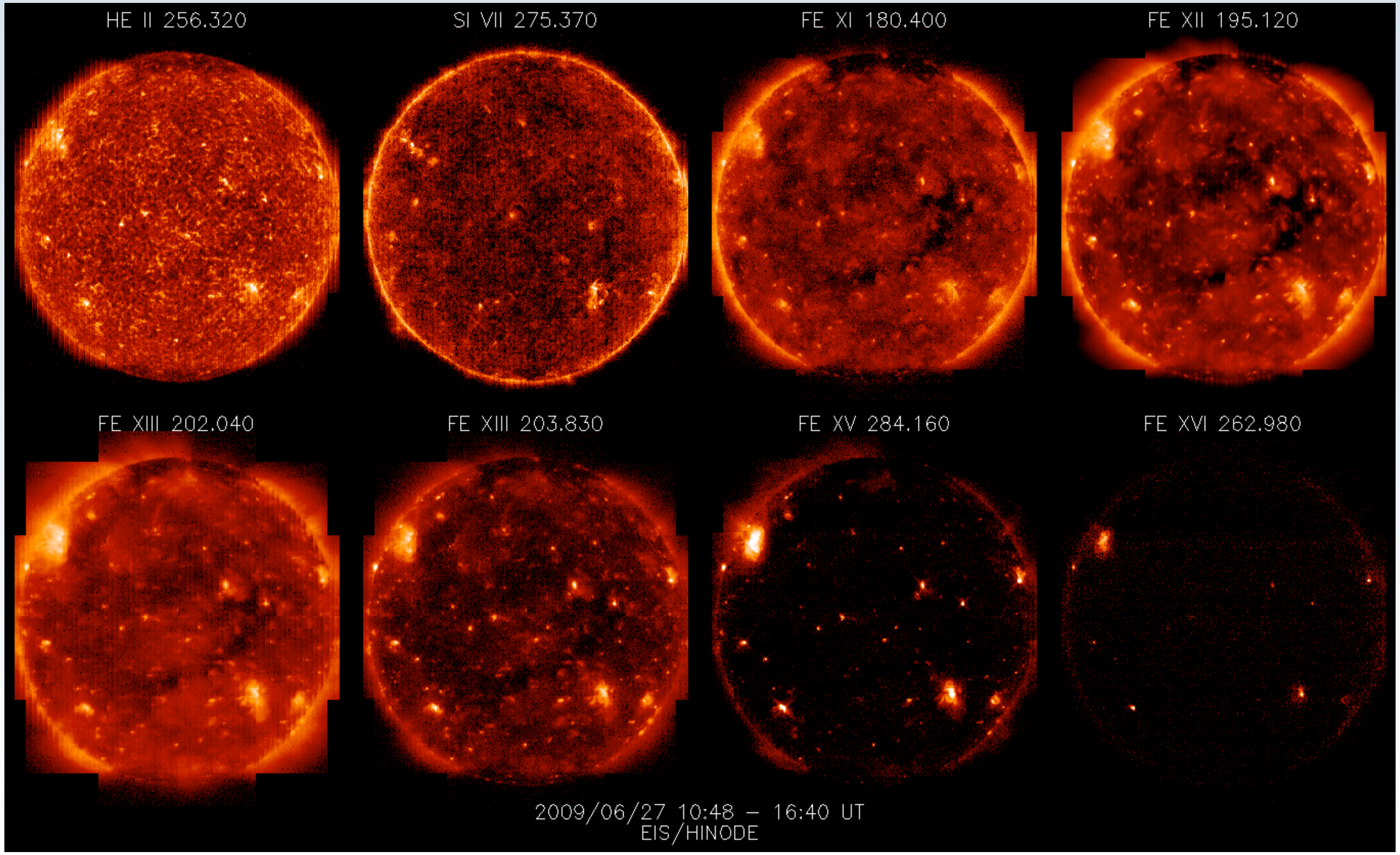
Energy flow from the photosphere to the corona

Louise Harra & UV/EUV sub-WG

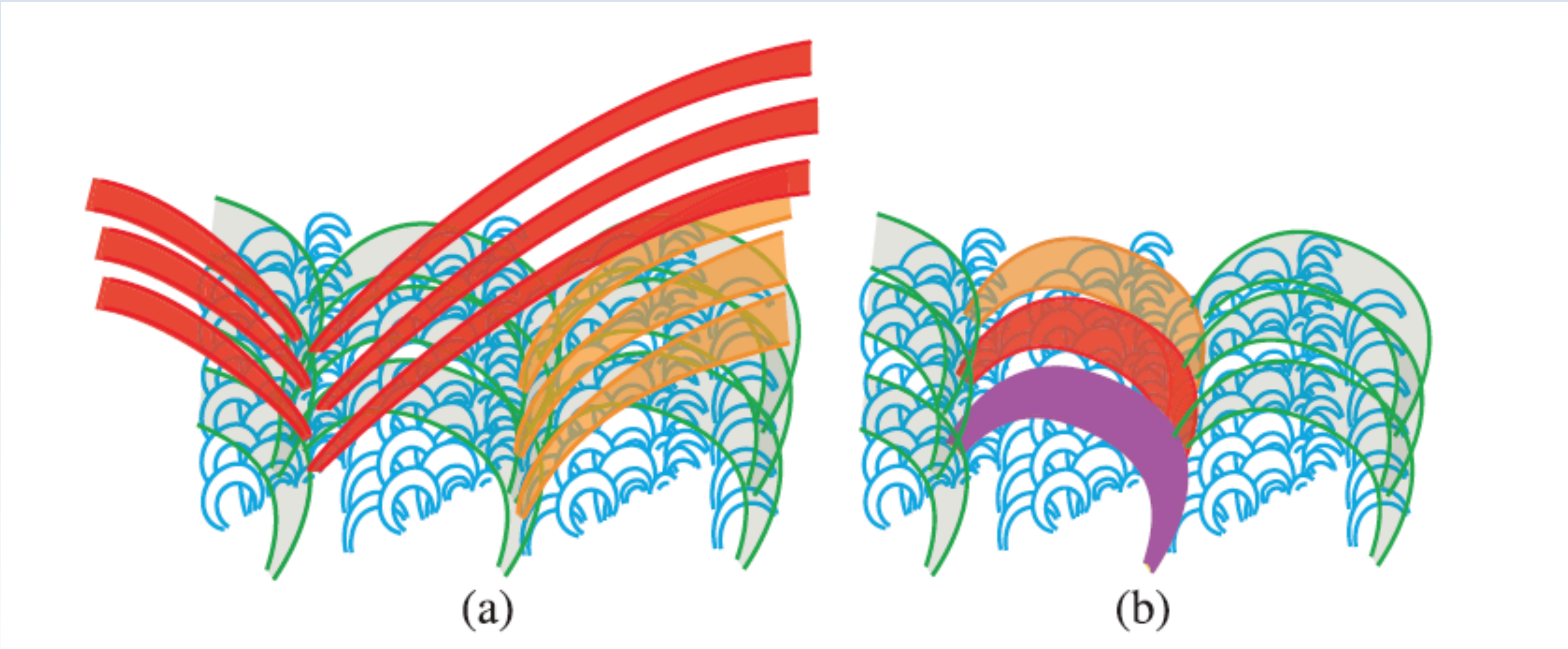


How is energy transferred from the photosphere through the chromosphere and transition region into the large scale coronal structures? What is the morphology of the transition region?

- Relationship between different layers of the atmosphere – both in closed and open field lines.
- Flows in active regions and coronal holes – where does the energy come from and where does it go?
- Emerging flux – responses in the atmosphere

