EUV Spectroscopy of solar flares observed by EIS/HINODE and IRIS

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Outline

- Background: Solar flares & EUV spectroscopy

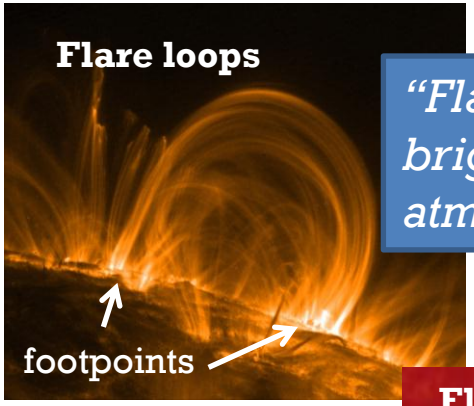
- Two events observed by IRIS & Hinode/EIS:

  - 9th March 2012

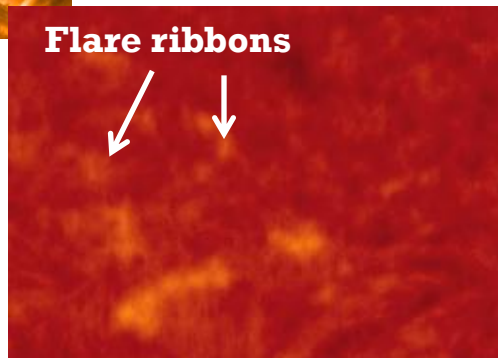
  - 3rd February 2014

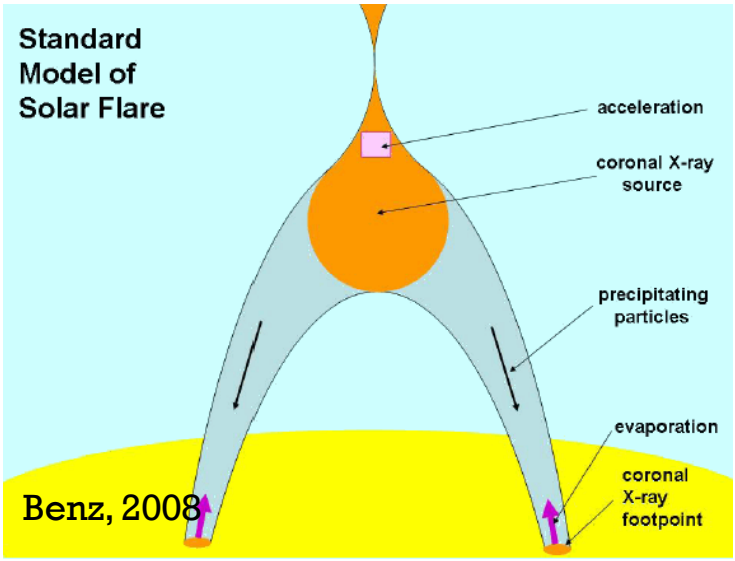
- Conclusions

EUV spectroscopy of solar flares



"Flare": sudden brightening in the solar atmosphere





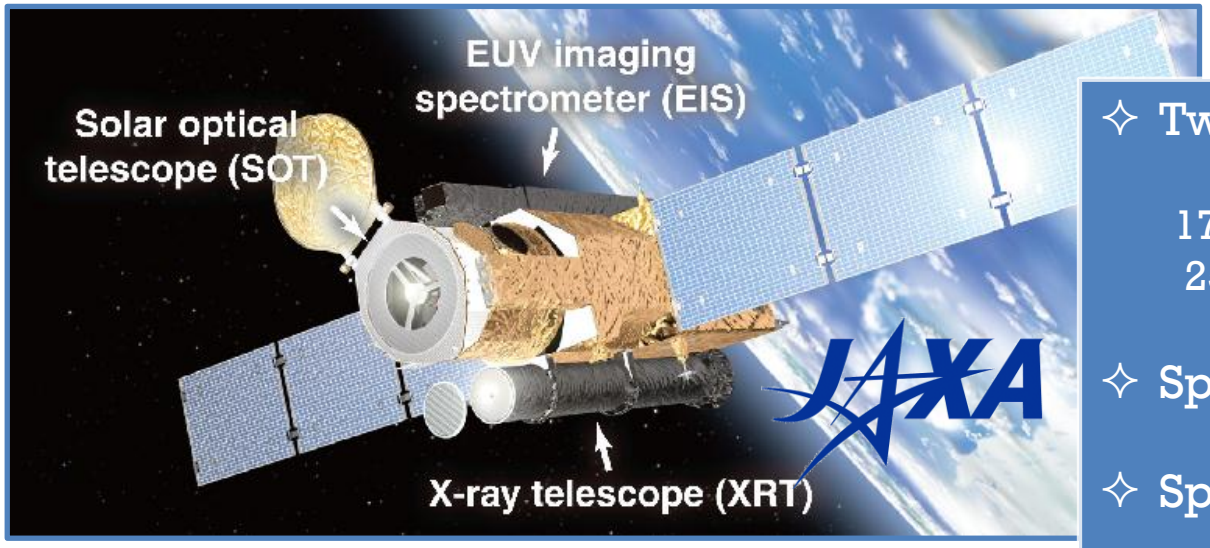
Spectral signatures of chromosperic evaporation are velocity blueshifts in high temperature emission lines (Doscheck (1980), Antonucci (1982))

