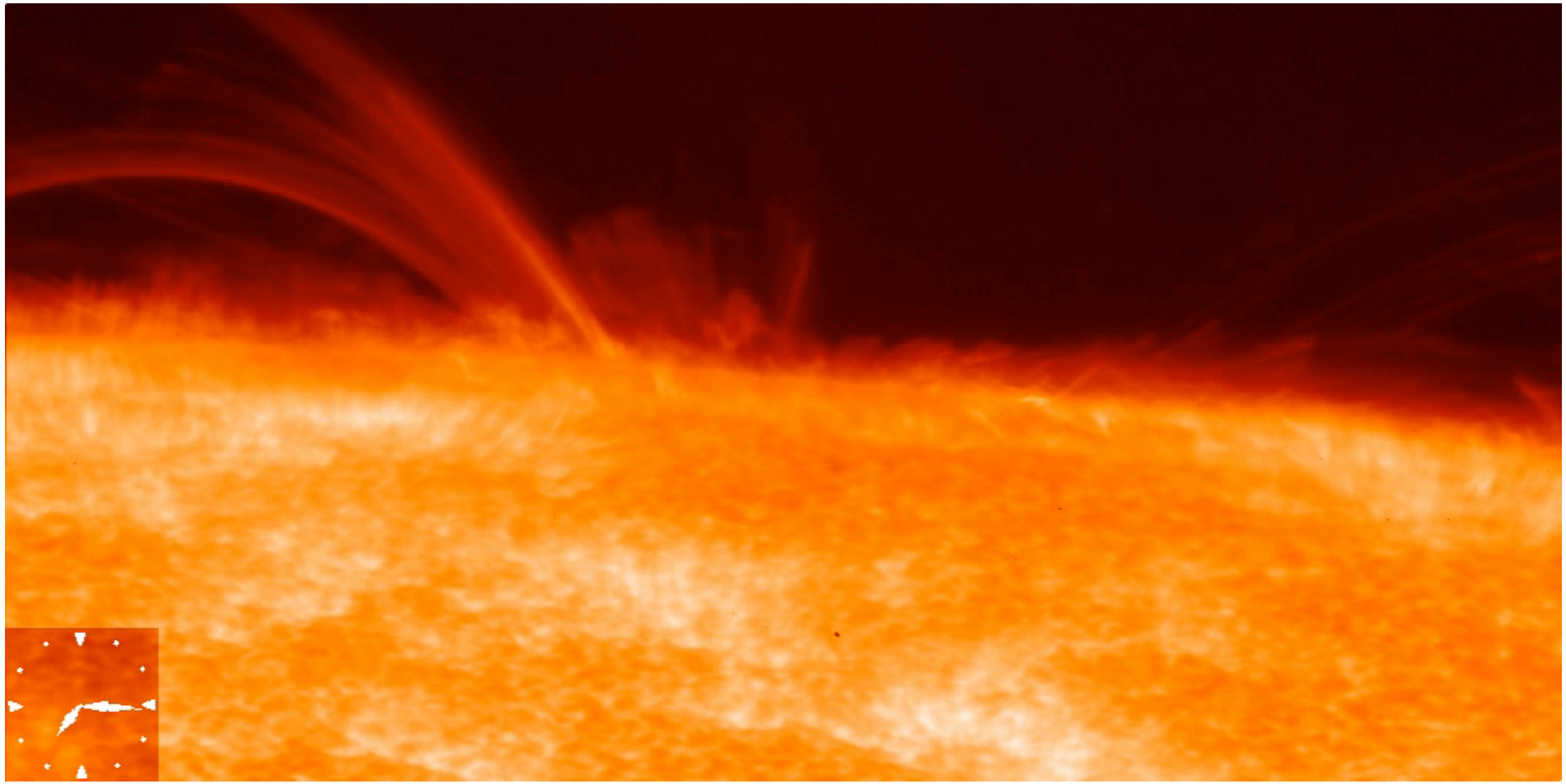
UCL Department of Space and Climate Physics
Mullard Space Science Laboratory

Solar Flares: the observations

Louise K Harra



Our ‘Understanding’ of Solar Flares

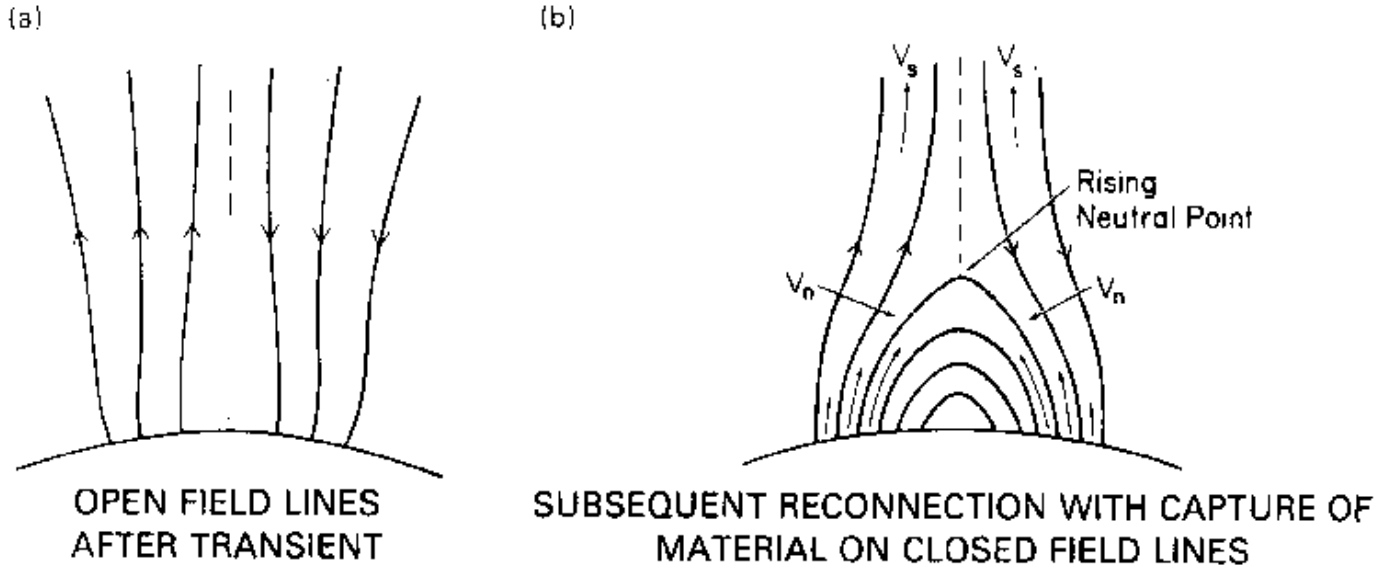
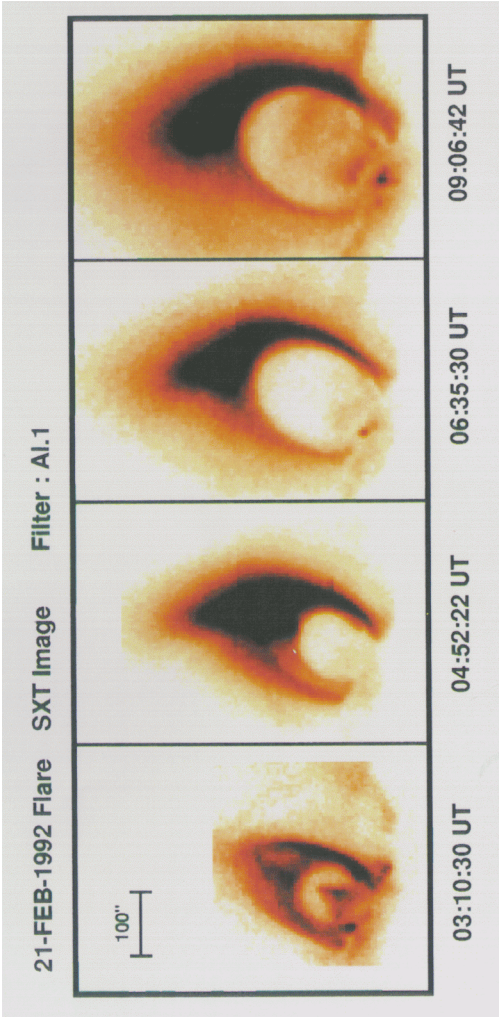
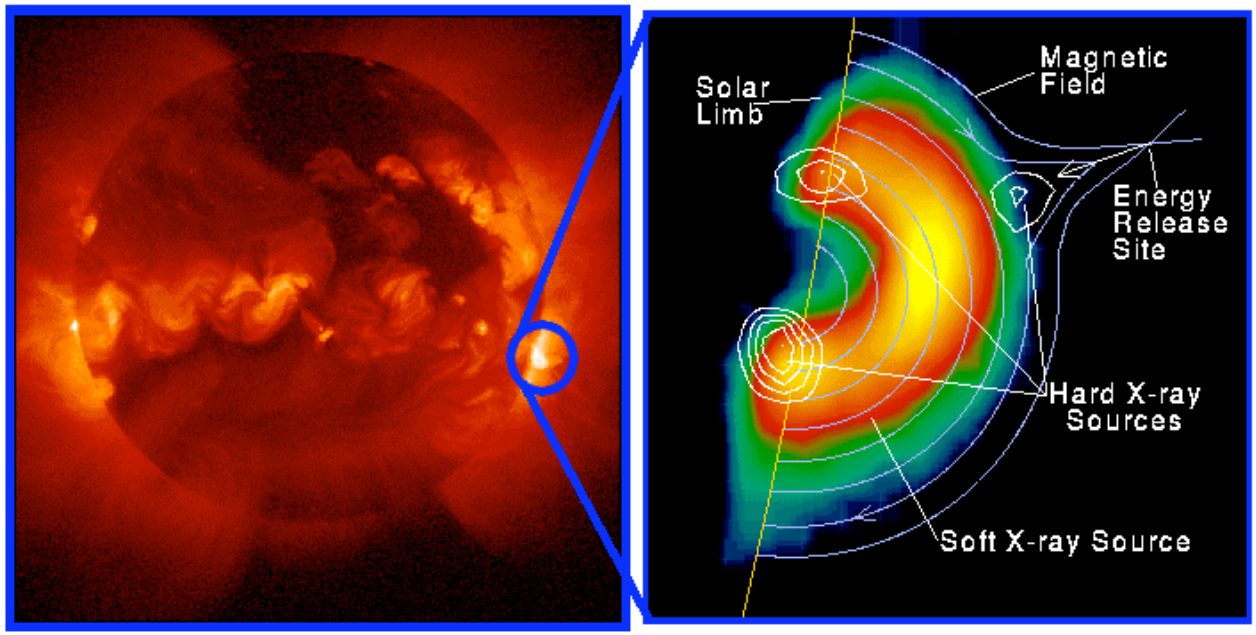


Fig. 9.5 Kopp-Pneuman model. (a) Initially open field configuration; (b) reconnection produces rising-loop configuration.

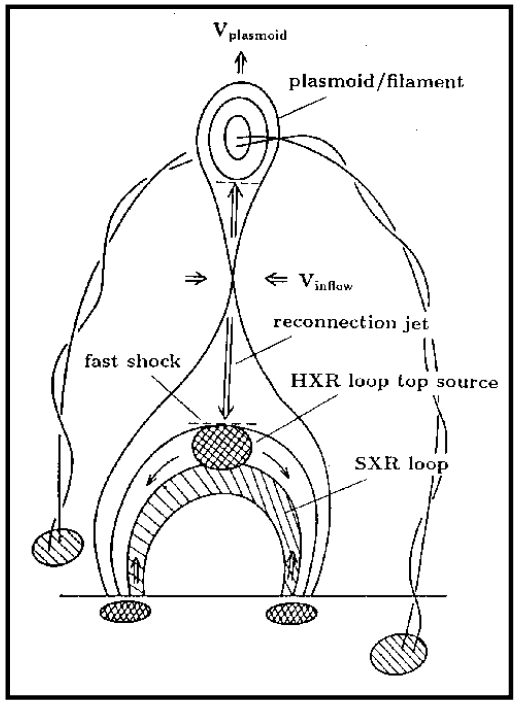


More evidence of reconnection…



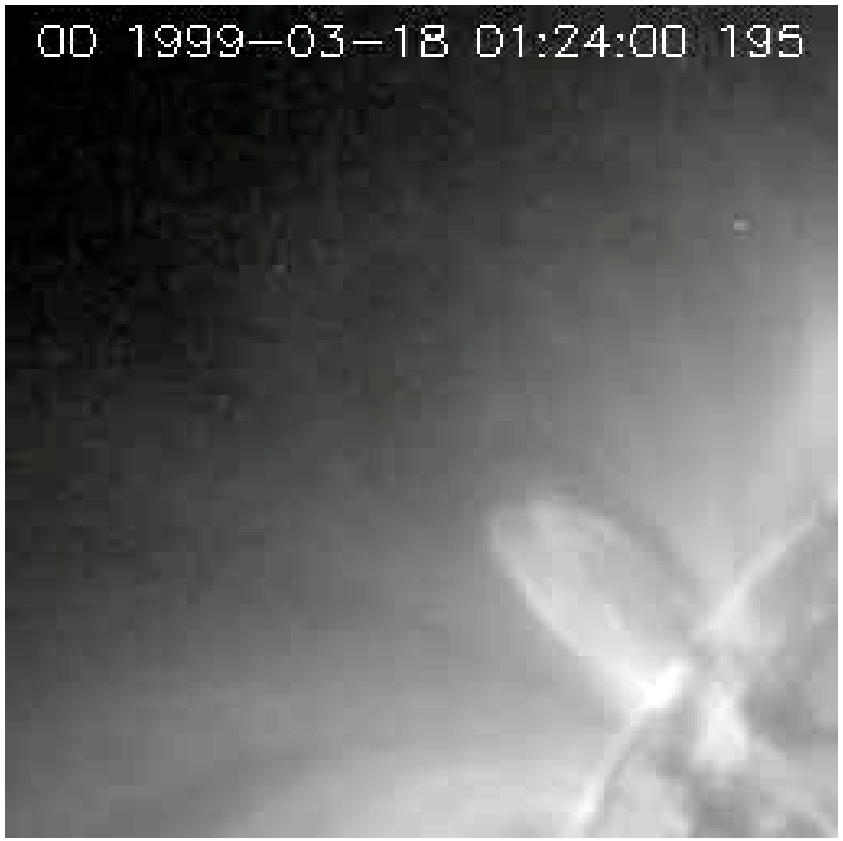
Yohkoh X-ray Image of a Solar Flare, Combined Image in Soft X-rays (left) and Soft X-rays with Hard X-ray Contours (right). Jan 13, 1992.