The solar transition region

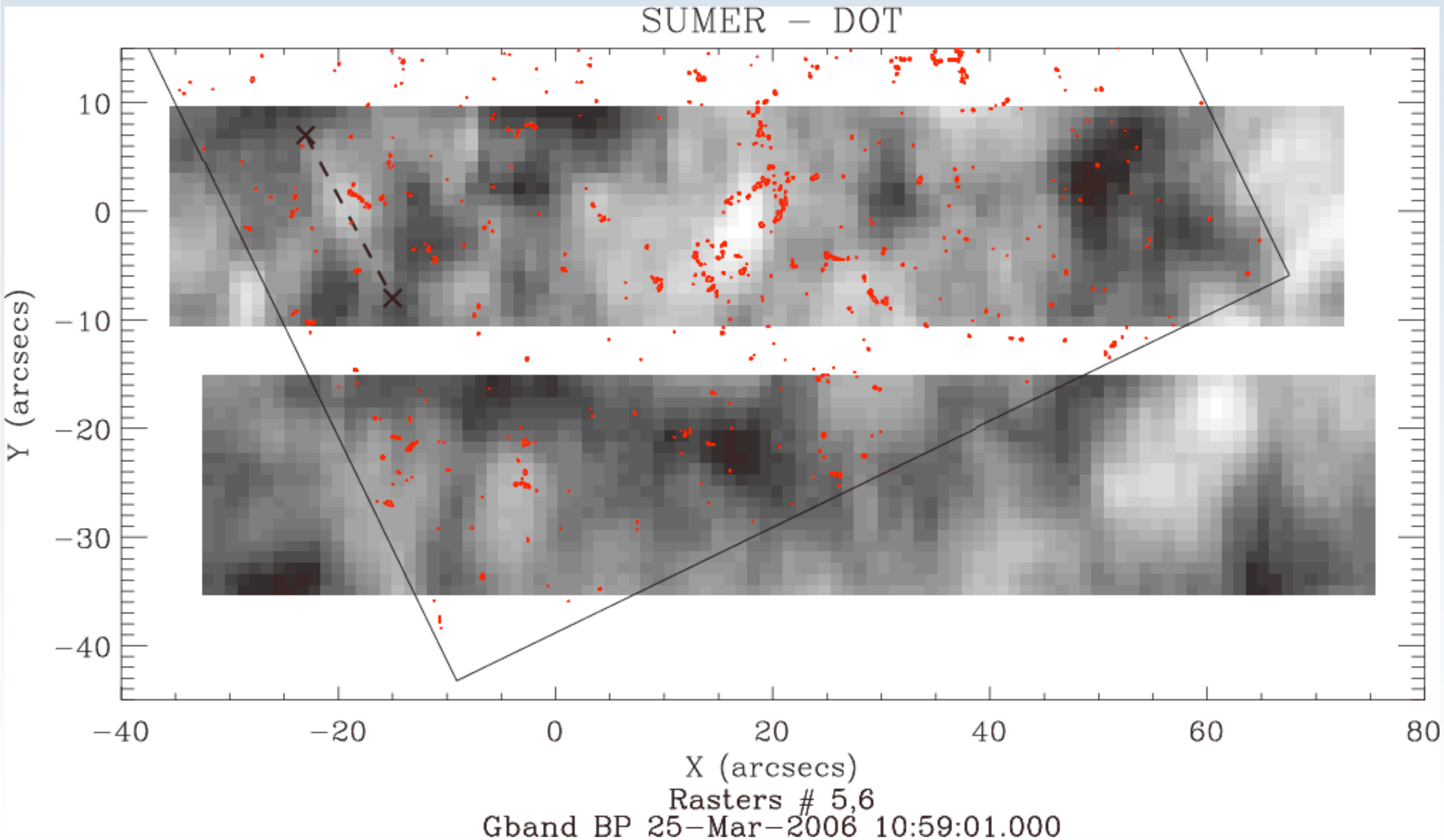
- There does not seem to be a continuous transition between the chromosphere and the corona that is measured (e.g. Feldman et al., 1999). SUMER found many small-scale loop-like structures
- EIS also shows low temperature loop probably arise at supergranular cell size, whereas hot loops connect supergranular cells or open fields.



Matsuzaki et al., 2007

Photospheric footpoints of quiet Sun transition region loops

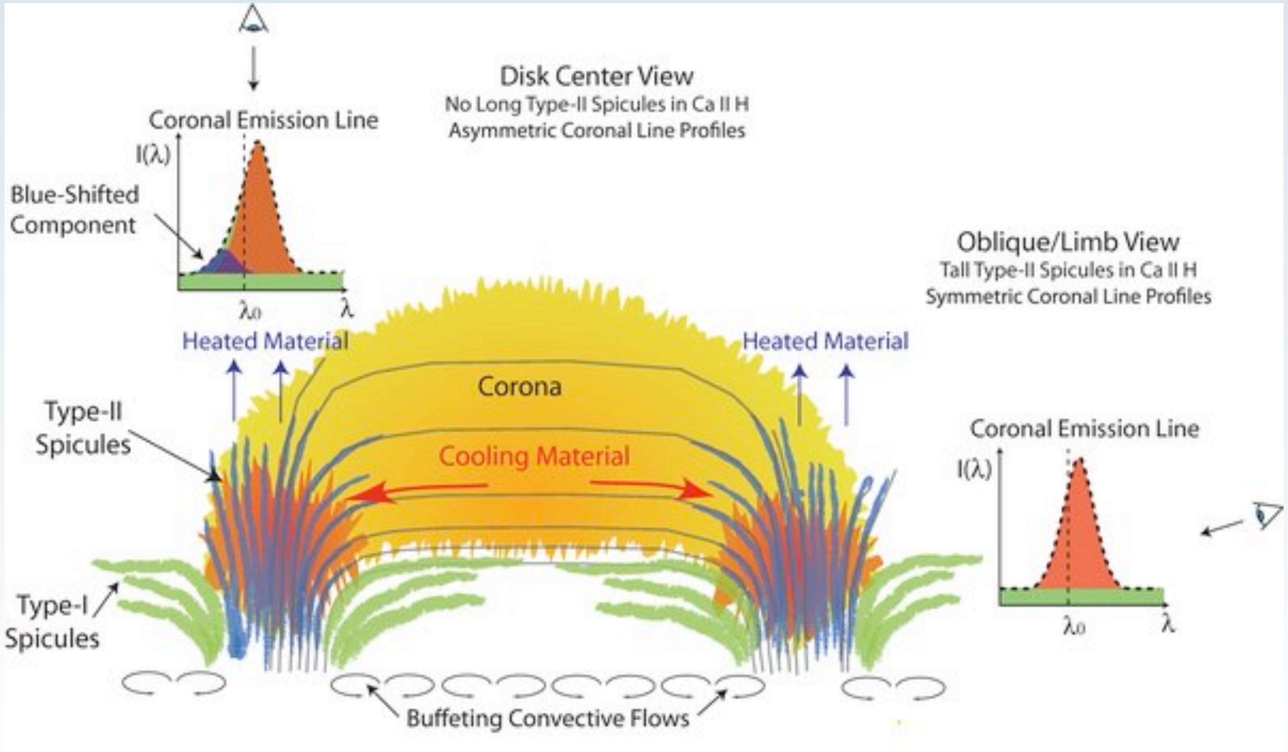
- Small cool loop-like structures fill the quiet Sun.
- Photospheric bright points are associated with TR structures, but not the brightest and not the strongest red-shifts.
- Explosive events not associated.

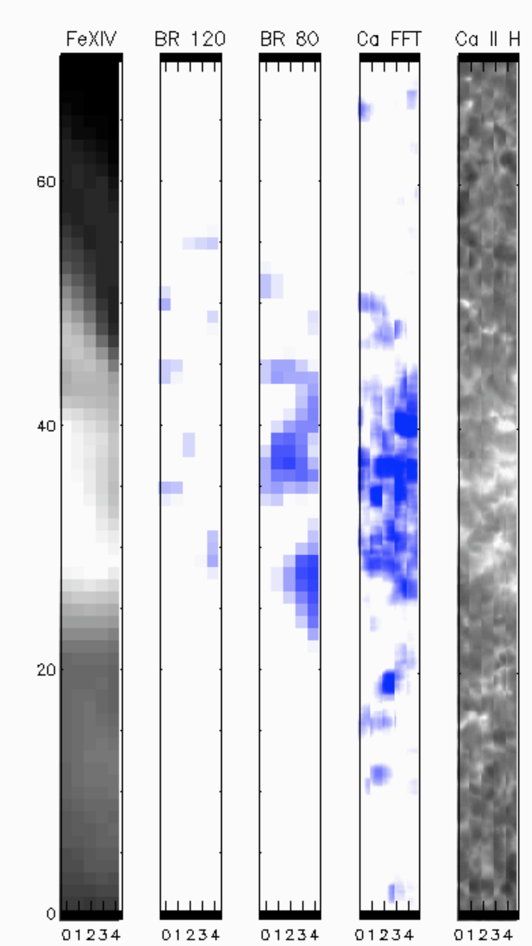


Sanchez-Almeida et al., 2007

Linking the chromosphere to corona

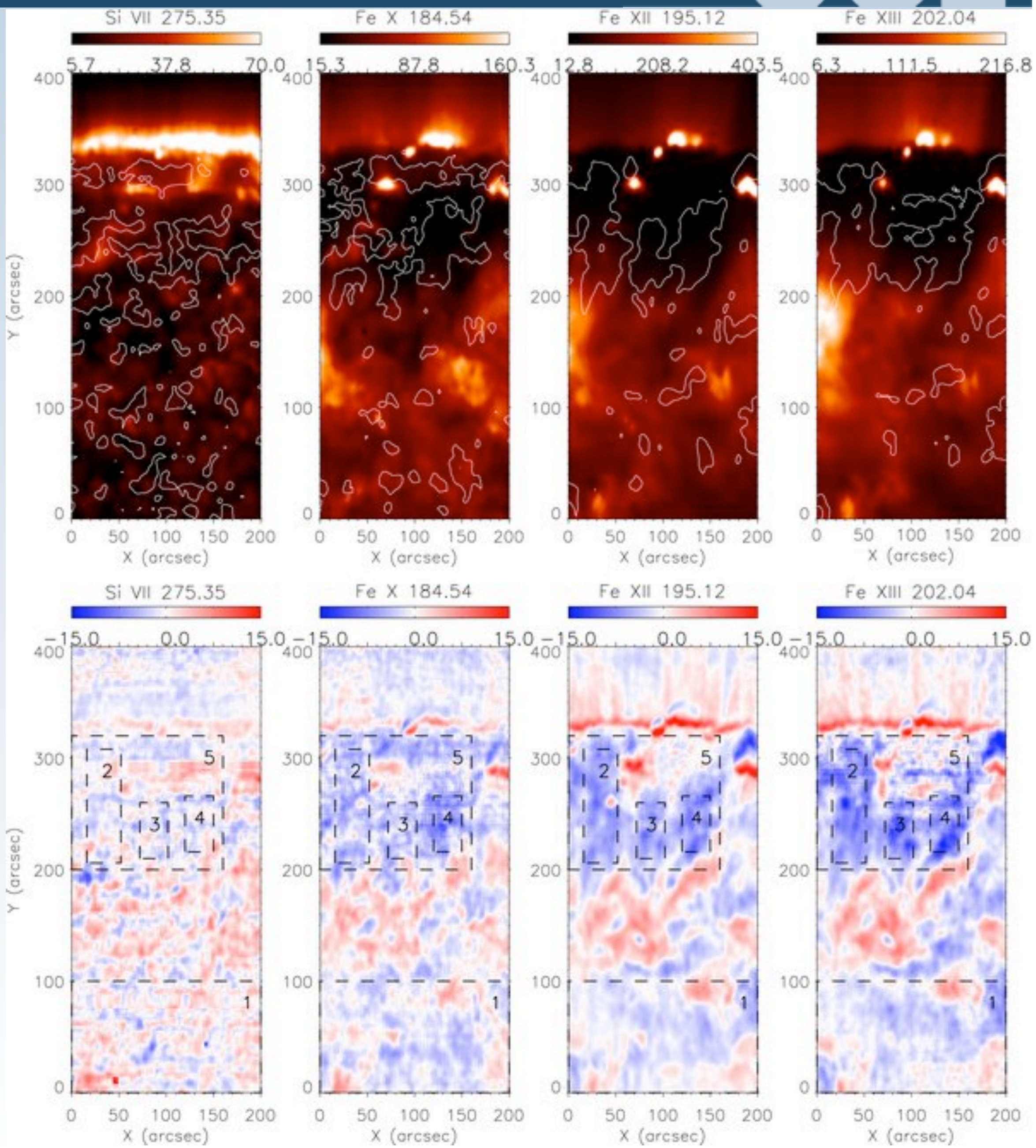
The weak emission in coronal and TR lines have a B-R asymmetry at a range of temperatures.
Explanation is that the chromosphere is heating the corona (De Pontieu et al., 2009, McIntosh and De Pontieu, 2009).





