Simultaneous IRIS and HINODE/EIS observation of an X-class flare

UNIVERSITY OF CAMBRIDGE

SUPA

CfA

Polito, V.[1], Reep, J[1], Reeves, K.K.[2], Simoes, P.[3], Del Zanna, G.[1], Mason H[1], Golub. L. [2]

(1) DAMTP, Centre for Mathematical Sciences, Wilberforce Road, Cambridge, CB3 0WA, UK, (2)Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge MA 01238, USA. (3) SUPA School of Physics and Astronomy, University of Glasgow

Abstract

We present the observation of an X-class flare obtained with the **Interface Region Imaging Spectrometer (IRIS)**, the **EUV Imaging Spectrometer (EIS)** and the **Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI).**

Thanks to the high temporal resolution of the IRIS and EIS spectroscopic observations, we are able to track the fast chromospheric evaporation from the flare footpoints during the early impulsive phase. In particular, strong blueshifts (~ 200 km/s) are simultaneously observed in both IRIS Fe XXI 1354 A and HINODE/EIS Fe XXIII 263 A hot (>10 MK) emission lines at one flare ribbon.

Multi-wavelength SDO/AIA and spectroscopic EIS and IRIS observations provide density and temperature diagnostics over time.

Finally, we have run 1D hydrodynamics simulations with the **HYDRAD** code to compare the plasma observables against theoretical predictions.

1. Overview of the flare

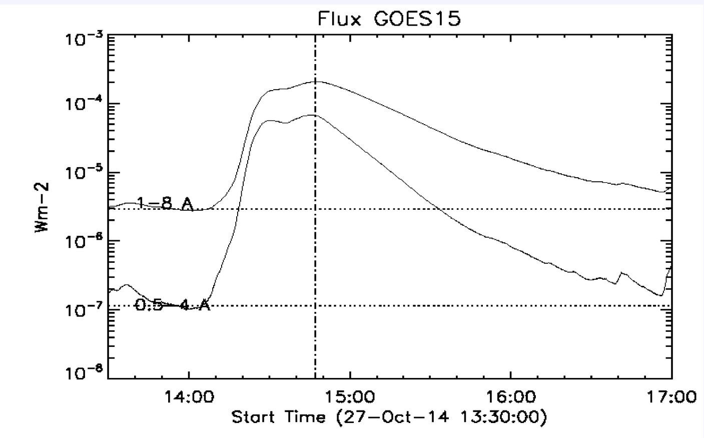
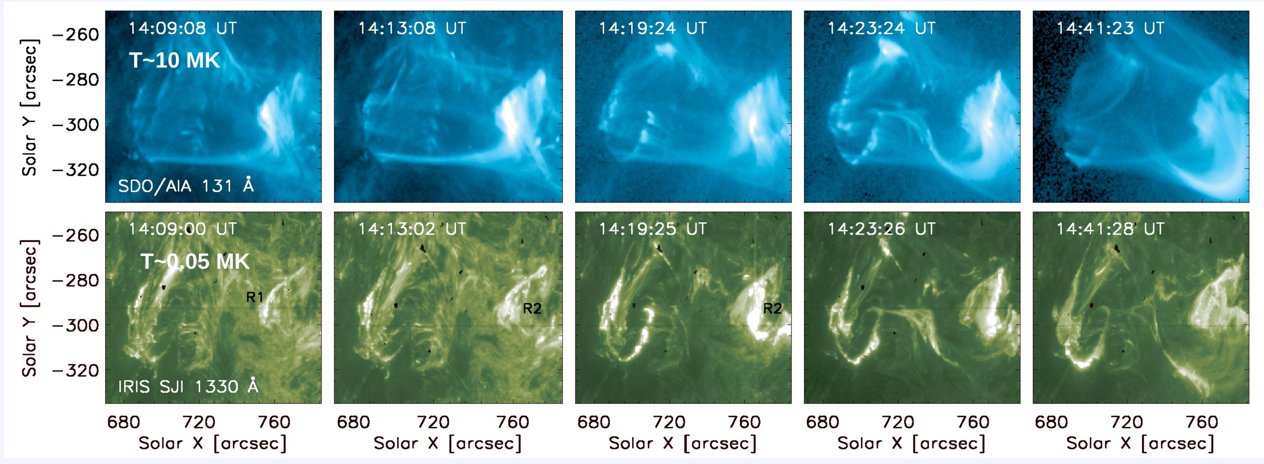


Fig.1 GOES soft X-ray light curves of the X-class flare.