Masuda et al, 1994

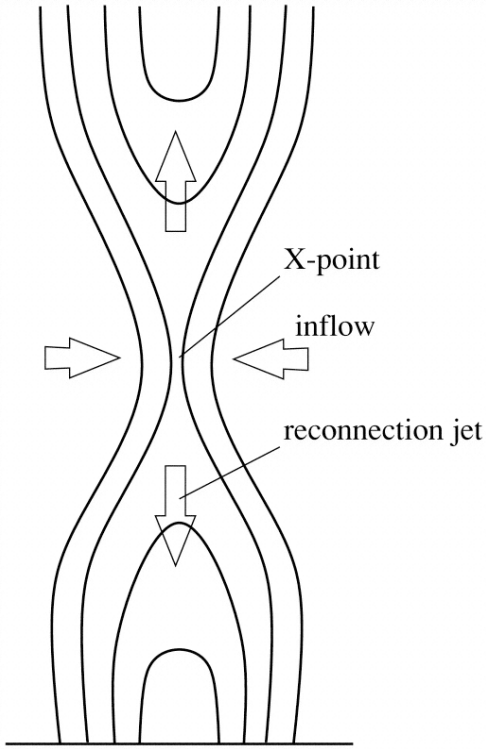


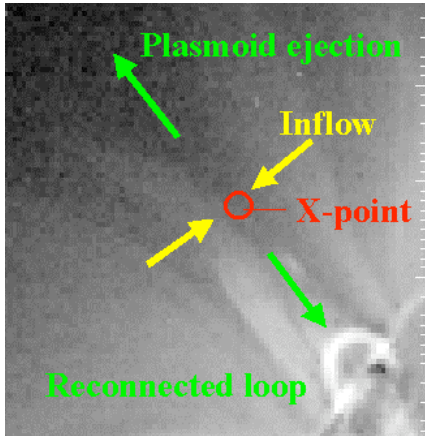
Shibata, 1998

Reconnection inflow…



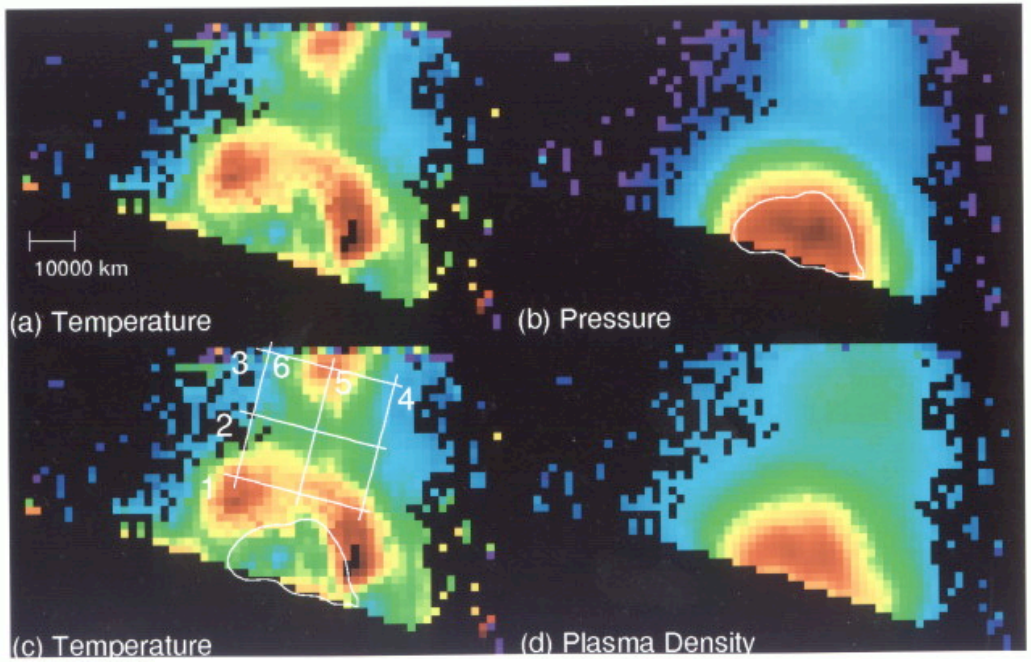
Yokoyama et al.

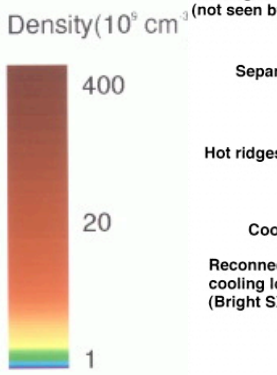


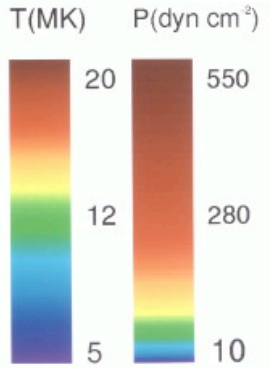


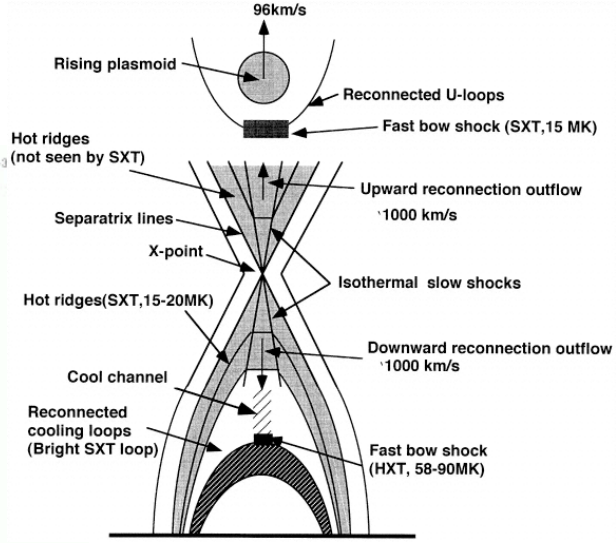
Observation of the upward moving plasmoid

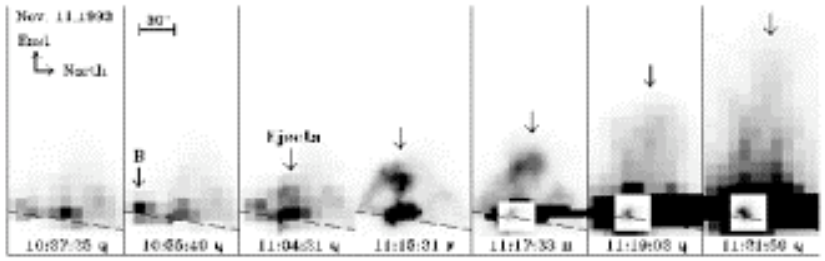
Tsuneta, 1997



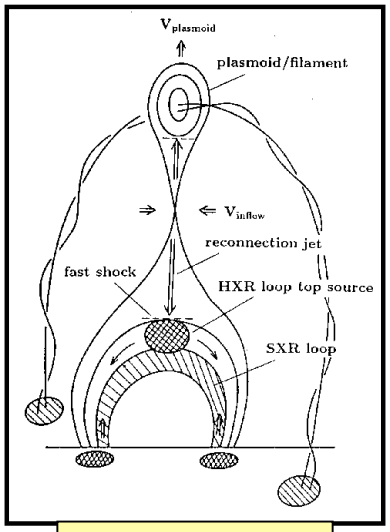








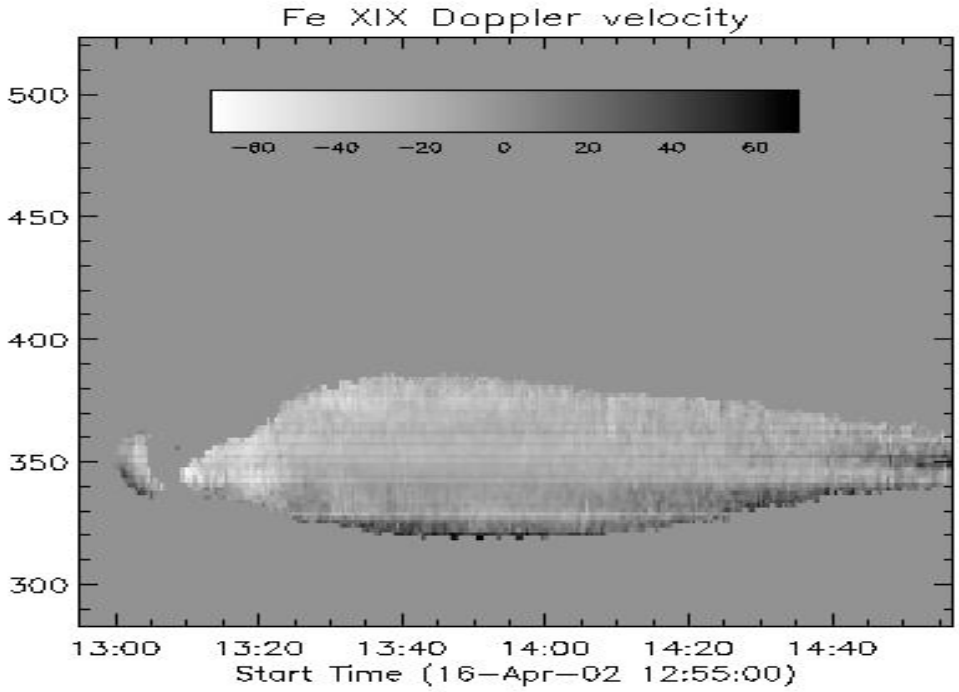
Plasmoid ejection (Shibata et al, 1995; Ohyama et al,1997



Shibata, 1998

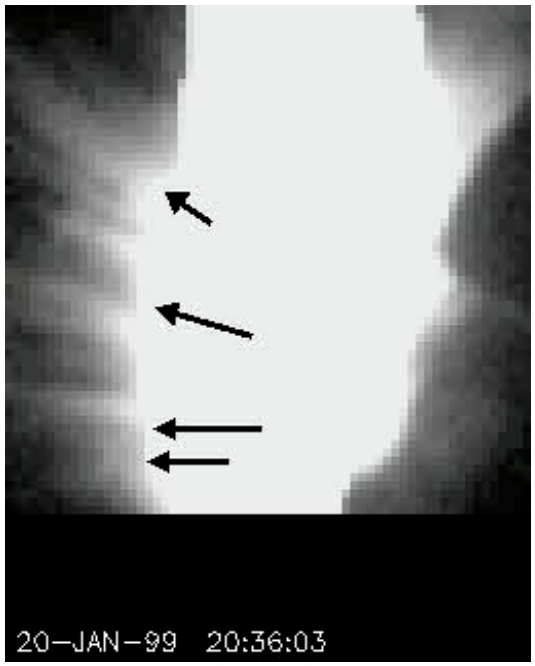
Evidence of erupting flux rope

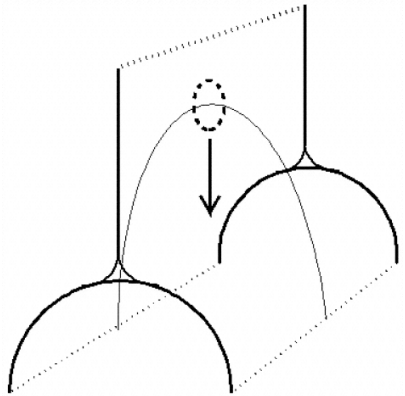
Goff et al., 2005 found evidence for a flux rope leaving the Sun followed by a flare. The flux rope shows evidence of twist



