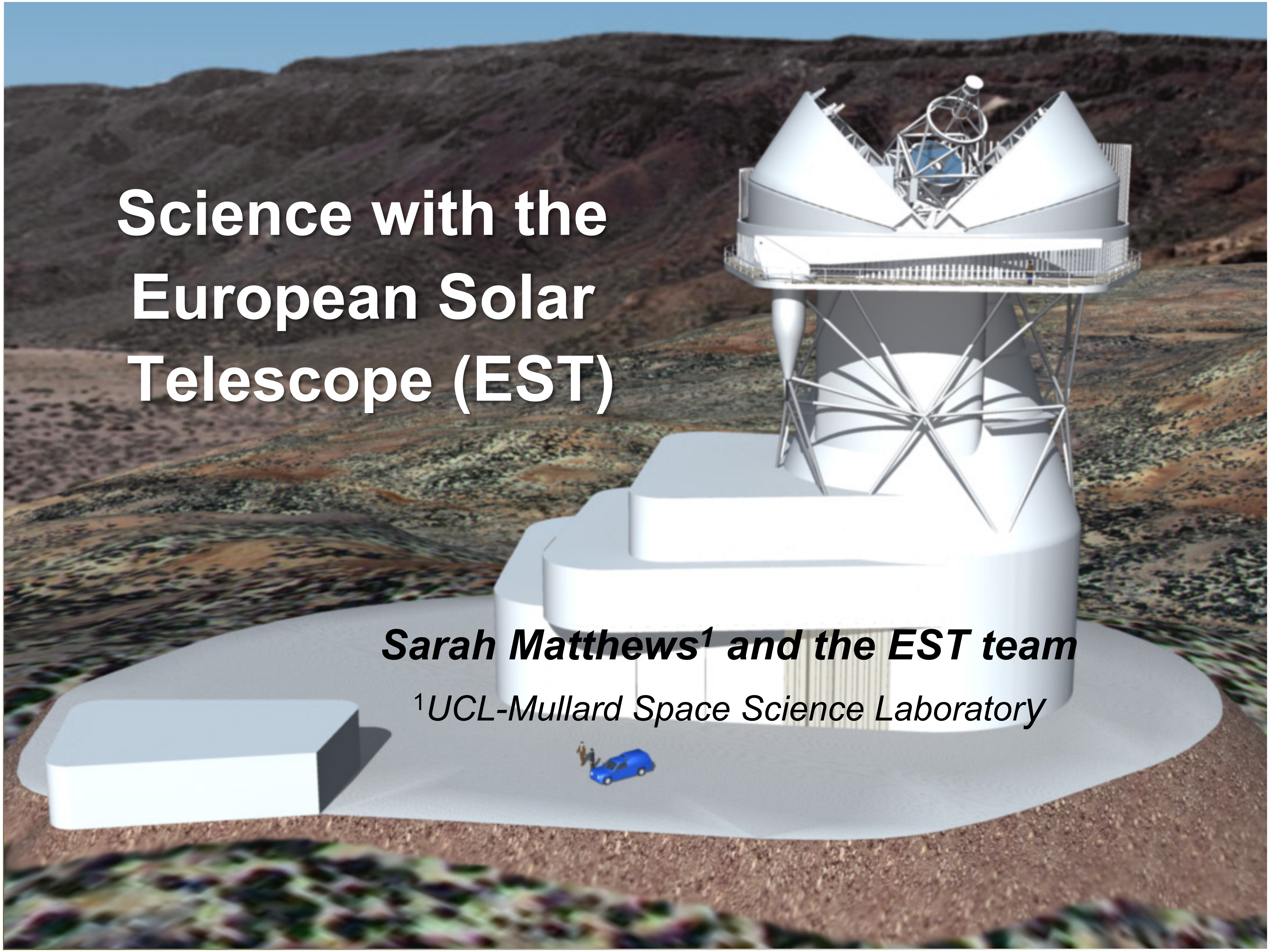
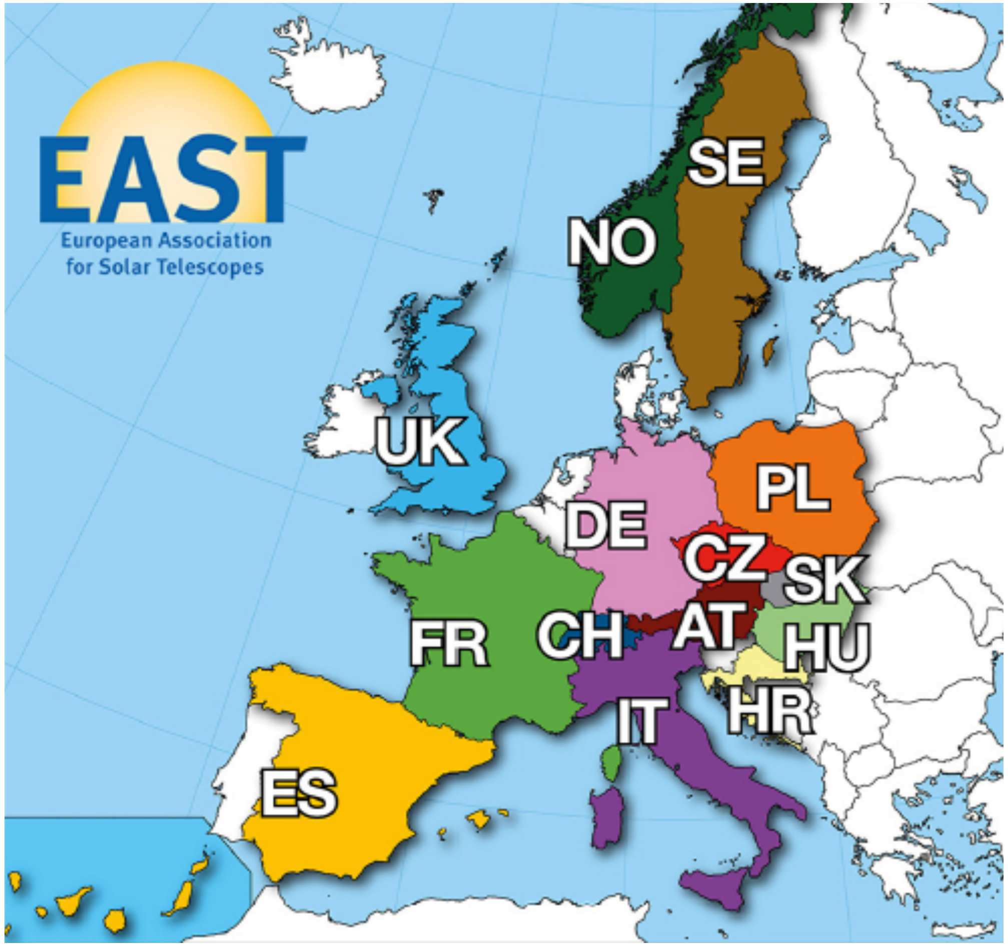


Science with the European Solar Telescope (EST)

Sarah Matthews*[1] *and the EST team

[1]*UCL-Mullard Space Science Laboratory*



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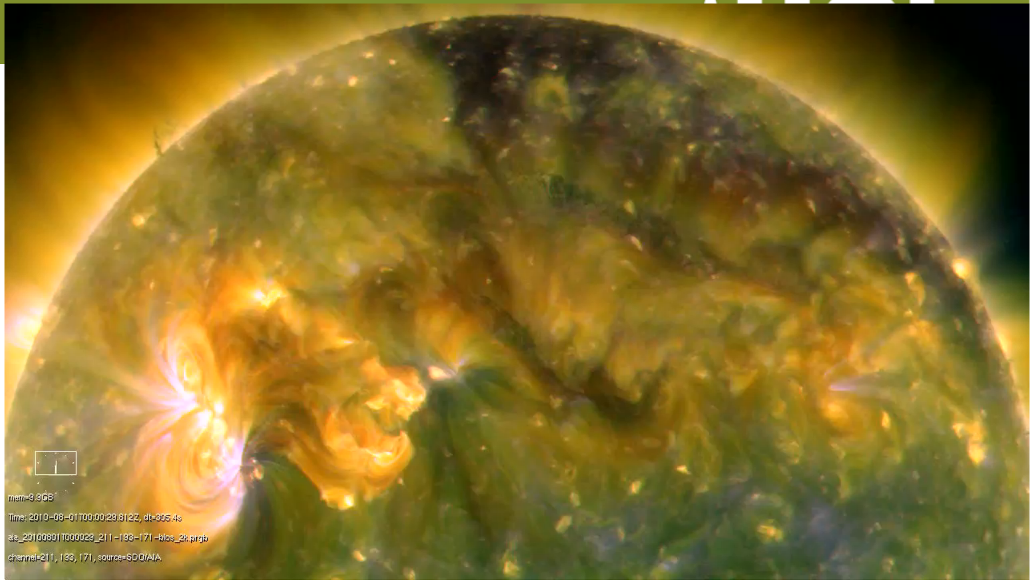
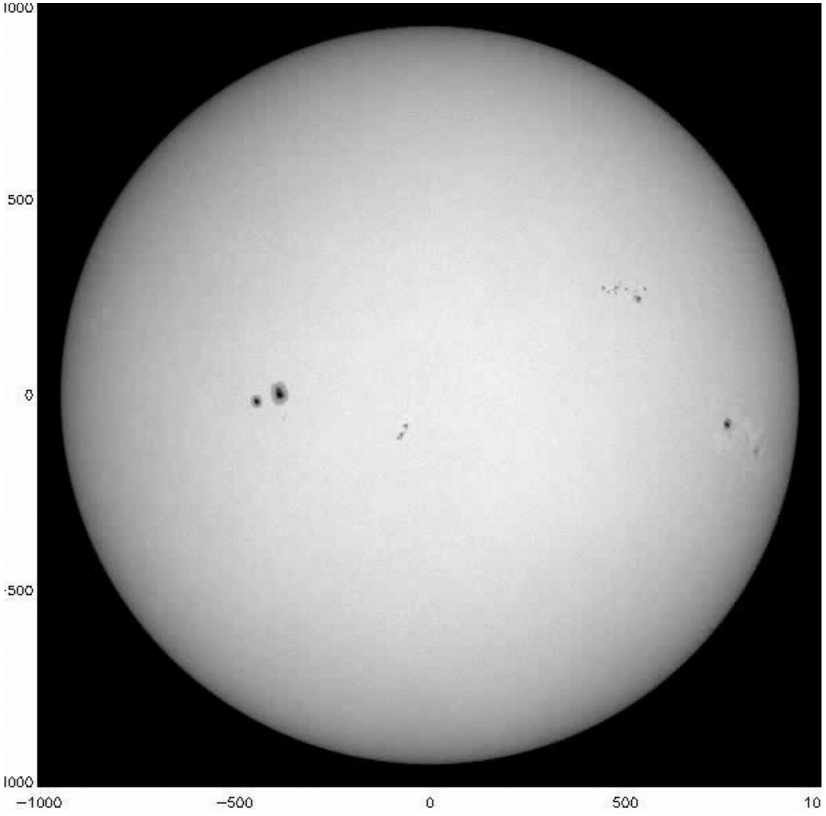
Why?

