Solar flares and eruptive events WG6

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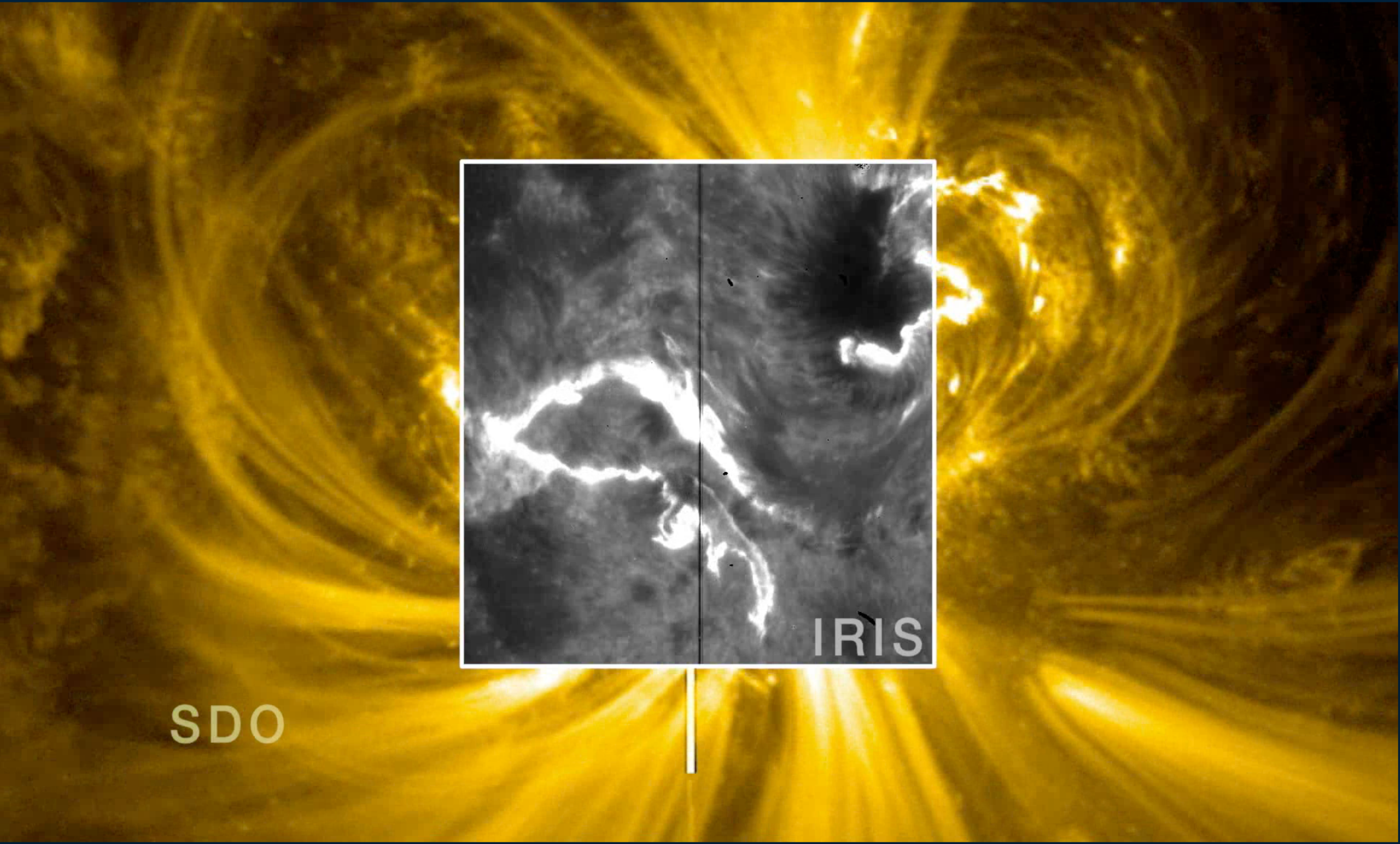
The flare chromosphere



Motivations

- How do we interpret chromospheric radiation to learn about the condition of plasma throughout the flaring lower atmosphere?
- How do we understand the magnetic field, its flare-related variations, and the relationship of these to other flare phenomena?
- How do we put this information together to learn about flare energy storage, release and transport?

Science topics identified by WG6

- Structure of the flaring (lower) solar atmosphere - temperature, flow speeds
- Diagnostics for non-thermal particles
- Magnetic field structure
- Magnetic field changes
- Pulsations and sunquakes
- Filaments and CMEs

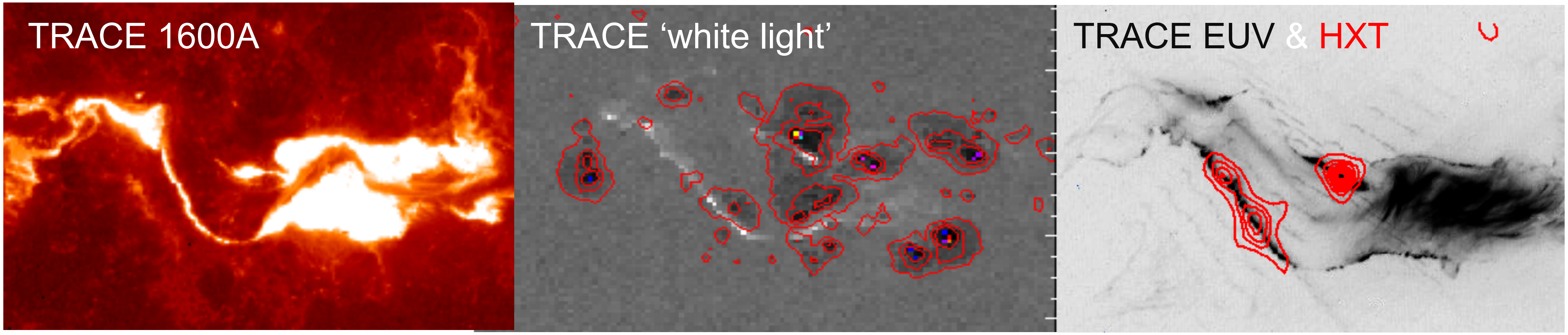
Flare emission in the lower solar atmosphere