TO INVESTIGATE THE NATURE OF SOLAR FLARES :

- Determine local plasma dynamics **(flows)** and parameters (**density, temperature, emission measure, abundances, etc.**) as a function of space and time, which can then be compared with theoretical models.

⟹ **NEED HIGH RESOLUTION EUV SPETROSCOPY**

Hinode/EIS (The **E**UV **I**mager **S**pectrometer)



- Two wavelength bands:

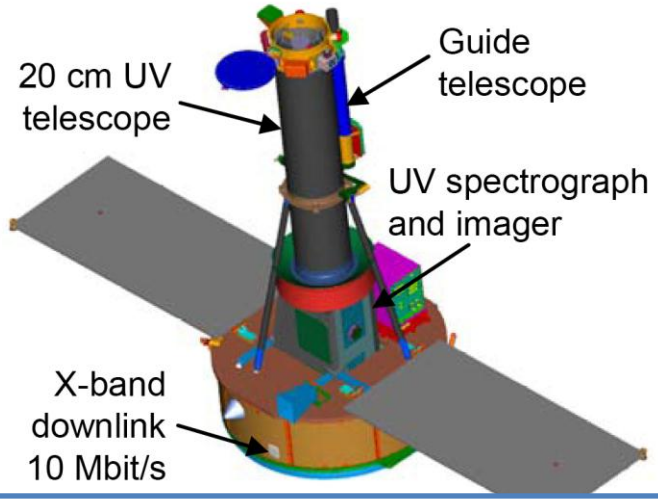
  170-210 Å(SW)
  250-290 Å (LW)

- Spectral resolution ~ 0.06 Å
- Spatial resolution ~ 3”

A JAXA/NASA/USA/UK project

- Transition region to coronal temperatures lines (0.05 MK< T_{max} <4 MK)
- Flare lines (T_{max} > 4MK), especially **Fe XXIII 263 Å (10 MK)**
- Density diagnostic lines (such as FeXII λ196/λ195, FeXIV ratios, SiX λ258/λ261)

IRIS (**I**nterface **R**egion **I**maging **S**pectrograph)



- Chromosperic (Mg h &k, OI 1355 Å) and transition region lines (SiIV, OIV doublets, CI 1356 Å)
- One coronal (Fe XII 1349 Å, 1.5MK) and one **flare line (Fe XXI 1354 Å, 10MK)**
  → **Has been observed before (Skylab, SMM, SUMER) but at lower resolution**
- Density diagnostics (OIV doublets)

IRIS Slit Jaw Imager (SJI)

- FOV 175"X175"
- 1330 Å, 1400 Å, 2796 Å, 2832 Å
- Bandwidth 55 Å/4 Å

IRIS Spectrograph (SG)