- Solar variability drives variability in the near-Earth environment
    - ➢ Magnetic field evolution drives that variability
- Unprecedented λ coverage, spatial and temporal resolution -> magnetised processes at intrinsic scales
    - ➢ A laboratory for astrophysics





EST Science Goals (a few)

- How does the magnetic field emerge to the surface & evolve?
- How is energy released and transported from the photosphere to the upper atmosphere?
- What is the origin of the localised explosive Sun?
- How is energy released and transported in solar flares?

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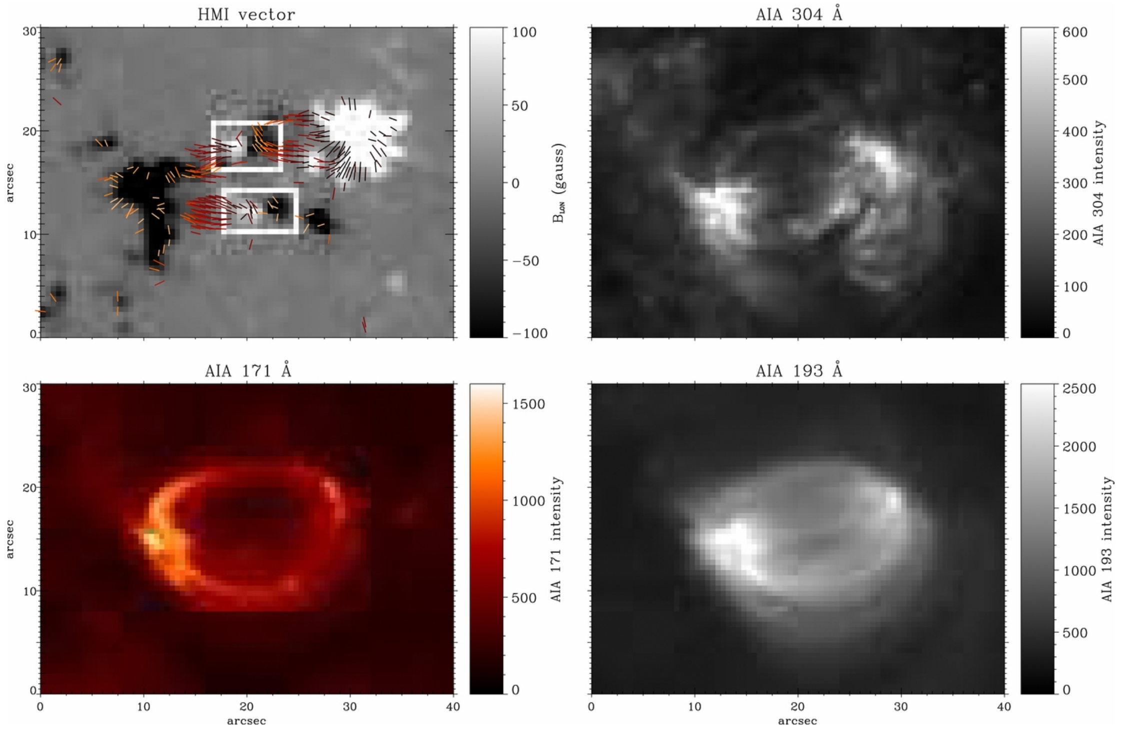
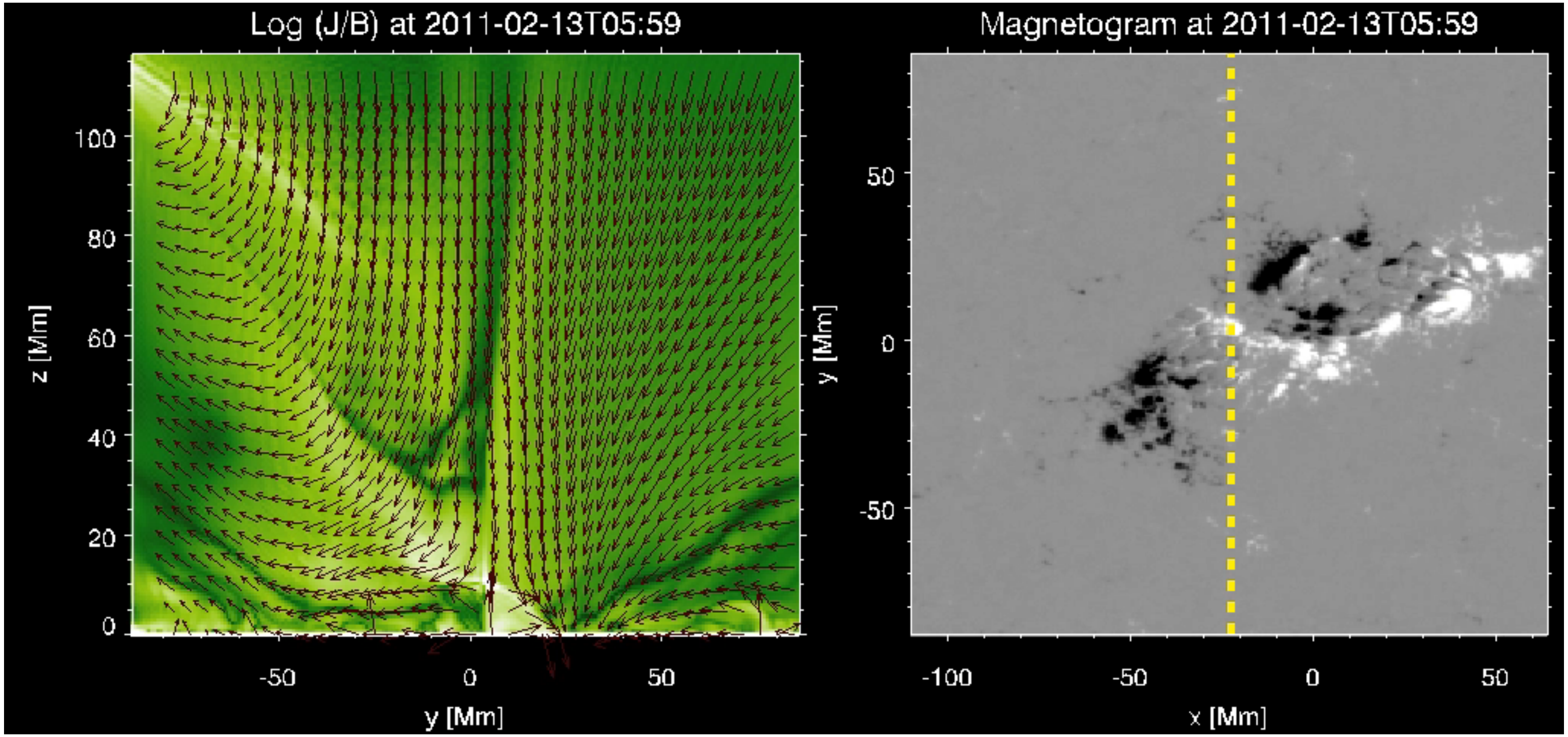
Magnetic flux emergence and evolution

- Flux emergence and evolution drive solar activity on all scales.
- Cannot fully understand the dynamo processes at work without also understanding transport to the surface.