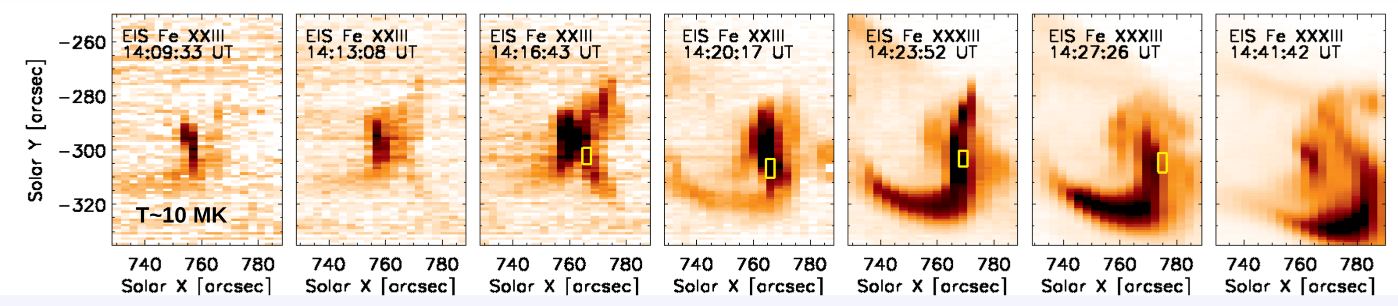


Fig.2 a) Overview of the flare over time in SDO/AIA 131 Å and IRIS SJI 1300 Å images. b) EIS Fe XXIII monochromatic images showing the evolution of the hot flare loops (>10 MK) over time.

Set of observations

- **IRIS:** 14:04- 17:44 UT
  8-steps raster, cadence 26 s, exposure time 3 s, roll angle 90º
- **EIS:** 11:02-17:27 UT
  20-steps raster, cadence 212 s, exposure time 9s
- **RHESSI :** 14:01-14:34 UT

2. Blue shifts at the footpoint of the flare loops with IRIS FeXXI and EIS Fe XXIII

- Large blue shifts (~200 km/s) in IRIS Fe XXI and EIS Fe XXIII high temperature lines are almost simultaneously observed (within 30s) at the eastern ribbon during the impulsive phase of the flare.