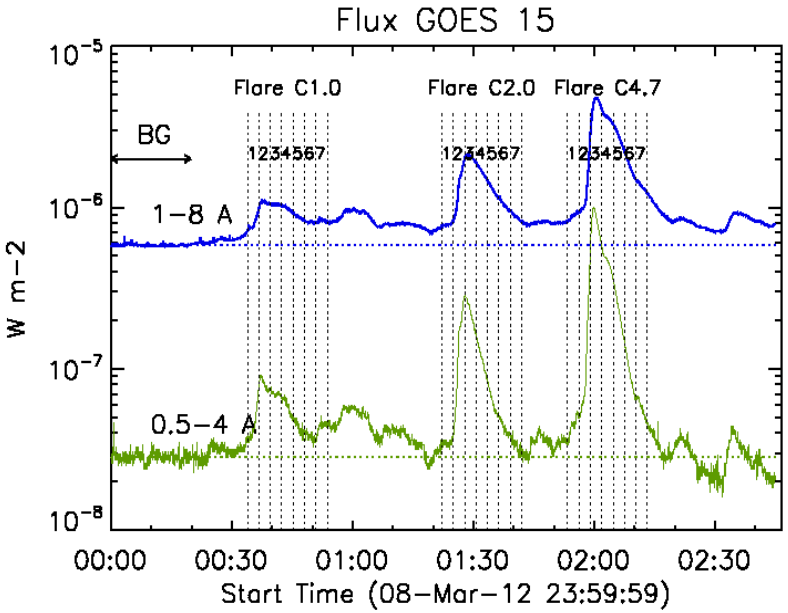
- Three wavelength passbands:

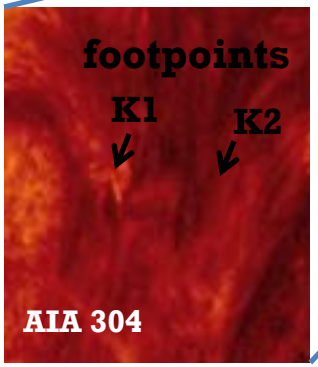
  FUV 1(1331.56-1358.40 Å)
  FUV2 (1390-1406.79 Å)
  NUV(2782.56-2833.89 Å)

- Spectral resolution ~ 0.026/0.053 Å
- Spatial resolution ~ 0.33" /0.4"