Centeno, 2012

Flux emergence: data-driven modeling



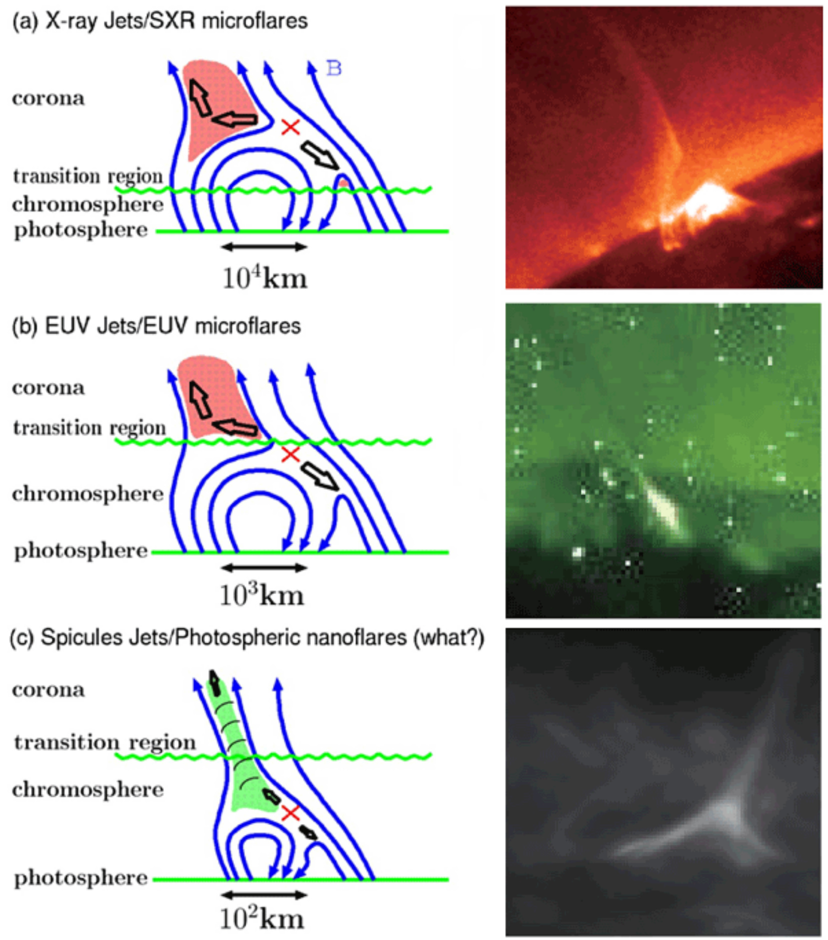
Cheung & DeRosa, 2012

Further advances require reliable vector velocity and magnetic field measurements.

Flux emergence and reconnection

- Flux emergence is a natural experiment for reconnection.
- Models need to reproduce observed manifestations, while including underlying physics

➢ EST observations can help constrain the models.

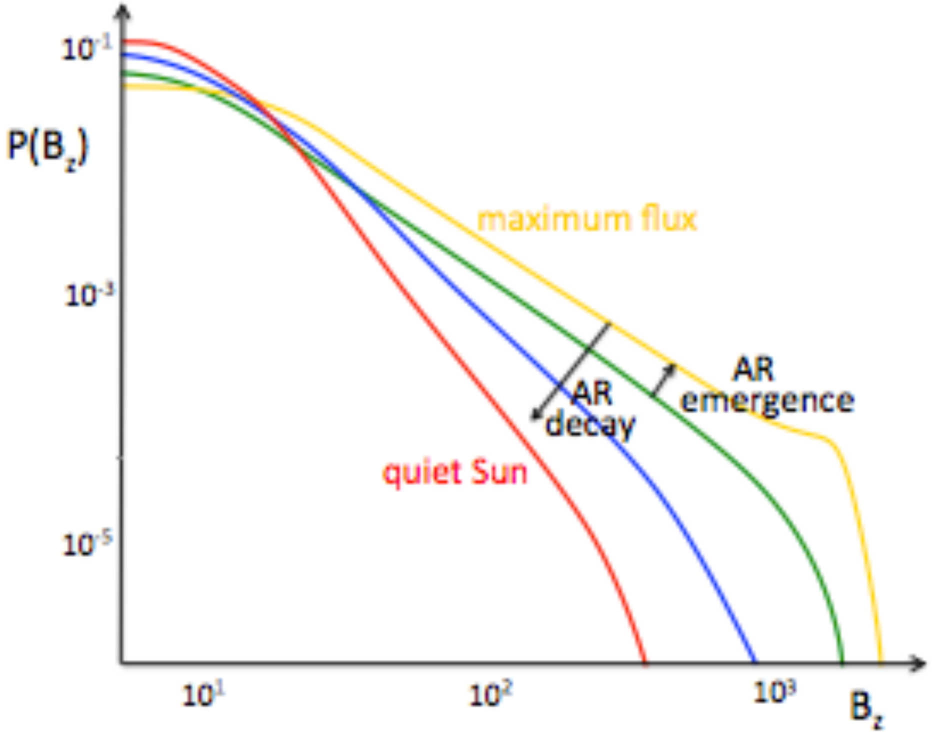


Shibata et al. (2007)

AR evolution

- Life cycle models of ARs may indicate depth from which AR fields originate.
- Recent work (Dacie et al., 2016) found B_Z distributions deviate from classical diffusion

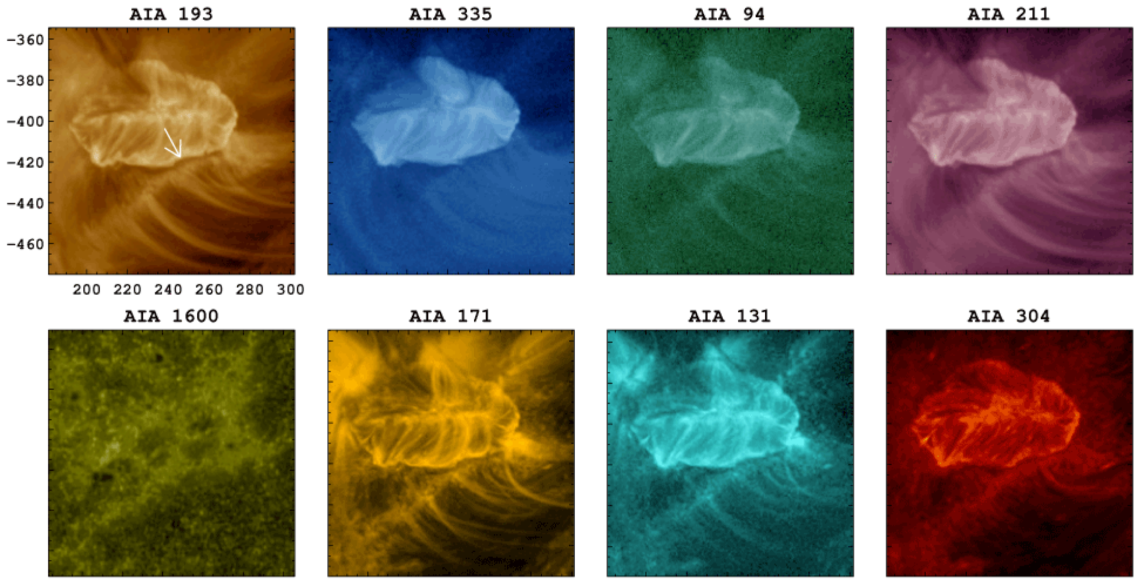
➢ Convection important in decay as well as emergence. How?

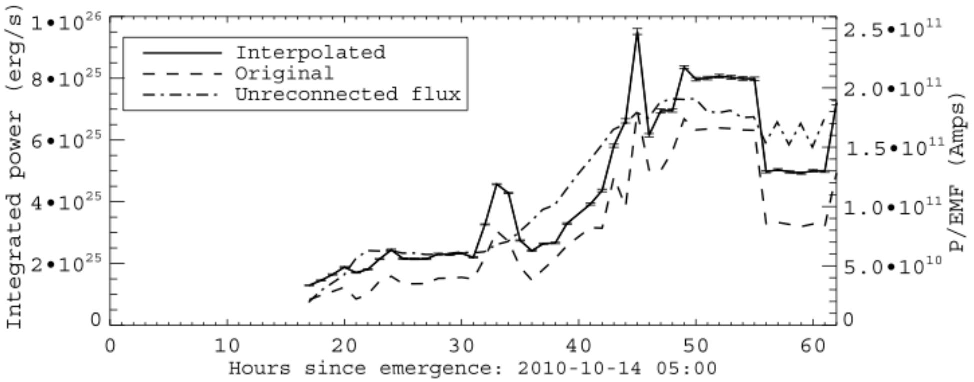


Dacie et al., 2016

Magnetic field emergence and heating

- Continuous horizontal motion of photospheric field will create current sheets -> nanoflares (Parker, 1988)
- Emerging flux can amplify this significantly.
- Energy can rival M/X-class flares.