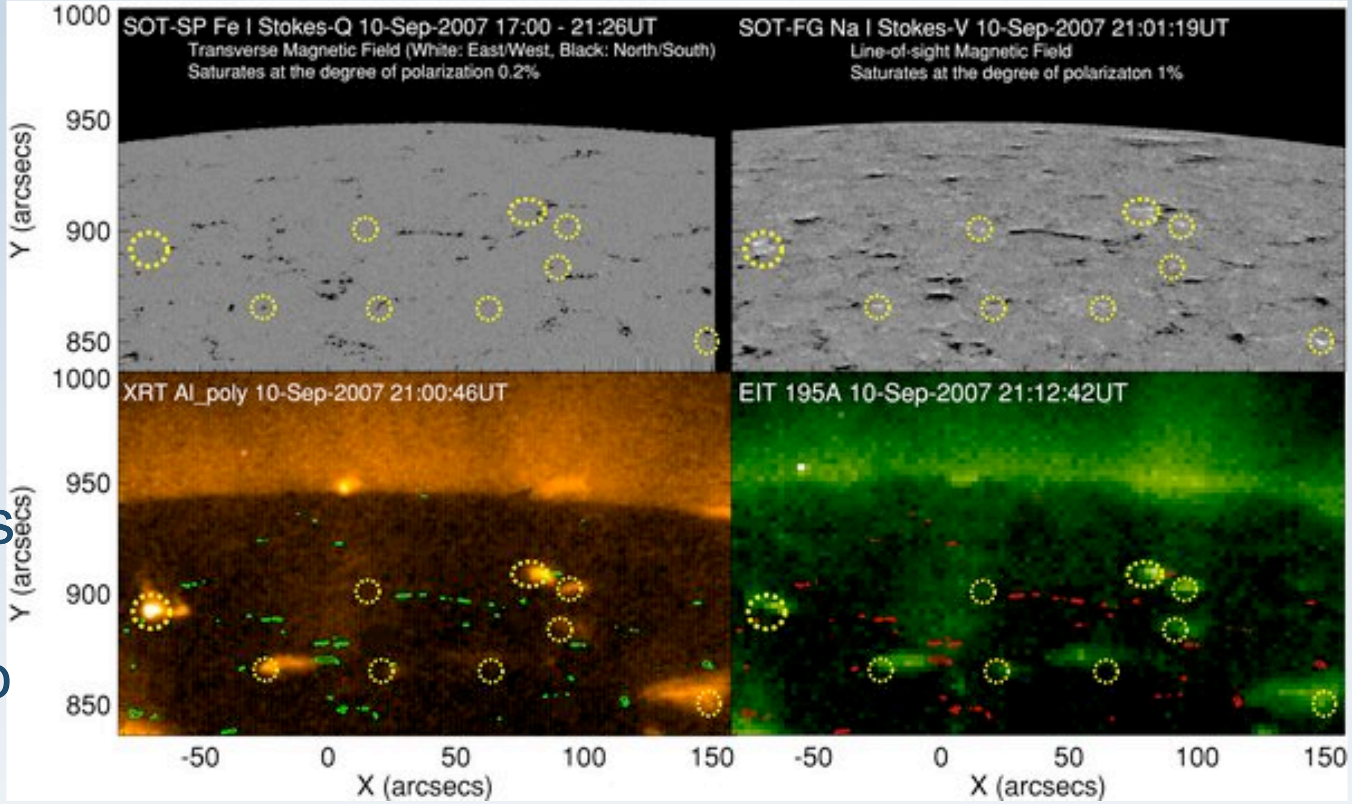
Fast solar wind outflow observed by EIS

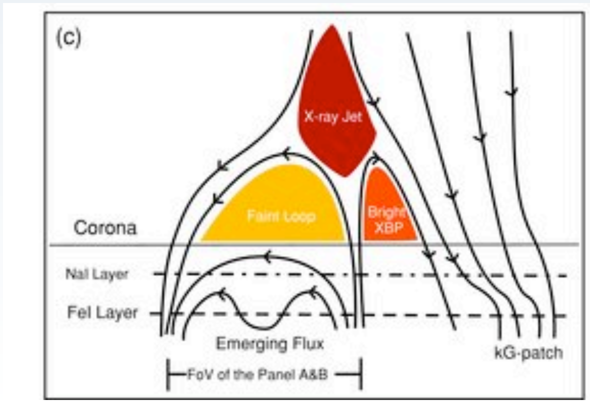
- The outflow seems to start in the TR and becomes prominent with increasing temperature (Tian et al., 2010).
- Patches of significant outflow are small in TR but merge in the corona – consistent with the solar wind being guided by expanding magnetic funnels.
- Plasma accelerated in the funnel above 5Mm, but originates from below the neighbouring loops (Tu et al., 2005).



Linking magnetic field and corona in the poles

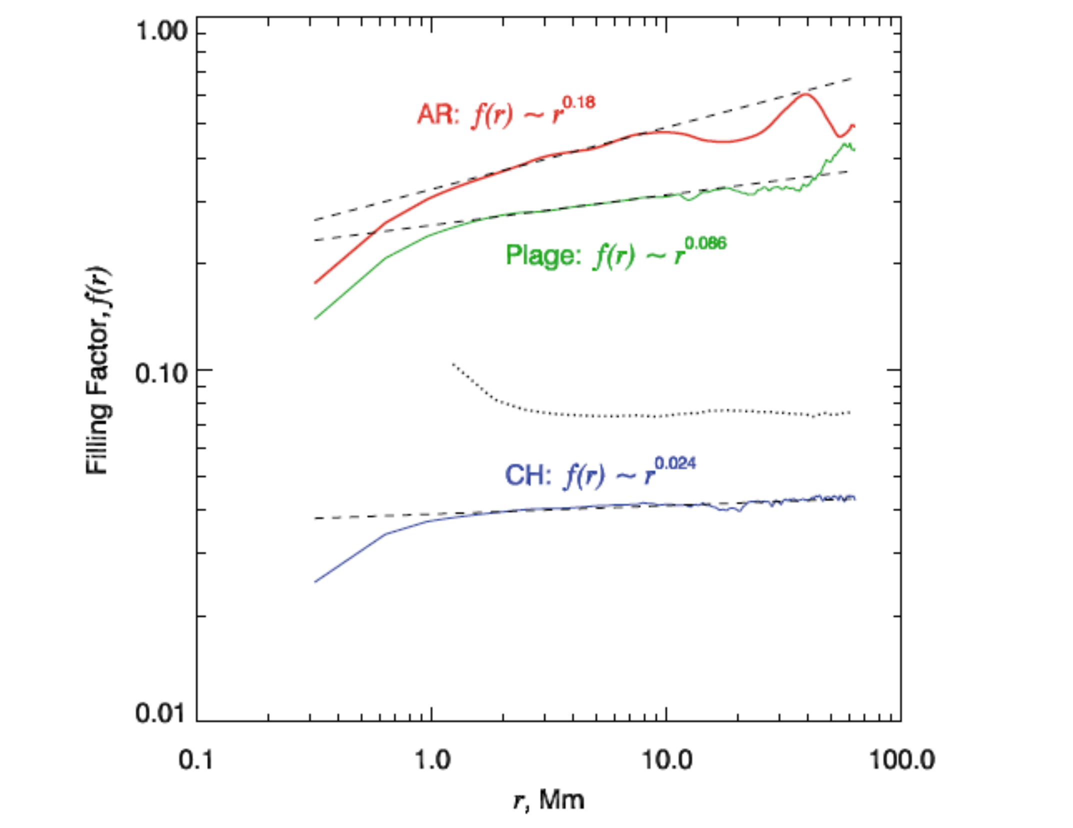
X-ray activity in the poles appears around minority polarities near the kG patches (Shimojo and Tsuneta, 2009)





Relationship between magnetic field and beyond.