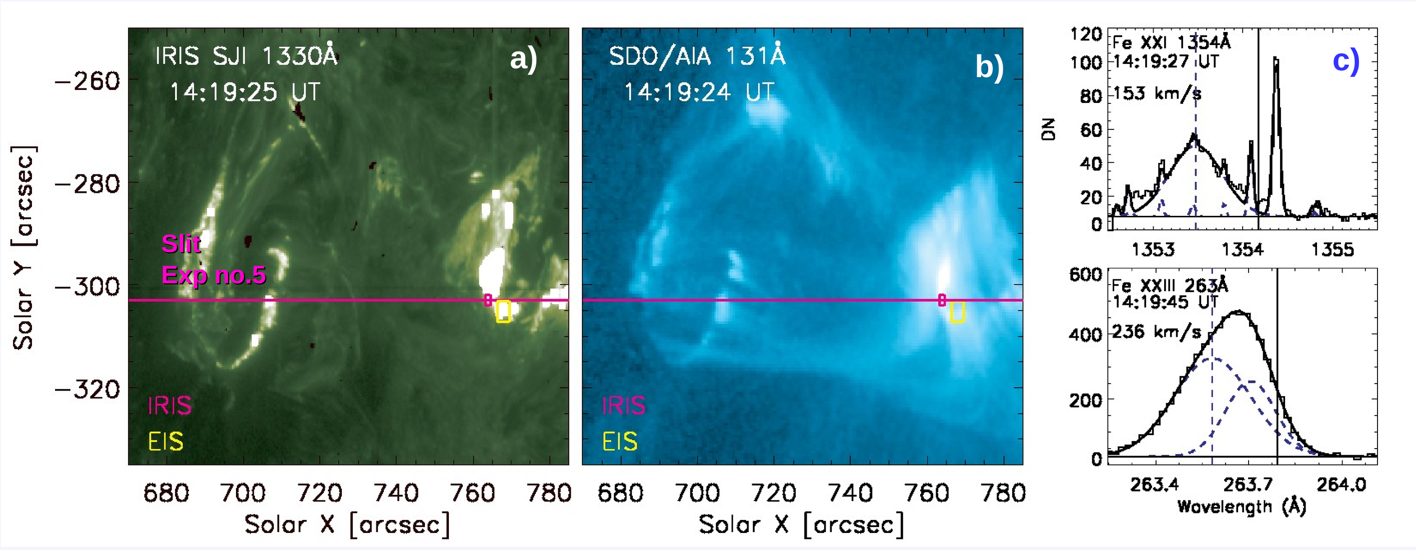


Fig.3 a-b)IRIS SJI 1330 Å and AIA 131 Å images during the impulsive phase. c) IRIS FeXXI and EIS Fe XXIII spectra acquired over the pink and yellow boxes in fig.3 a-b)

- We measure the IRIS FeXXI 1354.10 Å and SiIV 1402.77 Å emission over time at one slit position (fig.3a), at the footpoints of the hot loops visible in the high temperature lines (fig. 2)

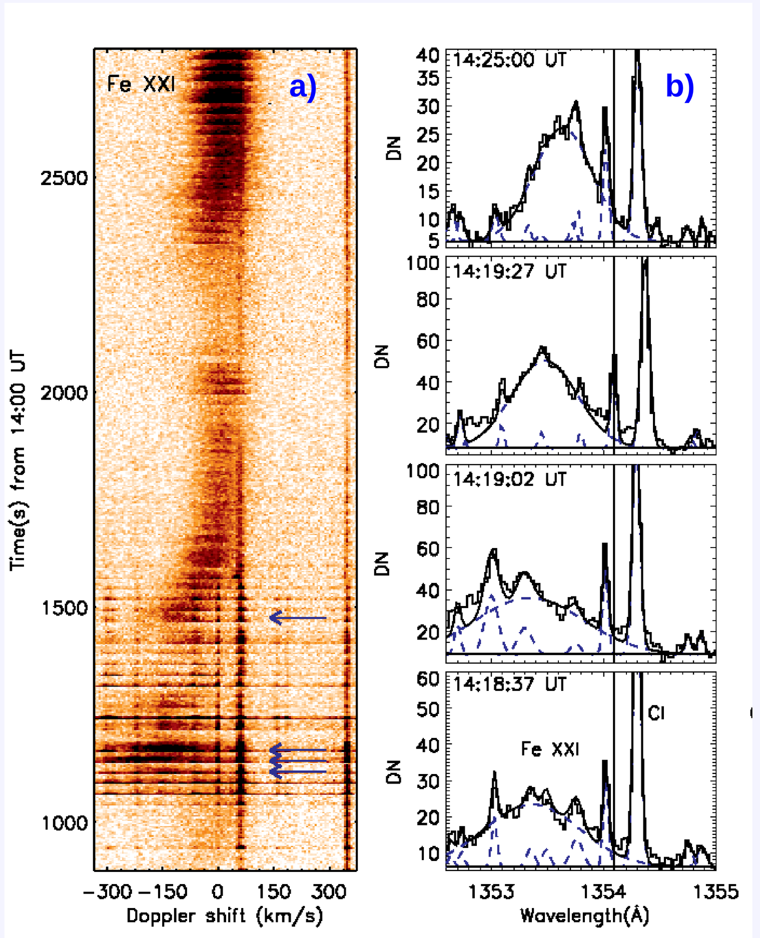


Fig.4 a) IRIS detector images of Fe XXI just above the ribbon over time. The corresponding velocity values are plotted in fig. 5.
b) Fe XXI spectra at particular times indicated by the blue arrows in fig. a) (increasing time from bottom to top)

