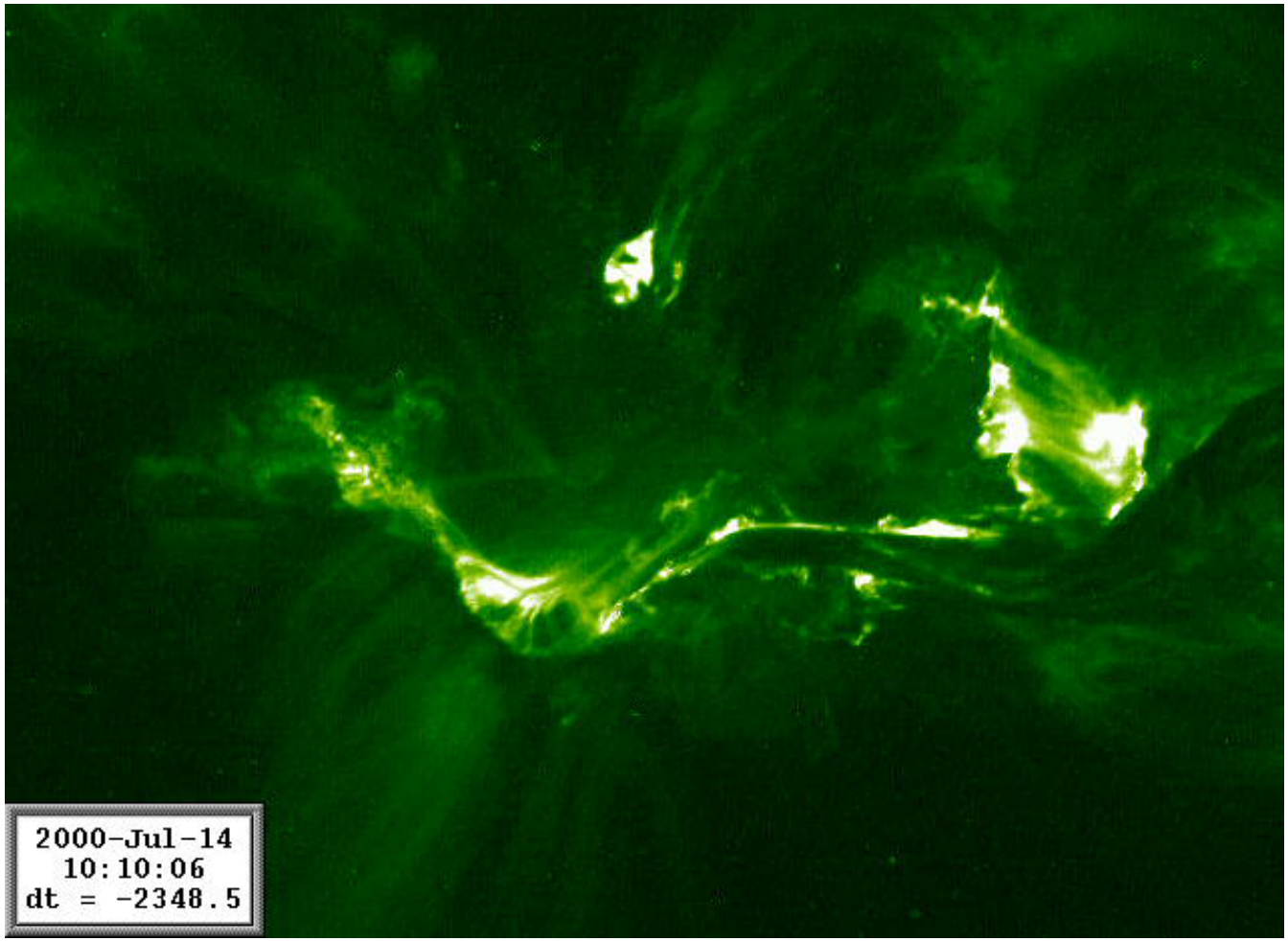
2000-Jul-14
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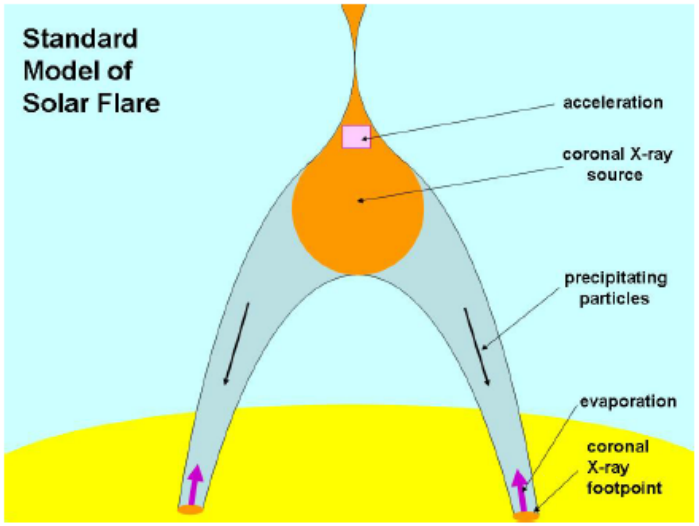
dt = -2348.5

Solar Flares

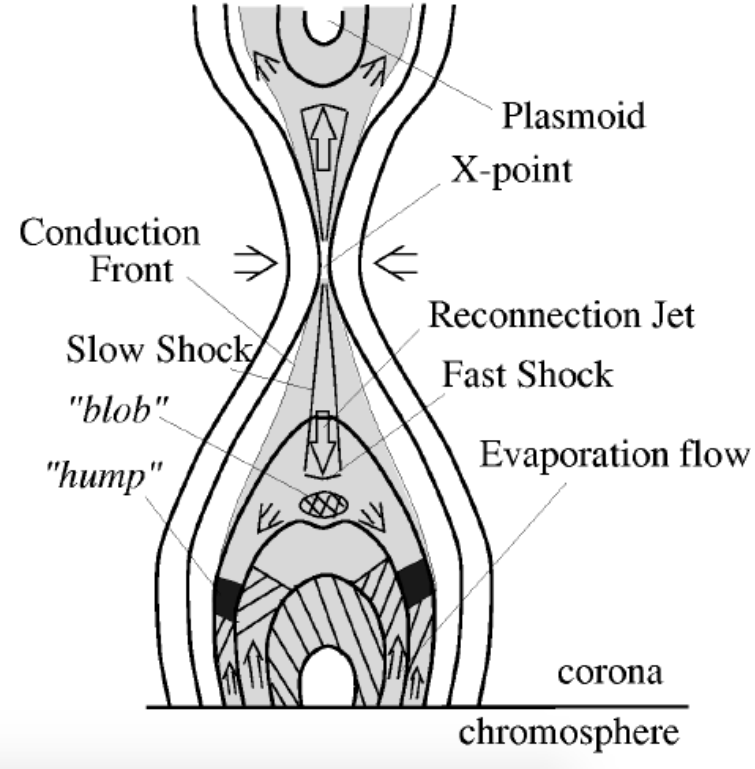
- One of the most energetic events in the sun
- Energy release via ***magnetic reconnection***
  - Magnetic → thermal, kinetic
- Energy transport
  - Radiation
  - Mass ejection
  - Shock formation
  - Wave propagation
  - Particle acceleration



