

Impulsive heating of solar flare footpoints above 10 MK

Paulo Simões

and

David Graham, Lyndsay Fletcher

SUPA School of Physics and Astronomy, University of Glasgow

Solar and Stellar Flares

Prague, 25 June 2014

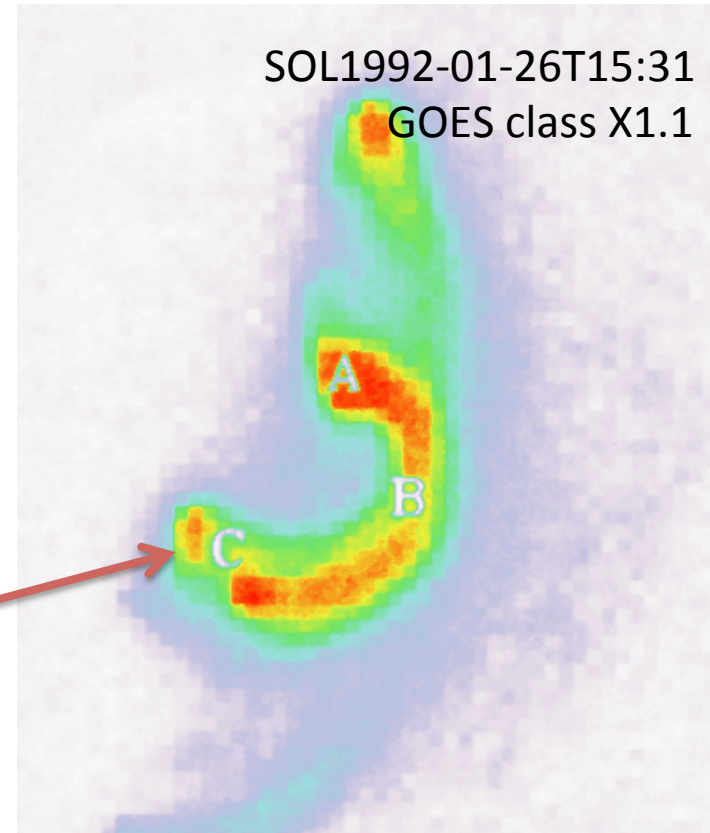
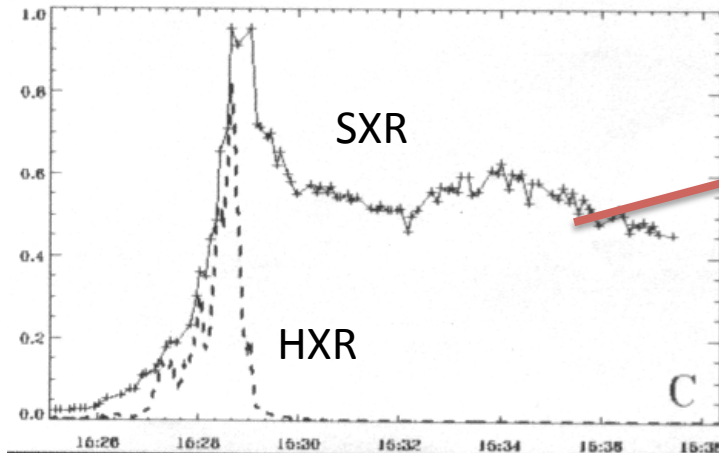


The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under grant agreement no. 606862 (F-CHROMA)

Background: impulsive SXR footpoints

SXR impulsive brightening observed in 40+ *Yohkoh* events.