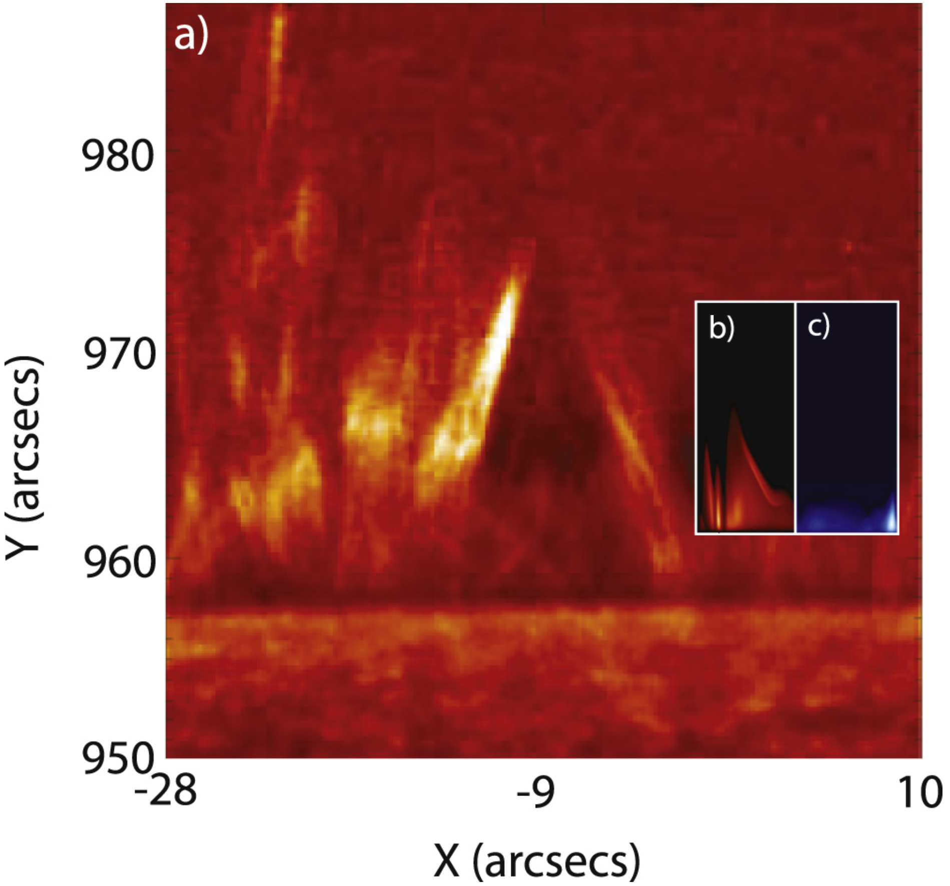




Tarr et al., 2014

Chromospheric heating & spicules

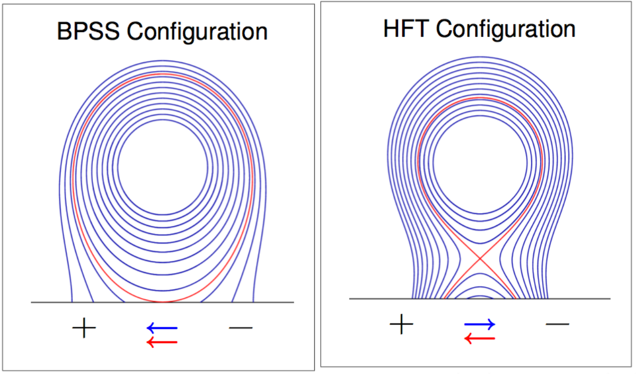
- Chromospheric heating and Type I spicules both produced by ponderomotive formation of shocks from transverse photospheric motion (Brady & Arber, 2016).
- Effect of non-local radiation transport and non-LTE?
- Type II spicules?

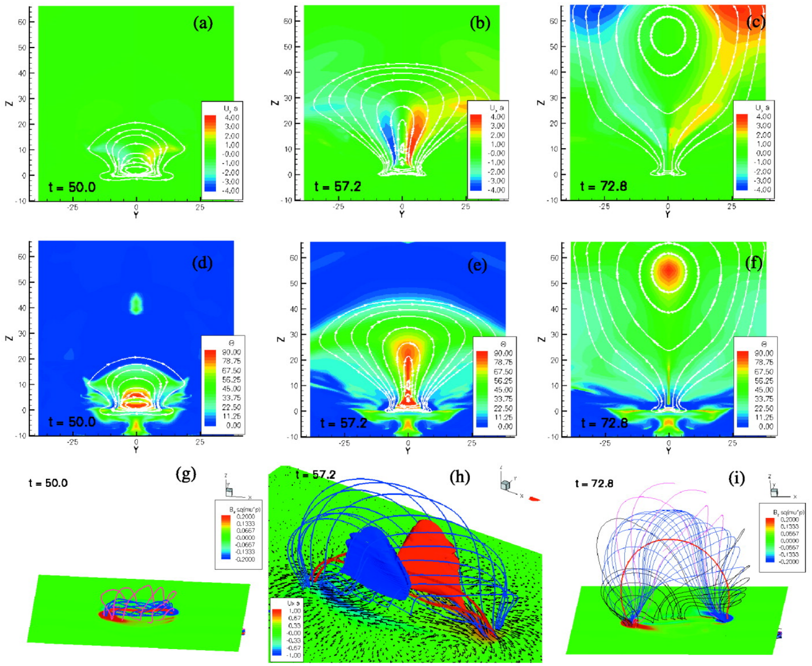


Brady & Arber, 2016
Tsiropoula et al. (2012)

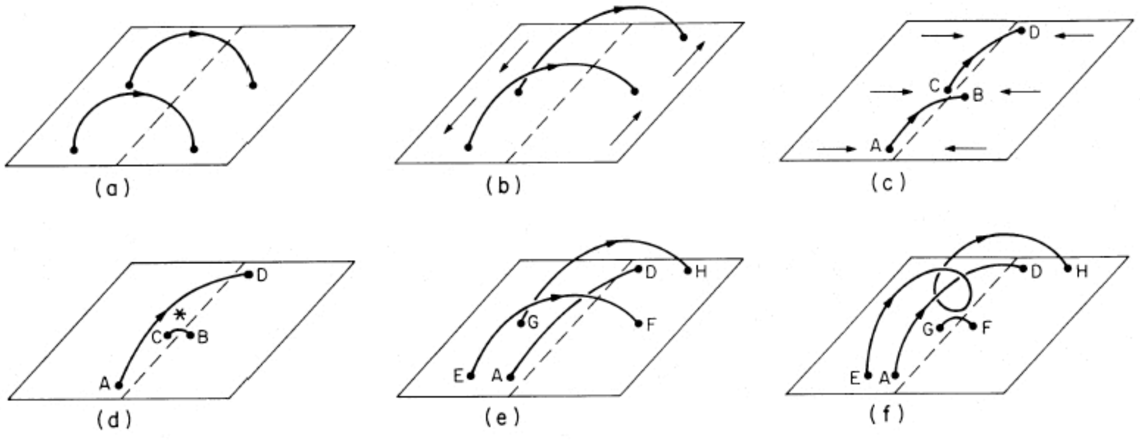
Magnetic flux rope formation and eruption

- Magnetic flux ropes believed to be present in many eruptions
- But when do they form?





Manchester IV et al., 2004

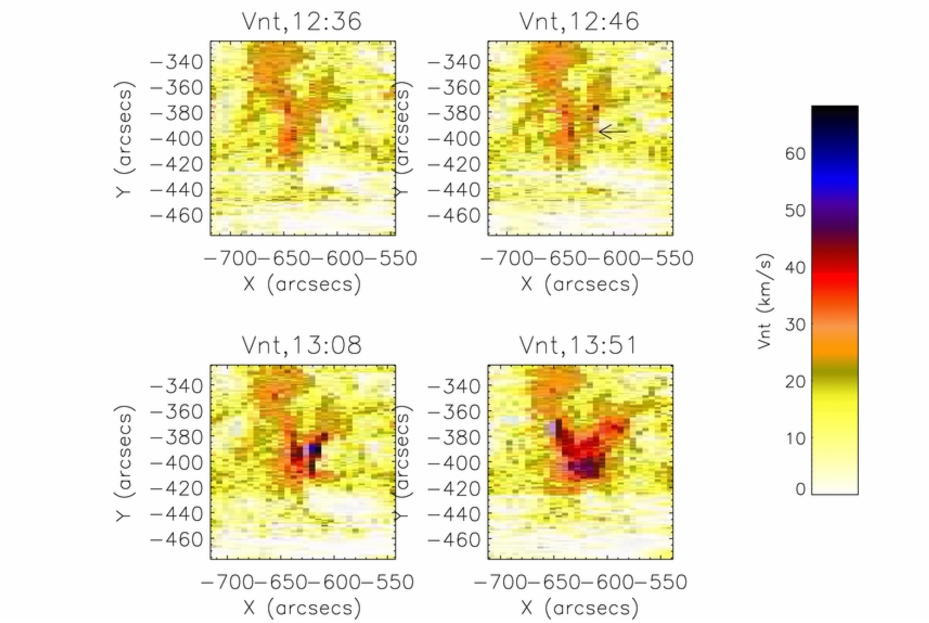


Van Ballagooijen & Martens, 1989

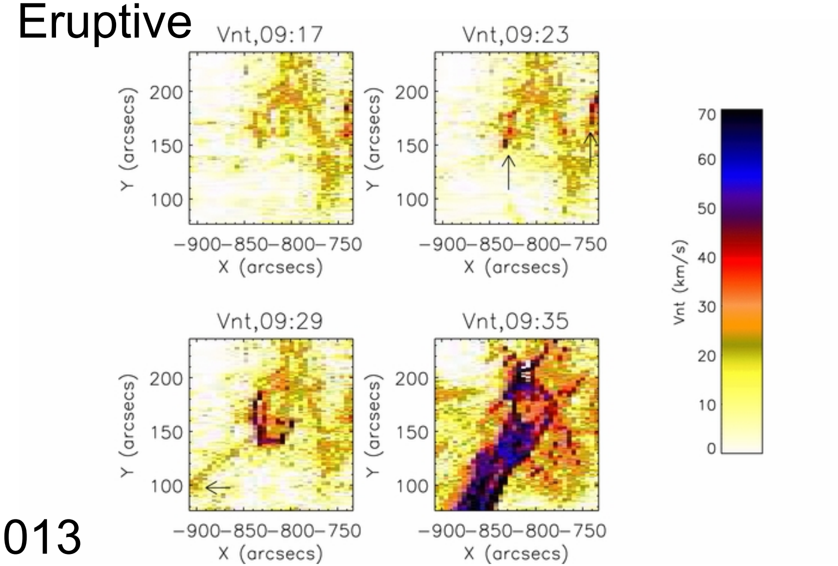
Coronal line widths as pre-flare/eruption indicators

- Increase 10s mins – hours pre-flare
- Spatial variations –
  - Non-eruptive around PIL
  - Eruptive –footpoints of erupting structure
- TR and chromosphere signatures?