A NASA project

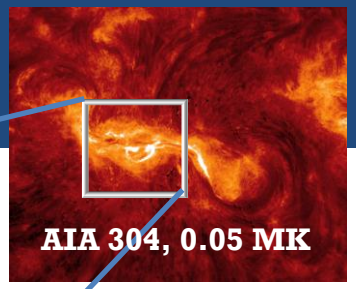
9th March 2012 observation

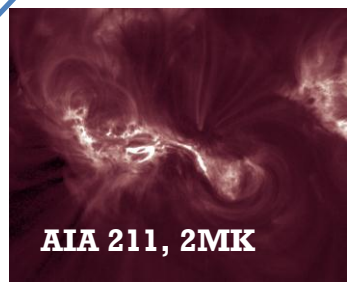


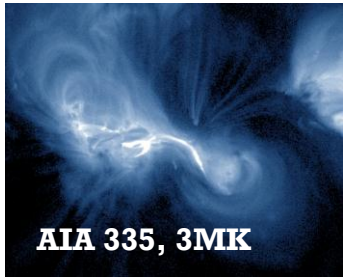


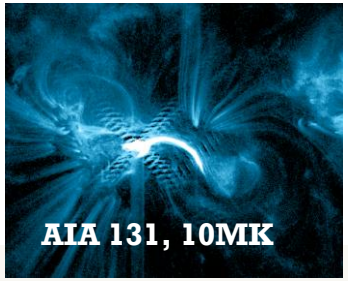
EIS STUDY

Short cadence 2" raster over the two flare footpoints



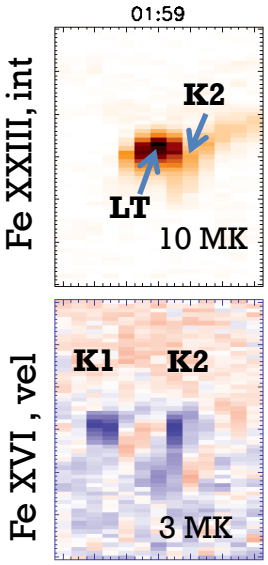




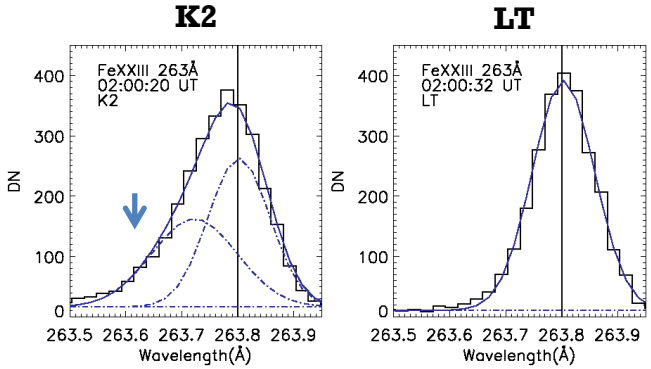


- 4 recurrent flares, from class C1 to M6.8 (from 00:37 UT to 03:24 UT).
- The last M6 flare was associated with a filament eruption (Doschek et al.2012)
- The first three (C-class) flares were all confined.

Footpoints observation : FeXXIII 263 Å (10 MK), FeXVI 262 Å (3MK), Fe XIV 264&274 Å (2MK)-Flare C4.7



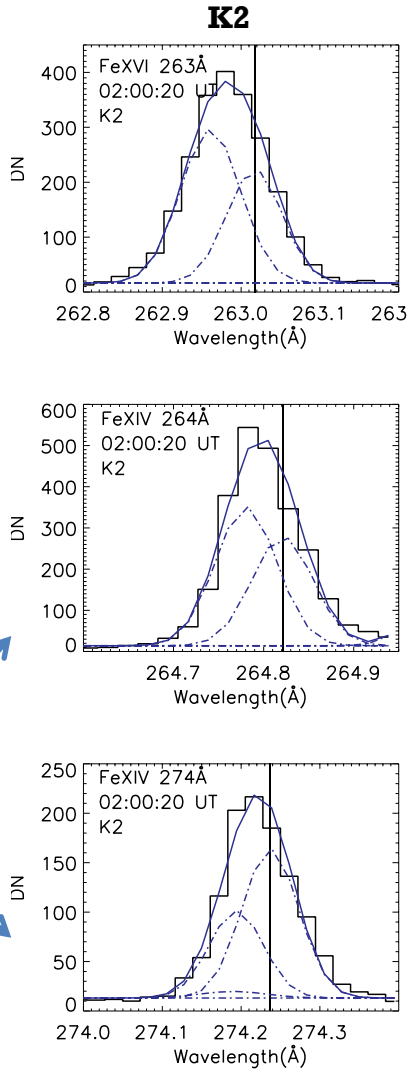
Fe XXIII 263



Blue asymmetry (~90 km/s) from one of the footpoints.

K1 & K2 – footpoints
LT- Loop Top

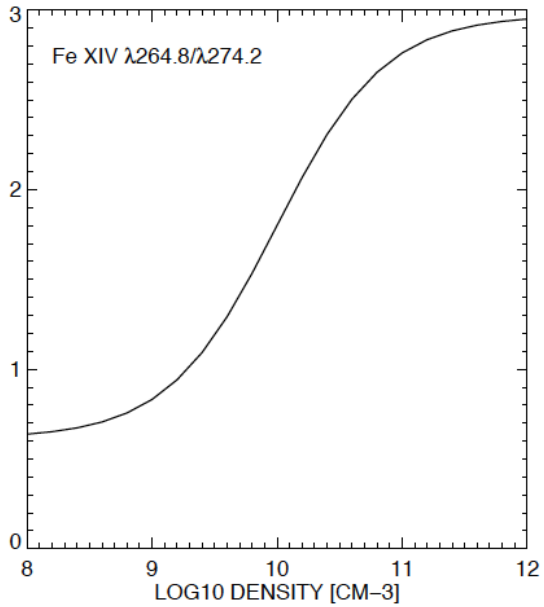
Fe XVI 263, FeXIV 264 & 274



Fe XIV λ264/λ274
Good density diagnostic ratio

- The λ264 is not blended
- The λ274 can be de-blended from Si VII λ274.18 using the ratio λ274/λ275