McTiernan et al. 1993,
Hudson et al. 1994, Tomczak 1999,
Mrozek & Tomczak 2004



Spectra suggests thermal origin >10 MK
Suggested: Collisional beam heating

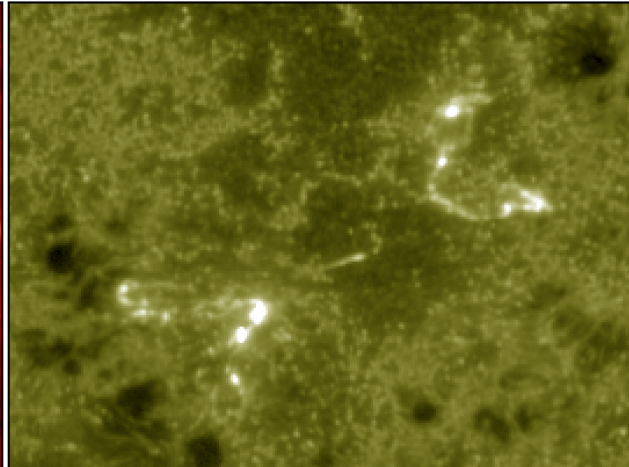
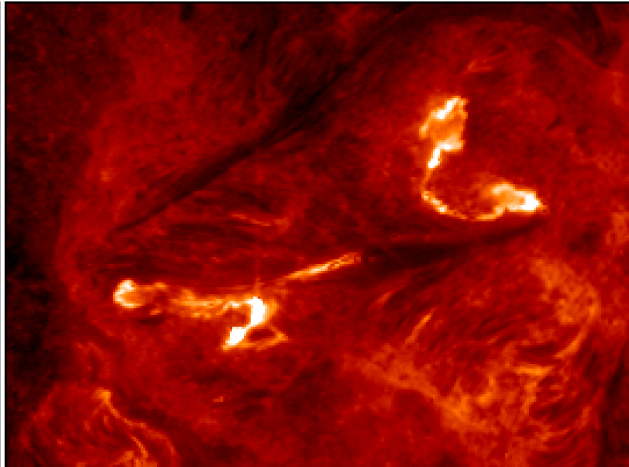
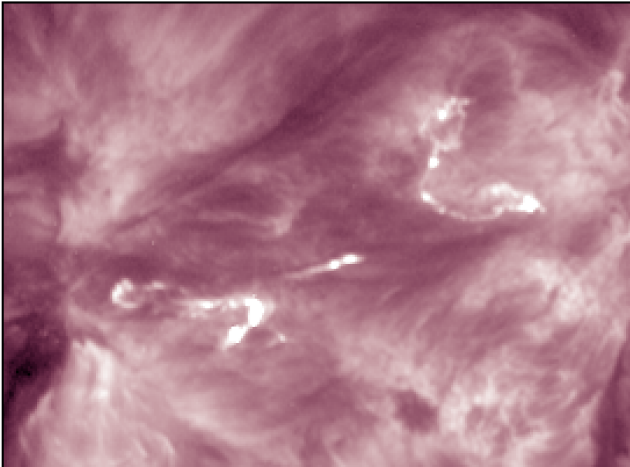
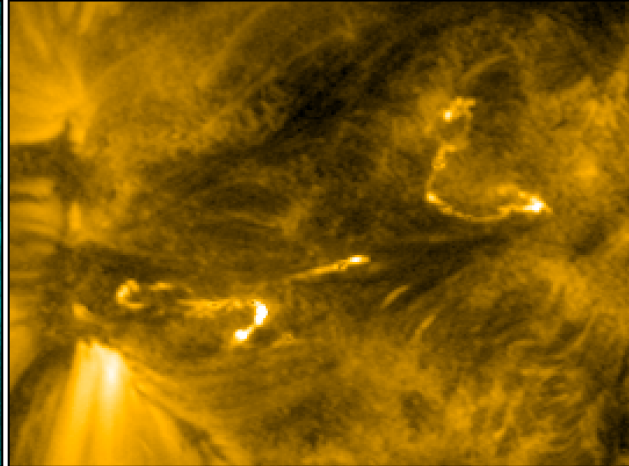
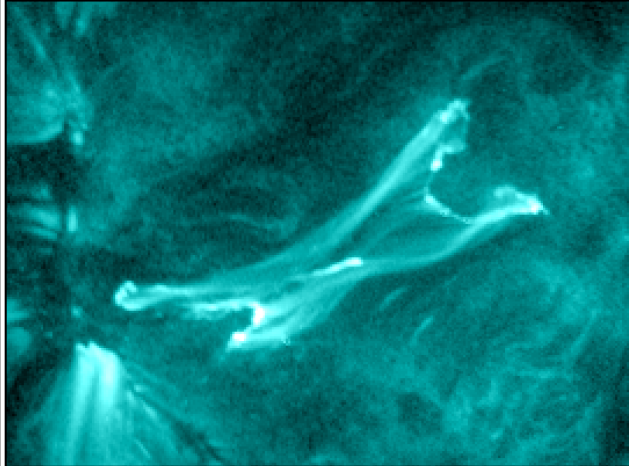
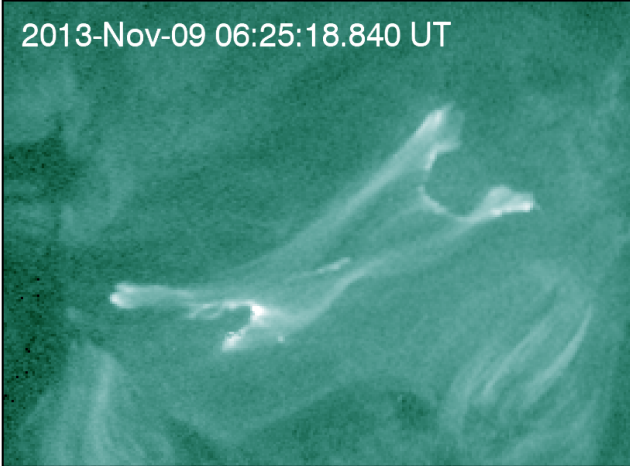
Other observations of (impulsive?) 1-10MK footpoints:
Watanabe et al. 2010 (EIS), Milligan 2011 (EIS), Del Zanna et al. 2011 (EIS),
Graham et al. 2013 (EIS), Fletcher et al. 2013 (AIA)