Non-eruptive



Eruptive

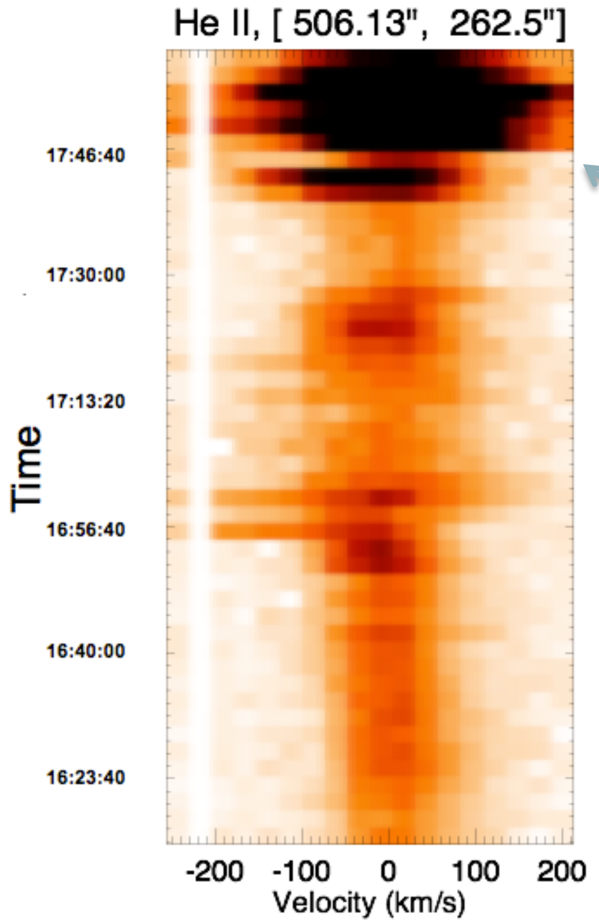


Harra et al., 2013

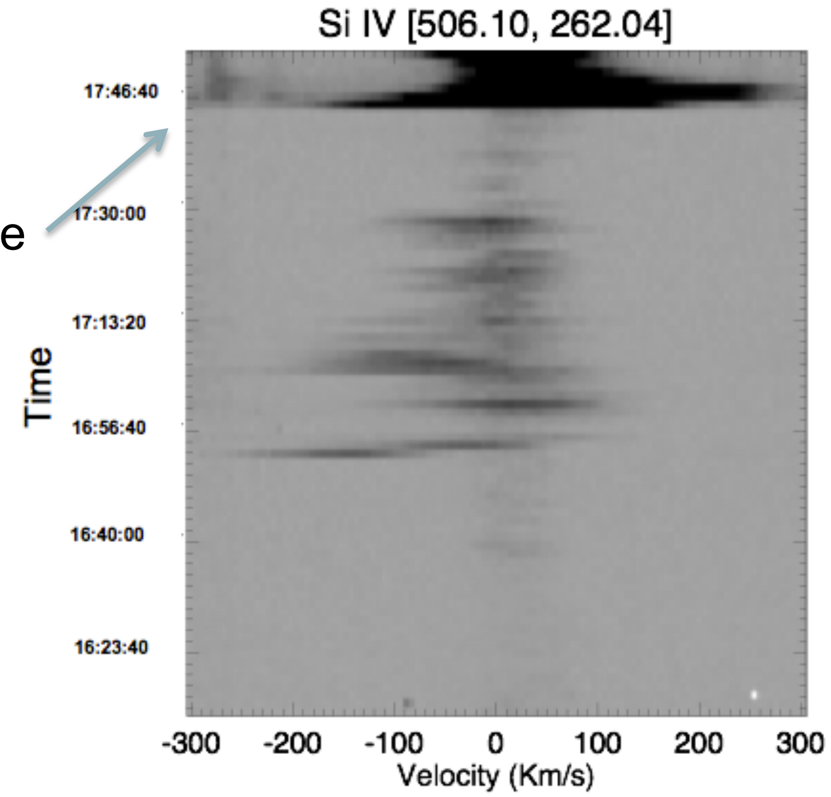
for Solar Telescopes

TR and chromosphere?

Significant dynamic activity (including Doppler flows) ~ 40 mins before flare onset – signature of building flux rope?


He II, [506.13", 262.5"]

X flare


Si IV [506.10, 262.04]

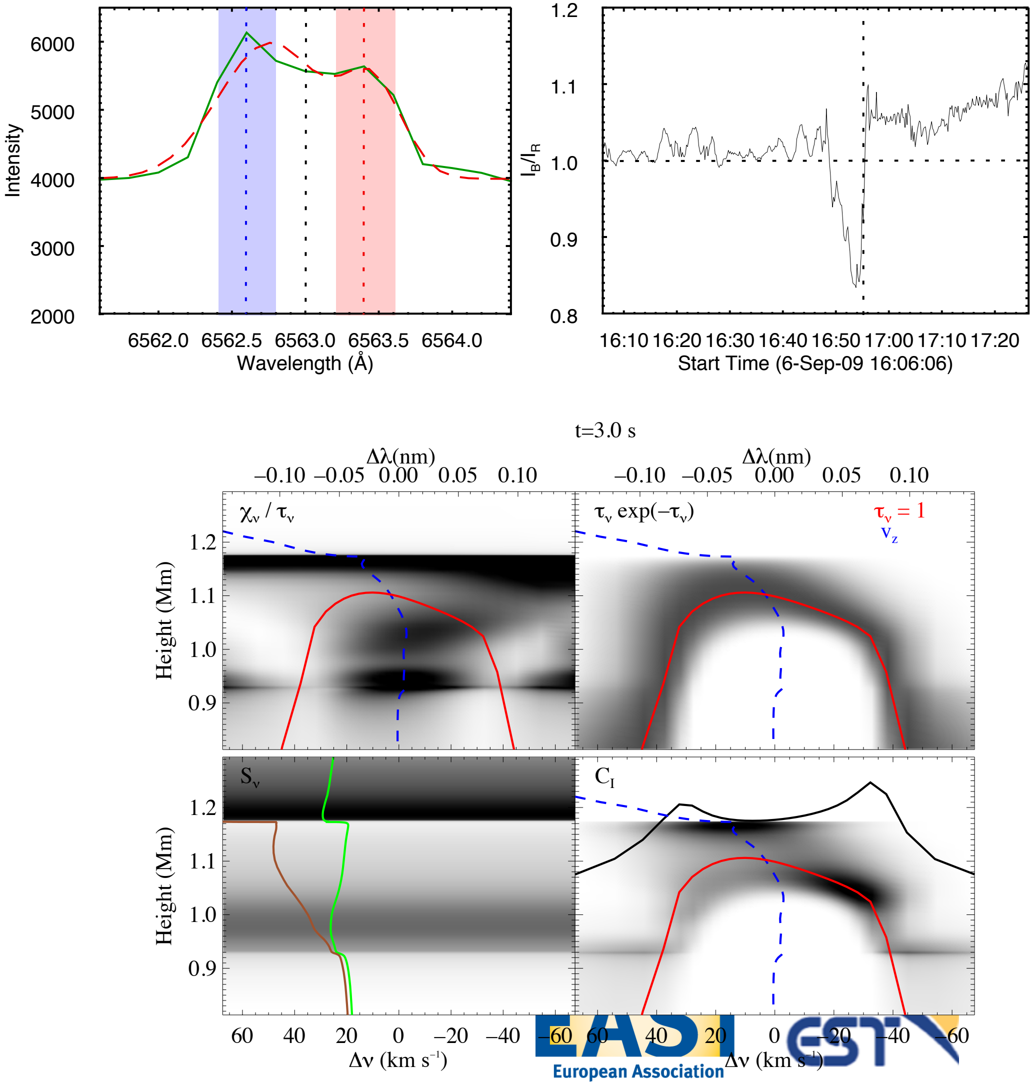
Woods et al. (2017)

Line shifts, asymmetries and velocity fields – beware!