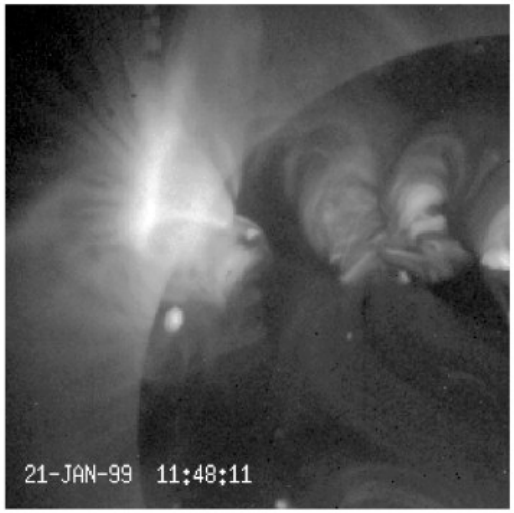
Reconnection downflows observed

v ≈ 90-500 km/s



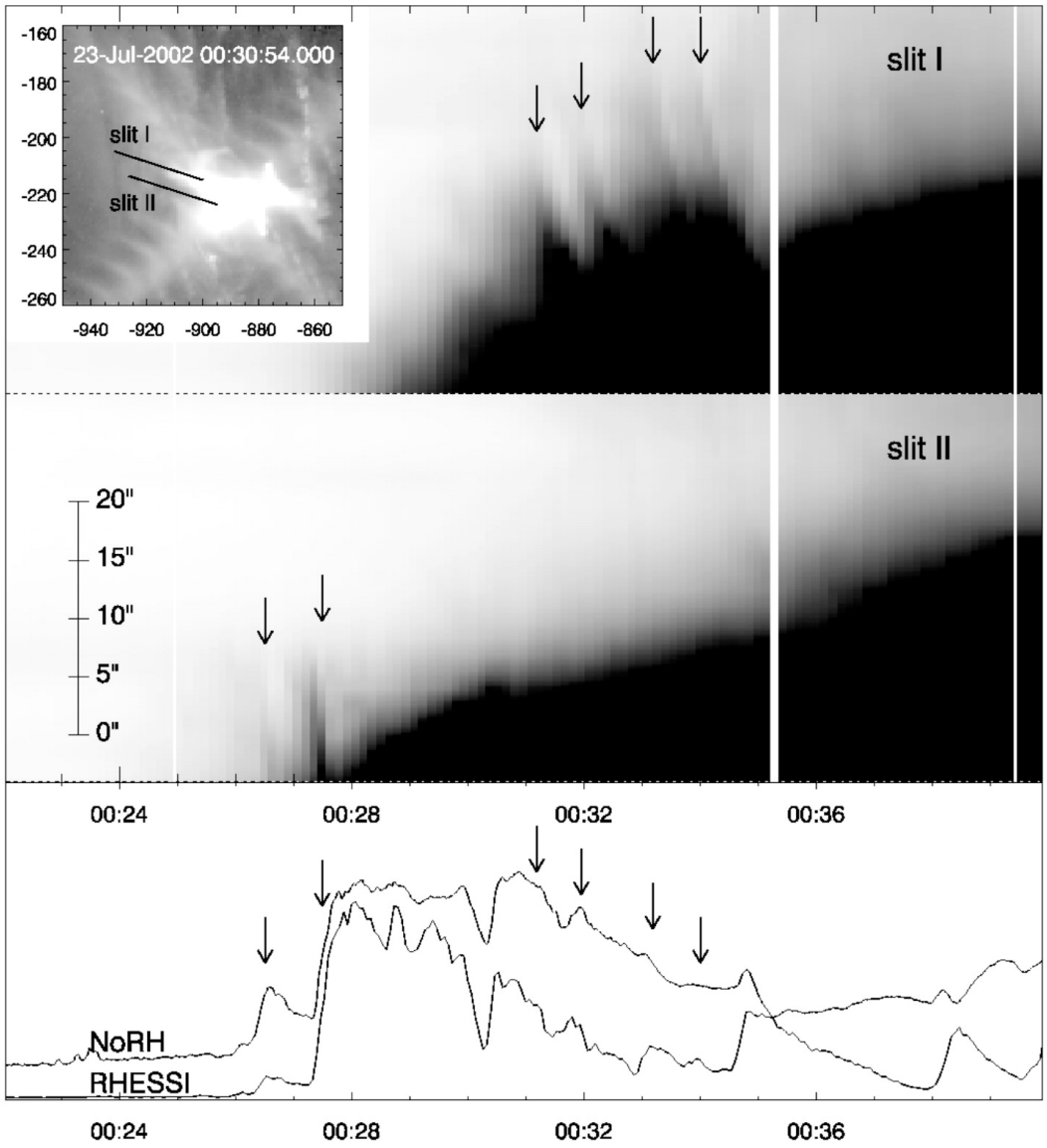


- evidence for shrinking back of field lines after reconnection
- patchy & intermittent reconnection process

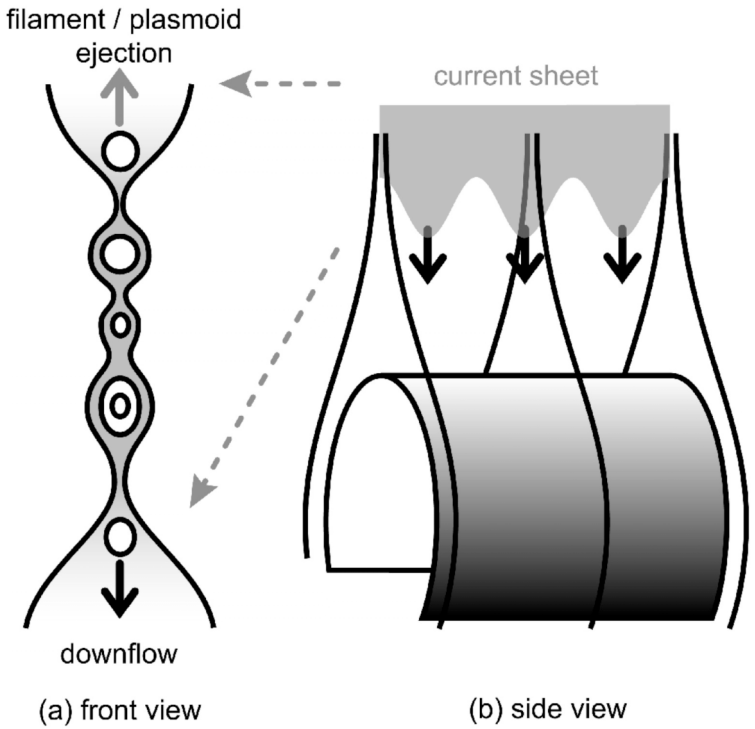


McKenzie & Hudson, 1999; McKenzie, 2000

22 such examples have been found in Yohkoh/SXT data

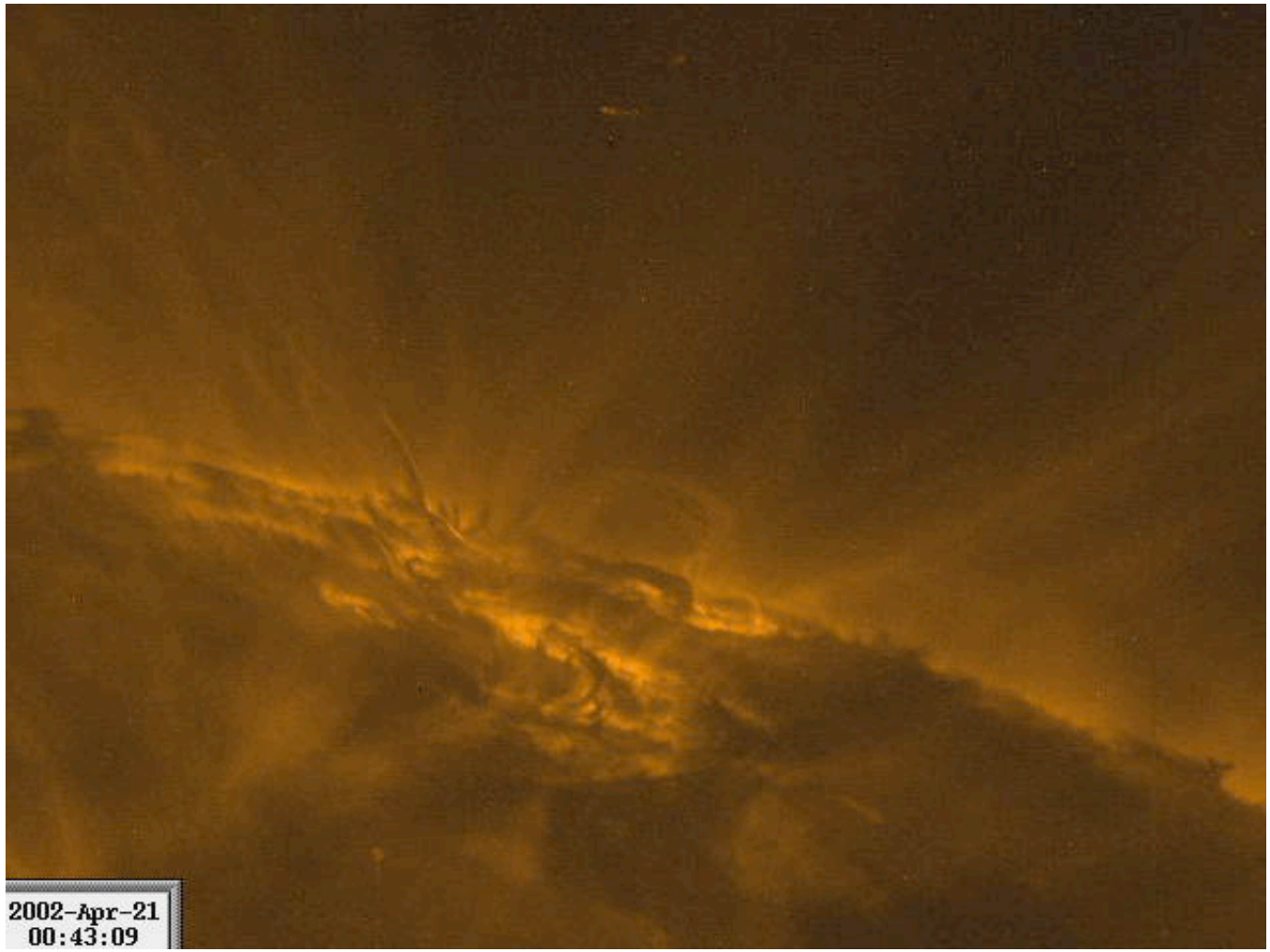


Asai et al., 2004



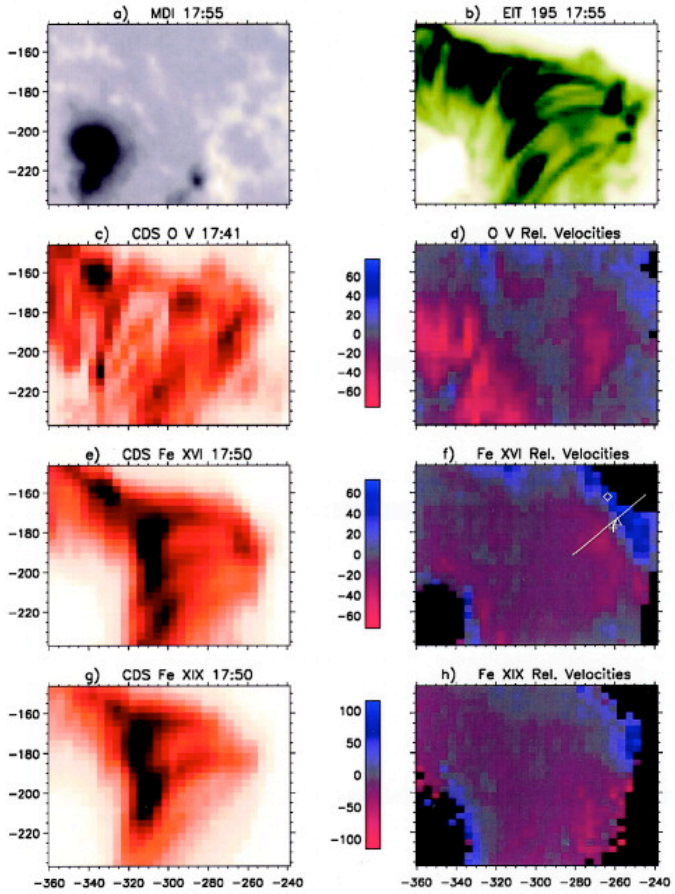
Start of these downflows are associated with non-thermal emission and microwave bursts!