- The total area and net flux of CHs are directly related to the solar wind speed.
- The filling factor is found to decrease below 2Mm.
- This suggests a multi-fractal structure and highly intermittent burst like energy release.

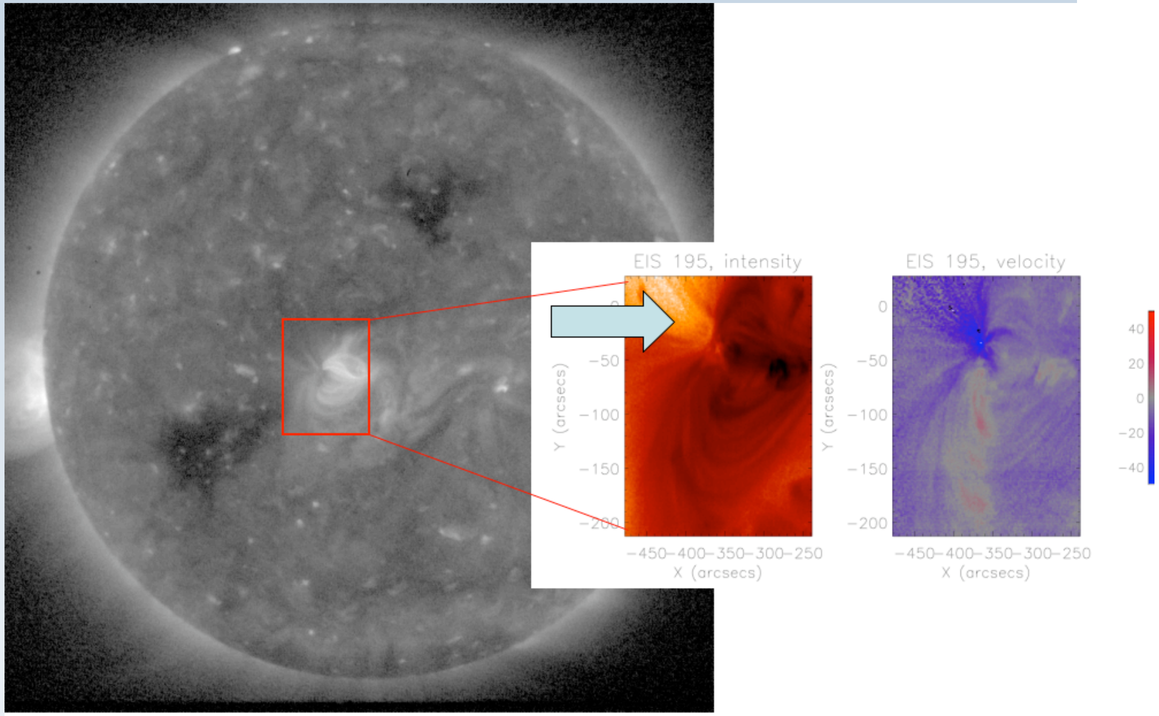


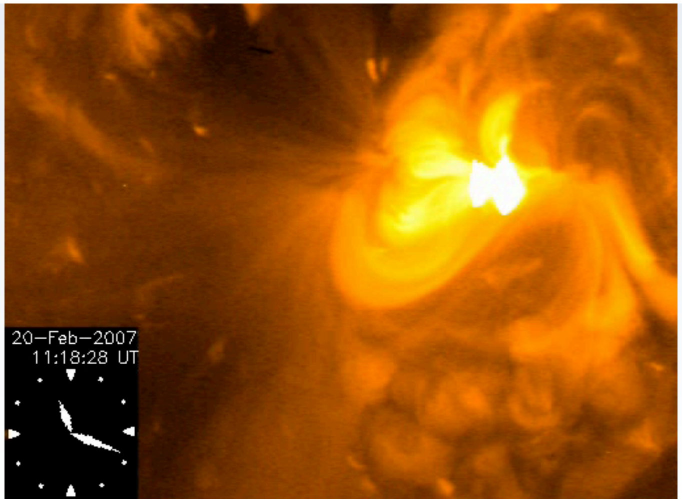
Abramenko et al., 2009

Slow solar wind

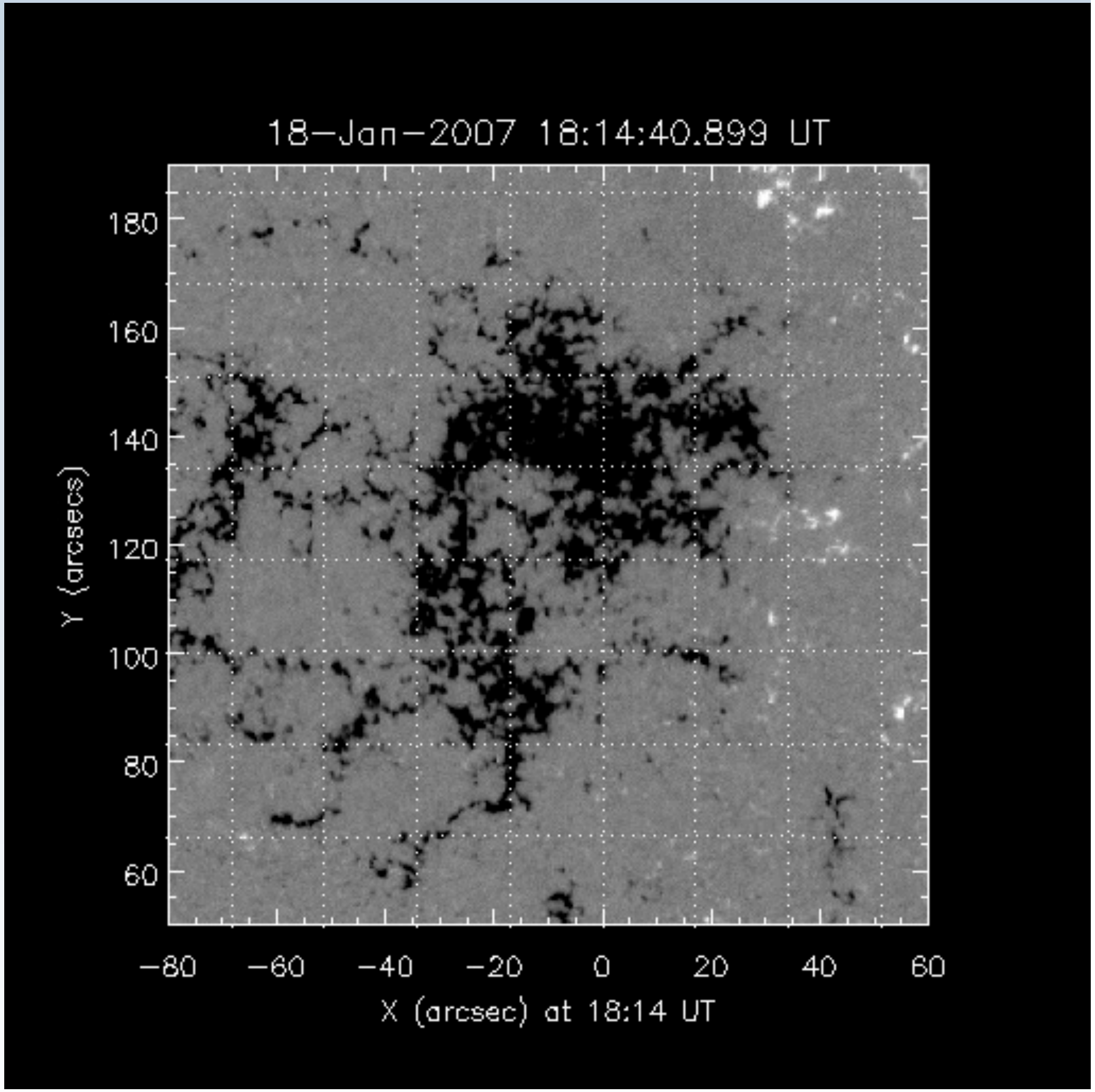
Sakao et al. 2007, showed continuous ‘spurting’ streams of plasma from the edges of active regions.