- Corona – optically thin, ‘simple’ interpretation of Doppler velocities
- Shifts in optically thick chromospheric lines also seen – not always what they seem (Kuridze et al (2016))

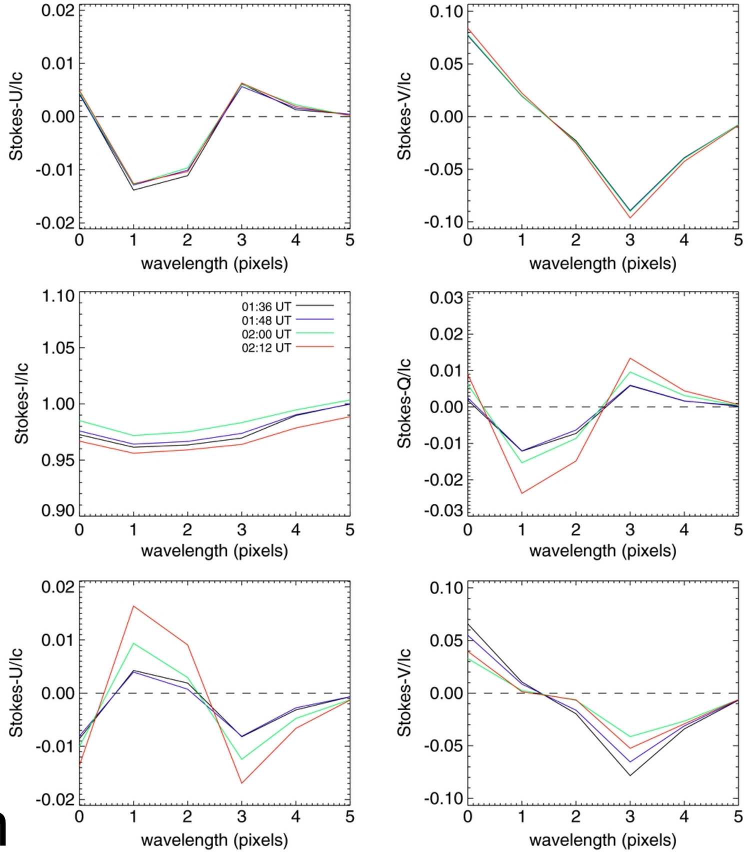
➢ EST - more lines/ better resolution – must have simulations

Kuridze et al., 2016

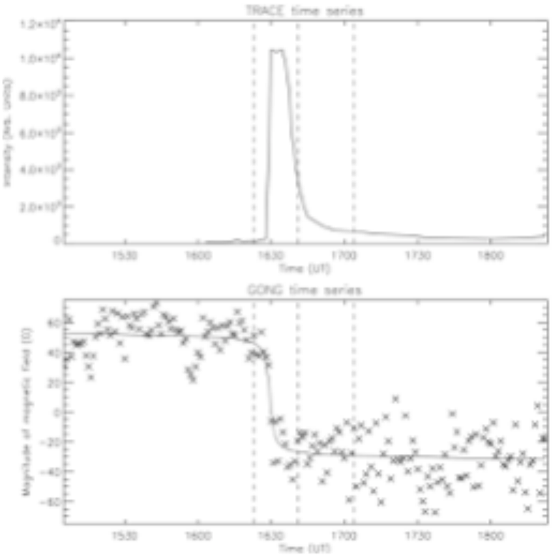


Magnetic field changes - irreversible

- Permanent changes in B firmly established – ‘coronal implosion’ (e.g. Sudol & Harvey (05); Petrie & Sudol (10).
- Increase of linear polarization not enough on its own – need relative variation of Q, U, and V.



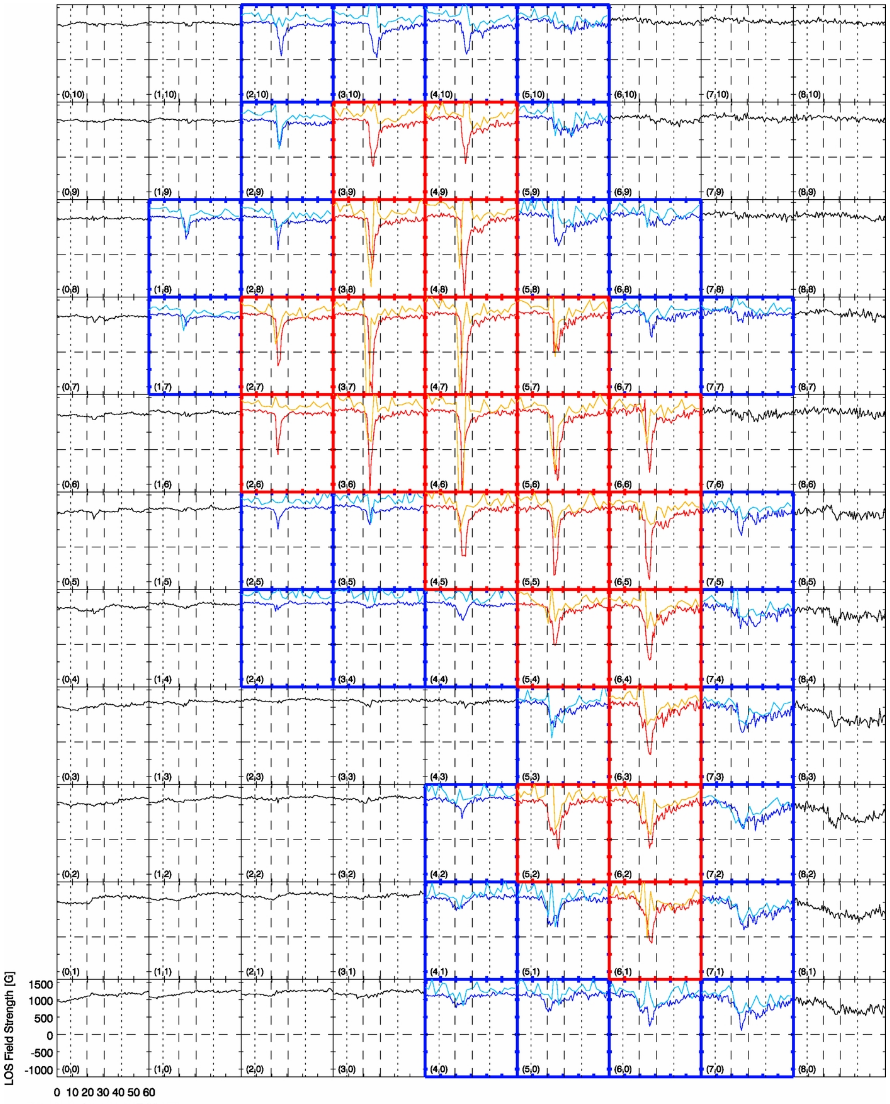
Gosain, 2012



Johnstone et al., 2009

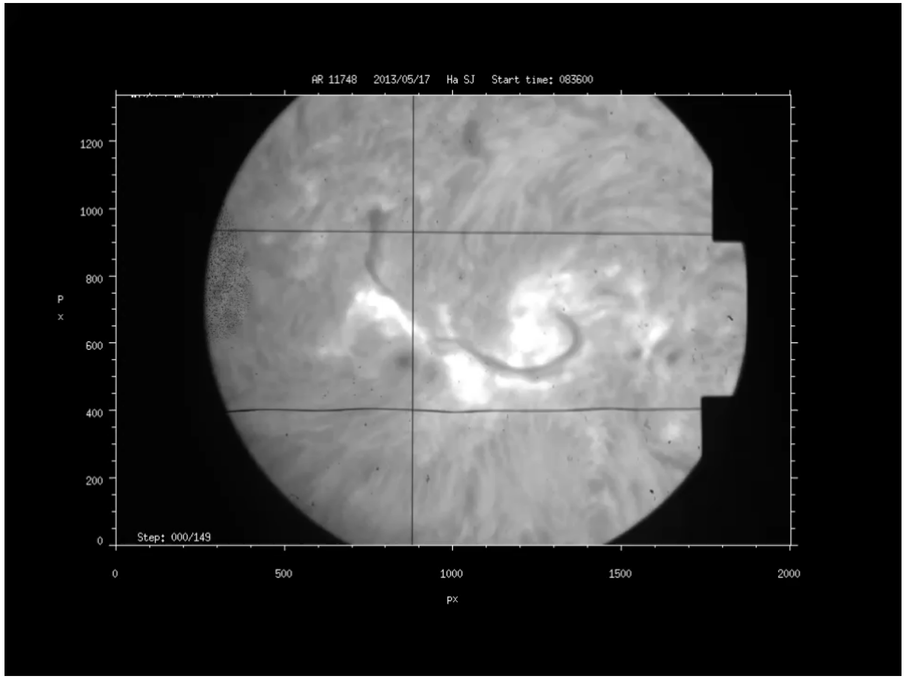
Magnetic field changes – transient reversals

- Artifact of flare related heating - (e.g. Patterson, 84; Maurya et al.,12)
- Strongest changes in weak field – full line profile (e.g. Patterson, 84)
- Changes in strong field – samples of the line profile only (e.g. Maurya et al., 12)
- Real changes in horizontal field (Harker & Pevtsov, 13 - consistent with field rotation
- Increases without reversal?
- ➢ Spectropolarimetry + line simulations