Downflow in action

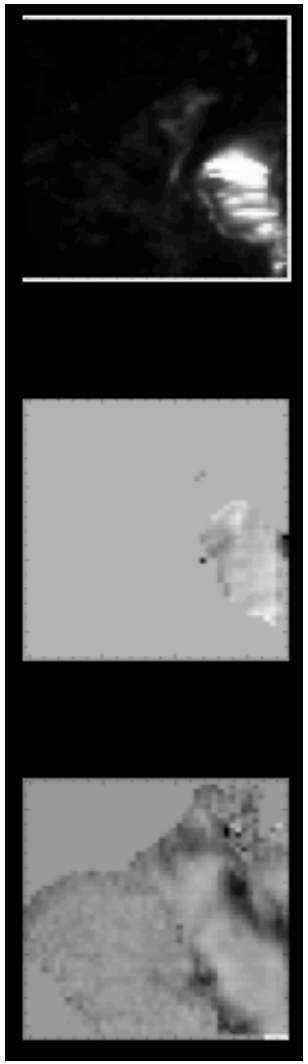


Chromospheric upflows and downflows:

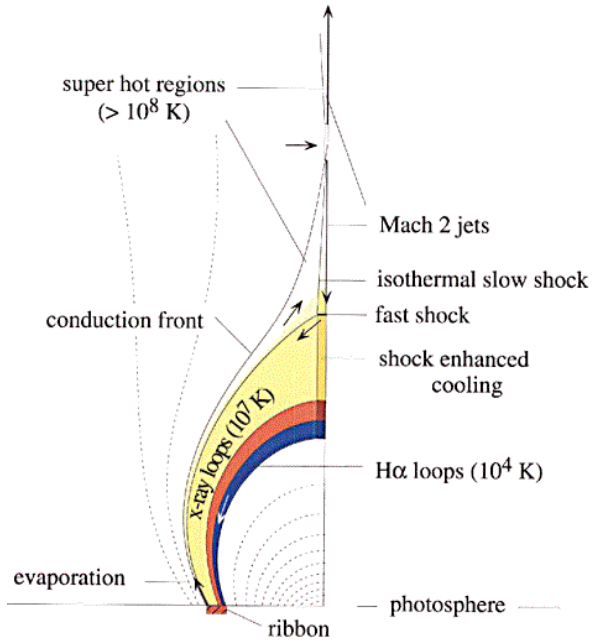
SOHO/CDS



Czaykowska et al (1999)



Harra et al (2005)



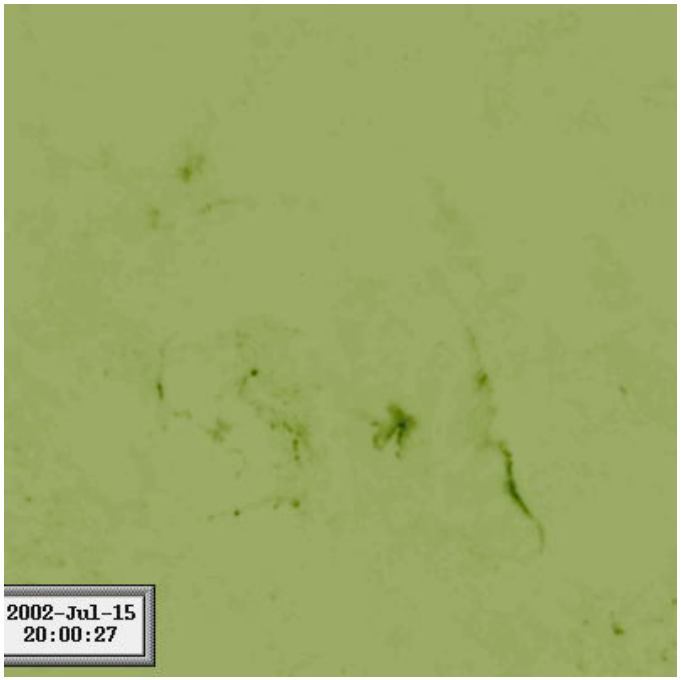
Forbes, 2002

Blueshifts along outer part of arcade (chrom. evaporation) redshifts along the inner part (cooling downflows)

Explaining evaporation

- Upflow velocities are lower than predicted from models (e.g. Brosius and Phillips (2004), Harra et al. (2005)).
- This has been explained by Warren and Doschek (2005) who modelled a succession of independently heated threads - the emission of the strongly blue-shifted thread is masked by the emission from other threads.

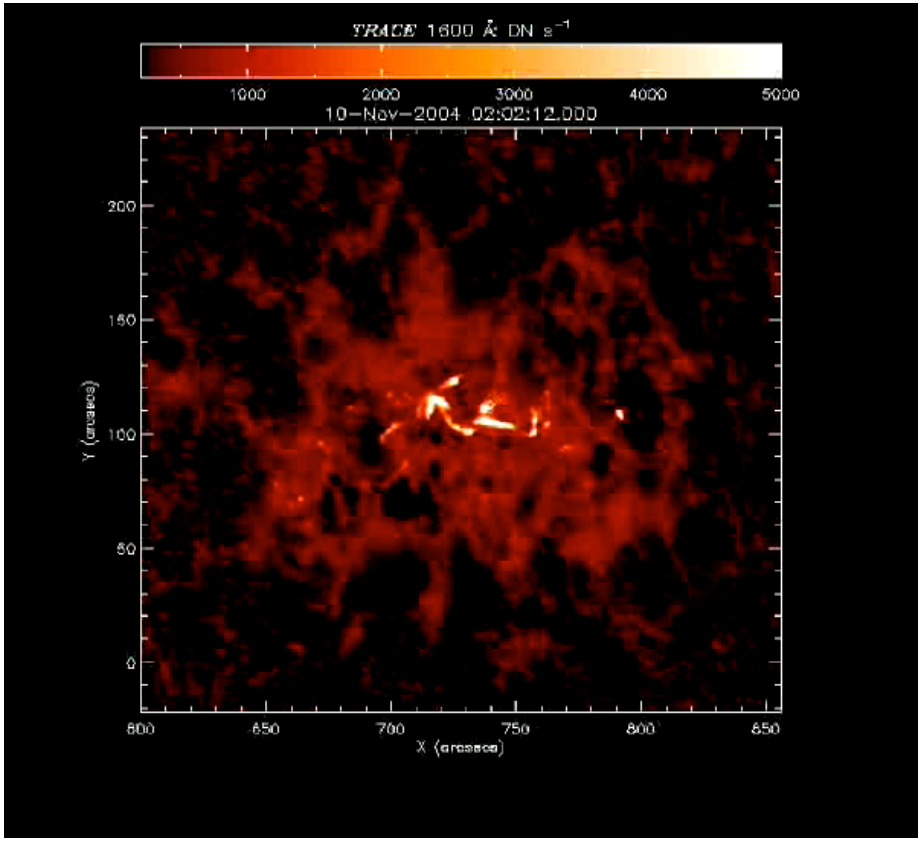
But??



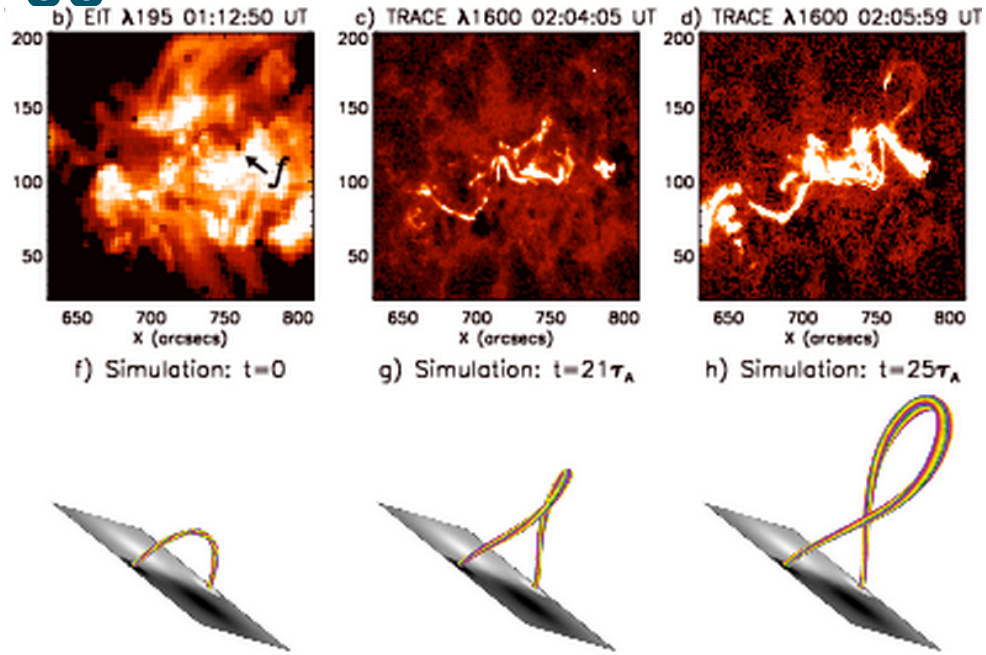
- Life is more complicated!
- We have seen evidence of inflow only “once”! Even that is in dispute…
- We occasionally see outflow.
- The velocities predicted from models are generally higher than observed.
- There are often bright loop tops in soft X-rays.
- Flare loops often show evidence of high twist.

And we cannot predict what exactly triggers a flare!

Can a kink instability be a trigger?

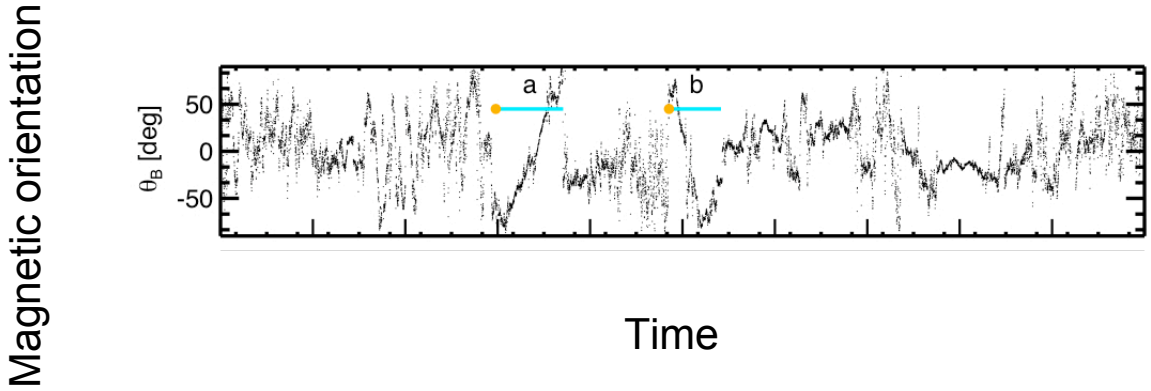


Williams et al. (2005)



This is the process where twist is abruptly converted into writhe.

Two magnetic clouds produced from the same active region - in opposite directions! Can twist be added between flares??



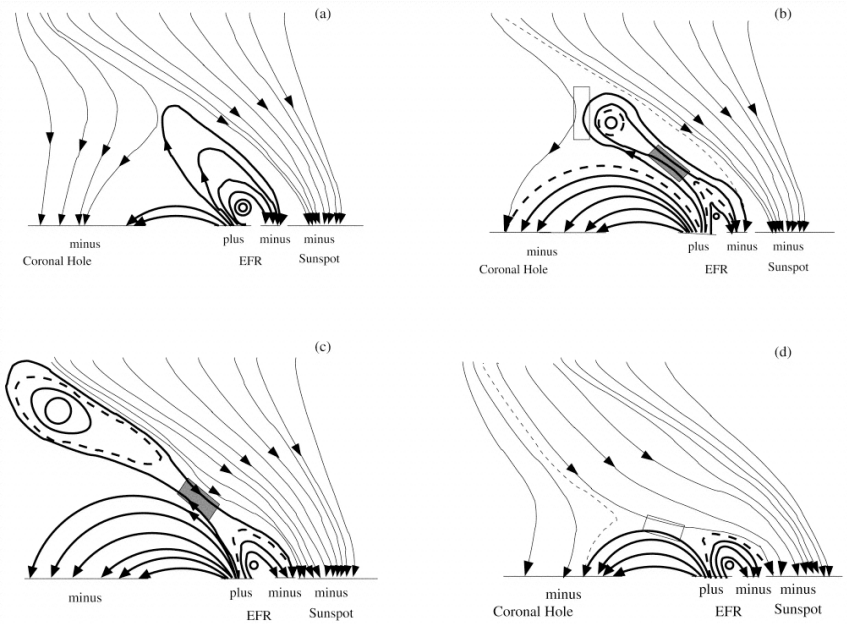
The flare related to these clouds were from the same active region with the same magnetic orientation - one explanation is that a twist of 160^o built up between events!