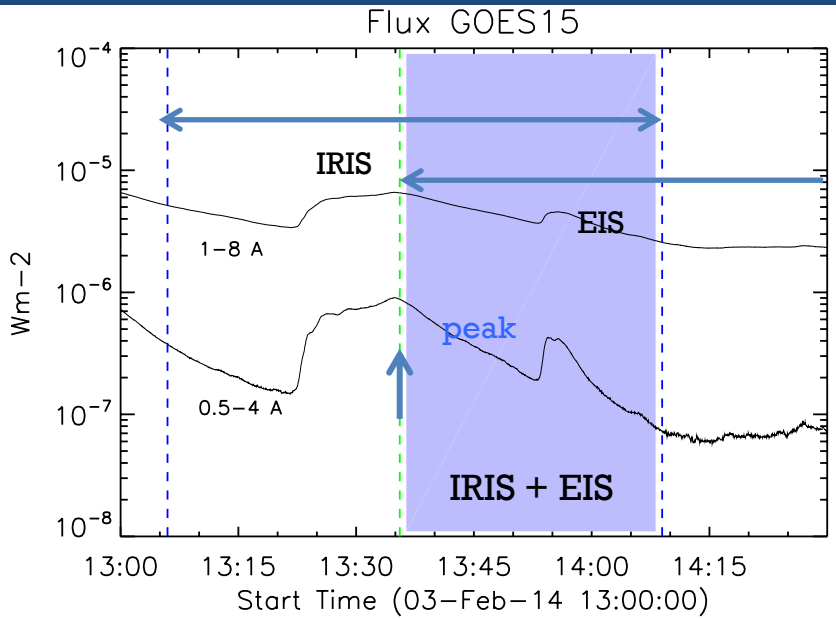
Density diagnostic from Fe XIV λ264/λ274