Flares emit across the **entire EM spectrum**; ribbons seen IR-EUV

Radiant energy is concentrated in **the UV-optical range**

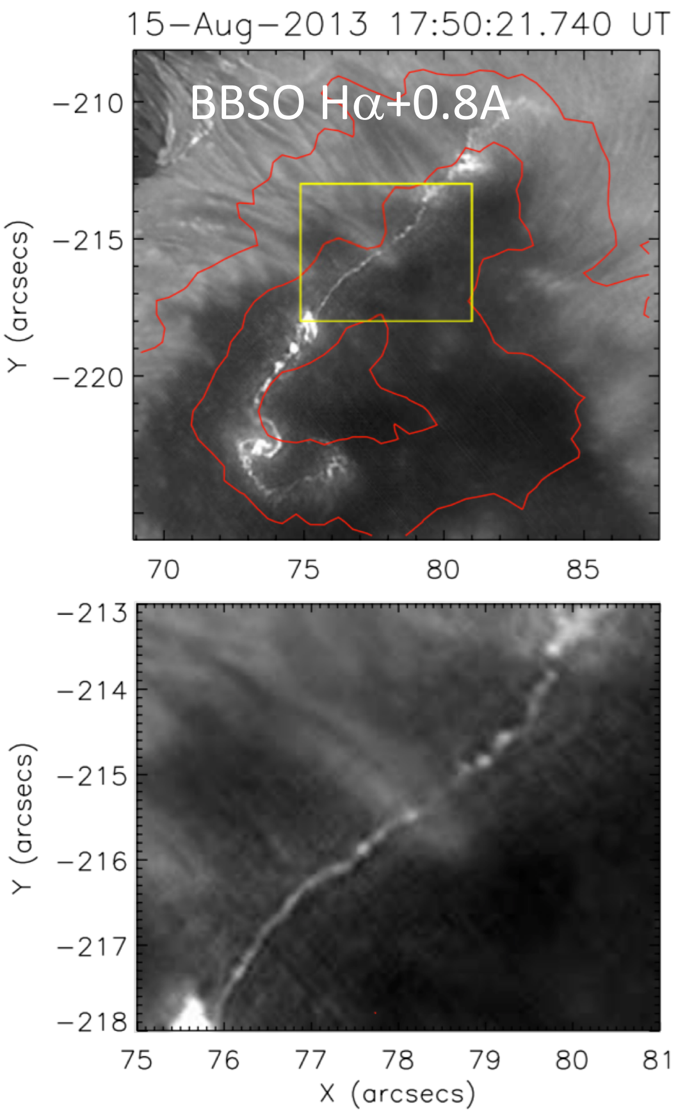
Emission is highly structured in **time, space, spectral** domains

Large **plasma speeds** are ubiquitous (evaporation/condensation)



Fletcher & Hudson 2001

The need for high spatial resolution



Sharykin & Kosovichev (2014)

Flare ribbons can be

- > 10000km long
- < 100km wide
- fragmented on ~ 100km scales

(These authors also show that ribbon is at site of strong vertical current.

They propose that energy deposition at ribbons is by joule heating.)

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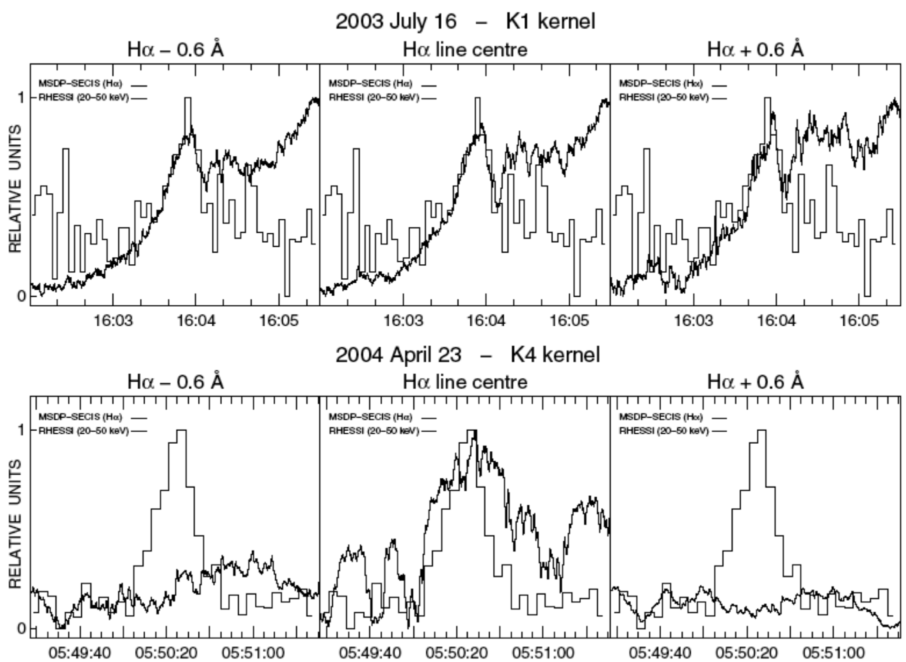
The need for high temporal resolution

- Variations are observed in Hα (heating) and HXRs (showing fast electrons) on timescales of seconds.
- HXRs and Hα sometimes correlated, but with times delays.



Białkow LC-MDSP-SECIS observations with 0.05-0.075s resolution (Radziszewski+07)