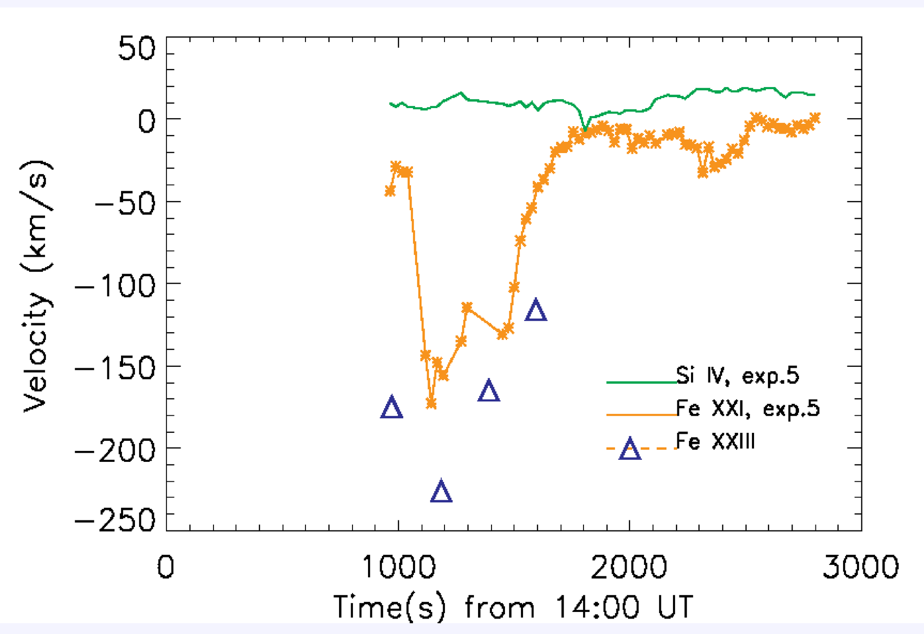


Fig. 5. Velocity blue shift of IRIS Fe XXI 1354.10 Å, Si IV 1402.77 Å and EIS Fe XXIII 263.77 Å over time (14:00 UT to 14:50 UT). We compare the observed values of velocity with the simulated results of fig. 10

3. Plasma diagnostics with IRIS/EIS/AIA

- The ratio of the IRIS OIV 1401 and 1399 TR lines provides a powerful electron density diagnostics. During the impulsive phase, we measure a OIV 1401/1399 ratio lower than 2.5, which indicates a density value outside the high density limit of 10^{12} cm^{-3} in CHIANTI v7.1 (assuming equilibrium conditions).
- However, we found that the emission from unidentified cool emission lines in the same spectral range is enhanced during the impulsive phase of the flare. These lines can blend the OIV line (see fig.7) and add an additional uncertainty in the density diagnostics.

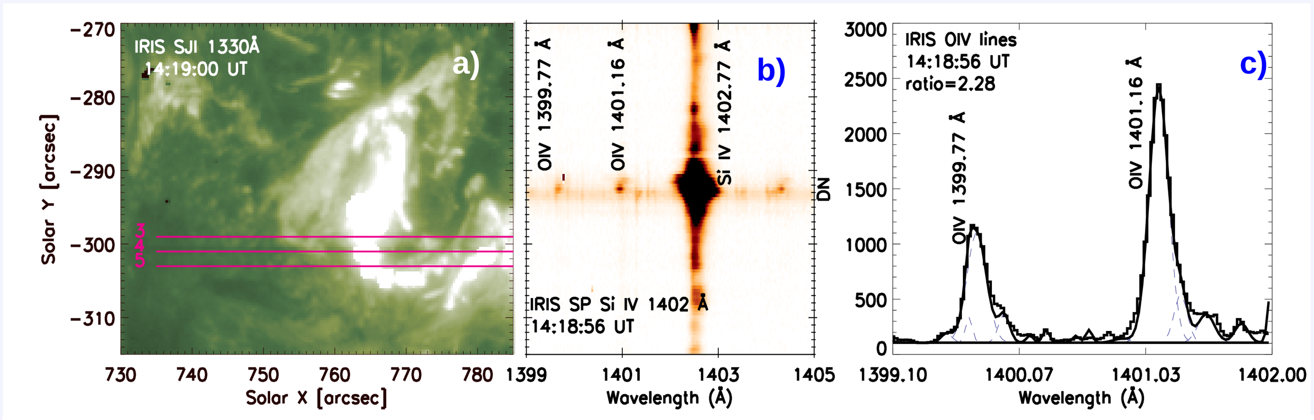
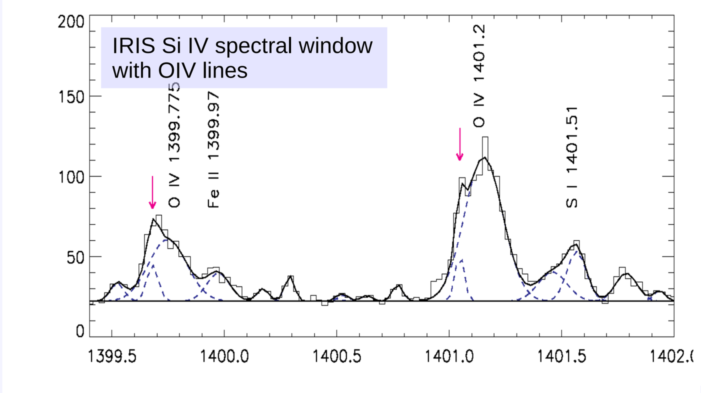