Benz, Living Revew in Solar Physics (2008)

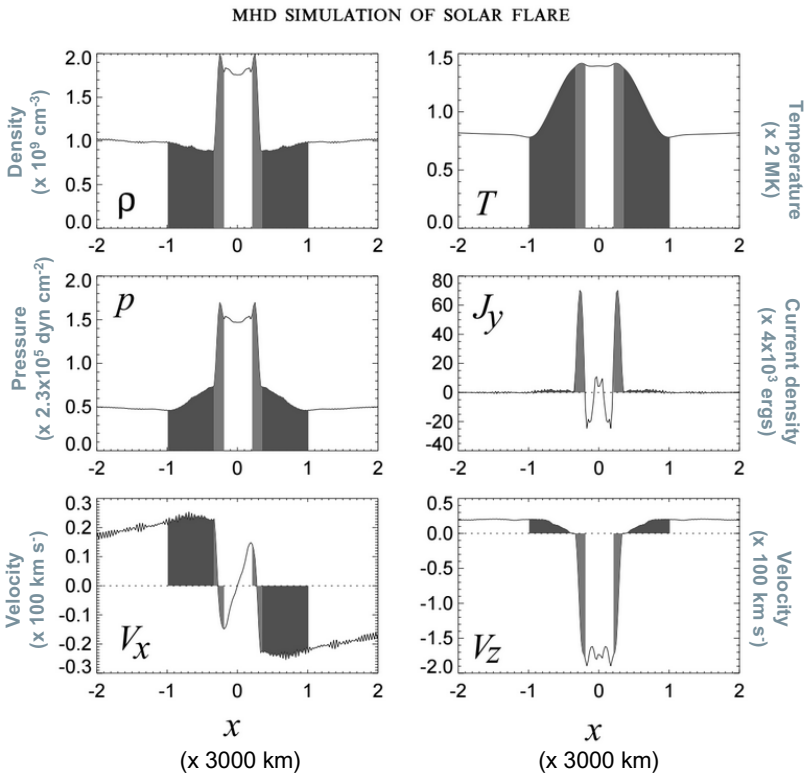
Reconnection and MHD shocks

- Reconnection site
  - Above loop tops
- Shocks, inflows, reconnection outflows
  - Magnetic tension snaps newly reconnected field lines away from reconnection point
  - Slow-mode MHD shock heating
    - Cool coronal Inflows → hot outflows, i.e. reconnection jets
  - ***Termination shock (TS)***
    - Fast-mode MHD shock
    - Supersonic reconnection jet collides with downstream plasma at loop tops



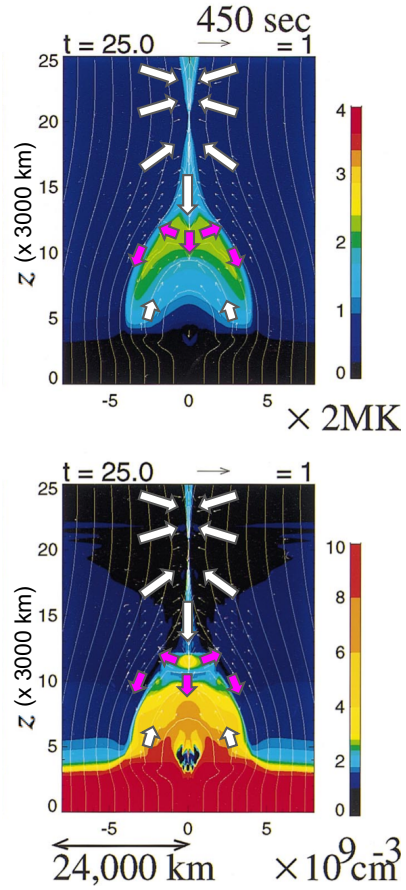
Yokoyama and Shibata, ApJ (2008)

1-dimensional plots along the x-axis
at z=15, t = 25



Yokoyama and Shibata, ApJ (2001)