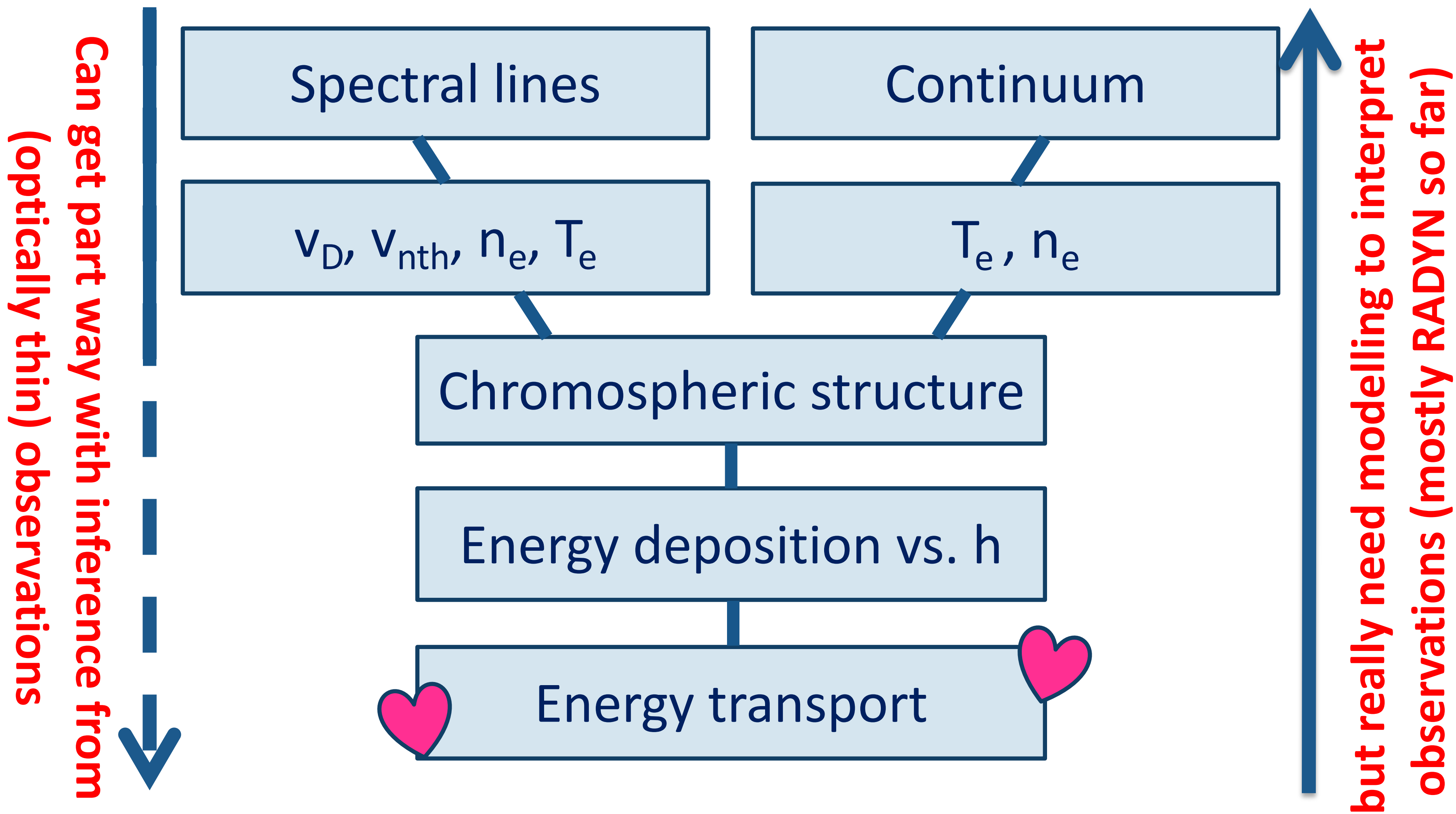
Hα produced (primarily) by increased heating.

Typically $\Delta t = t_{H\alpha} - t_{HXR}$ ~ 1-6s is observed (Radziszewski+07, 11)

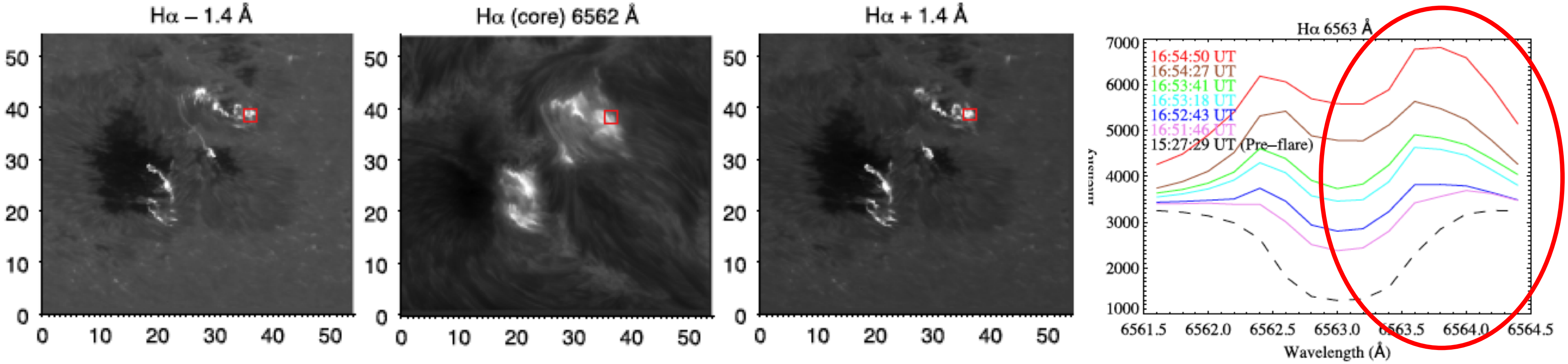
Time-dependent non-LTE models predict delay ~ 1s

Need to reduce effects of seeing to find true chromospheric fluctuations and timescales