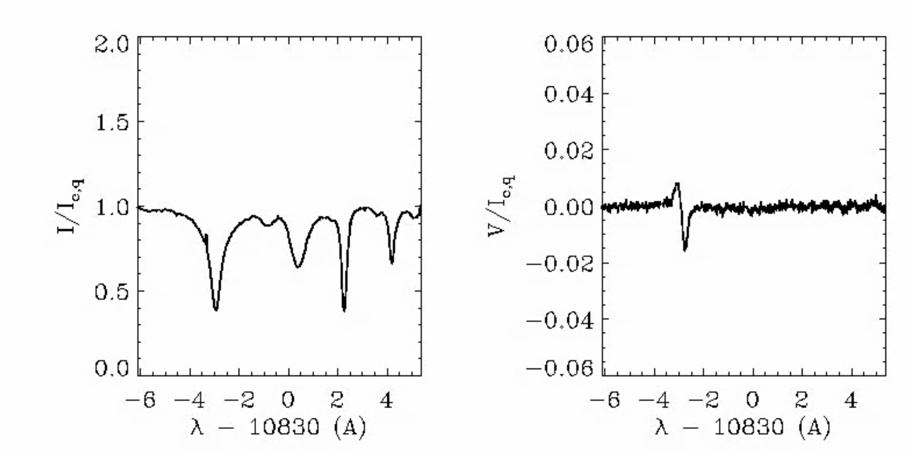


Harker & Pevtsov, 2013

Magnetic field changes in flares at high resolution



Si i 10827 Å; He 10830 Å



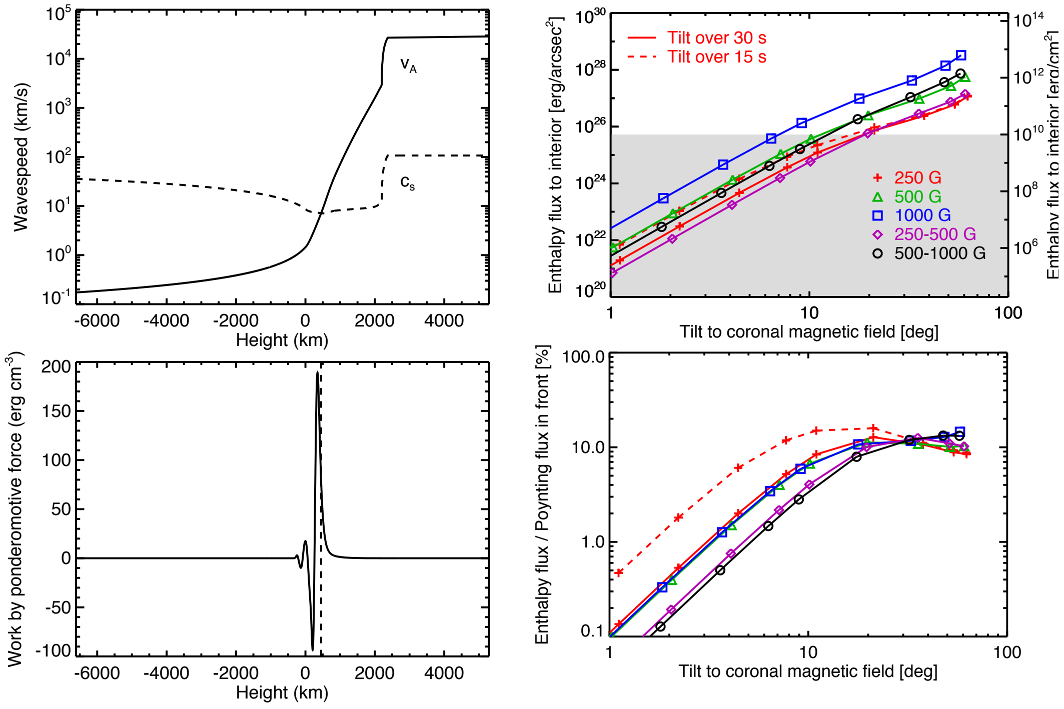
Kuckein et al., 2015

- B stronger in the chromosphere
- Rapid, transient decrease in B during impulsive phase
- Evaporation flows ~ 100 ms^{-1}

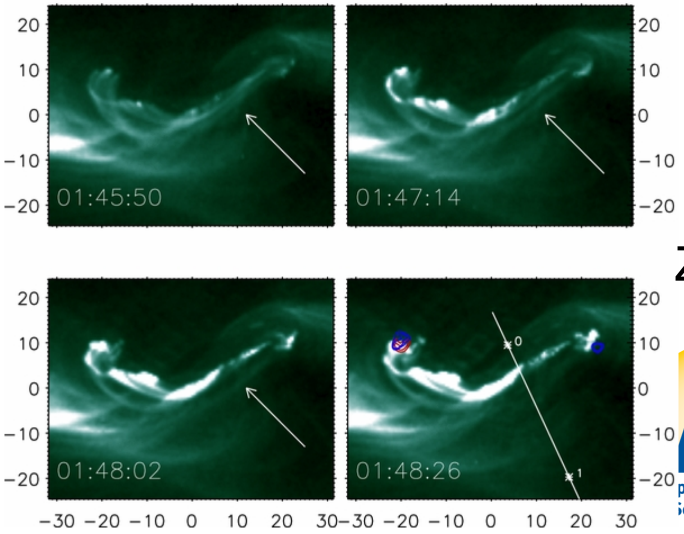
Magnetic re-structuring as a driver of sunquakes

- Chromospheric signatures of Alfven waves
- Increase in horizontal B/change in tilt – earlier timing for chromospheric B
- TR/chromo oscillations

➢ EST vector magnetic field/ chromospheric line profiles/Doppler shifts



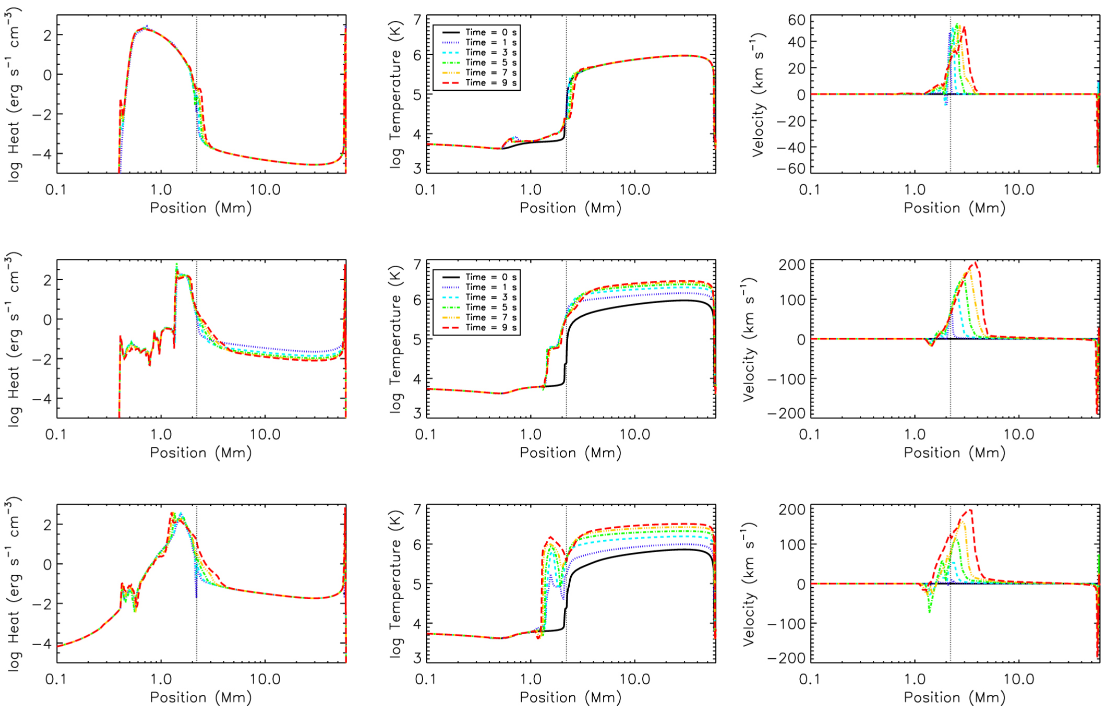
Russell et al., 2016



Zharkov et al., 2011

Role of Alfvén Waves?