Temperature distribution



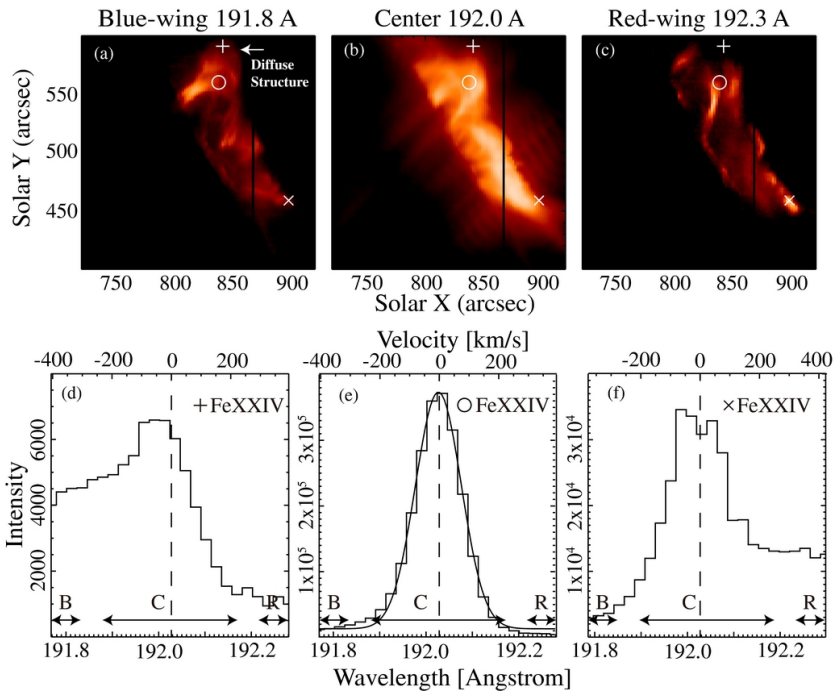
Density distribution

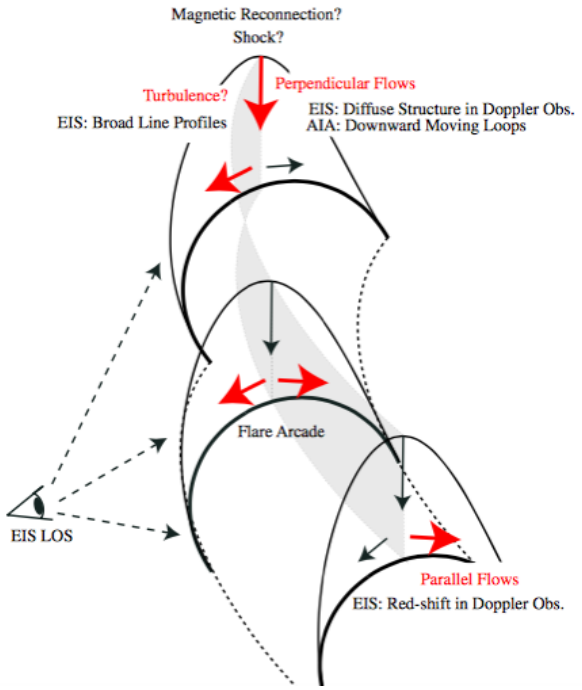
Signs of a TS

- Speed discontinuity of the fast downward jet accompanied by bidirectonal flows away from TS site
- Formation of bright, dense blob
  - Compressed reconnection jet plasma due to shock
  - Slow downward velocity

Termination shock - Previous related findings

- Fast downward-moving structure above LT
- Bidirectional horizontal flows on LT





Imada et. al, ApJ, 2013

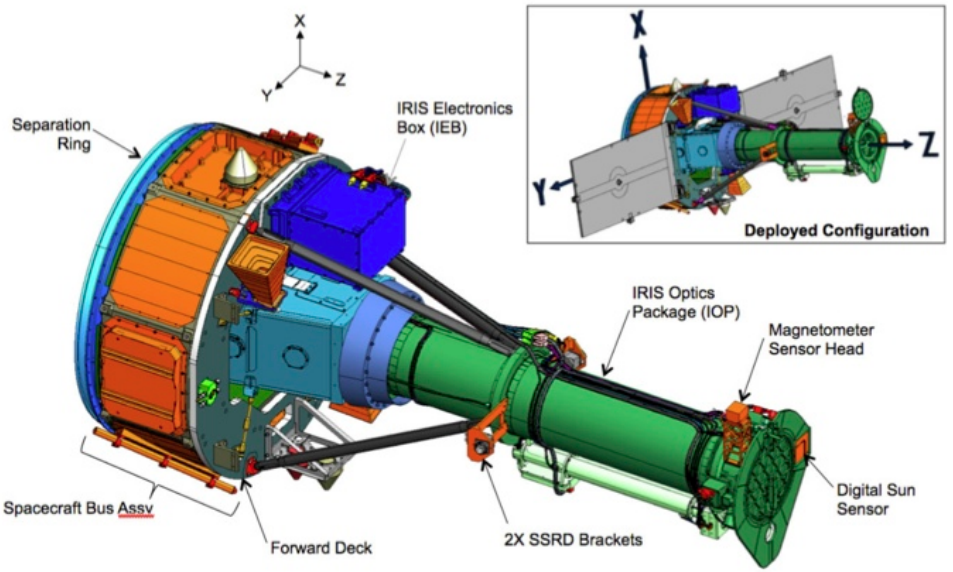
IRIS - The Interface Region Imaging Spectrograph

- UV Spectrograph

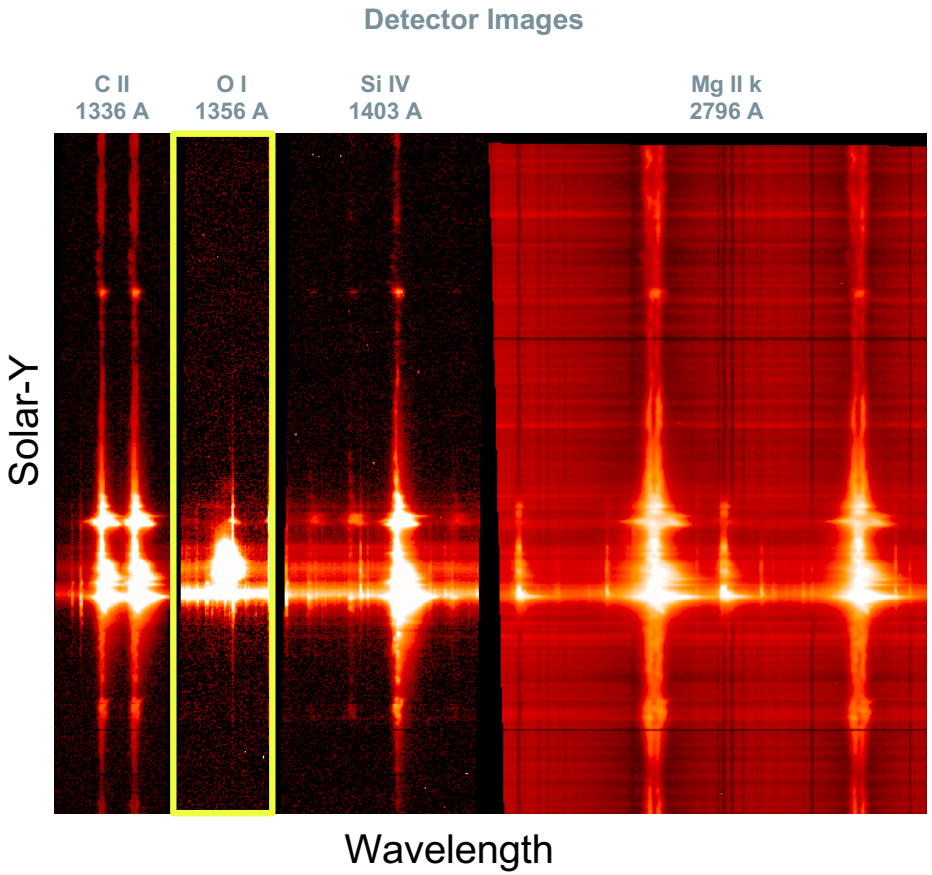
Band	Wavelength (Å)	Temperature (log T)
FUV 1	1331.7–1358.4	3.7–7.0
FUV 2	1389.0–1407.0	3.7–5.2
NUV	2782.7–2851.1	3.7–4.2