Fig. 6. a) IRIS SJI 1300 image with the position of the IRIS slit overplotted.
b) Corresponding detector image of the Si IV spectral window with the OIV lines.
c) Spectra of the OIV lines at the ribbon location



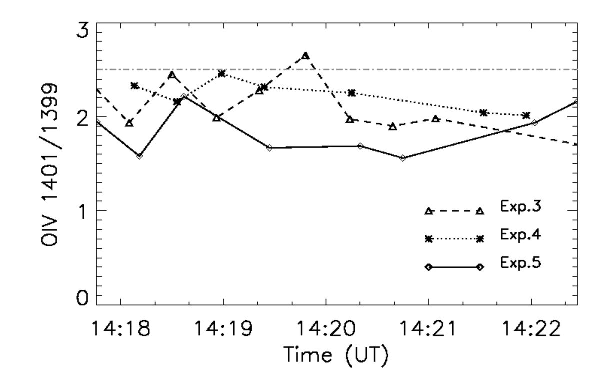
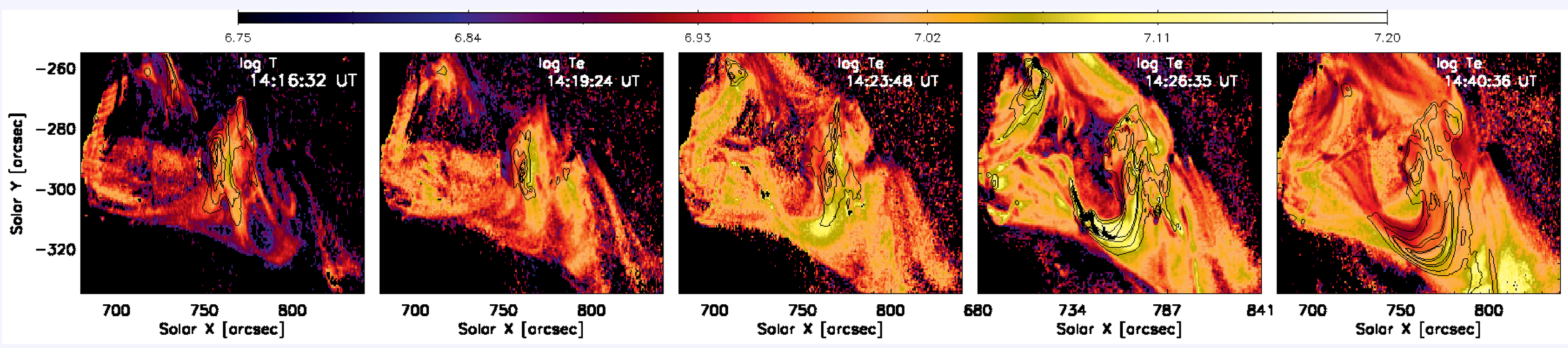


Fig. 7 (left) An example of OIV spectrum showing the blending with cool emission lines (arrows)

Fig. 8 (right) OIV 1401/1399 ratio at 3 IRIS slit locations along the ribbon during the impulsive phase of the flare. CHIANTI v7.1 high density limit indicated by the horizontal dotted line