The need for sampling over many atmospheric levels

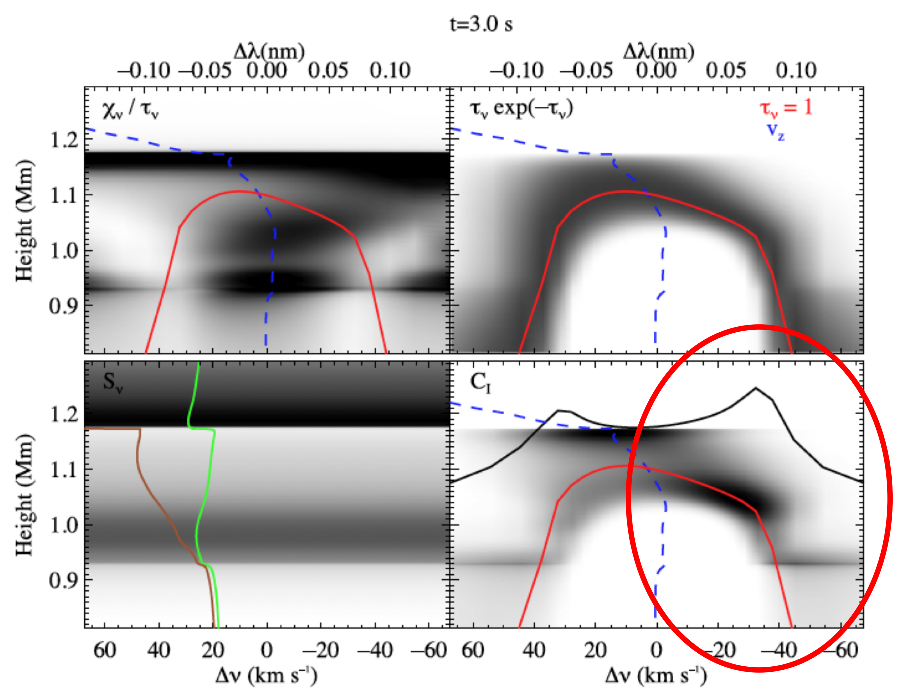


Example: interpreting Hα line profiles



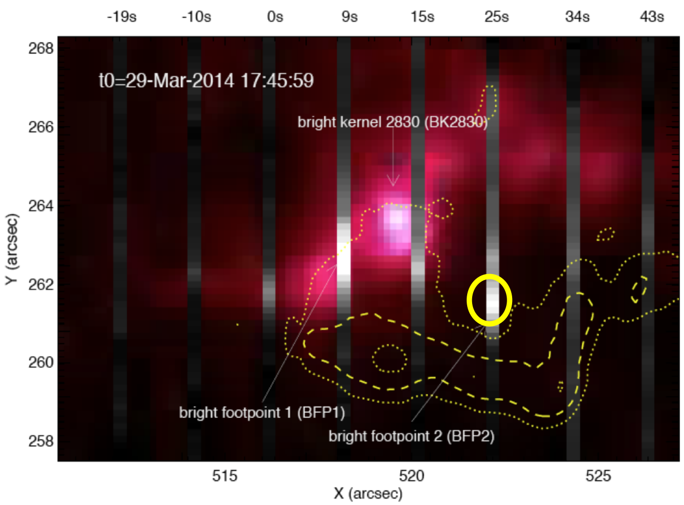
SOL2014-09-06T16:56 with CRISP, Kuridze+15)

- Hα line profile encodes both velocity and opacity structure
- RADYN simulations => enhanced red wing comes from opacity maximum being on blue side, i.e. blueshifted absorption not redshifted emission.



Example: IRIS two-component lines

Kowalski+17



- Cooler lines: enhanced static component and broad redshifted component.
- RADYN & RH modelling – stationary heated layer at ~500 km plus overlying downward moving condensation.
- Though broadening not explained, continuum cannot be modelled consistently.

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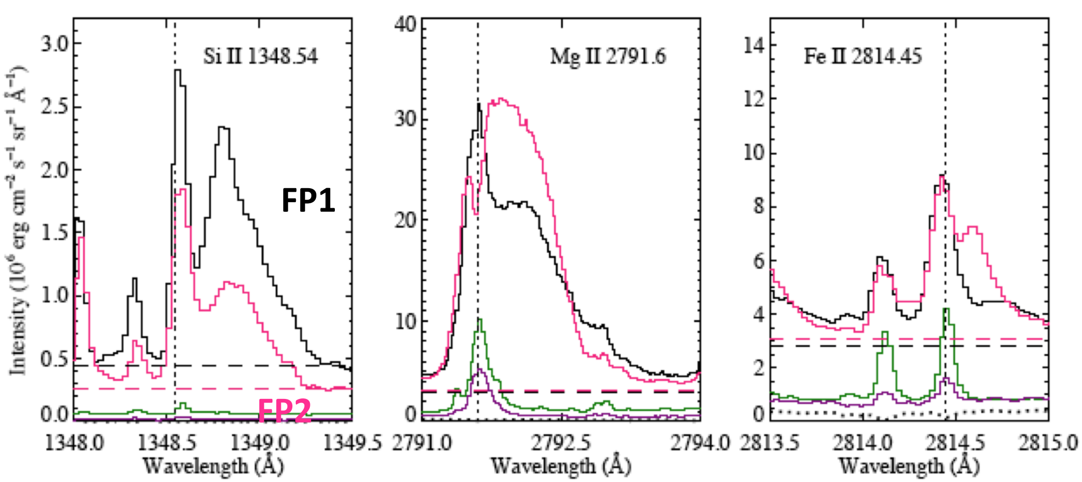

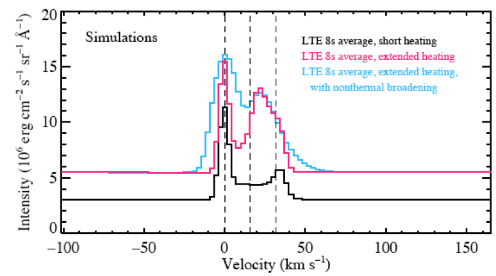

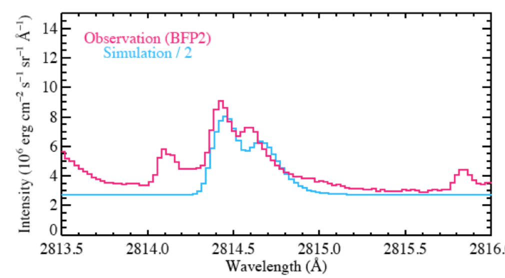

Discriminating heating mechanisms with multi-line observations

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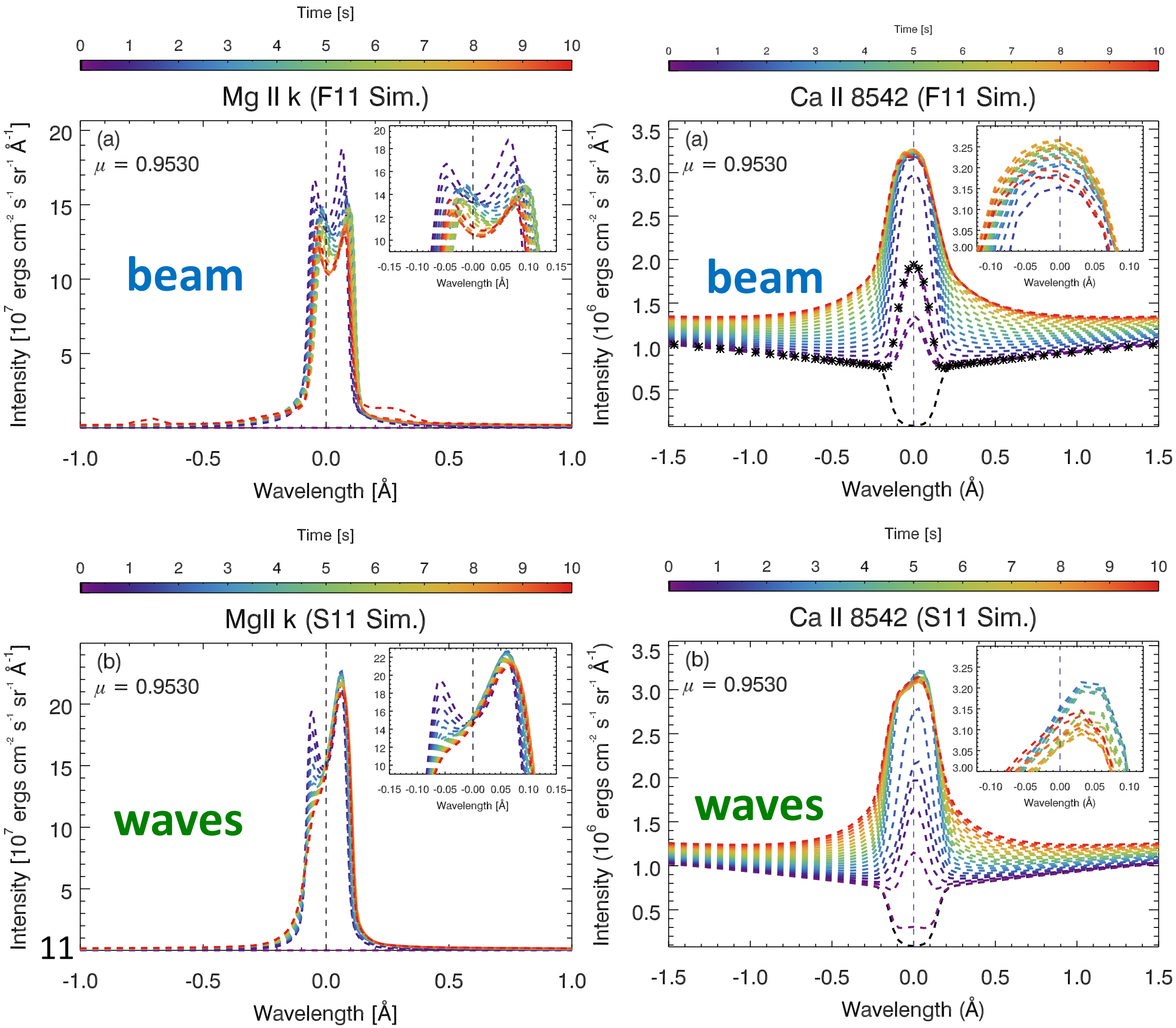
Mg II k Ca II 8542