Motivation

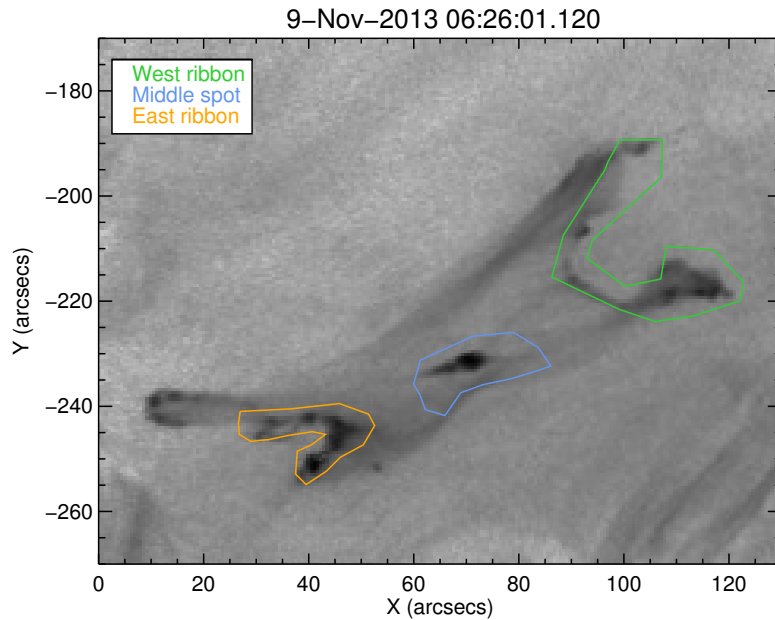
1. Can we observe ribbon/footpoint impulsive heating with SDO/AIA? (94, 131 Å)
2. Are the SDO/AIA data consistent with other instruments/wavelengths?
e.g. RHESSI (HXR), SDO/EVE (EUV spectral lines)
3. Is the ribbon/footpoint heating consistent with energy deposition of fast electrons?

SOL2013-11-09T06:38UT

2013-Nov-09 06:25:18.840 UT



SDO/AIA Images: impulsive EUV/UV



At the rising and impulsive phases:
ribbons are the brightest features
at 94 and 131 Å (and all other filters)

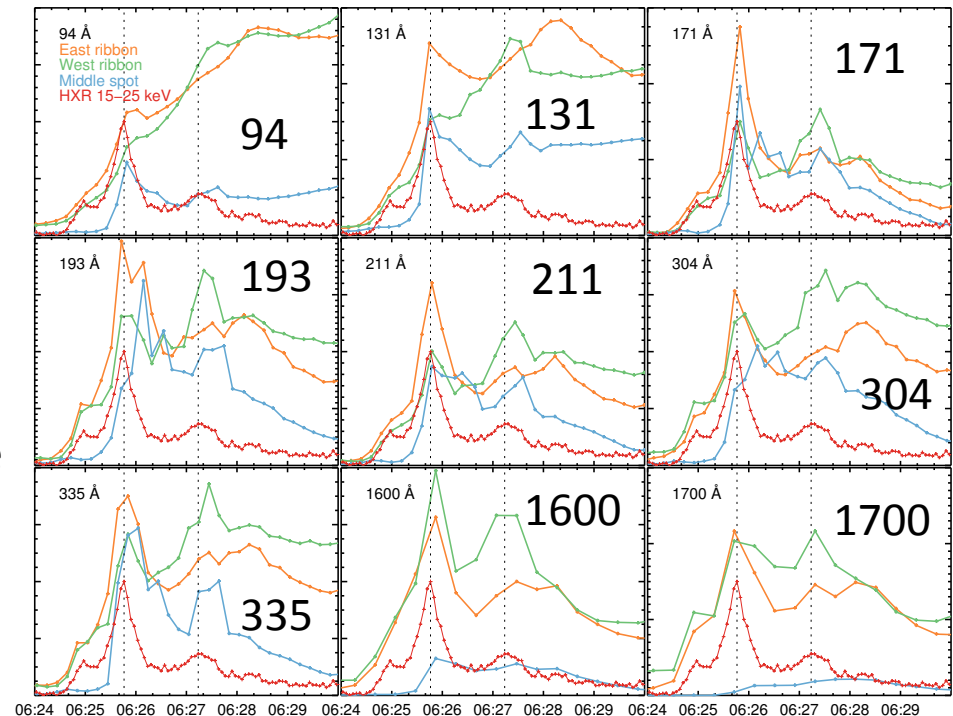
A bright coronal spot between the ribbons
is also evident (Simões et al. *in prep.*)

Three sources:

East and **West** ribbons + **Coronal** source

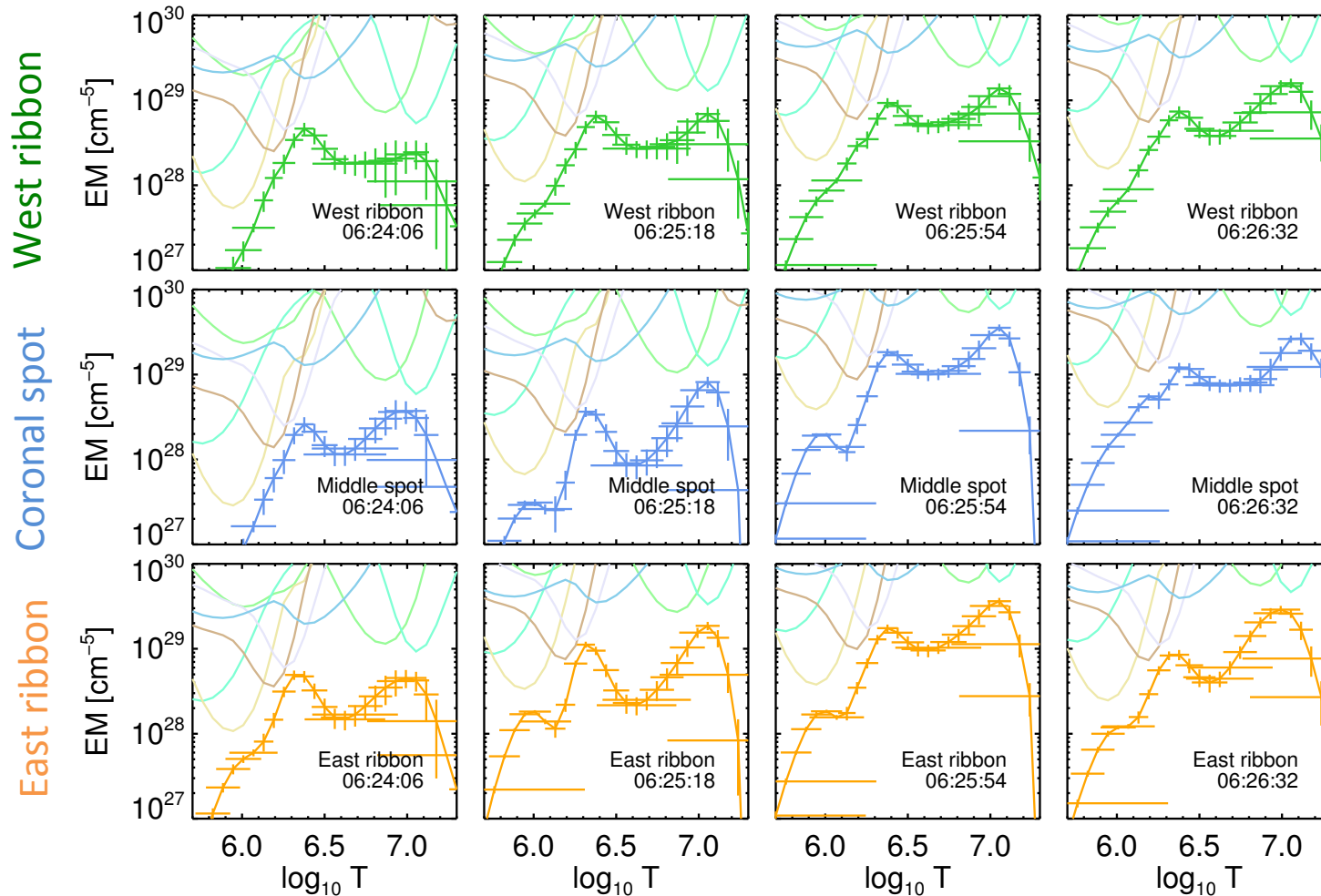
Impulsive emission at all AIA filters

Well associated with **HXR**



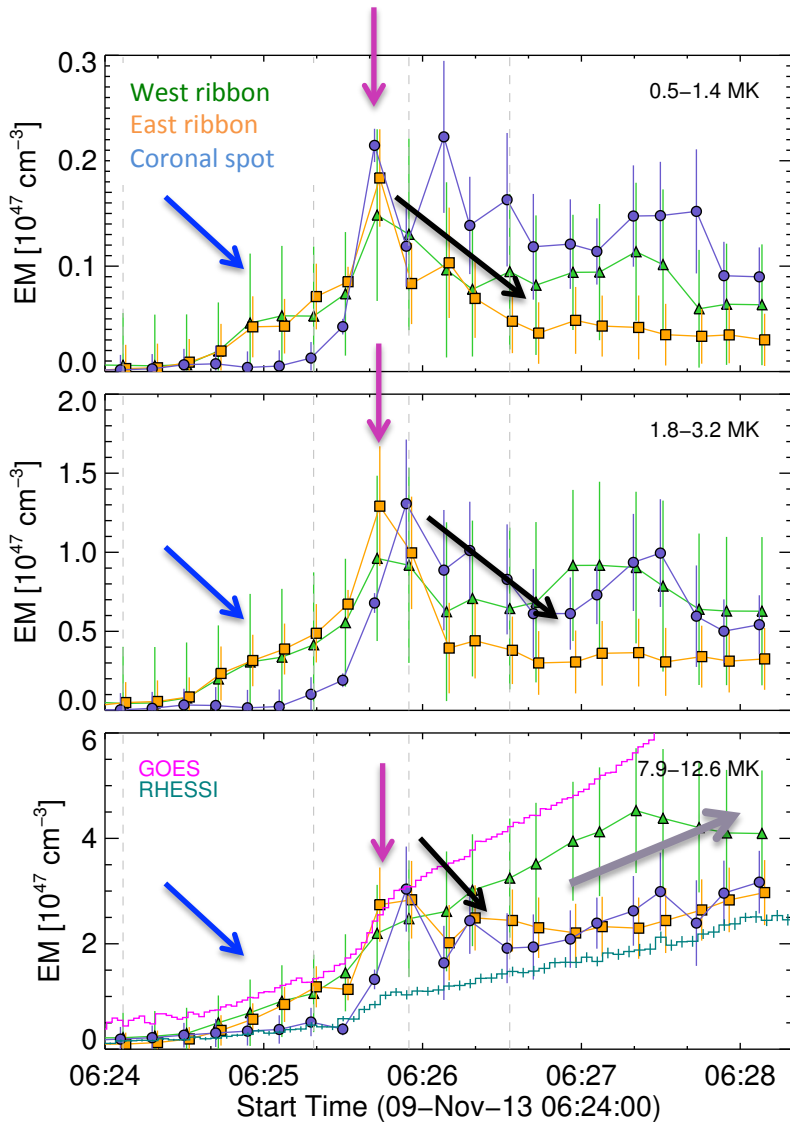
Emission measure distribution

DEM analysis* of AIA data shows the fast increase of EM at a broad range of temperatures



*DEM regularised inversion of AIA data (Hannah & Kontar 2012)

Impulsive heating



Onset: ←

The EM starts to increase at the **East** and **West** ribbons, at all temperatures – but not at the **coronal source**

Peak: ←

Cool and hot EM show a peak at 3 sources
Fast heating of the plasma ‘simultaneously’