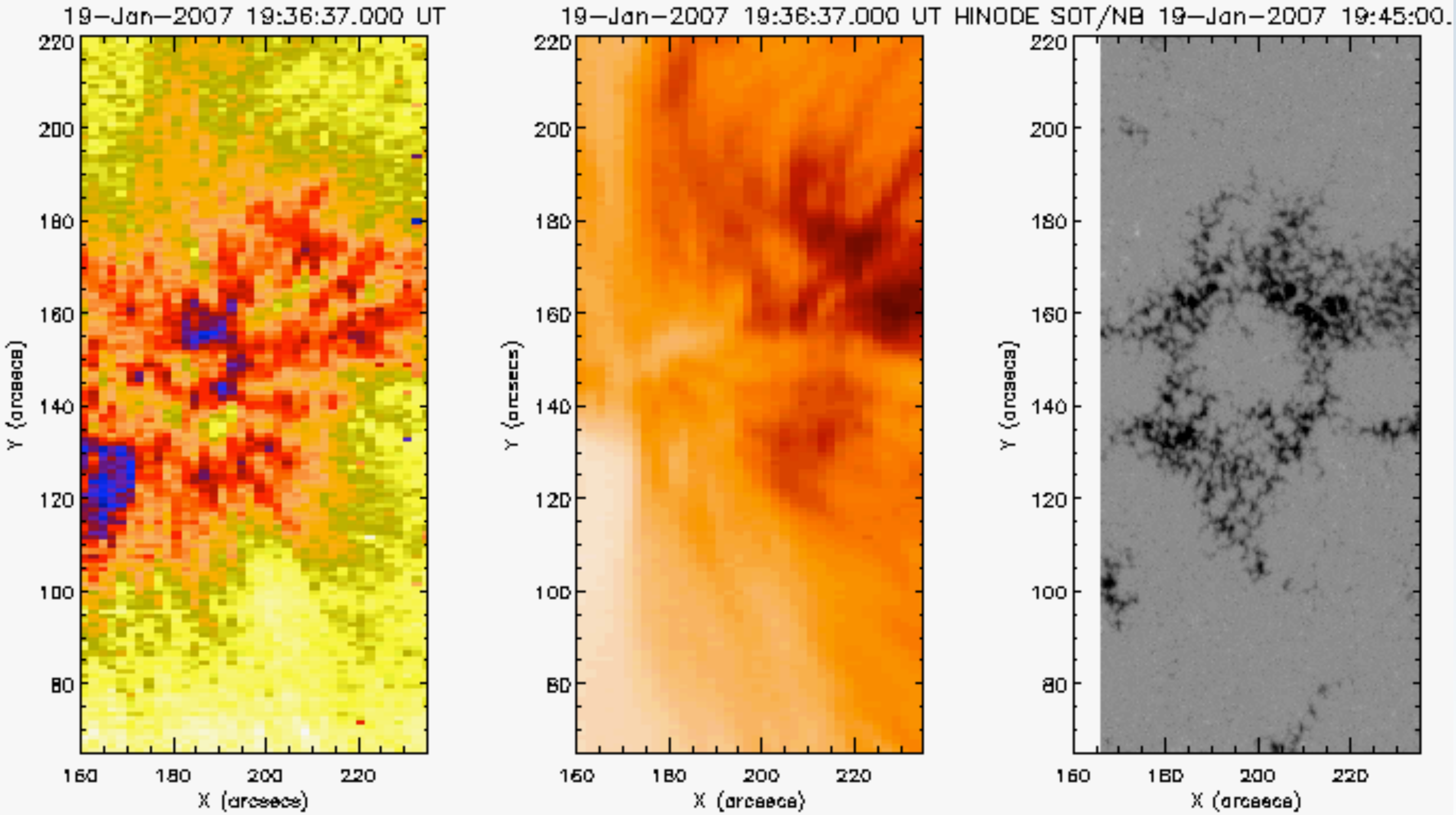
Outflows of up to 50 km/s are seen in the region of outflow in XRT, Harra et al. (2008).
Marsch et al. (2008) describe this as ‘coronal circulation’. Doschek et al. Del Zanna et al., Hara et al., Baker et al.





‘Unipolar’ footpoint – has many small bipolar fragments appear and disappear. (Hara et al., 2009)

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Y (arcsecs)
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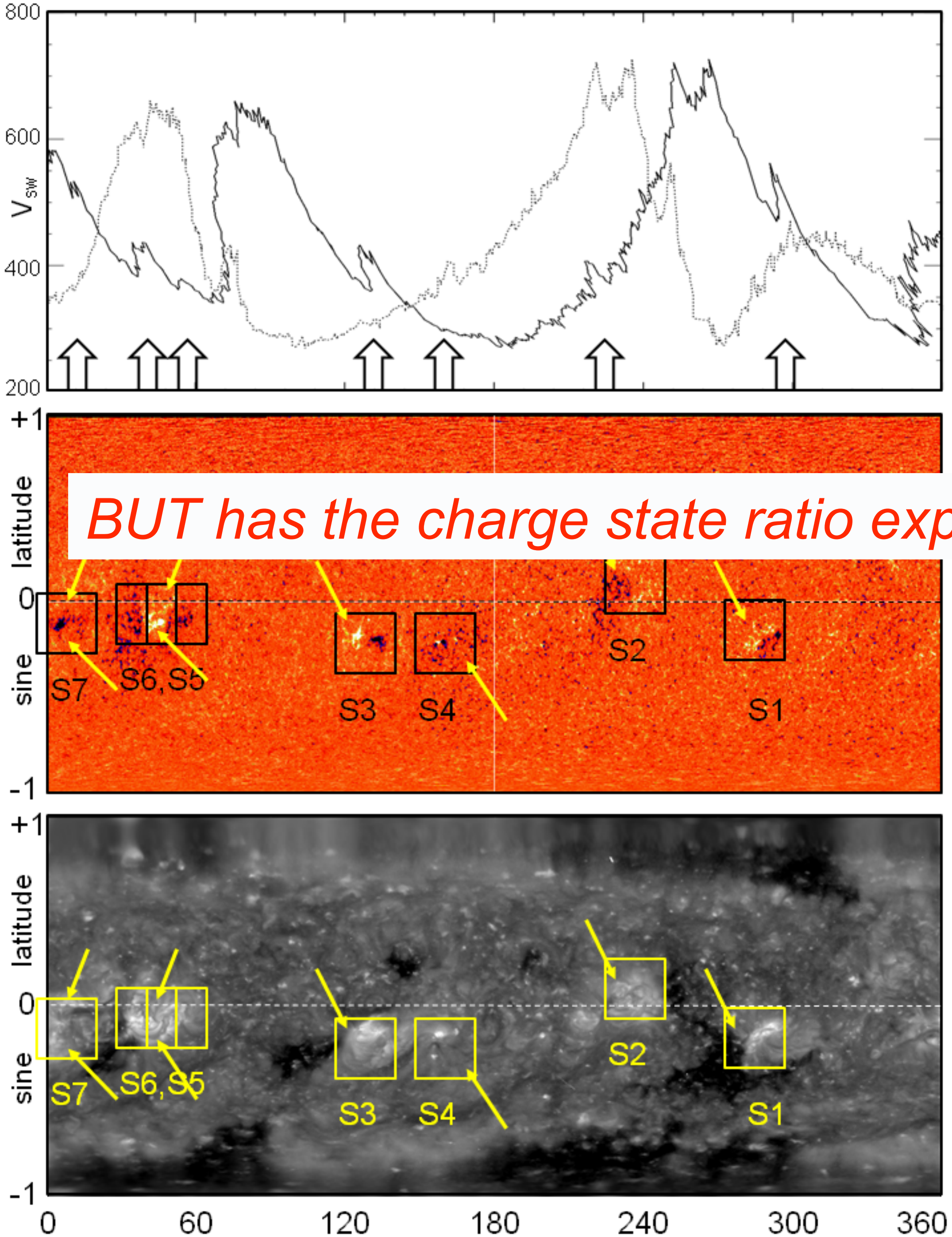


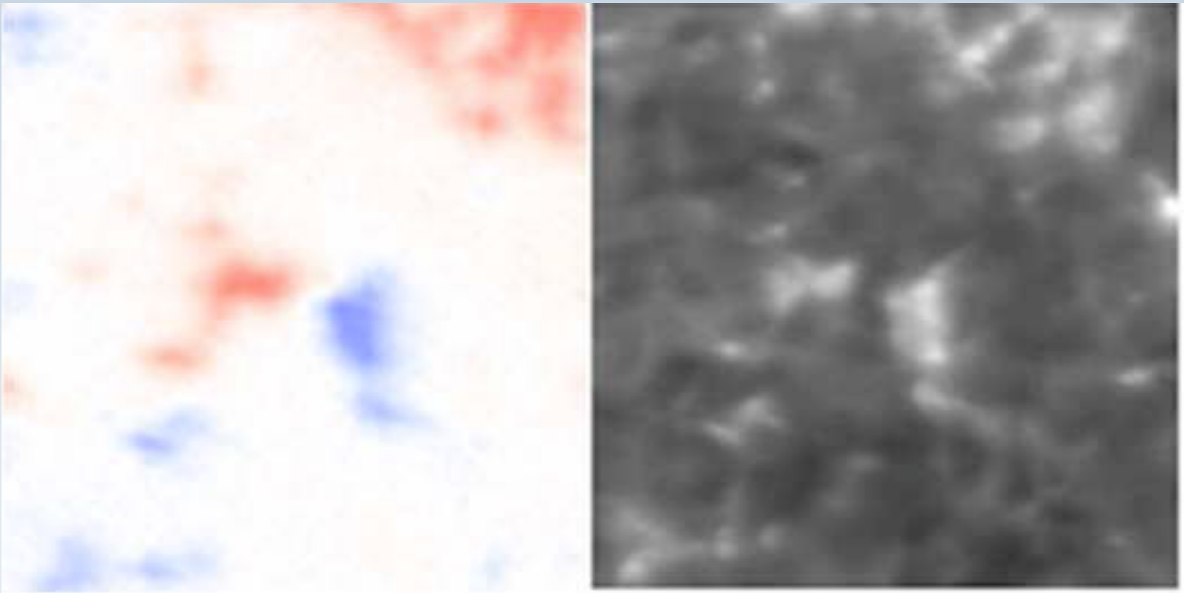
BUT has the charge state ratio expected from coronal hole.