(Harra et al., 2007)

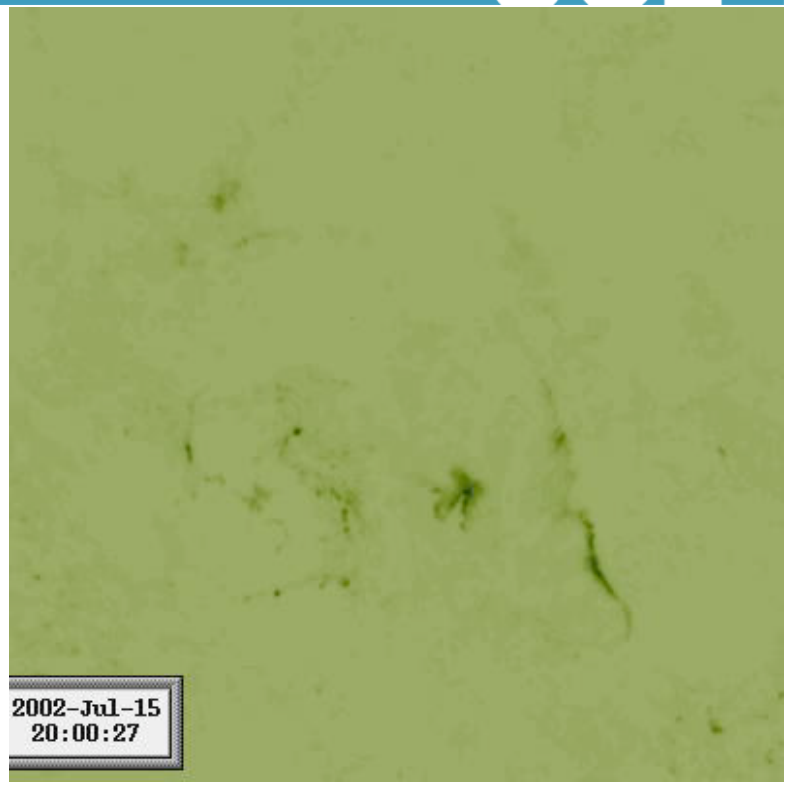
More observational evidence for kink instability

- Leka et al. (2005) determined that there is enough twist for the kink instability to be a trigger mechanism.
- For kink instability the twist and writhe must have the same sign. Rust and LaBonte (2005) found this to be the case.
- They also found that ‘sigmoids’ have exactly the same shape of a kink in stable equilibrium.

The Breakout model…



Sterling and Moore



Gary and Moore., 2004

- Some evidence has been found to support the breakout model - brightenings away from the main flare site are seen - and flows in the transition region (Harra et al. 2005).

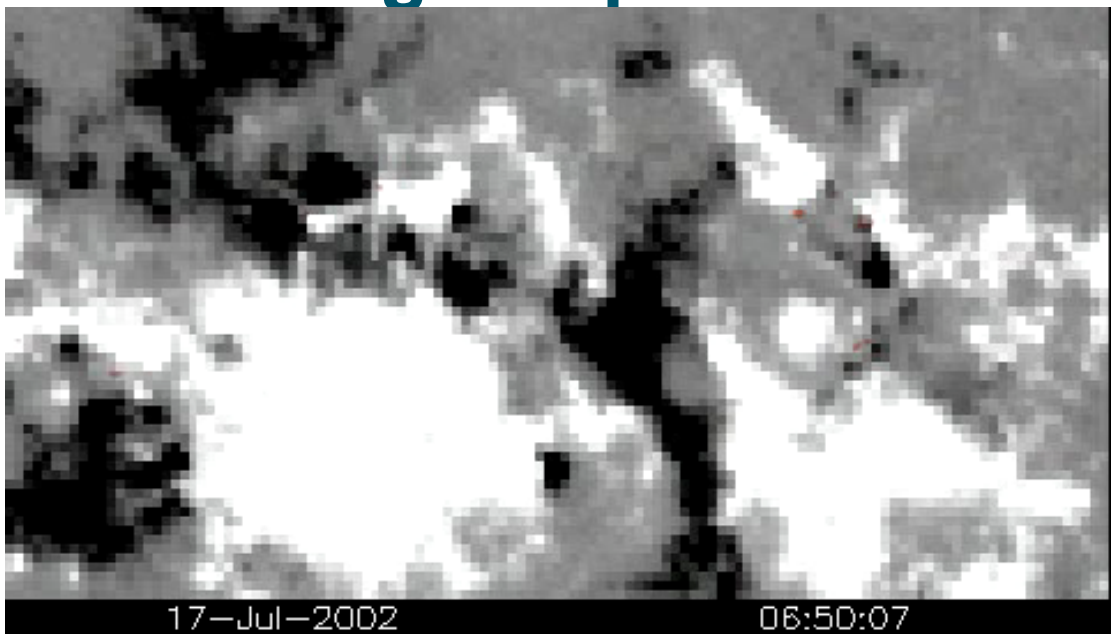
Loop top sources

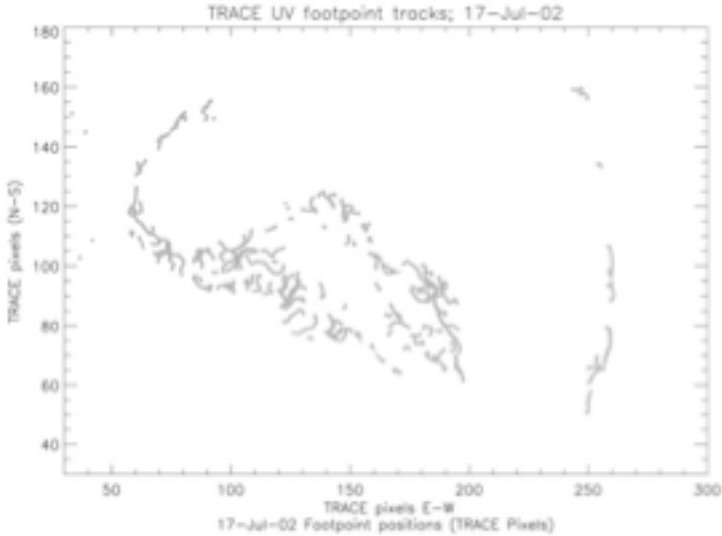
- RHESSI results show evidence for HXR loop-top source moving downward before moving upward.
- The downward motion lasts 2-4 mins (Sui, Holman and Dennis, 2004).
- Two main explanations;
  - Relaxation of the newly reconnected field lines from a sharp cusp to a more semicircular shape
  - Reconnection changing from slow X-point to much faster Petschek-type.

Reconnection rate

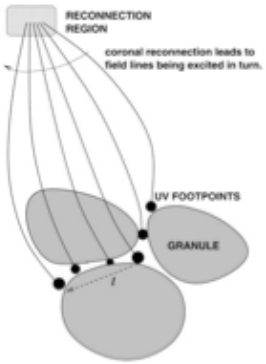
- In a 2 ribbon flare, the expansion rate can be used to determine the reconnection rate.
- Jing et al. (2005) found a strong correlation between the reconnection rate and the acceleration of erupting filaments.
- Fletcher, Pollock and Potts (2004) found that tracking UV flare footpoints can also provide a measure of the coronal reconnection rate.

Tracking footpoints

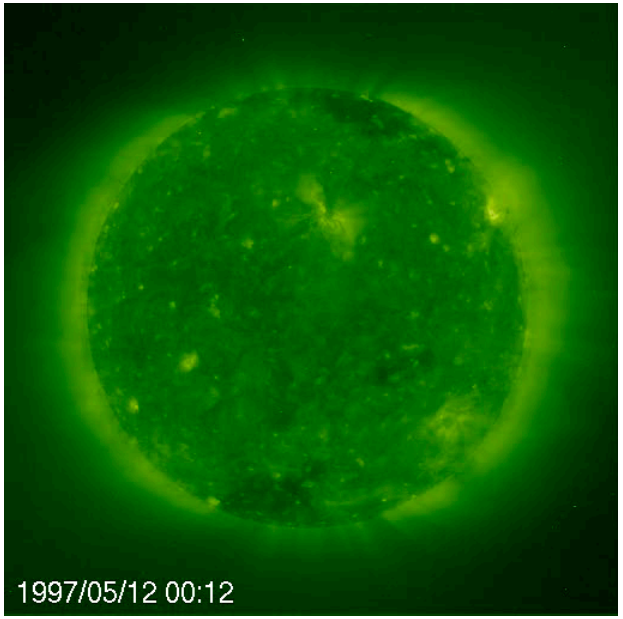


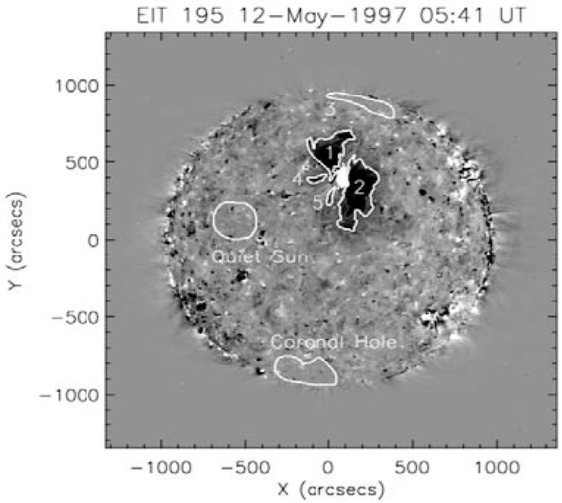


There is drift in footpoint position as well as footpoint meandering Fletcher, Pollock and Potts (2004)

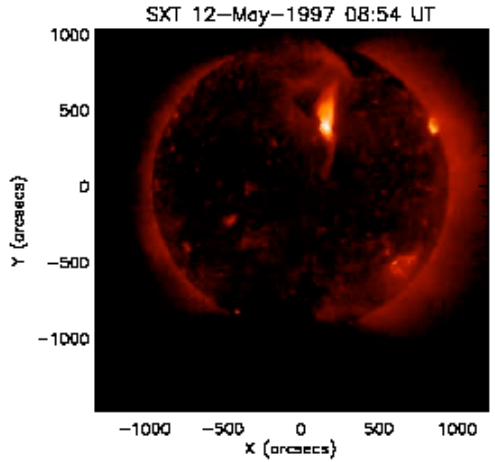


Flares: how they affect their environment

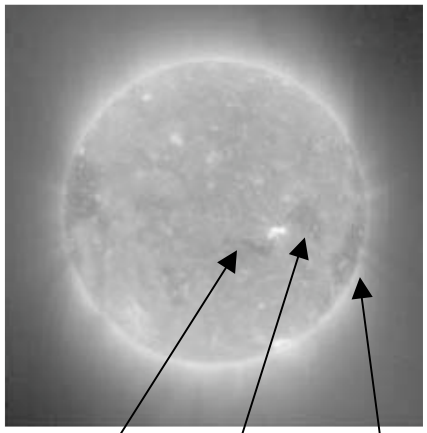


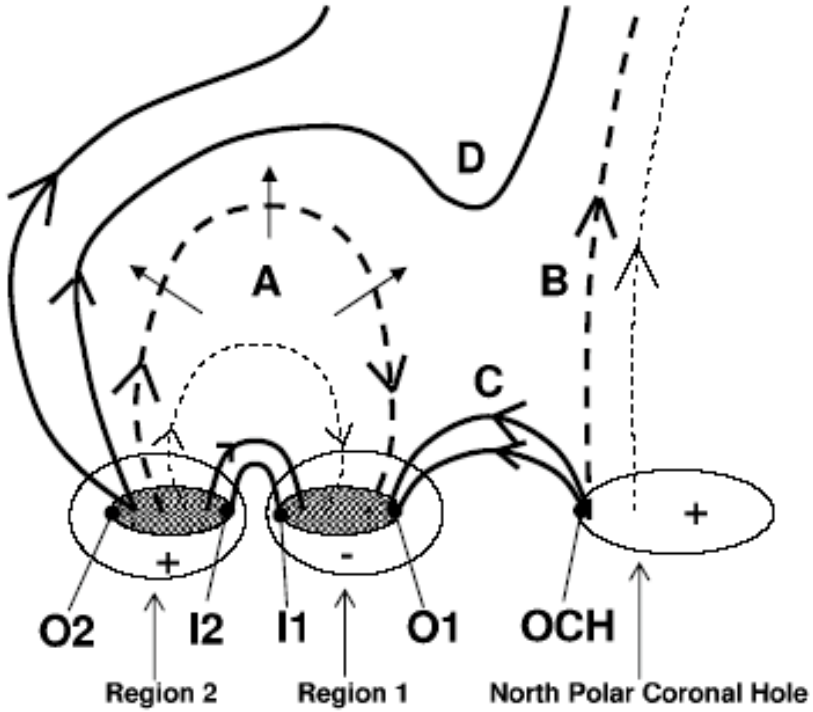


- Small flare took place
- Strong coronal wave signature
- Brightening along (& shrinkage of) north polar coronal hole boundary
- Filament eruption
- Full Halo CME
- Associated magnetic cloud reaches Earth 15th May 1997



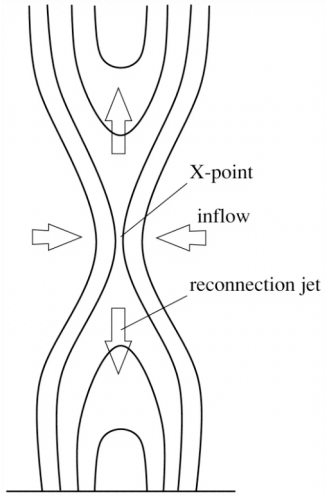
Flare loops interacting with coronal holes.