Cooling plasma: ←

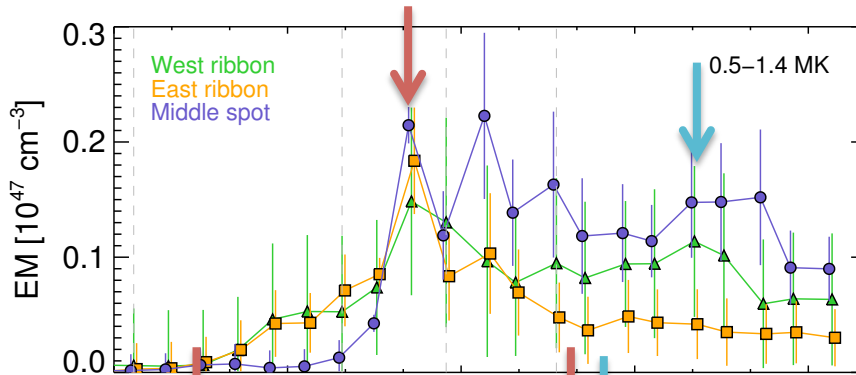
EM is impulsive at ribbons, implying fast cooling

Hot plasma: ←

Two components: impulsive + evaporation
EM gradually increases after the peak, filling of the loops.

Overall agreement with **GOES** and **RHESSI**

Transition region response

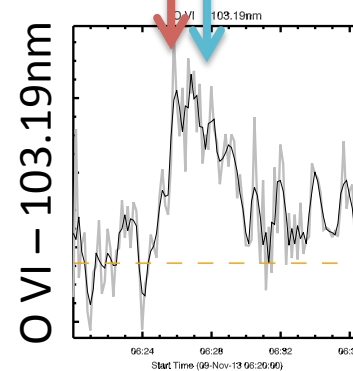
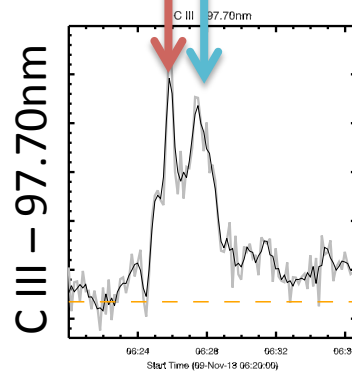
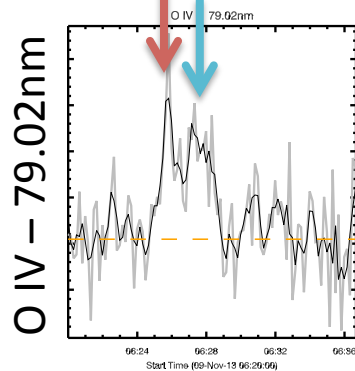
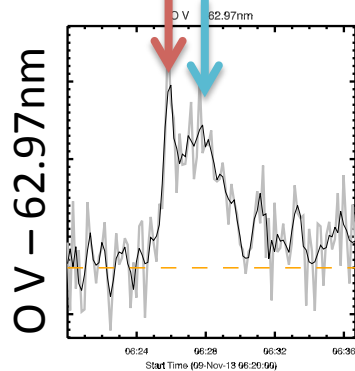
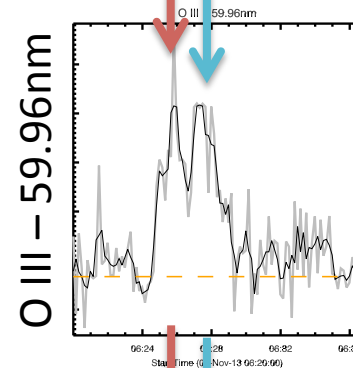
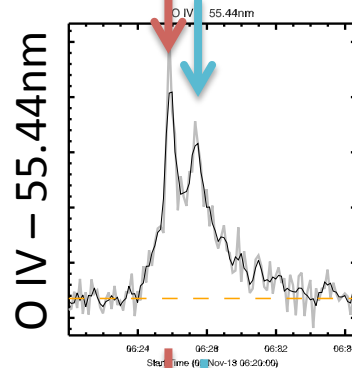
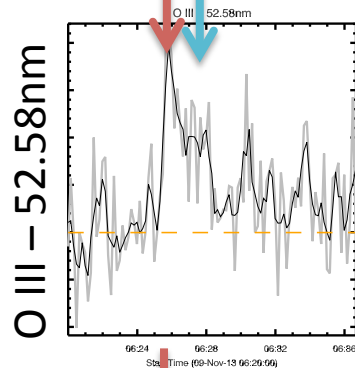
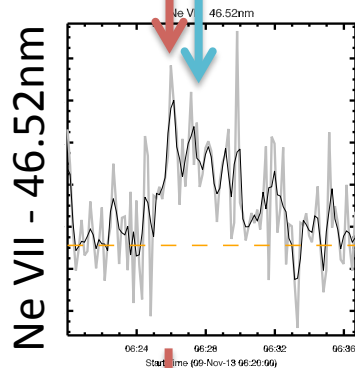