RADYN flare simulations run with electron beam heating (top) and Alfvén wave heating (bottom)

Different modes of energy input give qualitatively different line profile shapes

Effects depend on atmospheric layers sampled.

Note – relative timing of excitations will also be important

Kerr+ ’16

Continuum observations

Continuum is a major source of flare radiative loss.

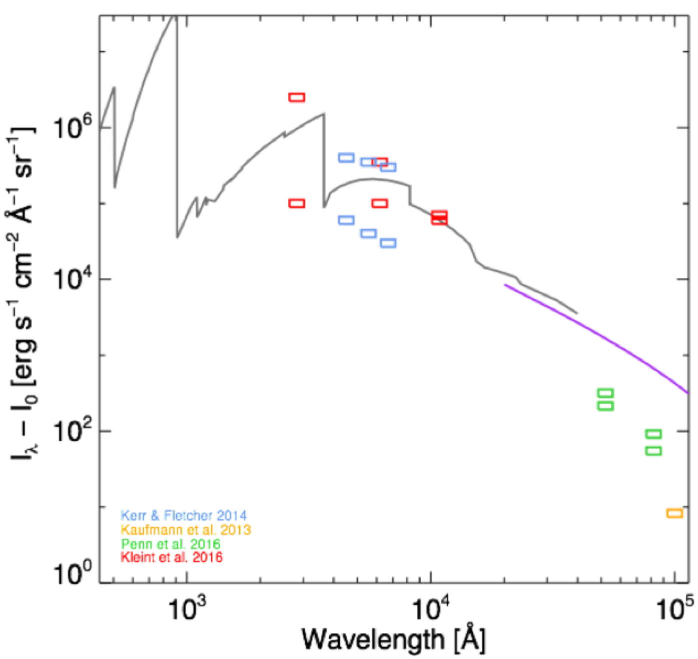
Radiation mechanism not yet pinned down

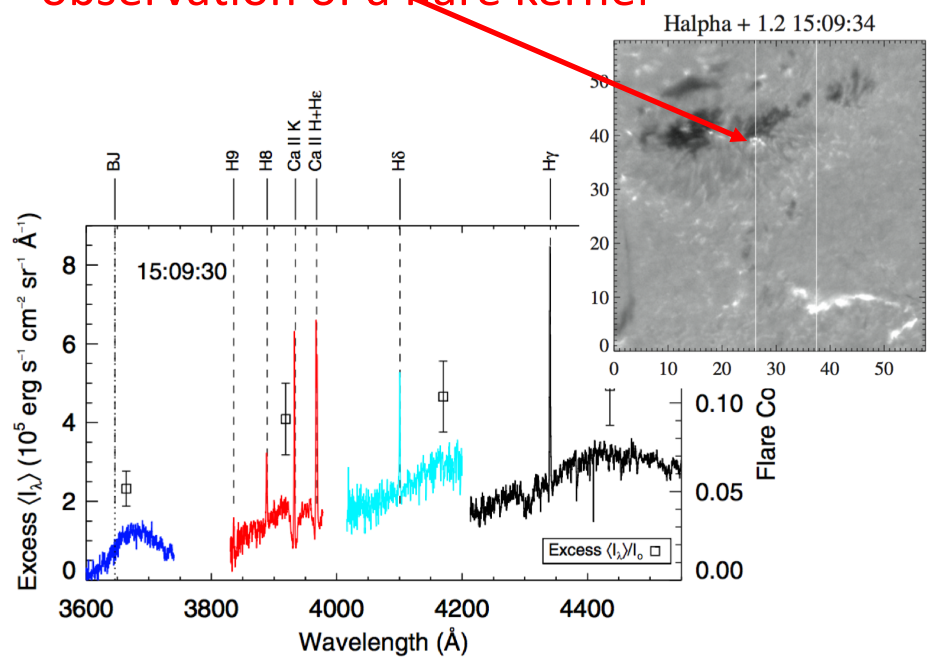
Need to sample around the Balmer jump and Paschen jump