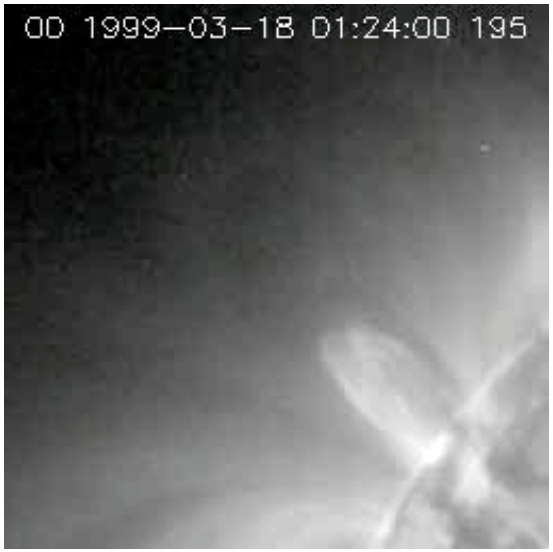
Dashed lines represent the pre-event magnetic structure and the *solid lines* the post-event magnetic structure. The *hashed regions* represent the main dimming regions.

Attrill et al., 2006



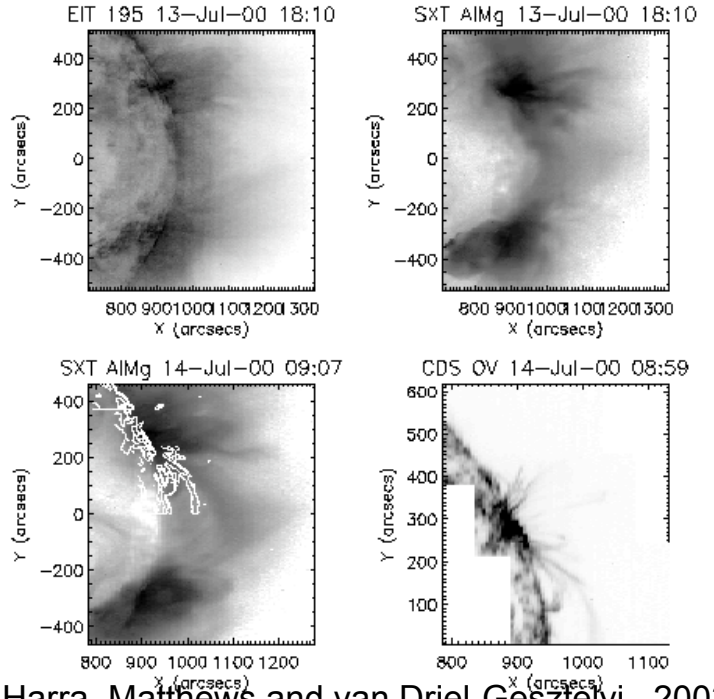
Are there similarities between normal flares and trans-equatorial loops?

‘Normal’ active region flare



Yokoyama et al., 2000

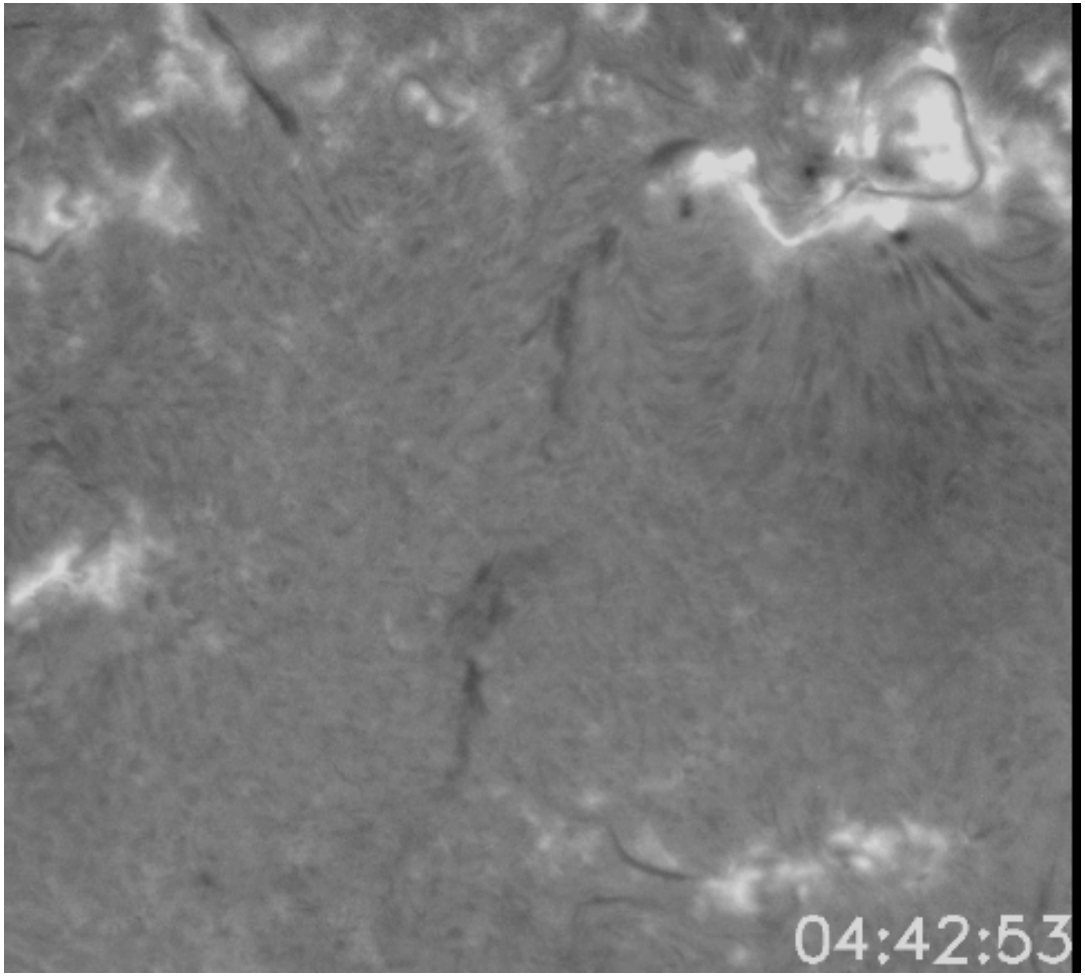
Trans-equatorial flare?



Harra, Matthews and van Driel-Gesztelyi., 2003

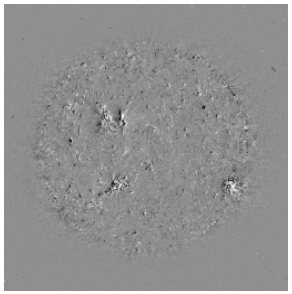
- ✓Hotter coronal emission shows heated plasma following reconnection
- ✓Transition region/chromospheric emission shows cooling plasma

Trans-equatorial filaments



Wang et al.(2006) show that the Bastille day flare is not isolated to the active region. Activation of the huge trans-eq filament precedes the simultaneous filament eruption and flare in the source active region.

The global impact…



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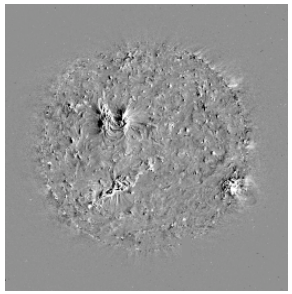
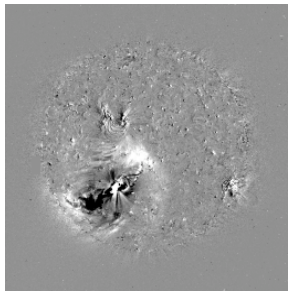


14:00



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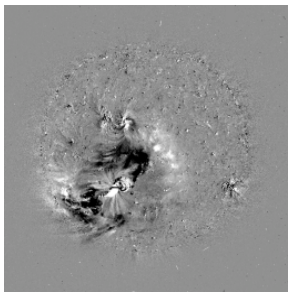

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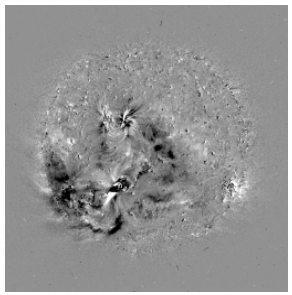

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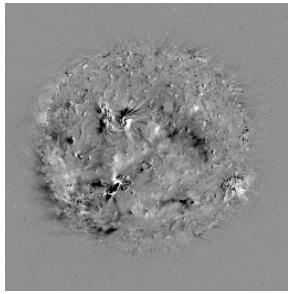

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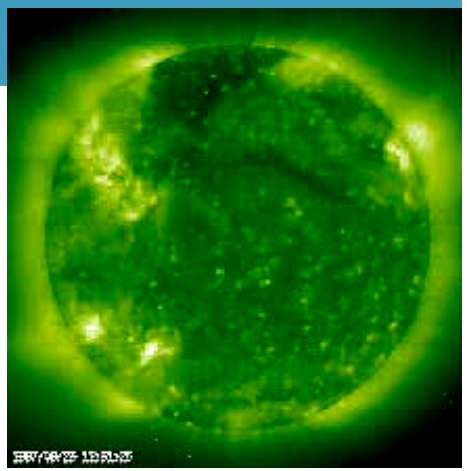
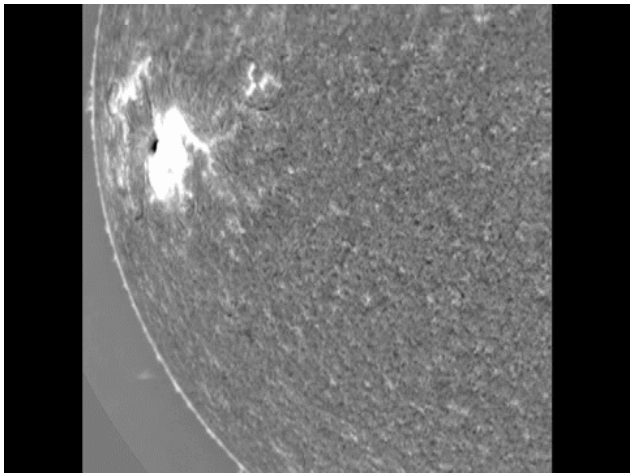




- Fast mode shock wave related to a flare (e.g Uchida's work, Warmuth et al. (2004)?
- Opening of field lines related to a CME (e.g. Delannee and Aulanier,)?

To date…

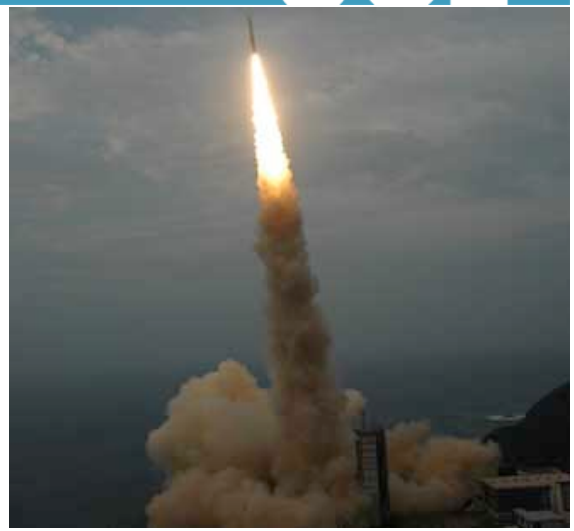
Flare are complex - few show all features expected from the ‘standard’ model.

They can also interact on a larger scale.

They can be made up of highly twisted flux tubes.

We are unsure of the trigger mechanism.