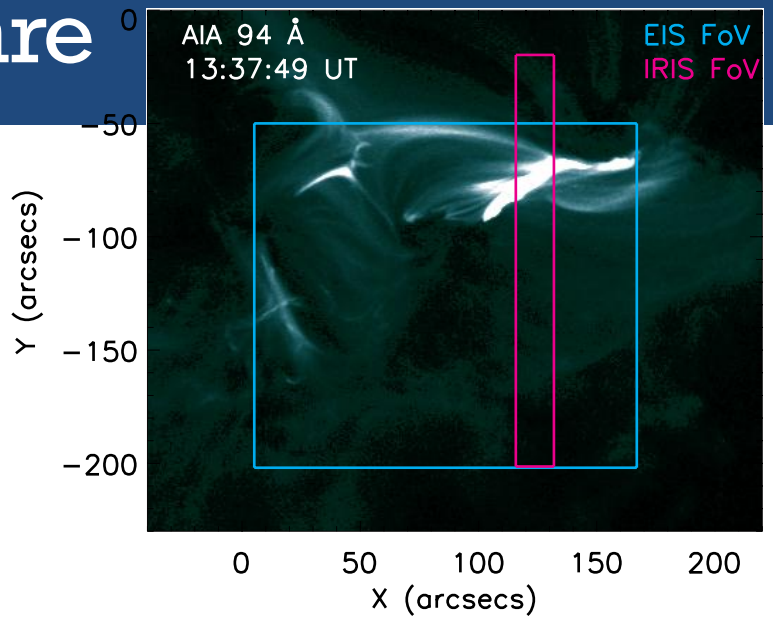


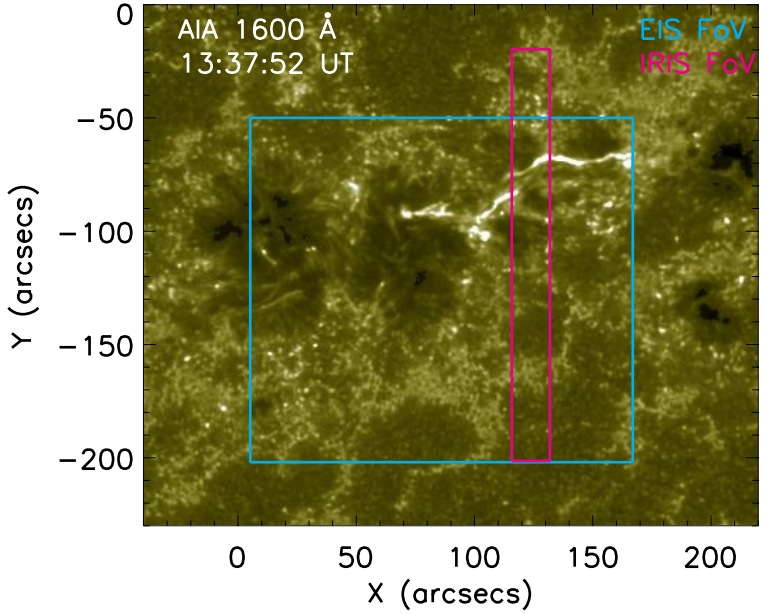
Ion	λ_{obs} (Å)	F (Å)	*vel* (km/s)	N_e (cm^{-3})
	02:00:49 UT – K1			
Fe XIV (rest)	264.821	0.08		7.9×10^9
Fe XIV (bw)	264.771	0.08	57	$>10^{11}$
Fe XIV (rest)	274.237	0.084		
Fe XIV (bw)	274.181	0.082	61	
Fe XVI (rest)	263.017	0.083		
Fe XVI (bw)	262.967	0.12	57	
	02:00:20 UT - K2			
Fe XIV (rest)	264.821	0.08		6.7×10^9
Fe XIV (bw)	264.781	0.08	45	$>10^{11}$
Fe XIV (rest)	274.237	0.084		
Fe XIV (bw)	274.154	0.081	47	
Fe XVI (rest)	263-017	0.083		
Fe XVI (bw)	262.961	0.089	64	
Fe XXIII (rest)	263.802	0.130		
Fe XXIII (bw)	263.723	0.180	90	

The density of the upflowing plasma increases more than an **order of magnitude from the pre-flare average density value (~ 5*10^9 cm^{-3})**