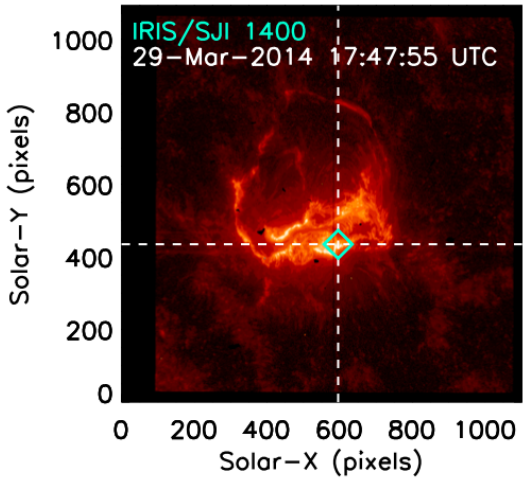
- Slit-jaw imager

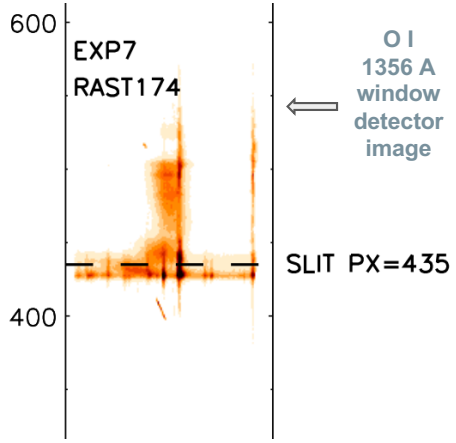
SJI Passband	Type	Wavelength (Å)	FWHM (Å)	log T
Glass	T	5000	2000	–
C II	M	1330	40	3.7–7.0
Si IV	M	1400	40	3.7–5.2
Mg II h/k	T	2796	4	3.7–4.2
Mg II wing	T	2832	4	3.7–3.8
Broad-band	M	1600	400	–

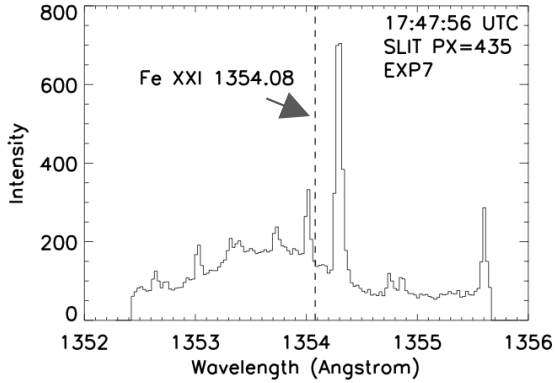


IRIS - The Interface Region Imaging Spectrograph



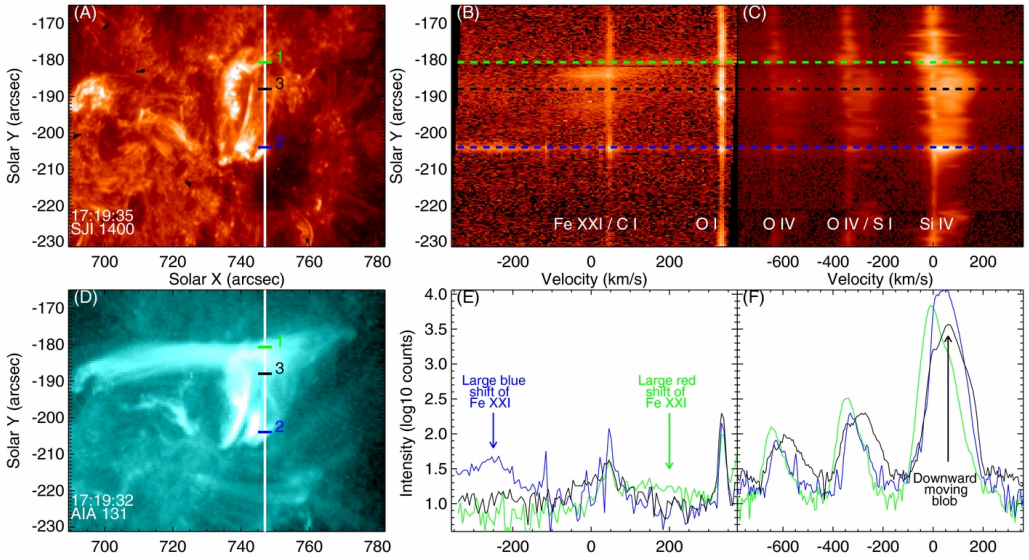


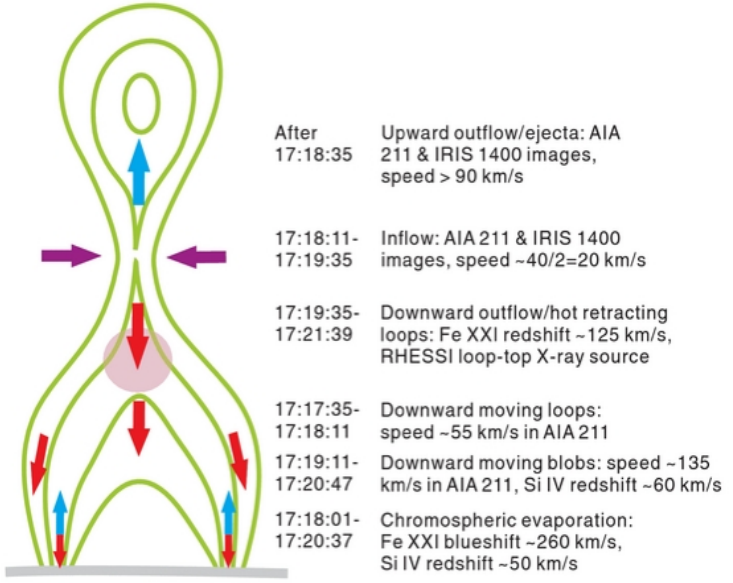




Termination shock - Previous related findings

- Fast downward outflow on LTs, v=~125 km/s
- Downward moving blob along loops, v =~135 km/s