Model-data comparison for some continuum measurements

Fortunate spectroscopic observation of a flare kernel

Kerr+18 in prep

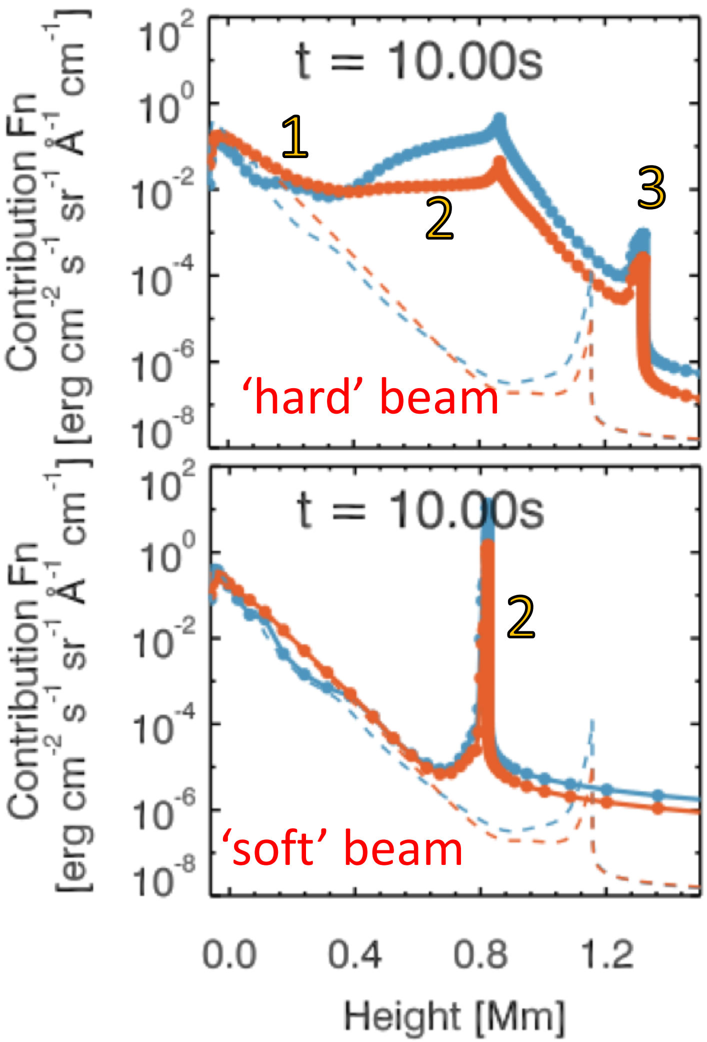




Kowalski+14

Optical/UV continuum modeling

Blue = 3550 A
Orange = 5790 A



Beam-heated models (Kerr+18 in prep)

Emission mechanism depends on nature of energy input. Shown here are a hard and a soft beam

- 1 = H^{-} recomb. continuum, Paschen-balmer backwarming]
- 2 = H recomb. following collisional ionisation by non-thermals
- 3 = H recomb. following collisional ionisation by thermals

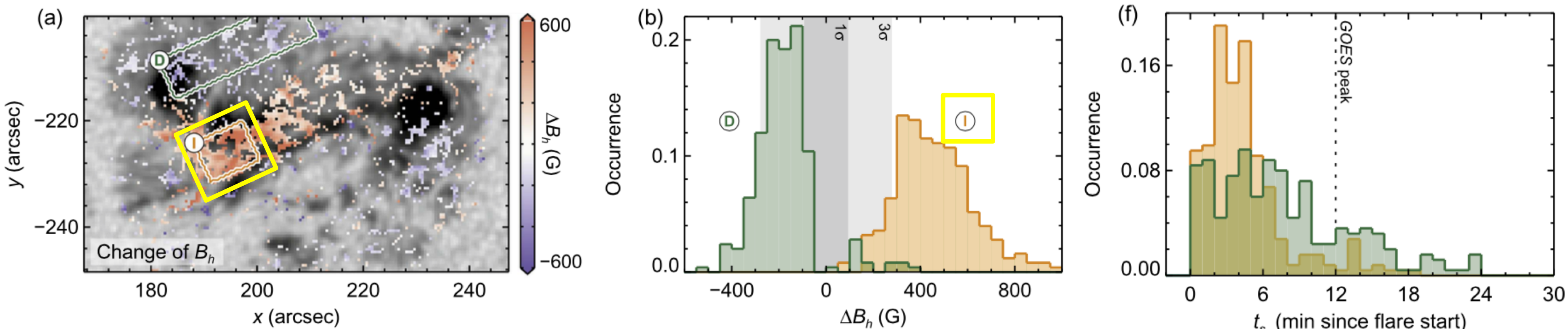
n.b. ionisation (thermal & non-thermal) and recombination is critical for flare energy balance.

Photospheric spectropolarimetry – field changes

Typically, abrupt changes in photospheric magnetic field occur during a flare as energy is released (e.g. Sudol & Harvey 2005, Petrie 2012, 2015).

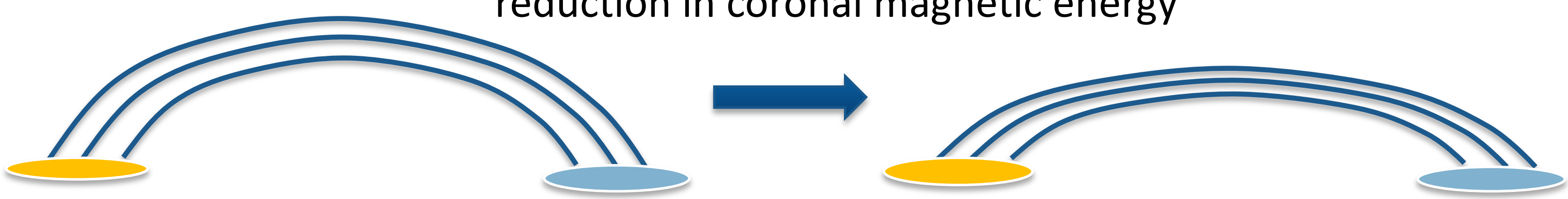
B_h increases across PIL

Change happens rapidly



Sun+17 using HMI

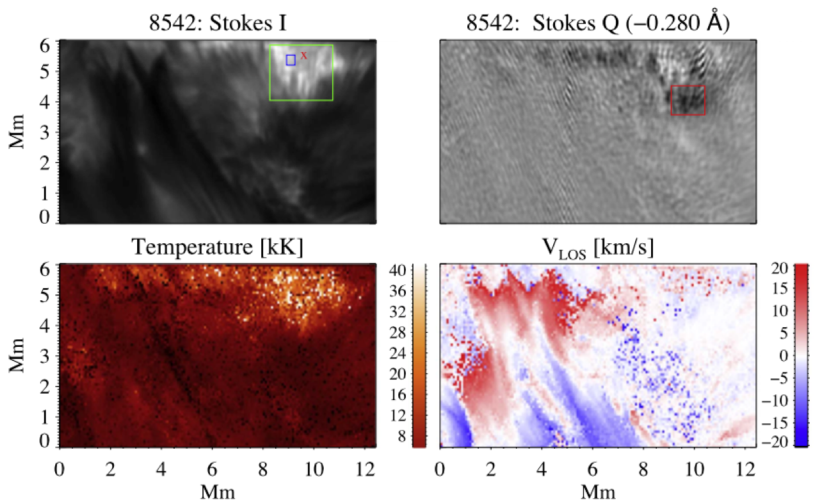
Field 'collapse' associated with reduction in coronal magnetic energy



What about change in vertical component of B, variations in shear or twist?