3rd February 2014 C6.5 flare





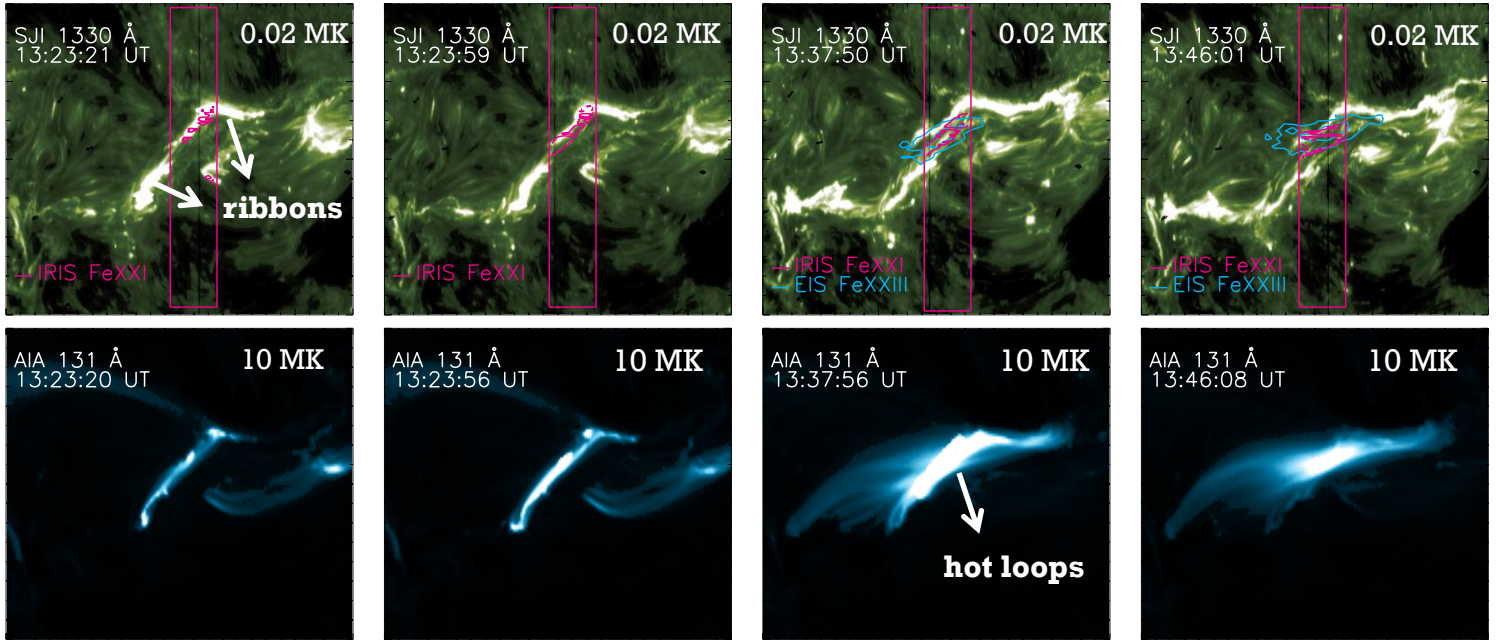


- Difficult to find co-spatial and co-temporal spectroscopic observations of solar flares! (small fields of view, scanning in opposite directions!)
- IRIS SJI and SDO/AIA used as context images

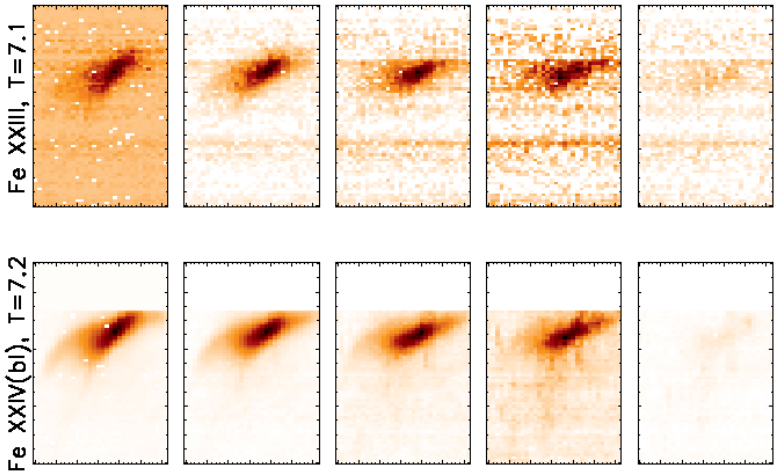
Polito, Reeves, Del Zanna, Golub, Mason, 2014 in prep.

IRIS/EIS observation of hot (10 MK) plasma

IRIS SJI 1330 A with **IRIS FeXXI and EIS FeXXIII** contours(top), AIA/SDO 131 A (10 MK) images (bottom)



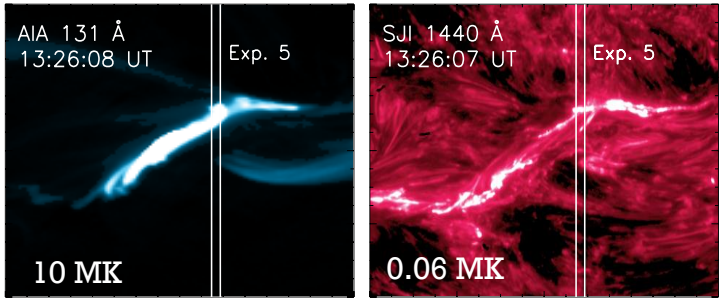
EIS FeXXIII-FeXXIV intensity(10 MK)



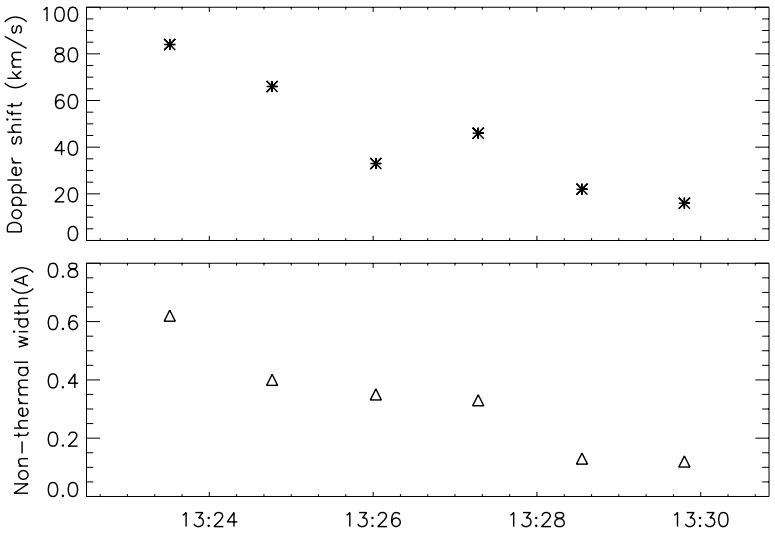
- The **FeXXI (10MK)** emission progressively moves from the northern ribbon towards the loop top
- EIS **FeXXIII and FeXXIV (10MK)** emissions are co-spatial with IRIS FeXXI.