The future…

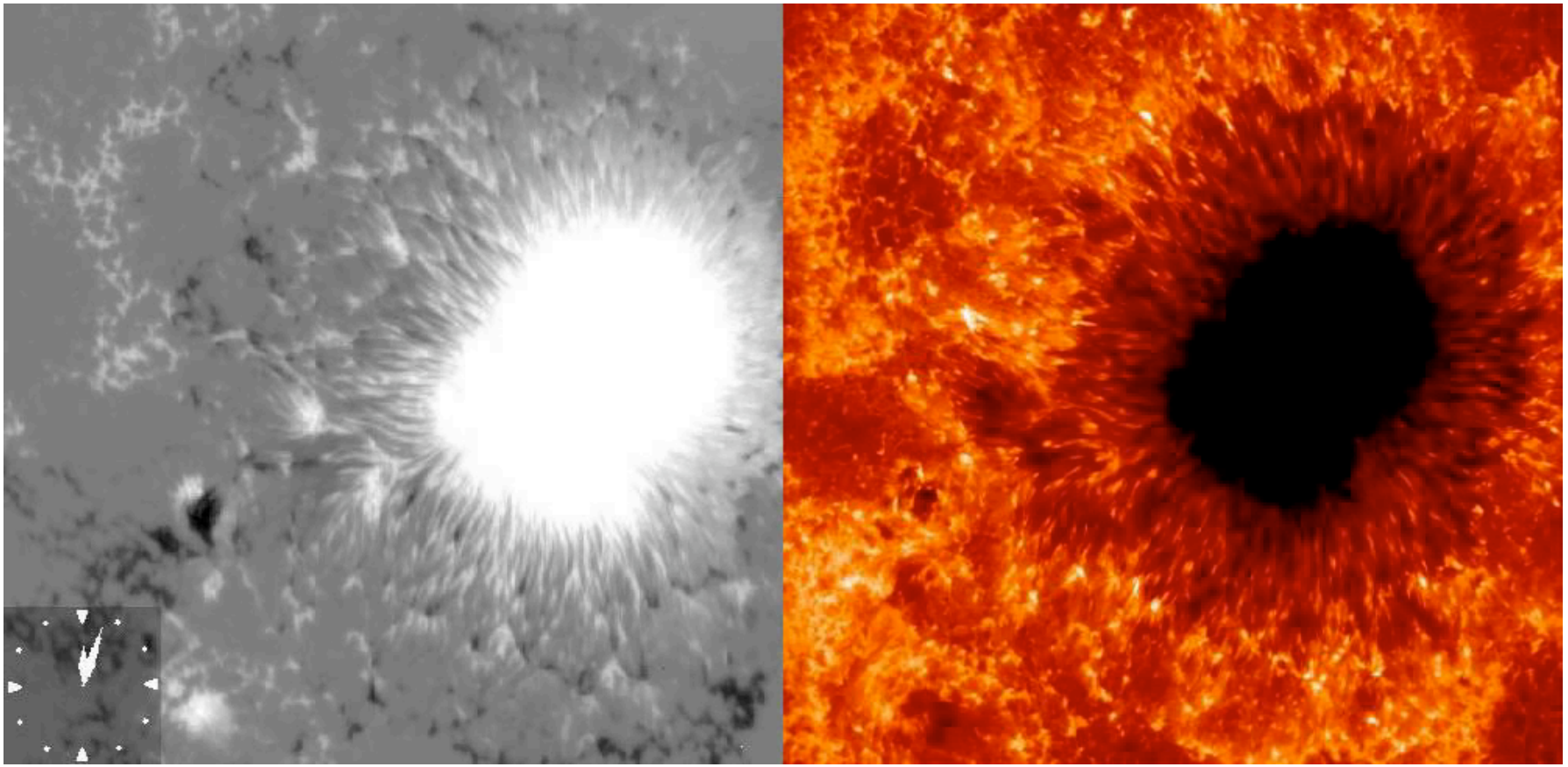


- Hinode was launched in Sep this year. We are just starting the first science ops.
- It has 3 instruments:
  - Solar Optical Telescope
  - X-ray Telescope
  - EUV Imaging Telescope

  All designed to understand flares further…
- STEREO launch followed and will start taking data very soon!