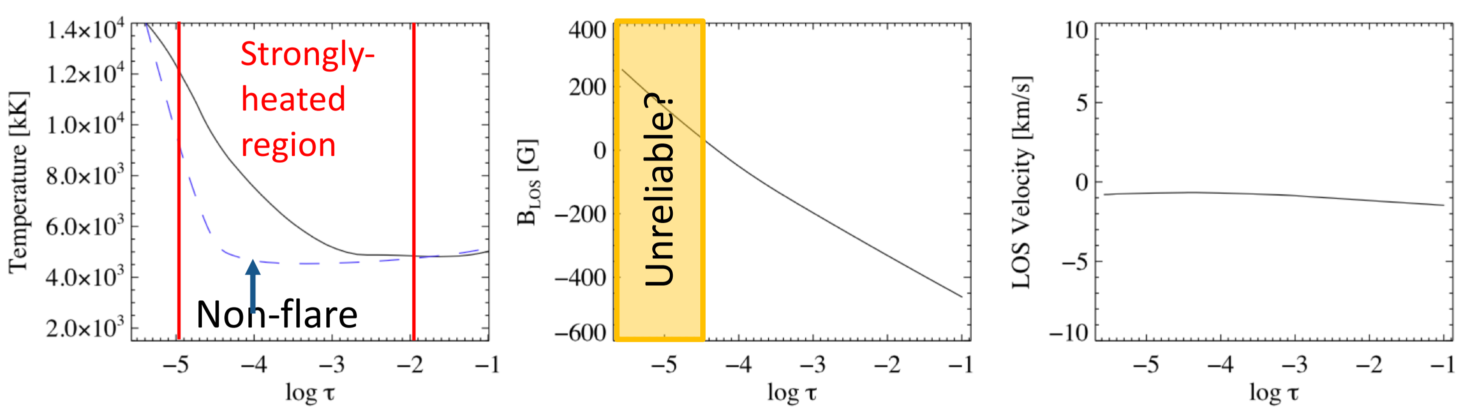
Chromospheric spectropolarimetry

Relatively few observations of this type (e.g. Kleint & Judge 2011, Fischer+12, Kuckein+2015, Kuridze+15)



Kuridze+18 use non-LTE inversions (NICOLE) of Ca 8542 to obtain chromospheric parameters in a flare.

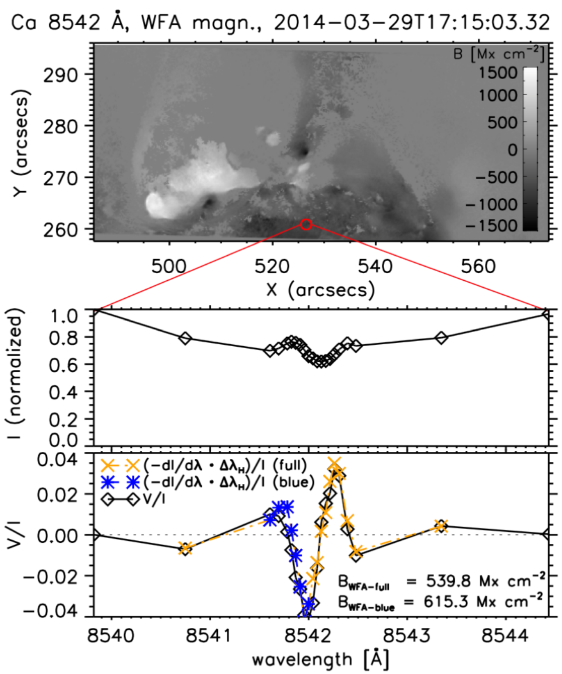
Though flare chromospheres are very far out of equilibrium – *caveat emptor*

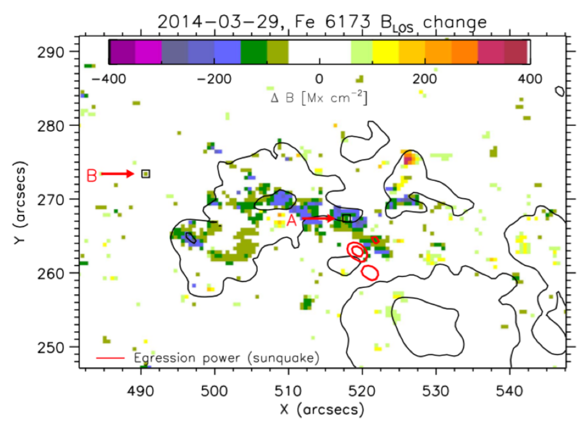


Chromospheric field changes

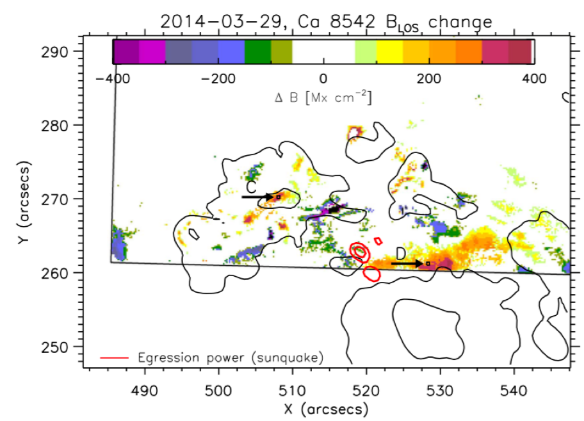
Kleint (2016) Ca 8542 spectropolarimetry of SOL20140329T17:48

- Zeeman splitting measurements, B_{LOS} from weak-field approximation
- Chromospheric field variations larger than photospheric field variations….
- …But not clearly related to photospheric changes
- Changes not consistent with simple 'collapse' of field – needs some (un)twisting?