Measuring hot (10MK) plasma upflows: Fe XXI blueshifts

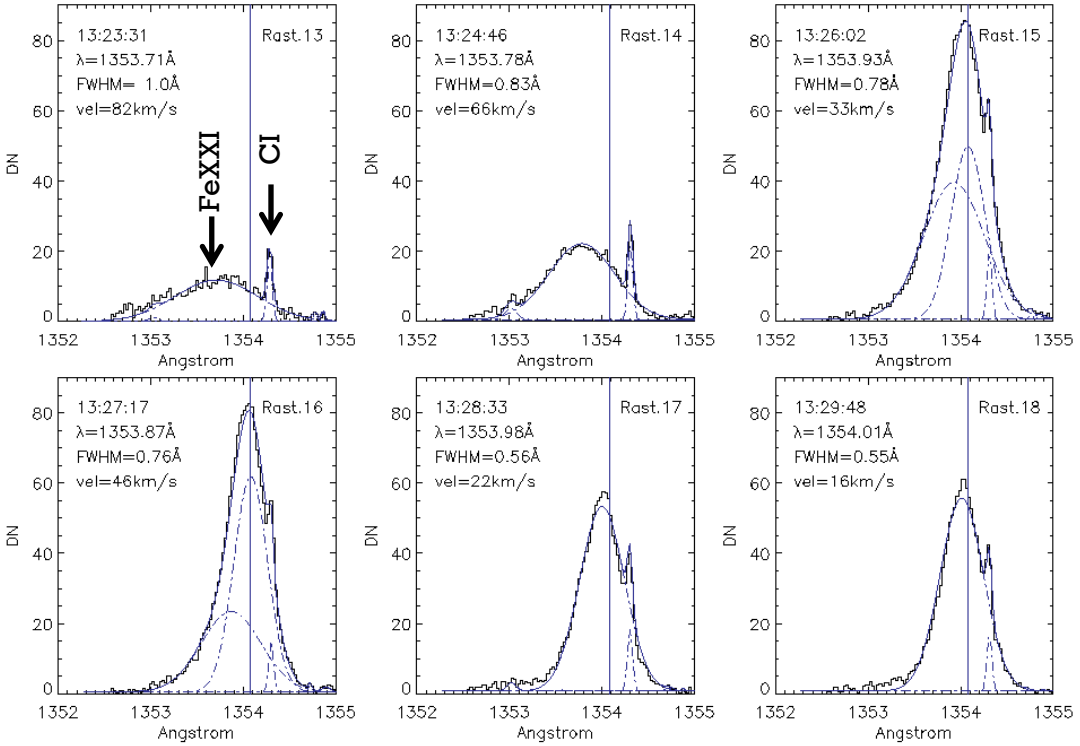
IRIS slit position



Fe XXI blue shift velocities and non-thermal widths in function of time



Fe XXI profiles on the same location (ribbon)over time



- In the early phase we see a **broad and totally blueshifted** FeXXI emission. The velocity and non thermal width of this emission decreases with time.
- Towards the peak of the flare, we see an **increase of the rest component** coming from the flare loops as they fill.

Conclusions

- High resolution spectrometers such as IRIS and EIS provide useful tools to study the nature of flares and flare-related events

FURTHER WORK WILL INVOLVE…

- Looking for more joint observations(IRIS,EIS, SDO, RHESSI,..) to obtain a broad wavelength coverage
- Comparison with 1D hydrodynamic models which simulate the plasma response to different heating mechanisms (HYDRAD, RADYN..)
- Magnetic field extrapolation also provides important information (heating source and conversion of energy).

Acknowledgements. Thanks to the IRIS team at the Harvard-Smithsonian Centre for Astrophysics and the Hinode/EIS team

Thank you for your attention!