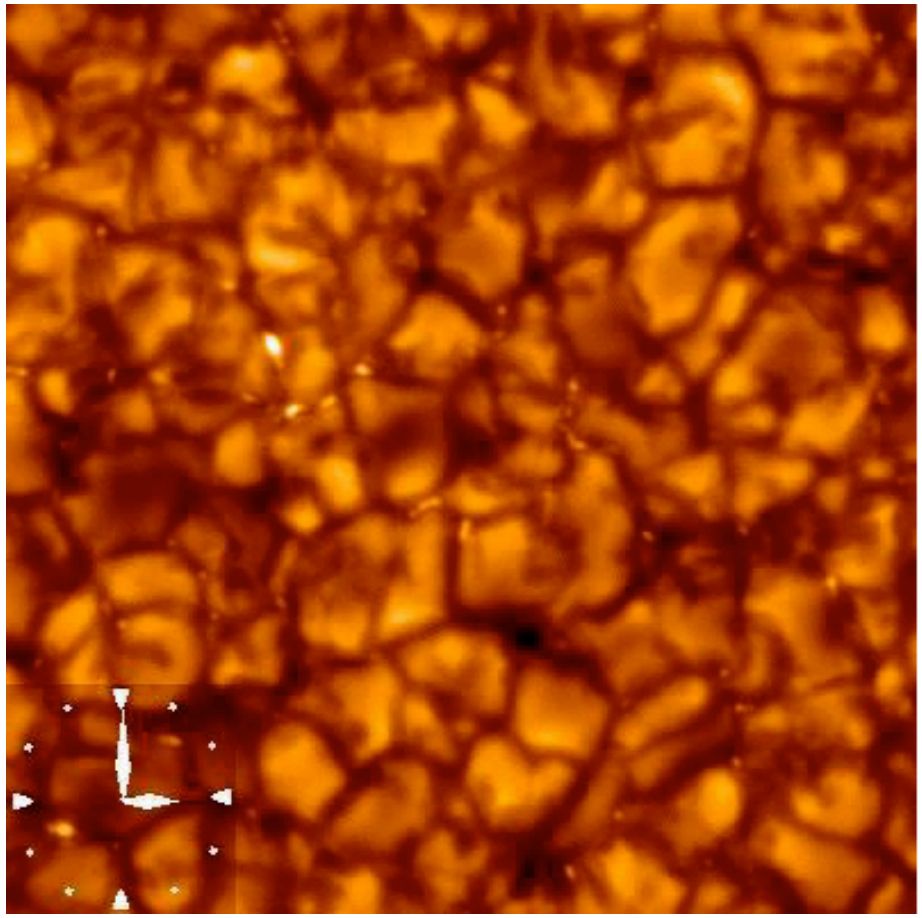
SOT images of a sunspot

magnetogram Ca II H

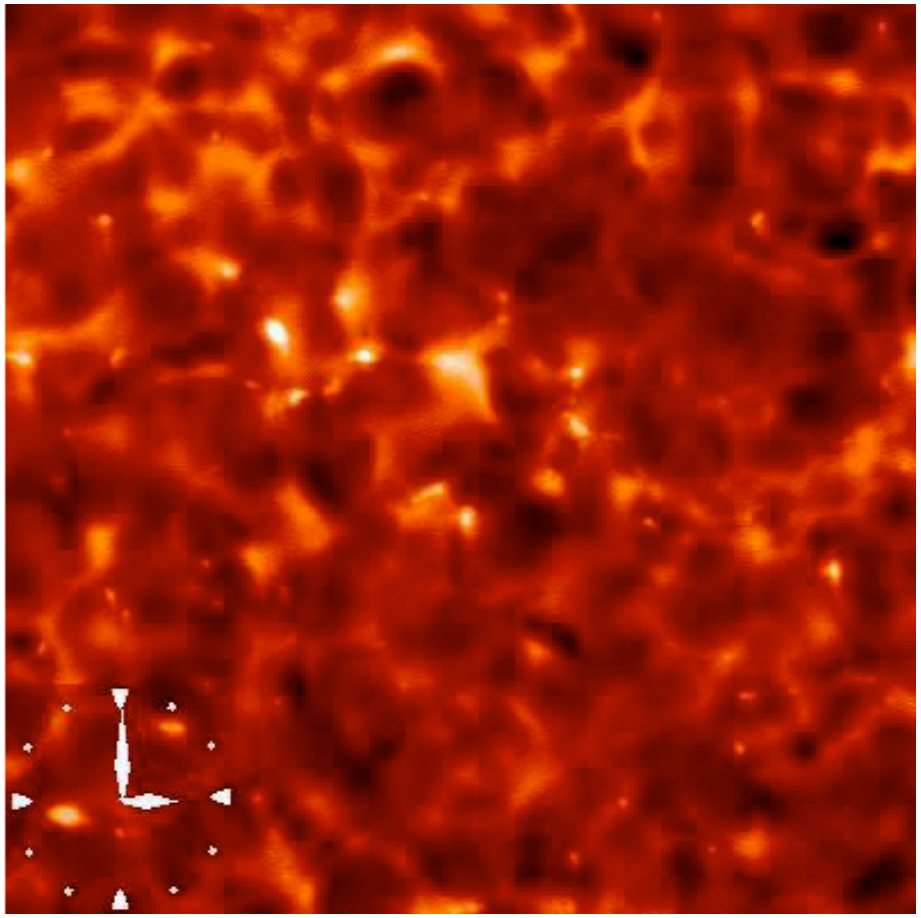


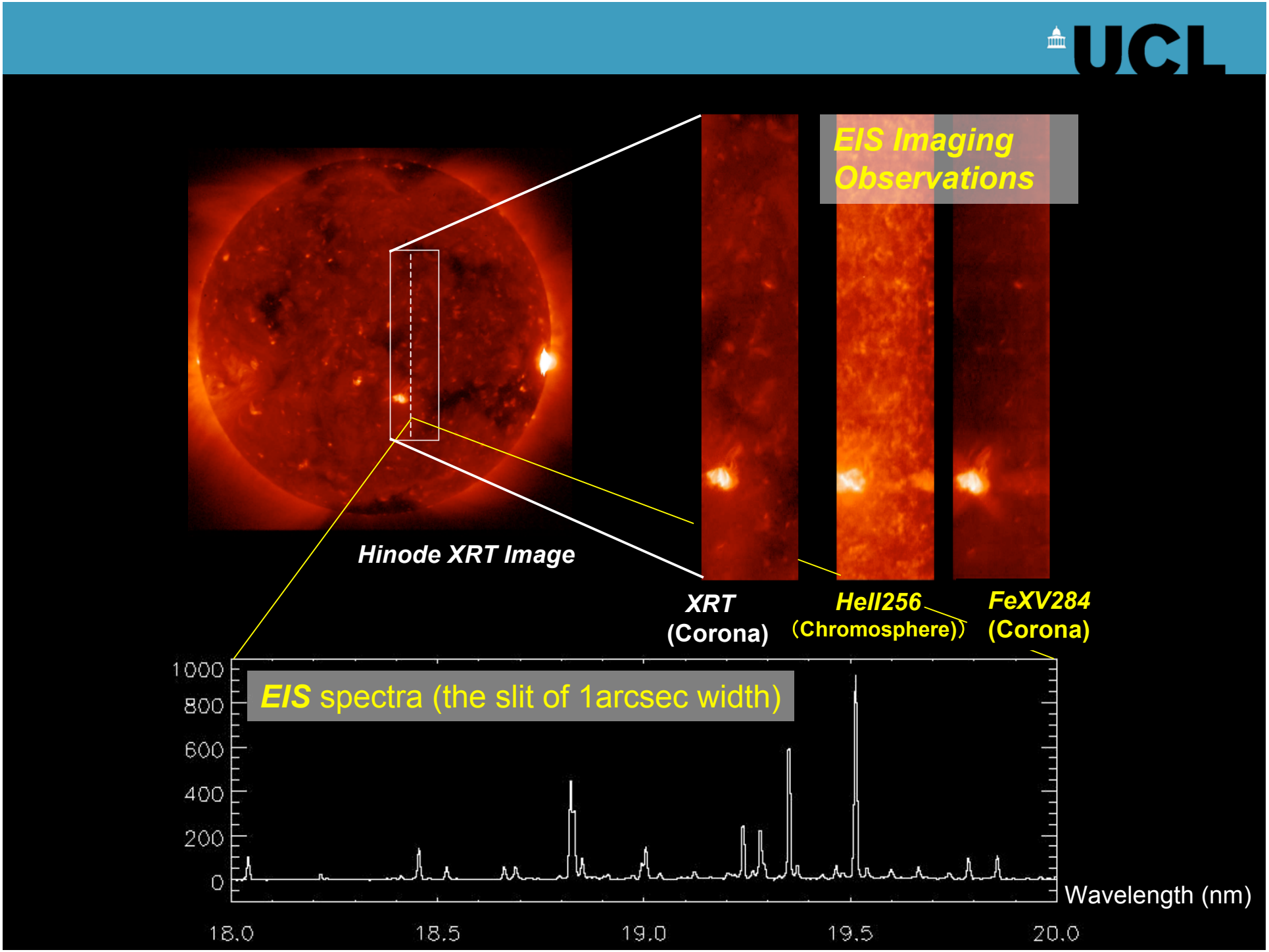
Hinode movie of granules

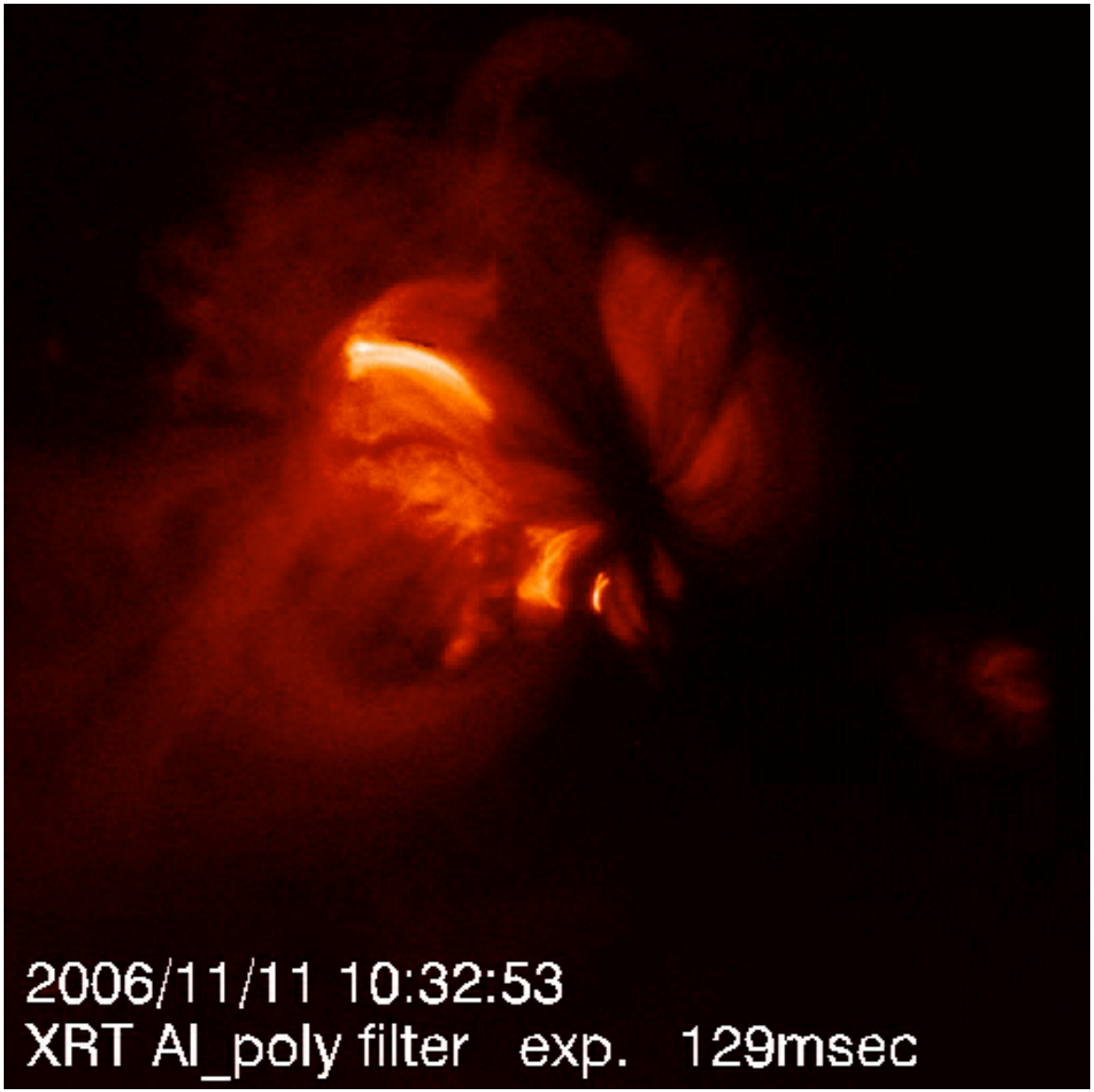
G-band



Ca II H movie



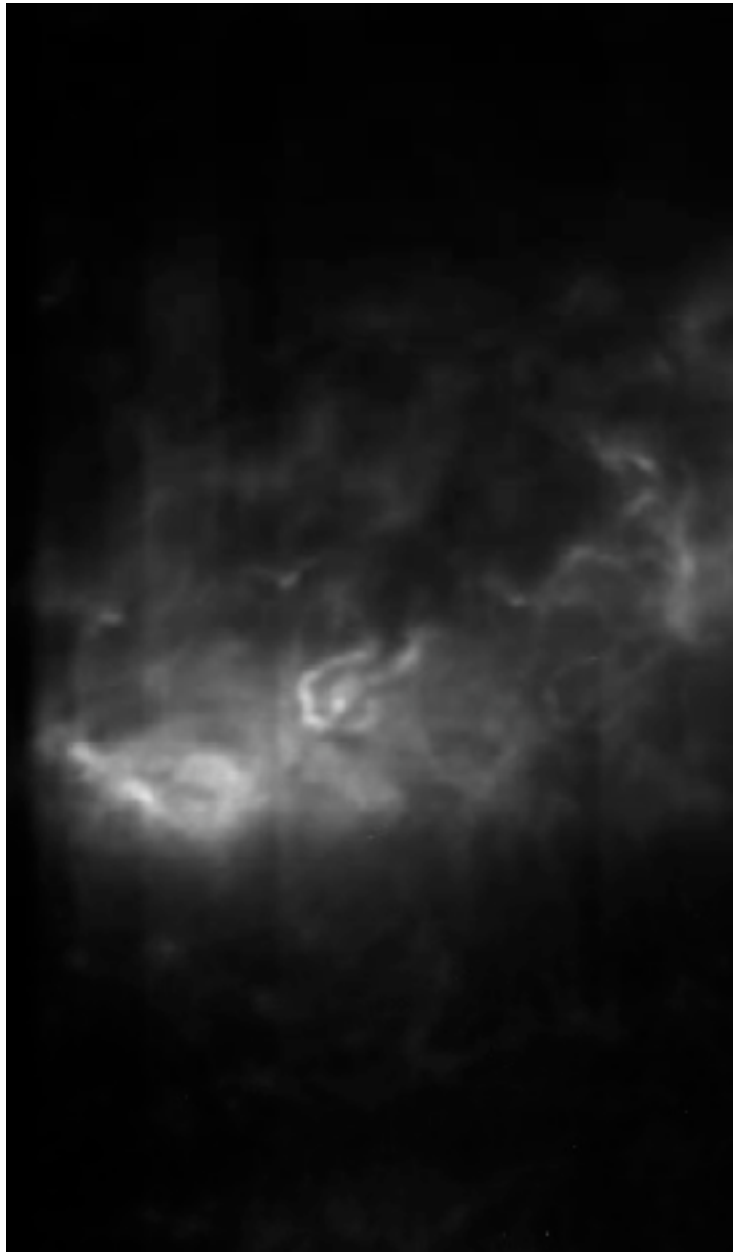

EIS Imaging Observations
Hinode XRT Image
XRT (Corona)
HeII256 (Chromosphere)
FeXV284 (Corona)
EIS spectra (the slit of 1arcsec width)
1000
800
600
400
200
0
18.0
18.5
19.0
19.5
20.0
Wavelength (nm)

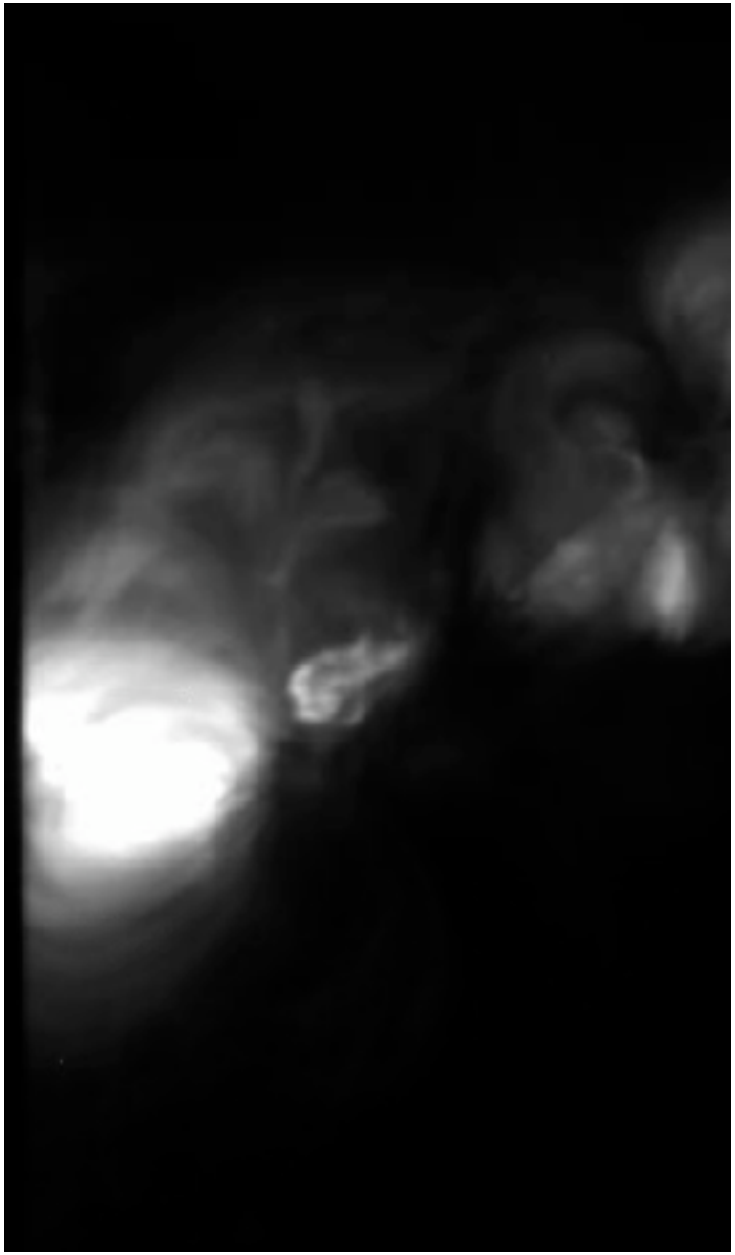

2006/11/11 10:32:53
XRT Al_poly filter exp. 129msec

EIS Fe XV - evidence of downflows?

Our view of flares WILL change in the next couple of years!

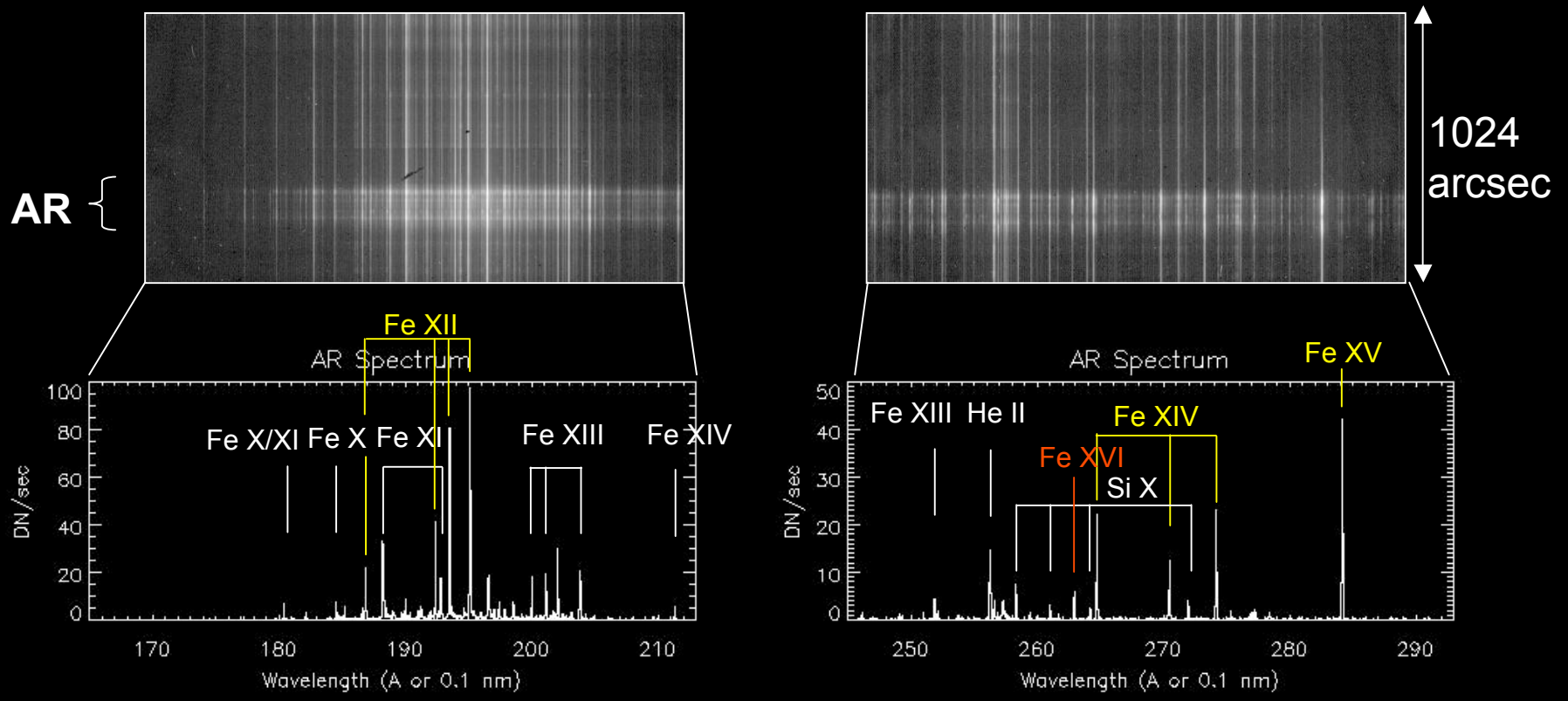

UCL





EIS Slit Observation

- Slit of 1arcsec width -



2006 Nov 04 ~11:50 UT: 160 sec exposure