# Can superposition of evaporative flows explain the broad high temperature IRIS Fe XXI profiles during solar flares?

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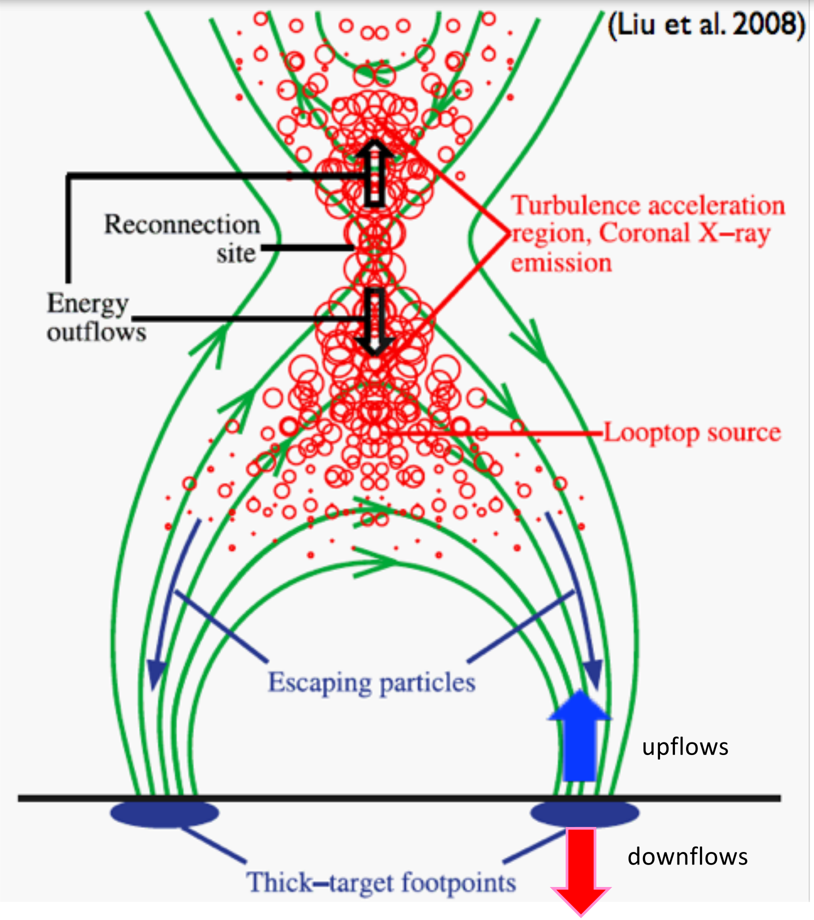
# Unsolved questions in the standard flare model