Wind speed at ACE and backmapped wind speed at the Sun (black)

Synoptic map (MDI)

Synoptic map (EUVI)

Response of the atmosphere to small emerging flux

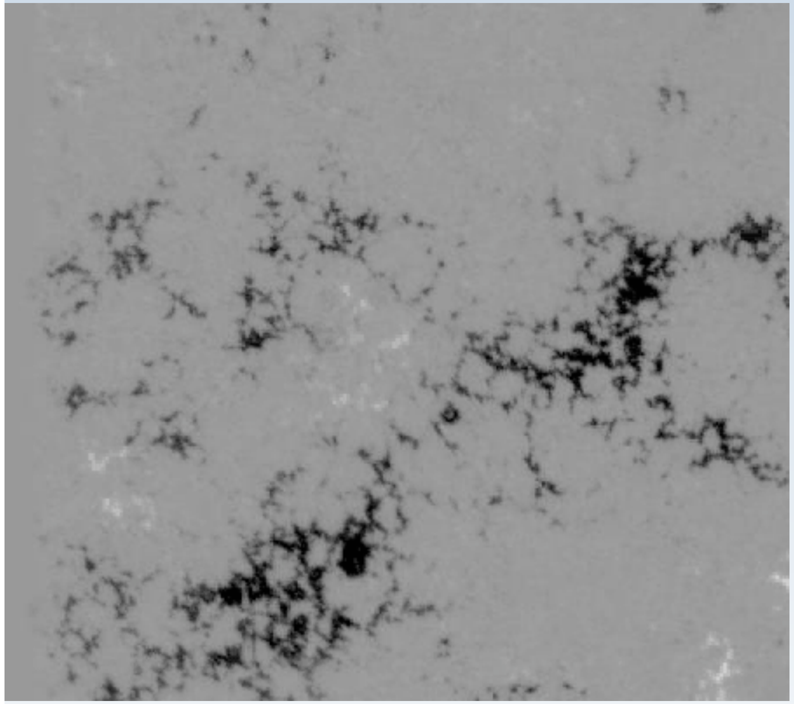


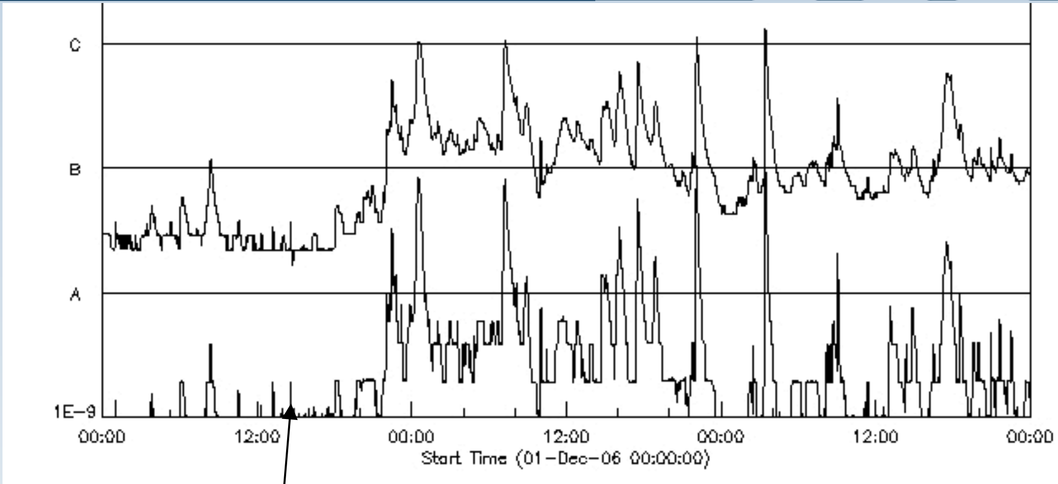
Guglielmino et al., 2008

- Emerging flux in the photosphere is associated with chromospheric brightenings (e.g. Ca II H).
- Even these small-scale flux emergences heat the chromosphere and corona (e.g. Li et al., 2007, Guglielmino et al., 2008).
- The Ca II heated before the coronal emission.

Response to emerging flux in the corona

1-Dec 16:00-2-Dec 16:00





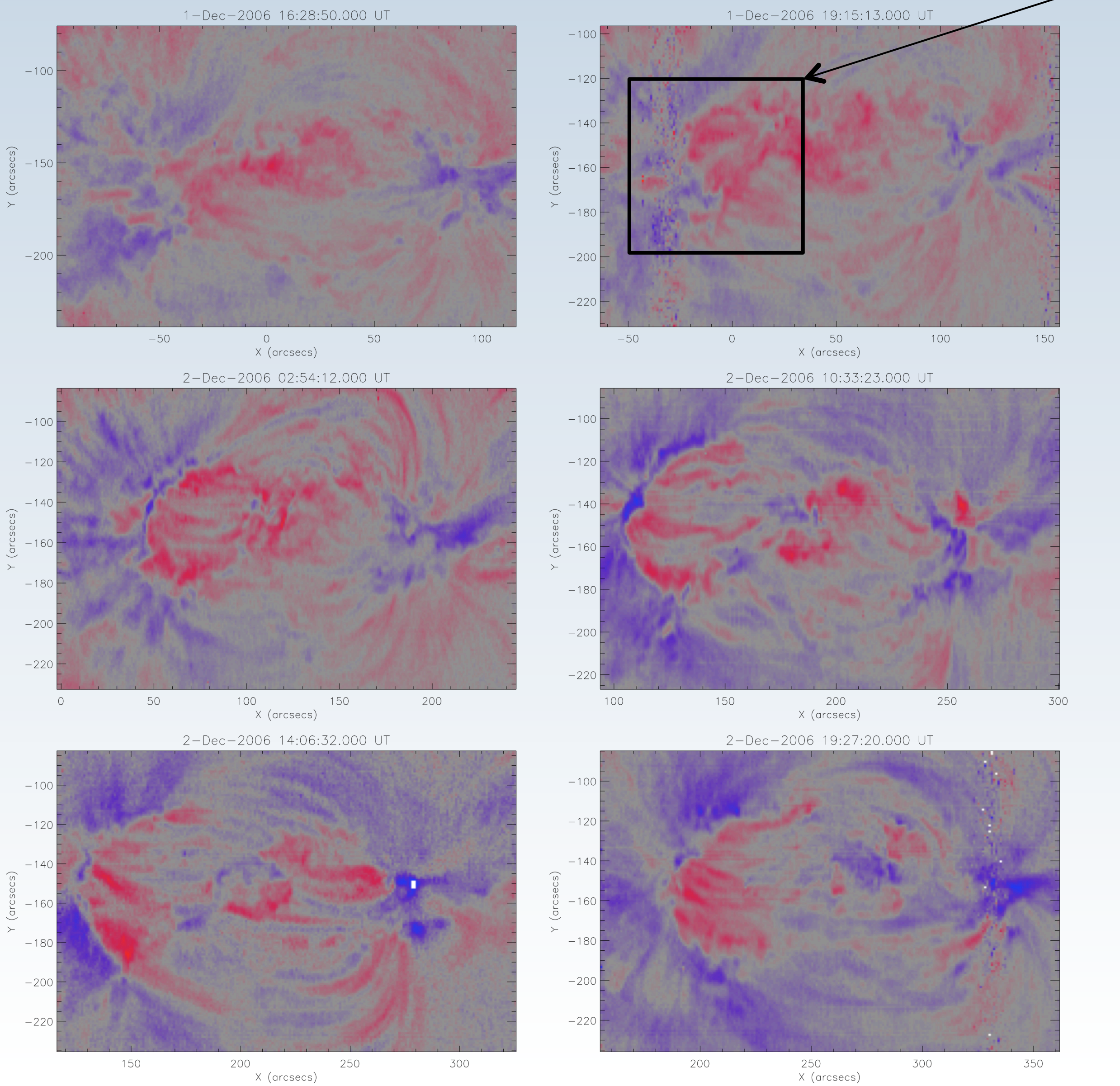
Flux emergence

Magara, 2008

Harra et al., 2010

Coronal enhancements are rarely seen in the 'fragmented' magnetic region – but chromospheric enhancements frequently seen.

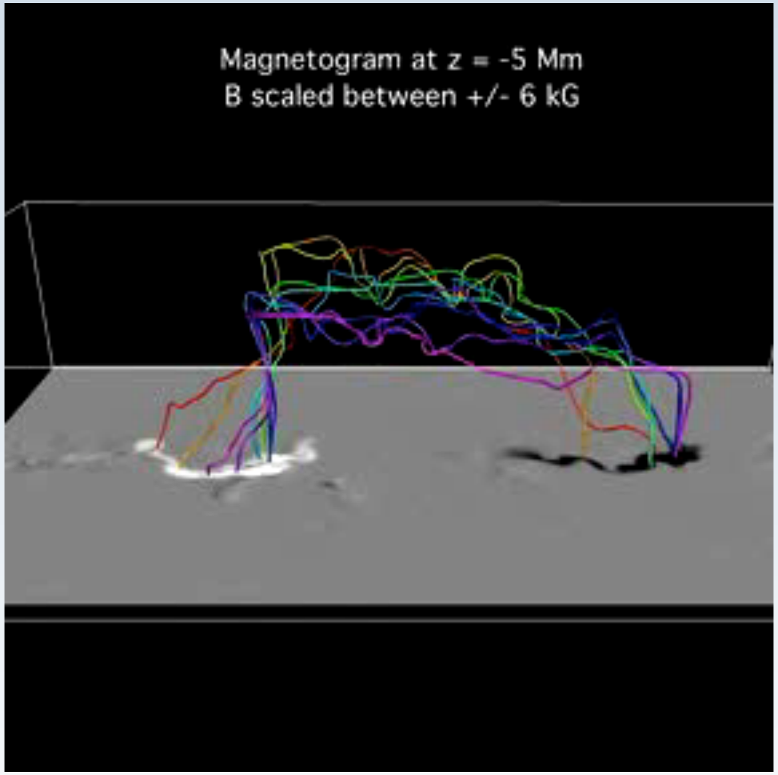
Active region flow onset



EF region

Progression of flux emergence over 27 hours produces enhanced outflows at the edges of the active region (Harra et al., 2010).