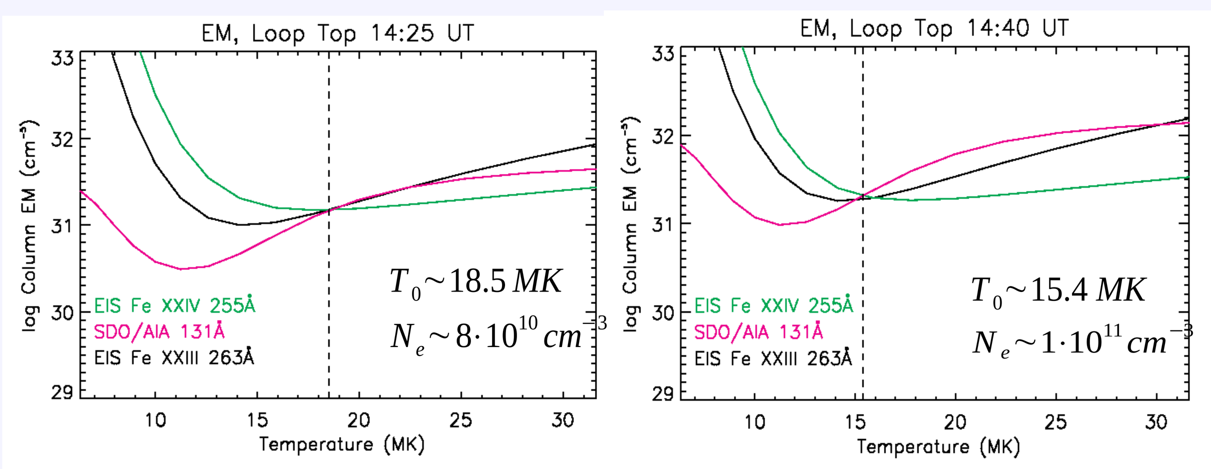
- During flares, the AIA 131 Å and 94 Å emission are dominated by Fe XXI (formed at 10 MK) and Fe XVIII (formed at 7 MK), respectively. The ratio of the two bands provide a tool to estimate the temperature of the flare plasma.

Fig. 8 Temperature maps obtained from the AIA 131/94 ratio at different times during the flare with the AIA 131 Å intensity contours



- For an isothermal plasma at temperature T_0, the emission measure (EM) can be expressed as the ratio between the observed intensity and the contribution function at that temperature.

$$EM_h(\lambda)=I_{obs}(\lambda)/G(\lambda,N_e,T_0)$$



The EM loci curves give an estimation of the equilibrium temperature T_0 and provide a lower limit of the electron density

Fig.9 EM loci curves at the times of the flare peaks in the soft X-ray (fig.1). The derived values of temperature and density are indicated in the figures.

4. Comparison with HYDRAD 1D hydrodynamical simulations

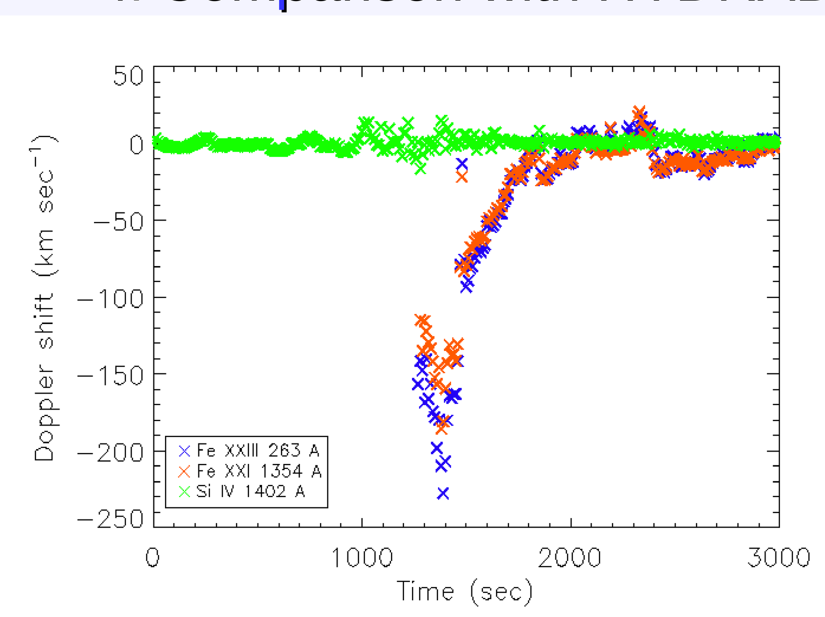


Fig. 10 Synthesized doppler shifts for 3 spectral lines as might be observed with IRIS and EIS, as a function of time, and assuming equilibrium ionization.