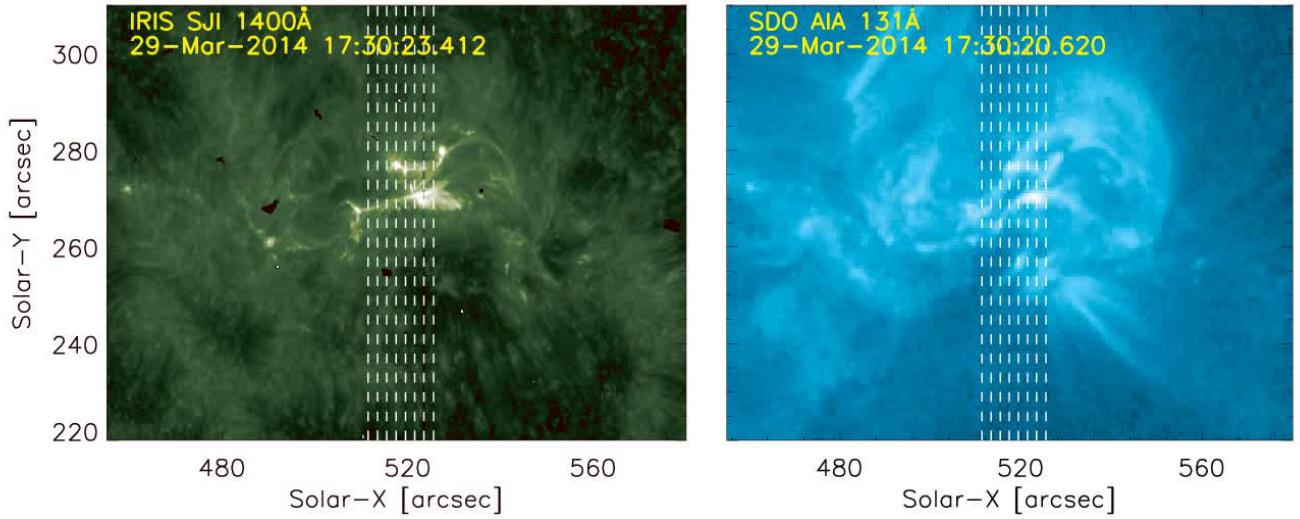
Images from Tian et. al, ApJ, 2014

Methodology

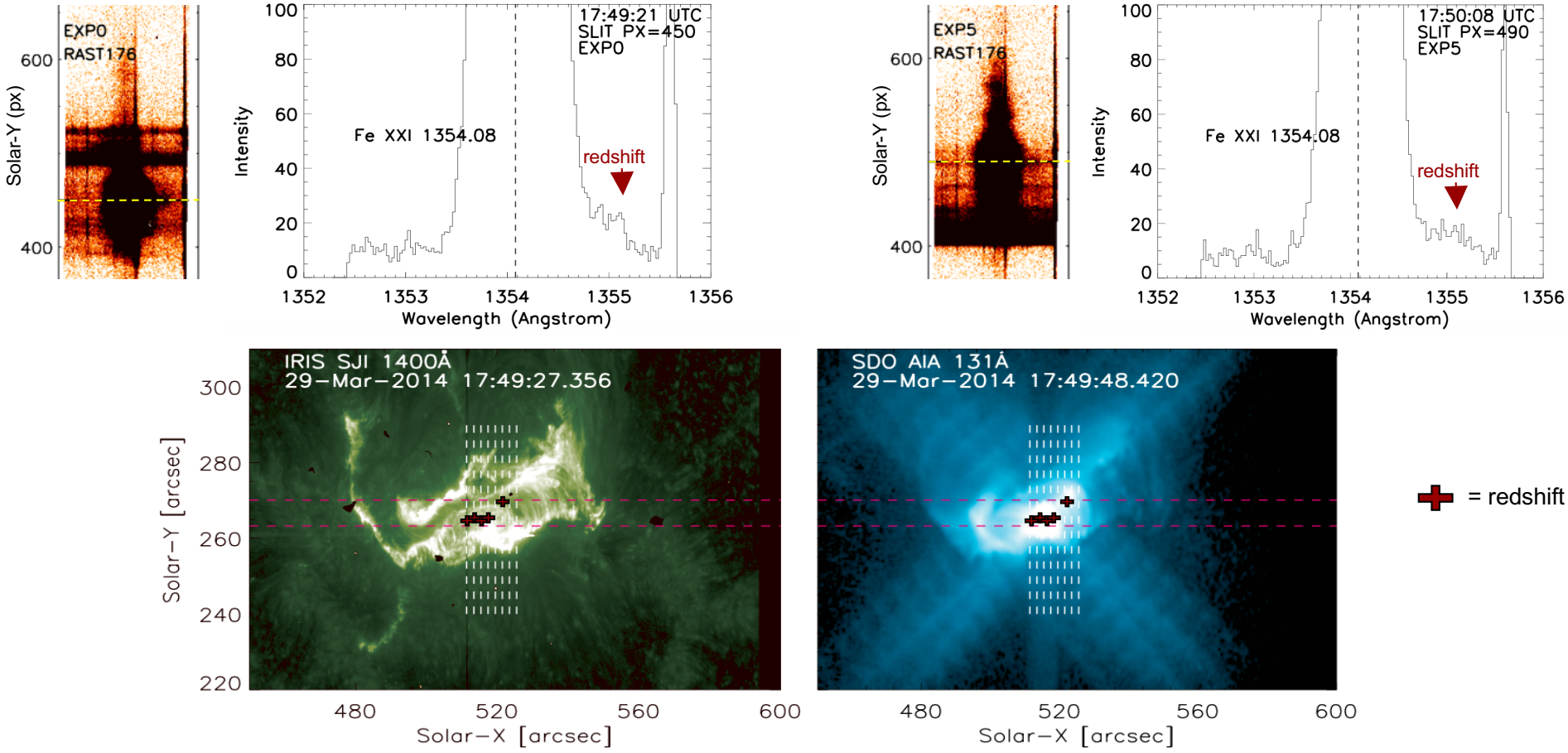
- Analysis of IRIS UV imaging and spectral data
  - Spectral observations
    - Looked for redshifted Fe XXI (1354.08 A) emissions in LT region
      - Reconnection downflows, plasma motions away from TS site
    - Formation of Fe XXI line only during flare, plasma T = > ~ 10 MK plasma
  - Imaging observations
    - Spatial context
    - Cotemporal 1330 SJI imaging
    - Co-alignment with AIA imaging observations
      - AIA 131 A passband - dominated by Fe XXI emissions during flares