Simulations of emerging flux



Cheung et al., 2008

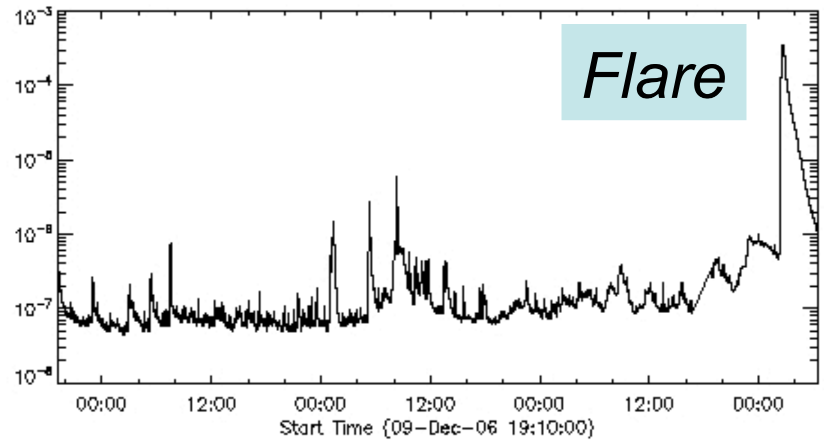
- 3-D MHD simulation of rise of buoyant magnetic flux through convection zone into photosphere.
- Interaction of convection downflows and the rising magnetic flux tube undulates it to form serpentine field lines.

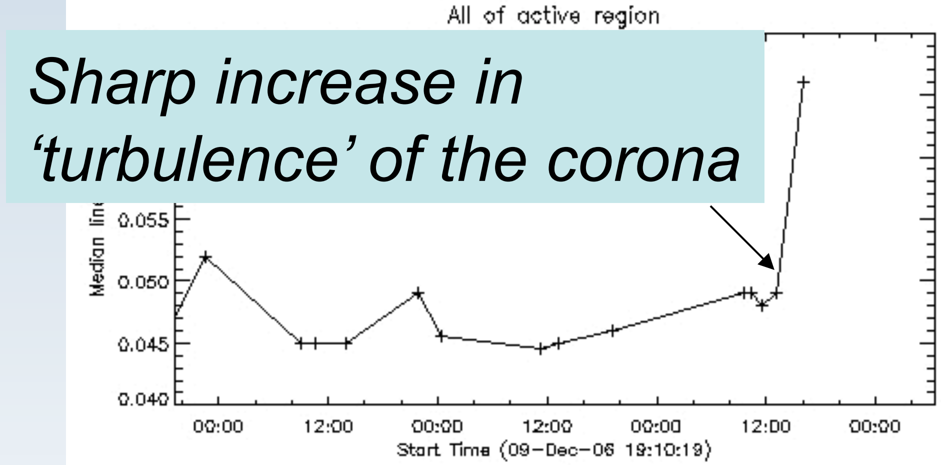
What is the relationship between magnetic field evolution, flux emergence, and solar eruptions? What is the initiation mechanism for flares and CMEs?

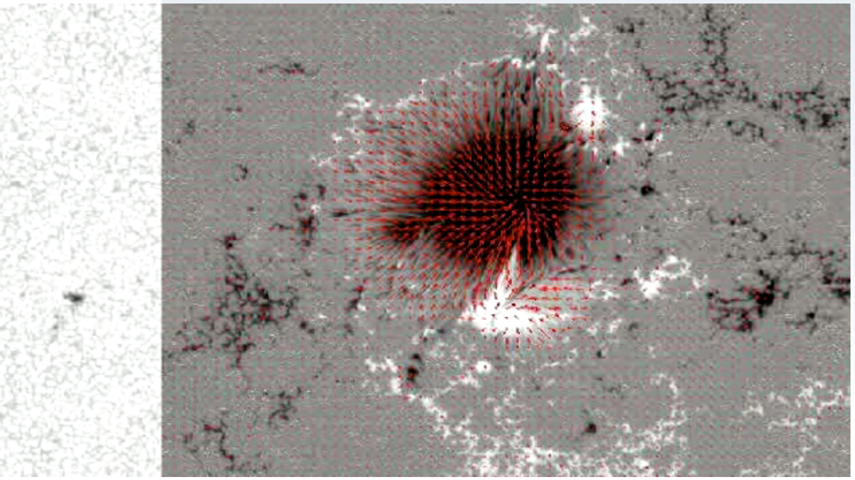
- Pre-flare/CME triggers.
- Response to eruptions

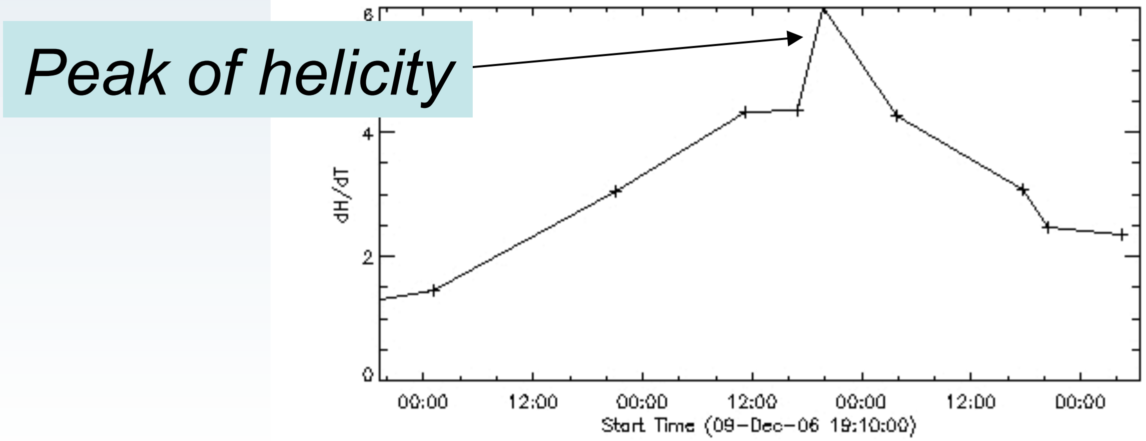
Build-up to flares

- With Hinode we can measure the helicity build-up following flux emergence (Magara and Tsuneta, 2008).
- We can follow the response in the corona (Harra et al., 2009).