- **1D hydrodynamic simulation** of the flare loop undergoing heating by an electron beam with **HYDRAD** (Bradshaw & Mason 2003, Bradshaw & Cargill 2013, Reep et al 2013)
- The time profile of the heating is taken assuming that the time derivative of the soft X-ray flux is proportional to the hard X-ray flux, and thus the electron heating.
- Cut off energy and spectral index are obtained from RHESSI

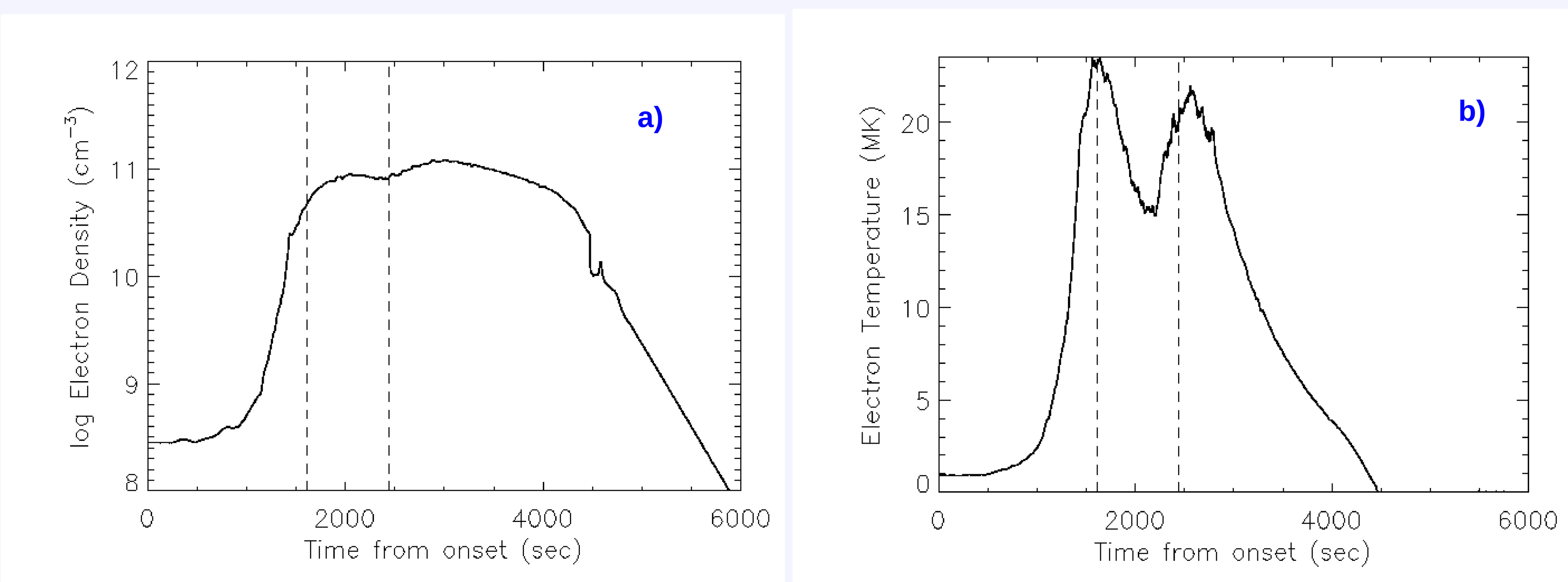


Fig. 11 The values of the electron density (left, a)) and temperature (right, b)) at the apex of the coronal loop as a function of time.

5. Summary

- Blue shifts during the impulsive phase of the 27th October flare are observed in the IRIS Fe XXI and EIS Fe XXIII spectral lines at almost simultaneous and co-spatial locations at one flare ribbon. The line profiles present broad and significantly blue shifted profiles (up to ~200 km/s in EIS Fe XXIII and 160 km/s in IRIS Fe XXI) during the impulsive phase of the flare.
- The ratio of the density-sensitive IRIS OIV lines is consistent with an electron density at the flare ribbon being > 10^{12} cm^{-3} during the impulsive phase. However, these lines are found to be blended with cool emission lines, thus further investigations are needed.
- AIA temperature maps provide a temperature structure of the flare plasma over time. We find that the ribbon locations reach temperature of at least 10 MK during the impulsive phase. These are the roots of the hot temperature (>10 MK) loops observed few minutes later.
- EM loci curves show that the apex plasma temperature decreases from ~18 MK to ~15 MK from 14:27 UT to 14:40 UT (times of the two peaks in the GOES light curves of the flare) . Correspondingly, the electron density remains constant at around 10^{11} cm^{-3}

The observed values of blue shifts, temperature and density are consistent with HYDRAD 1D hydrodynamics simulations of the flare loop undergoing heating by electron beam.

Acknowledgements. VP acknowledges support from the Isaac Newton Studentship, the Cambridge Trust, and the IRIS team at Harvard-Smithsonian Centre for Astrophysics. HEM and GDZ acknowledge support from the STFC. LG and KR are supported by contract 8100002705 from Lockheed-Martin to SAO.