Results: 2014-03-29 Flare (OBS 3860258481)

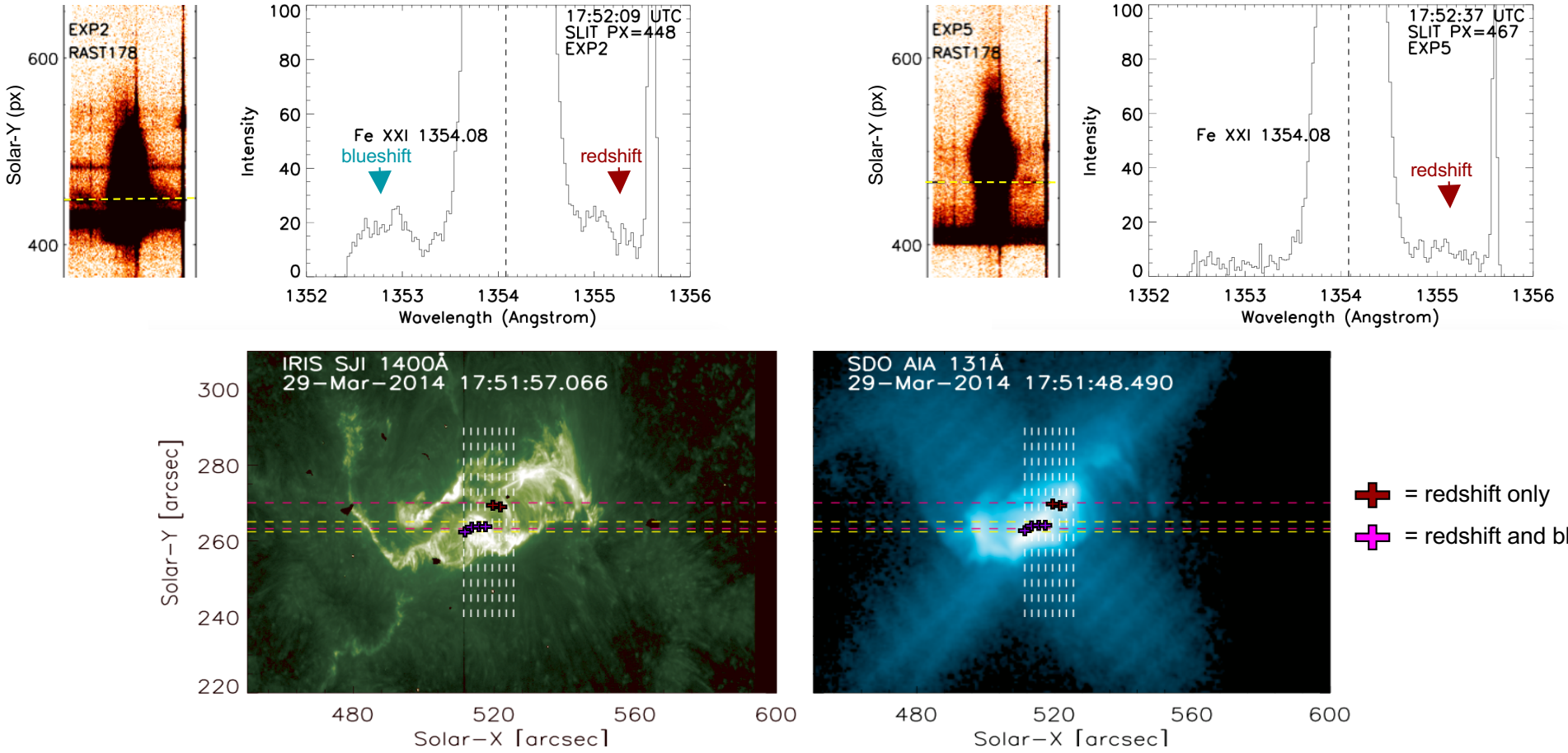
- 180 rasters
- Very large coarse 8-step raster
  - Step = 2''
- Exposure time: ~8s



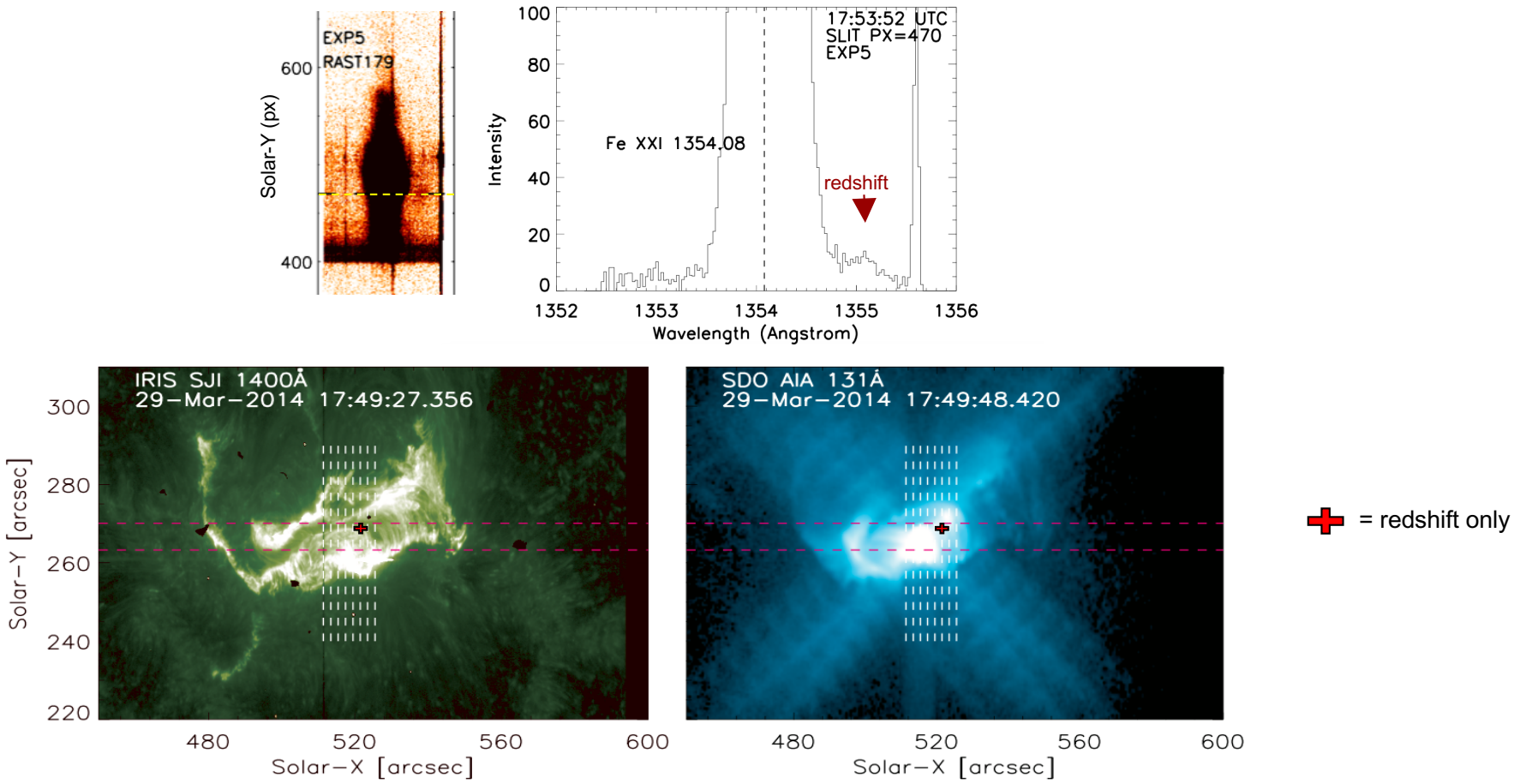
Results: 2014-03-29 Flare (OBS 3860258481)