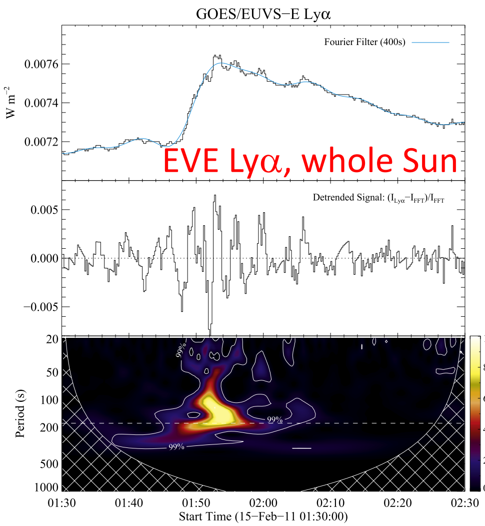
Photospheric changes (G-band)



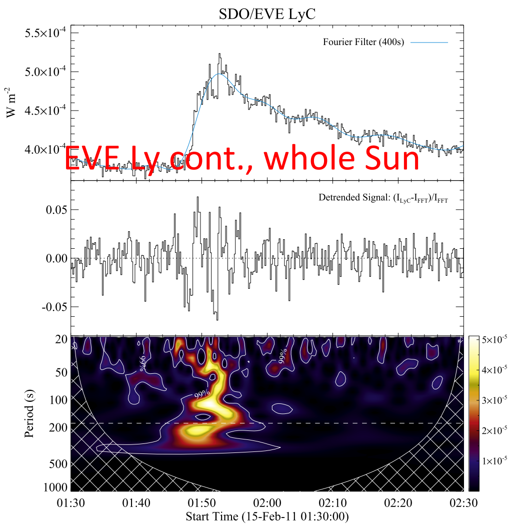
Chromospheric changes (Ca II 8542)

Chromospheric pulsations

Hints of chromospheric pulsations during flares – what is their cause and how are they related to other processes in the flaring atmosphere?

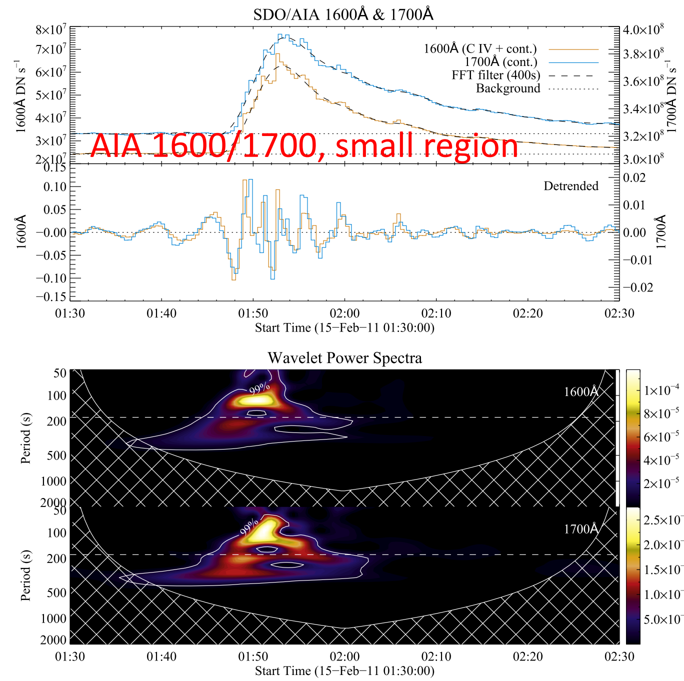


τ ~ 100 - 200s



τ ~ 100-300s

Milligan+17

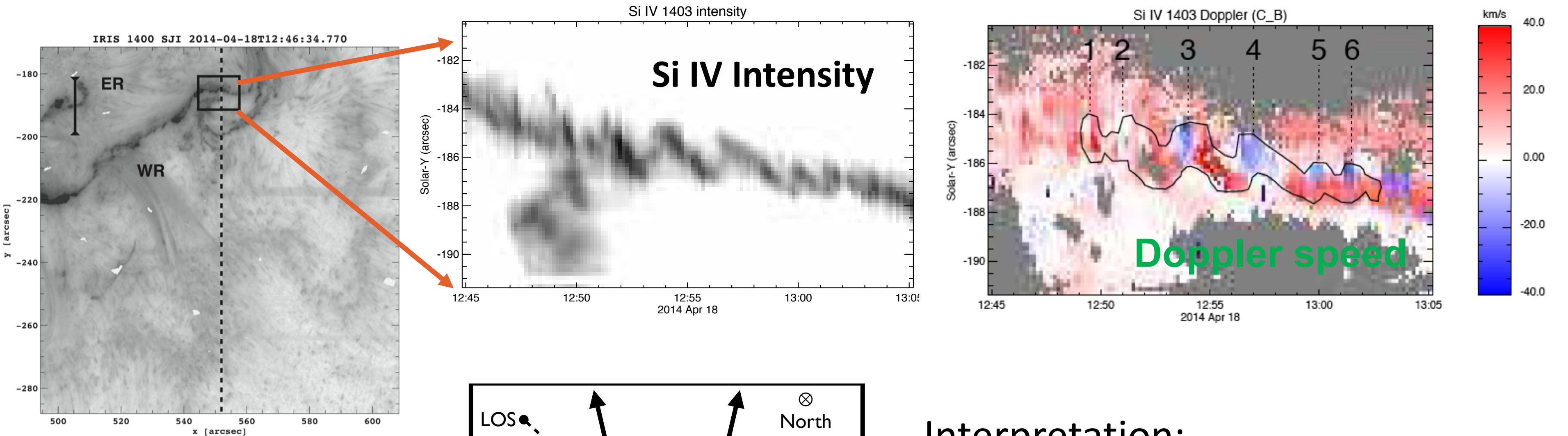


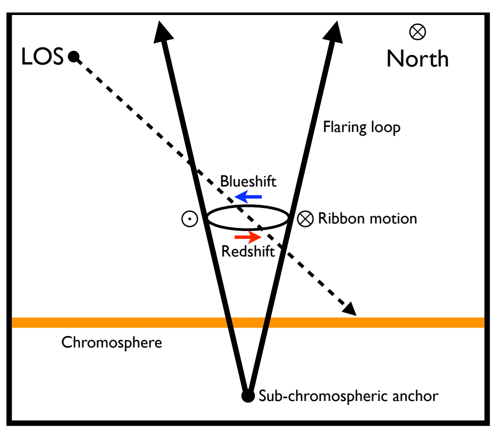
τ ~ 100s

- just “flare bursts” – e.g. oscillatory reconnection
- Temporarily enhanced chromospheric oscillations?
- Chromospheric counterpart of coronal loop oscillations?

Field oscillations in low atmosphere?

SOL2014-04-18T13:03 Brannon+2015 fit Si IV with a double gaussian.
One component oscillates between blue and redshift, and another which is more consistently red-shifted





Interpretation:

- oscillation of field in transition region
- Could this persist into the chromosphere photosphere?

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Conclusions

EST is well suited to solving some critical problems in flare physics

- Observations that simultaneously probe multiple layers in the chromosphere are vital to understanding flare energy transport
- Highest possible time resolution is crucial (sacrifice spatial resolution!)
- Magnetic field evolution is central, but a lot can also be done using spectroscopy alone

Catching flares during their initiation will be challenging, but experience shows not impossible