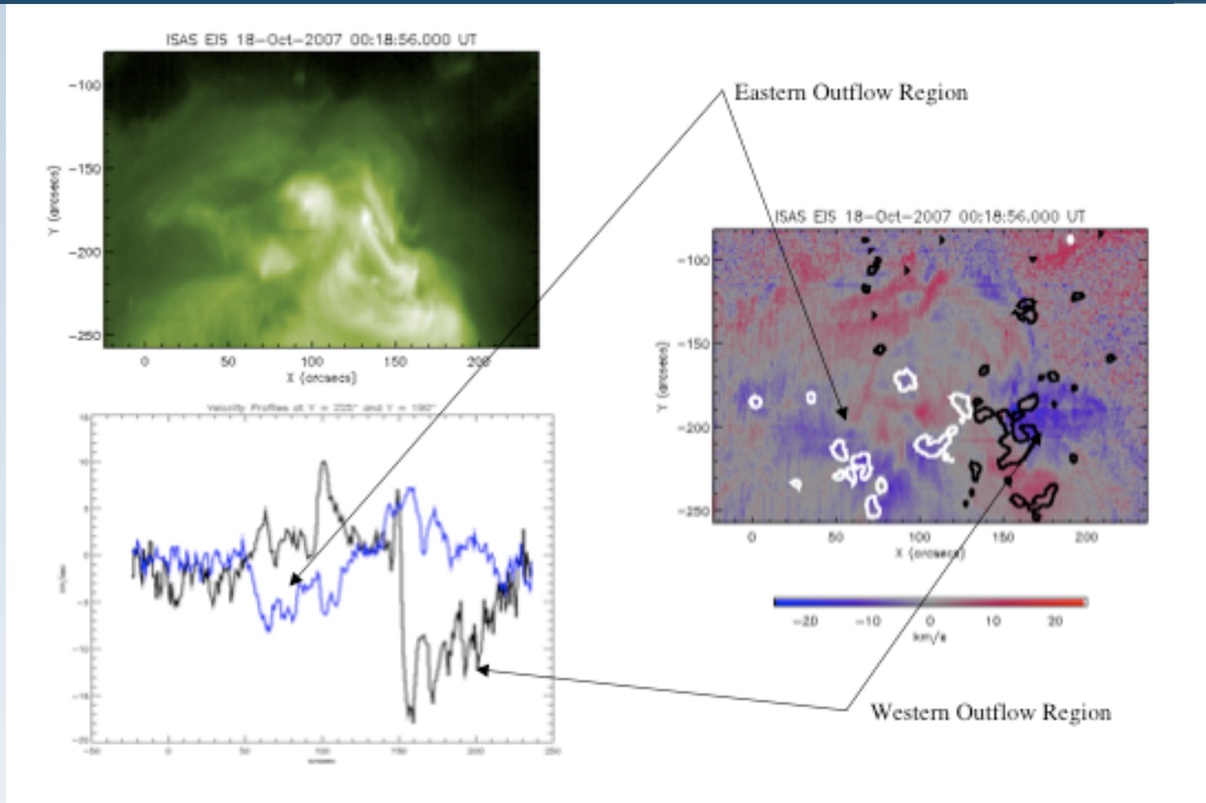








Precursors also seen in small events

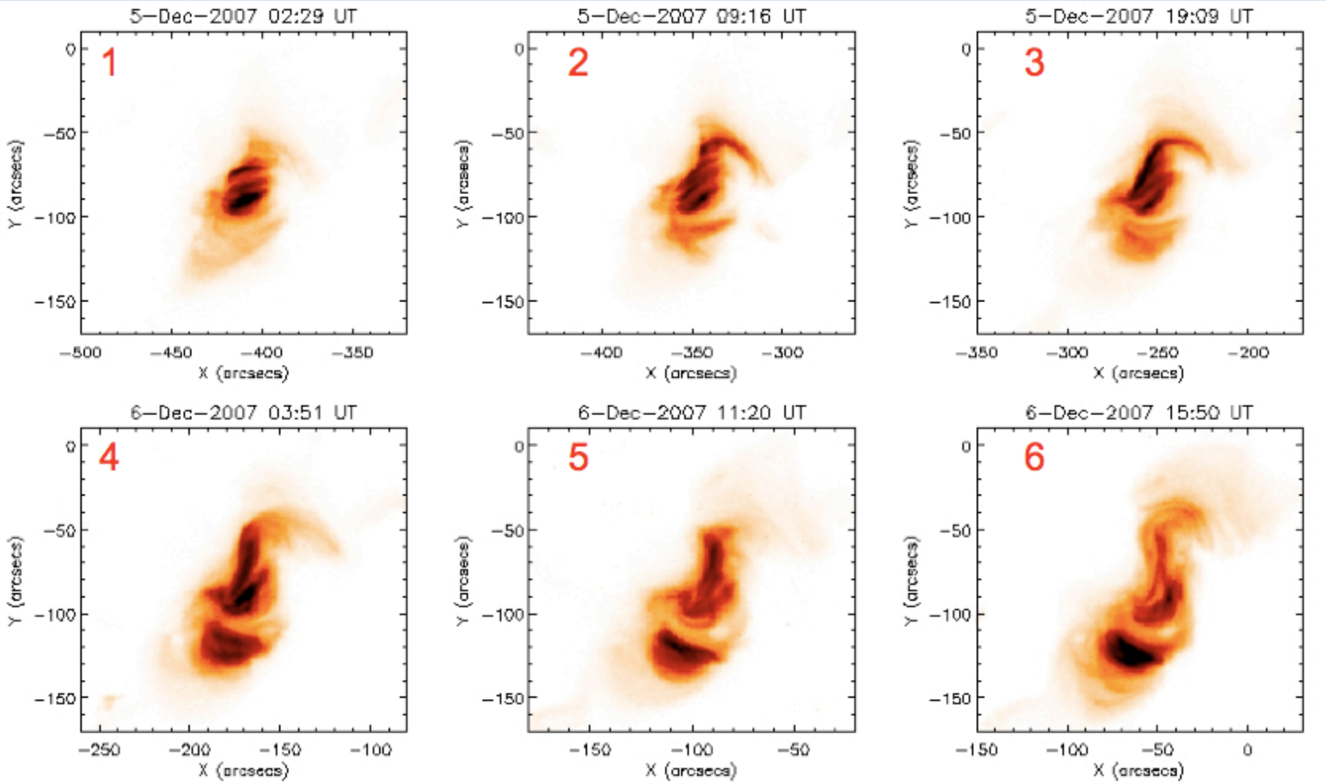


•Few hours prior to CME, outflow velocity intensifies on western side of AR in vicinity of filament along PIL
•Magnetic flux falls 10% per day during AR expansion and eruption suggesting flux cancellation destabilizes the tied-down field-> increasing twist in and expansion of flux rope -> CME
•Pre-eruption expansion of flux rope containing filament provides required increase in compressive forces causing intensification of outflows?

Baker et al 2007 and Murray et al 2010

Arcade to flux rope transition

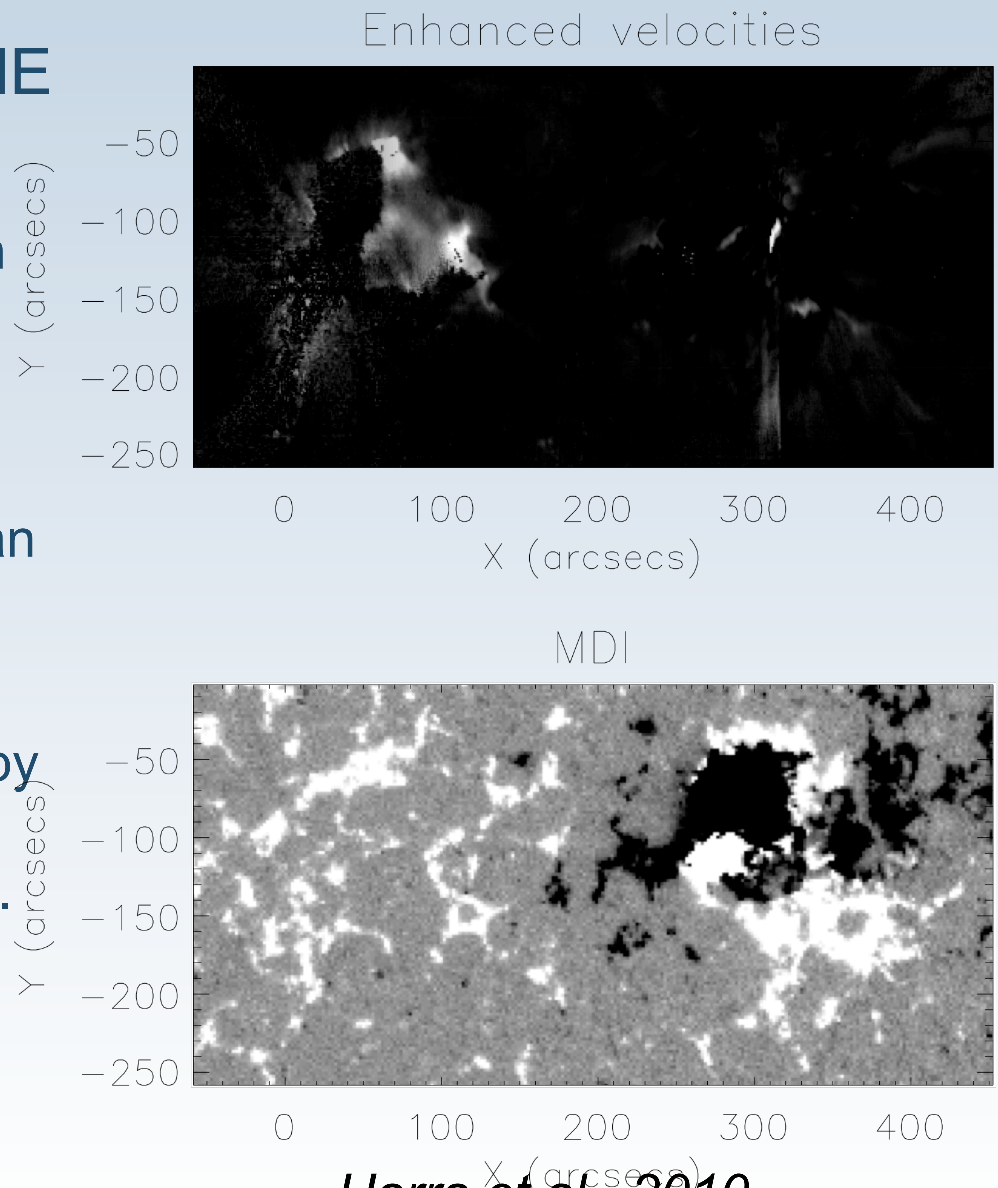
- The soft X-ray arcade develops high shear over 2 days and transitions to sigmoidal before the eruption.
- The centre of the sigmoid makes an inverse crossing of the polarity inversion line 50 mins before the eruption.
- The formation of the flux rope is driven by fragmentation of the main polarities, motion due to supergranular flows and cancellation at the polarity inversion line.



Green,Wallace & Kliem, 2010

Exploring the source of a CME

- Spectroscopy allows us to look at both the core dimming region and the distant dimming region (Harra et al., 2007).
- This allows a more accurate determination of the source of an ICME.
- The relationship with temperature has been derived by Imada et al. (2007) – providing boundary conditions for models.



Harra et al., 2010

Summary

- The formation of outflow from active regions and its link to the solar wind is still confused.
- We need to observe the pre-flare build-up – which requires observing very small scale phenomena (such as flux cancellation).
- We need fast enough cadence to see the active region with the core 'dimmings' and the outside region to see the 'secondary' dimmings.
- The solar wind starts 'outflowing' between 5-20 Mm. We have a few snapshots of change in altitude.
- There is a clear change between the chromosphere and above - this needs to be understood in terms of plasma outflow and heating.

We need to observe spectroscopically through the atmosphere with a high time cadence and large FOV. EUVS covers from 10^4K to 10^7K plasma, 10 times effective area, spatial resolution of ~0.3", FOV 400"X400"