SDO/EVE MEGS-B

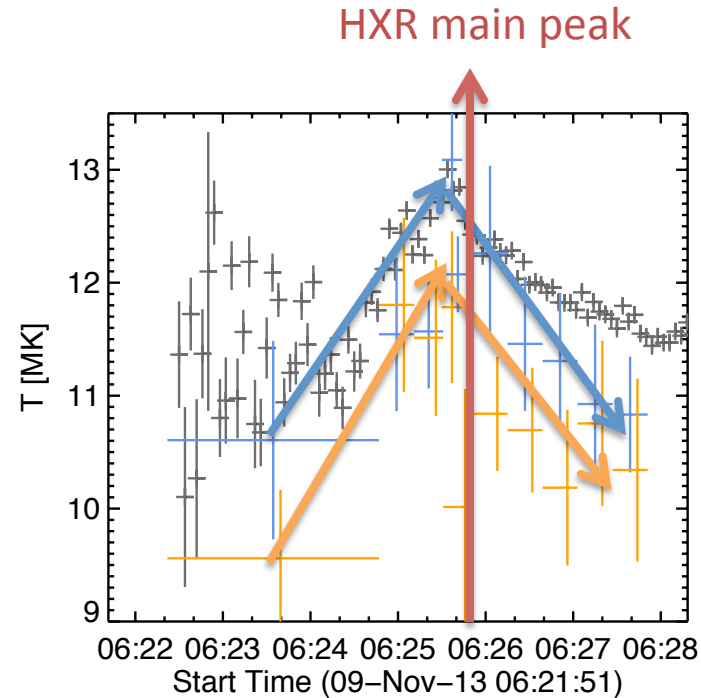
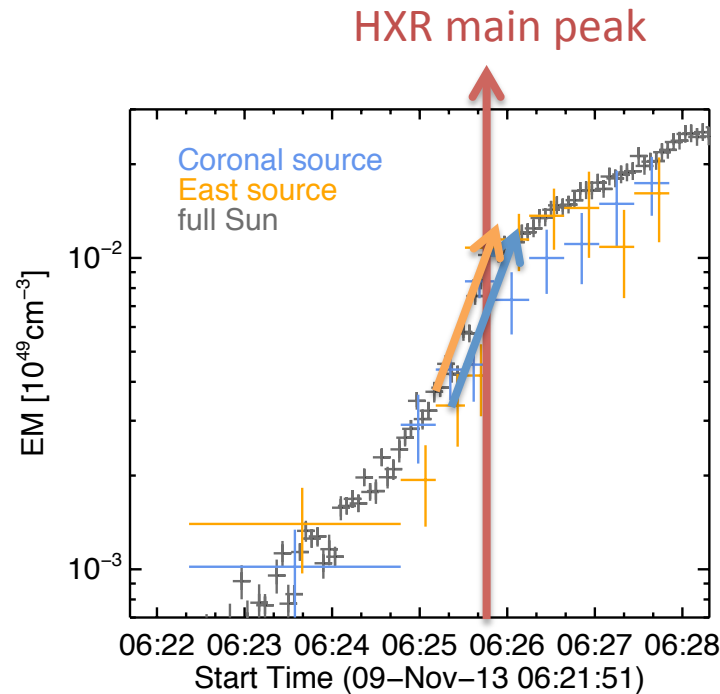
Transition region lines

$T = 6 \times 10^4 \sim 5 \times 10^5 \text{ K}$

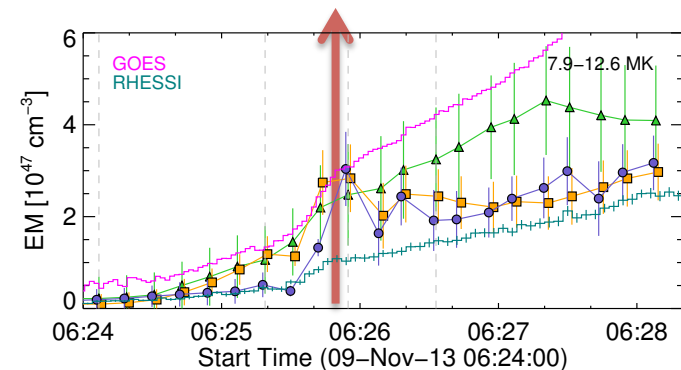
Two peaks: good association with AIA EM 0.5-1.4 MK