- Additional energy transport mechanism
- Can heat the TMR ~ 100 K -> WLF? (Russell & Fletcher, 2013
- Can also heat chromosphere & produce evaporation (Reep & Russell, 2016)

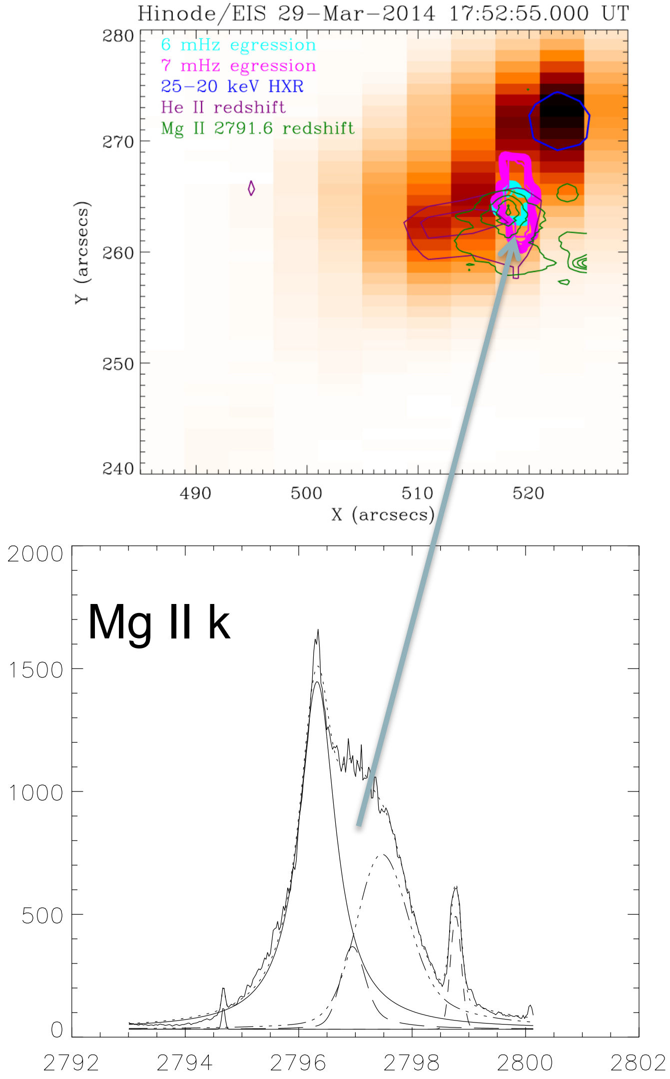


Reep & Russell, 2016)

Evidence?

- Broadening of chromospheric lines/ absence of co-spatial HXR emission
- Phase shift between transverse field changes & flows

➢ EST line profiles/ vector B



v_D =134.7 km s^{-1} => wave energy flux ~ 10^{11} erg $cm^{-2}s^{-1}$ (Matthews et al. 2015)

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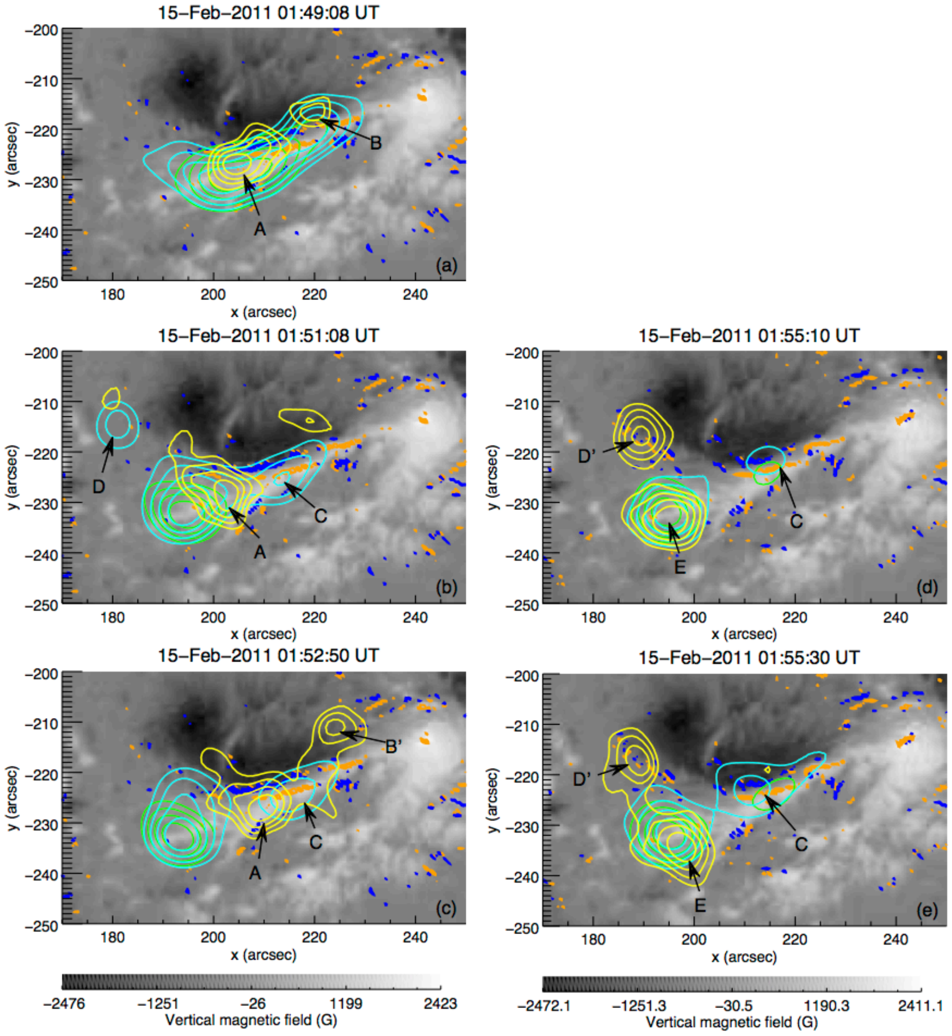
How & where are particles accelerated?

- New insights from 3D:
  - Coronal X-ray emission overlies photospheric current ribbons
  - New >50 keV HXR source appears with increased photospheric current
  - > clear link between particle acceleration and reconnecting current sheets

➢ EST –chromospheric currents – where HXR sources are formed



Musset et al., 2015

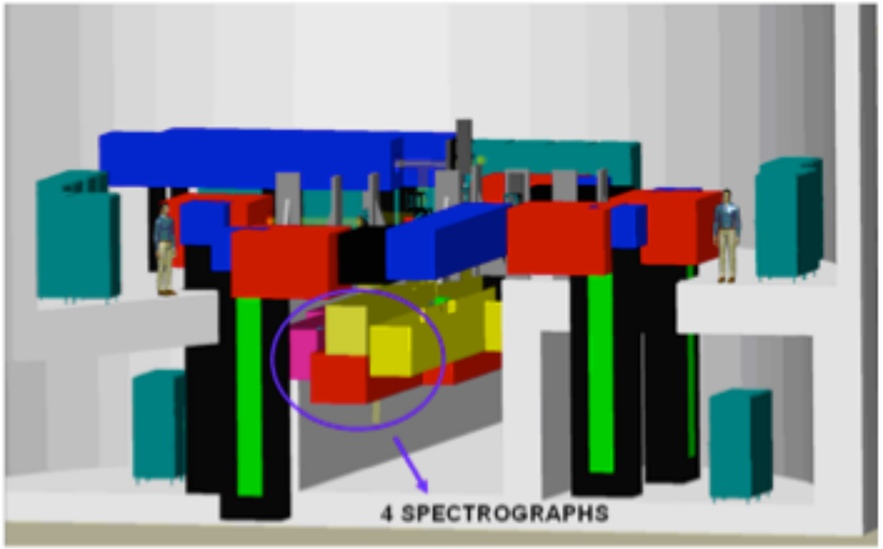
Telescope and instrumentation key requirements

- High angular resolution, with AO and MCAO for atmospheric distortion correction
- High precision polarimetric capabilities, for accurate magnetic field determination
- Simultaneous observation of photosphere and chromosphere

But….

•Small patch of the Sun at high spectral & spatial resolution in narrow spectral range => photon starvation.

•Polarimetric measurements at required sensitivity to accurately measure small-scale fields are even worse…



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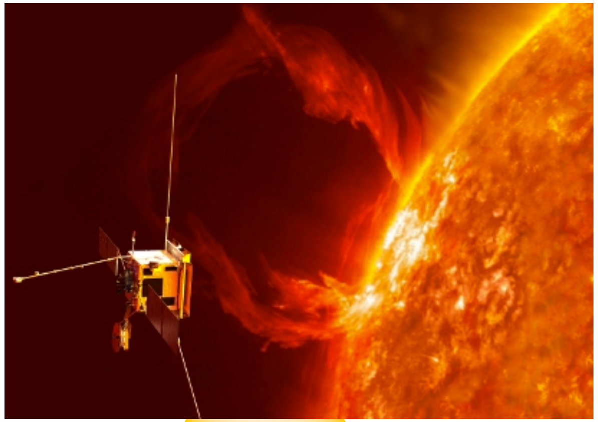
EST Design Baseline

- 4-meter diameter
- On-axis Gregorian configuration
- Alt-Az mount
- Simultaneous instruments
  - ✓ Broad-band imagers
  - ✓ Narrow-band tunable imagers
  - ✓ Grating spectrographs
- AO/MCAO integrated in the optical path

Complementarity with DKIST, Solar Orbiter, NGSPM

- High resolution, long-term studies become a reality – DKIST+EST (weather permitting!)
- Imaging/spectroscopy of the TR and corona to constrain energy transport to the outer atmosphere (SO/NGSPM(?))
- Out of ecliptic vantage points to constrain 3D structure; solar wind/ energetic particle origins (SO).

DKIST (credit: NSO/AURA/NSF)



Solar Orbiter (ESA/NASA)

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In summary

- High cadence, high spatial, spectral resolution and spectropolarimetric measurements of the lower atmosphere are needed to match the resolution of current models.
- EST and DKIST will be exceptional and unparalleled tools. (Too expensive from space).
- Must have imaging/spectroscopy of the TR and corona to understand the whole picture – Hinode(?)/IRIS(?)/Solar Orbiter/NGSPM (can’t do it from the ground).
- We need to build a new (international) generation with the expertise to exploit them fully.

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The end

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