Results: 2014-03-29 Flare (OBS 3860258481)



Results: 2014-03-29 Flare (OBS 3860258481)

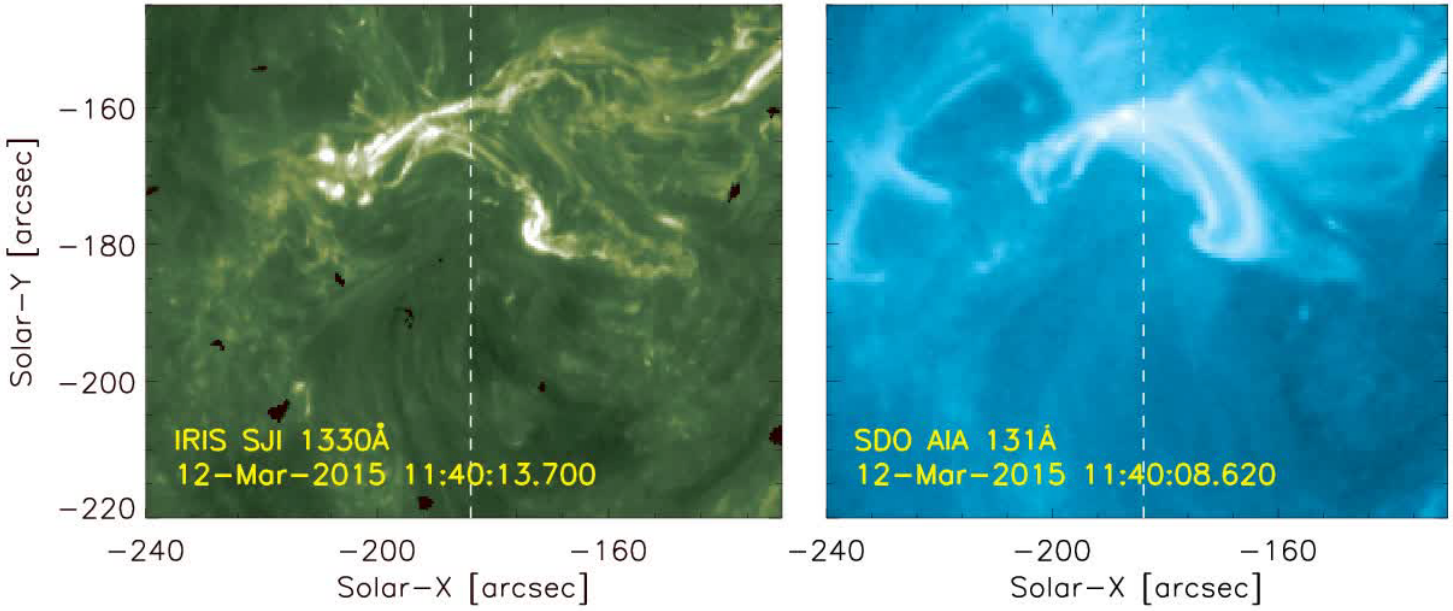


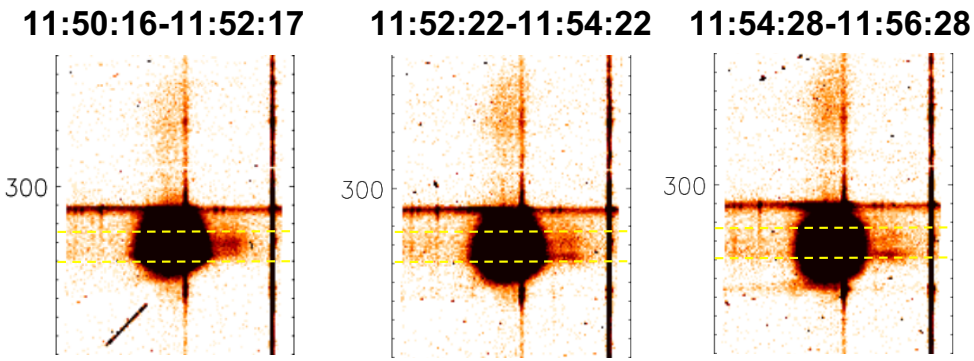
Results: 2014-03-29 Flare

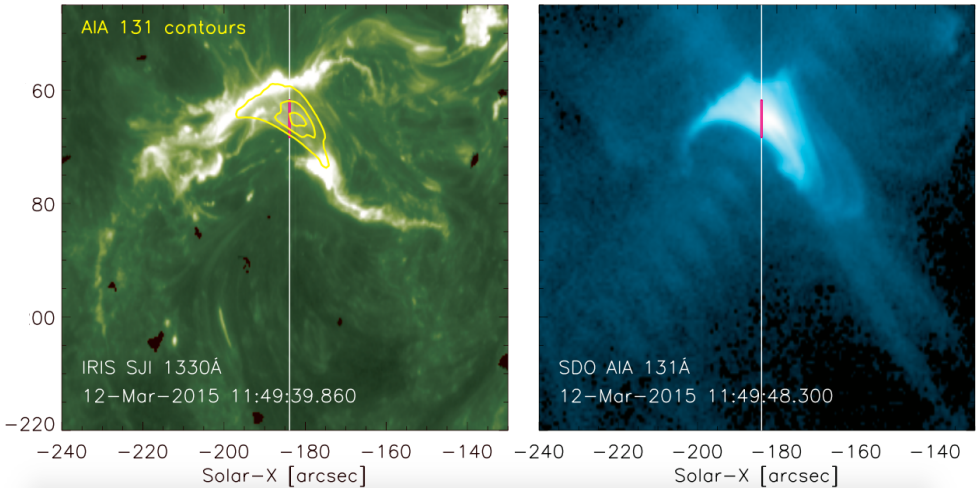
- Summary
  - Redshifts on bright loop top bar, v = ~ 100-200 km/s
    - Possible downward flows along the LOS on the bright loop top bar region
  - Cospatial blueshifts and redshifts, v = ~ 100-200 km/s
    - Redshifts: Possible downward flows along the LOS on bright loop bar region
    - Blueshifts: Chromospheric evaporation from ribbon

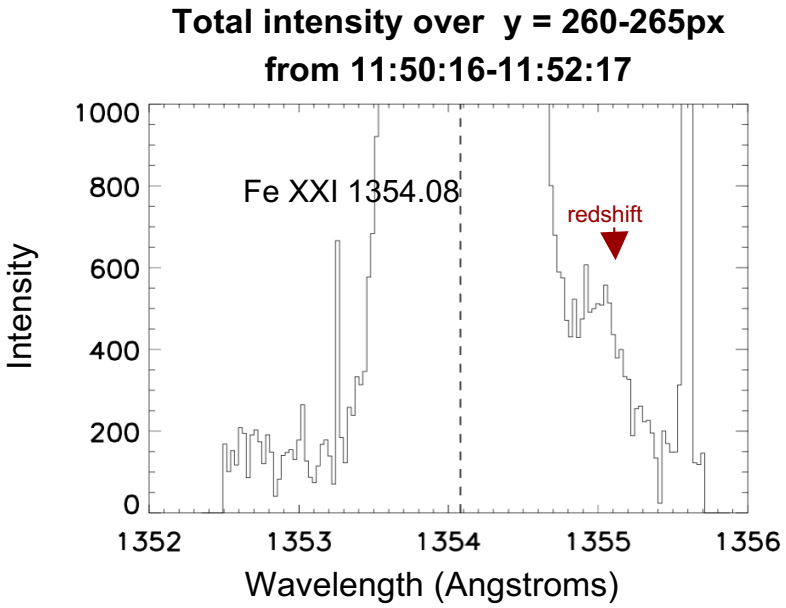
Results: 2015-03-12 Flare (OBS 3860107053)

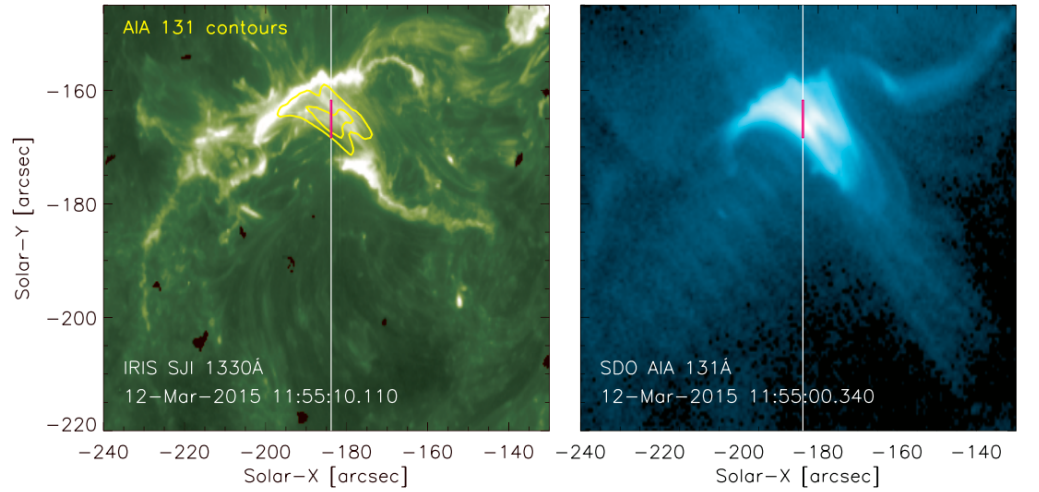
- 11:48:11-12:00:40 UTC
- Large sit-and-stare
- Exposure time: ~5s




11:50:16-11:52:17
11:52:22-11:54:22
11:54:28-11:56:28
300
300
300


AIA 131 contours
IRIS SJI 1330Á
12-Mar-2015 11:49:39.860
SDO AIA 131Á
12-Mar-2015 11:49:48.300
60
80
00
-220
-240 -220 -200 -180 -160 -140
Solar-X [arcsec]


Total intensity over y = 260-265px
from 11:50:16-11:52:17
Fe XXI 1354.08
redshift
Intensity
1000
800
600
400
200
0
1352
1353
1354
1355
1356
Wavelength (Angstroms)


AIA 131 contours
IRIS SJI 1330Á
12-Mar-2015 11:55:10.110
SDO AIA 131Á
12-Mar-2015 11:55:00.340
-160
-180
-200
-220
Solar-Y [arcsec]
-240 -220 -200 -180 -160 -140
Solar-X [arcsec]

Results: 2015-03-12 Flare (OBS 3860107053)

- Summary
  - Redshifts on bright loop top bar region, v = ~ 100-200 km/s
    - Possible downward flows along the LOS on the bright loop top bar region

Conclusion

- Cannot conclusively determine that termination shocks occurred
- Identified flows indicative of a TS were identified in the form of redshifted Fe XXI emissions in two separate flares
- Similarities
  - Location: bright loop top bar
  - Comparable speeds; and emission intensities and widths
  - Appeared in gradual phase, right after the flare peak
  - Redshifts persisted for ~5 and ~10 minutes, respectively
- Further investigation
  - Redshifts appeared at later time (gradual phase) than expected (impulsive phase)

Acknowledgements

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