Temperature evolution

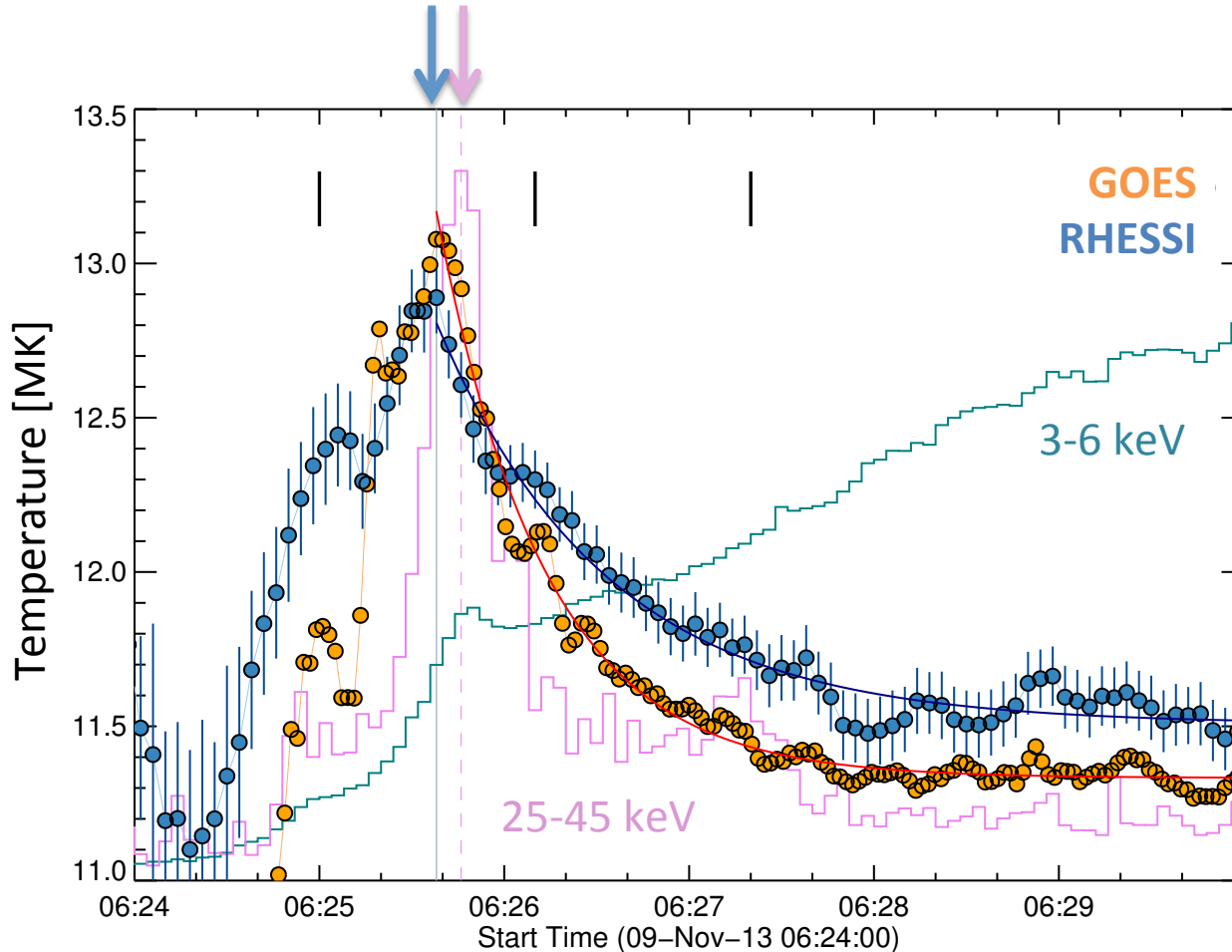


RHESSI imaging spectroscopy:
East ribbon and **Coronal source**
Both show a temperature peak
around 12 MK along with a steep
rise in the EM



Temperature peak from SXR/HXR

Main HXR peak *lags* the temperature peak, by about **10 secs**.



RHESSI and GOES
better sensitivity
to $T > 10\text{MK}$

Both show similar
impulsive temperature
peaks, reaching $\sim 13\text{MK}$

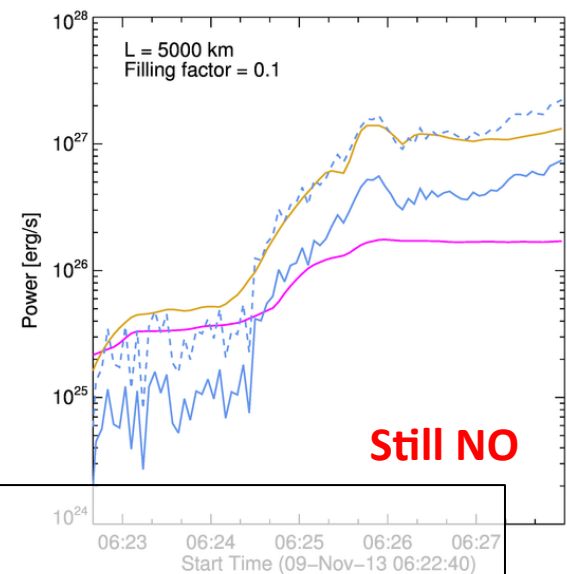
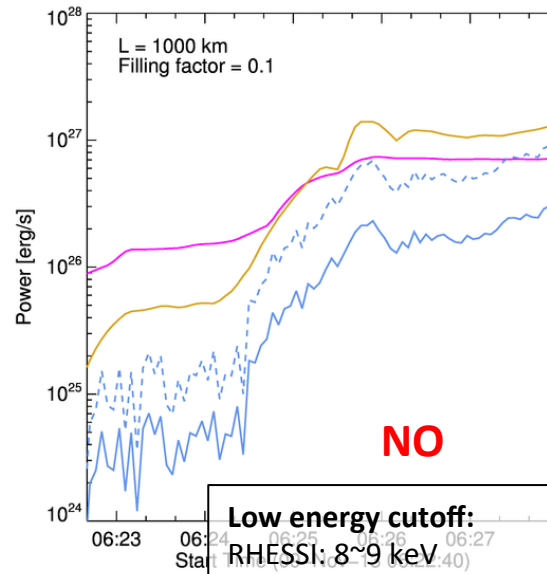
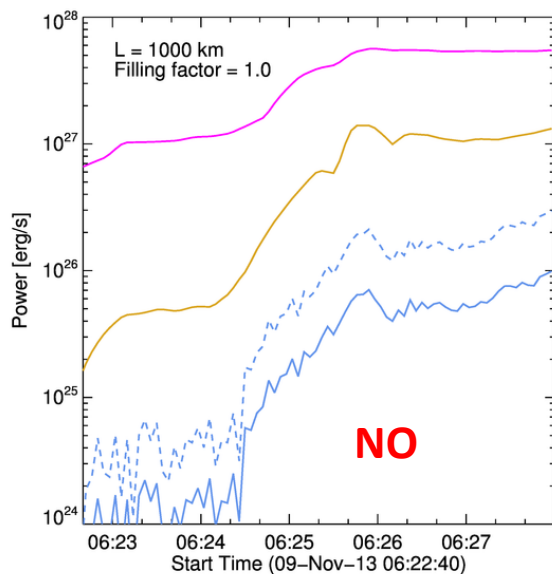
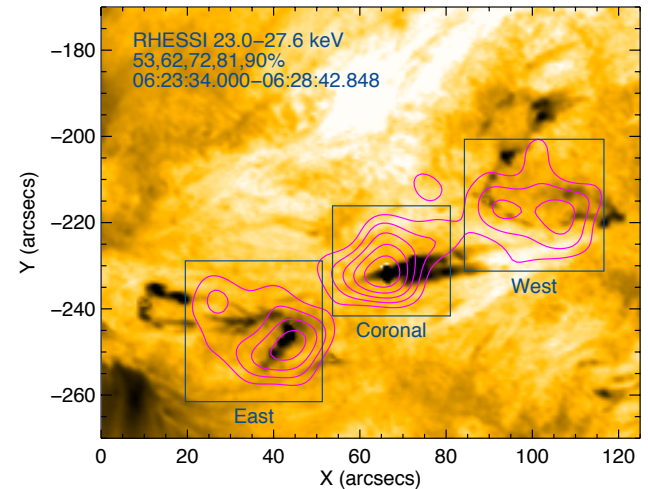
Fast cooling
e-folding time 35-55 s
Consistent with
conduction

Energy budget (East ribbon)

Heating of 10 MK ribbon plasma and energy losses by **conduction** and **radiation**

RHESSI shows evidence for non-thermal electrons at the three main sources.

Can the electron beam supply the energy by **collisional heating** (Fletcher et al. 2013, Emslie 1978)?



Low energy cutoff:
RHESSI: 8~9 keV
Needed:
E_{min} < 3 keV (L=1000km, filling factor=1)
E_{min} < 6 keV (L=5000km, filling factor=0.1)

Summary

SOL2013-11-09, GOES C2.7, two-ribbon flare

1. Can we observe ribbon/footpoint impulsive heating with SDO/AIA?

- Early heating phase of ribbons up to 10MK (AIA, DEM)
- Impulsive heating of ribbons up to 10MK (AIA, DEM)

2. Are the SDO/AIA data consistent with other instruments?

- EM values from AIA DEM are consistent with EM from GOES and RHESSI
- SDO/EVE TR lines well associated with HXR and ~ 1 MK plasma from AIA-DEM

3. Is the ribbon/footpoint heating consistent with energy deposition of fast electrons?

- *Ribbon plasma* is heated up to ~ 13 MK and cools rapidly to $10\sim 11$ MK (RHESSI)
- HXR peak *lags* the temperature peak (~ 10 secs)
- Electron beam energy is NOT sufficient to heat the ribbon plasma up to 10 MK
- Heating by Alfvén waves? (Emslie & Sturrock, 1982; Fletcher & Hudson 2008, Russell & Fletcher 2013 – also see A. Russell poster)