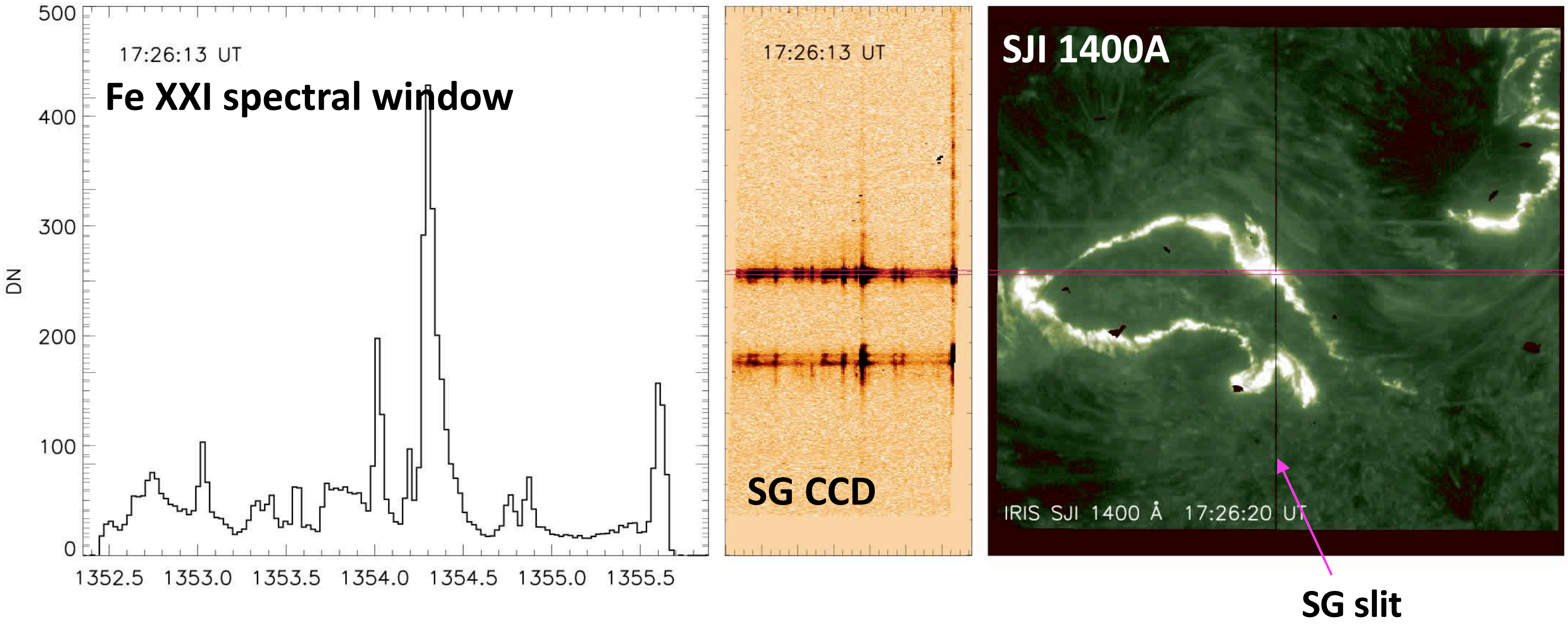

- *How and where is the energy produced and stored?*
- *How is the energy released and transported?*
- *How does the plasma respond to the heating?*

➢ Chromospheric ***evaporation*** ->
***blueshifts*** in UV/SXR spectral lines (T>10 MK).

➢ Chromospheric ***condensation*** ->
***redshifts*** in cooler chromospheric and TR lines

# Chromospheric evaporation: new insights from IRIS

*IRIS allows the measurement of the Fe XXI line during flares at unprecedented spatial and temporal resolution, providing new insights into the chromospheric evaporation process*



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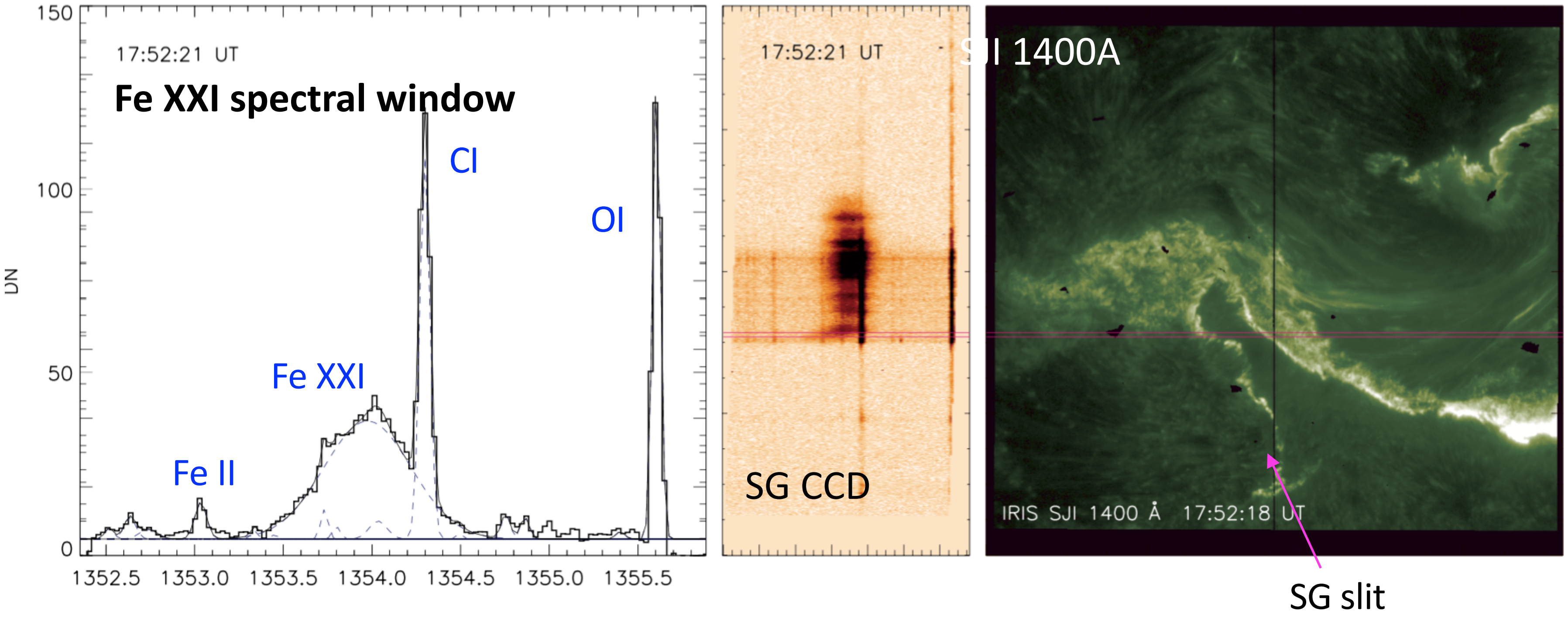

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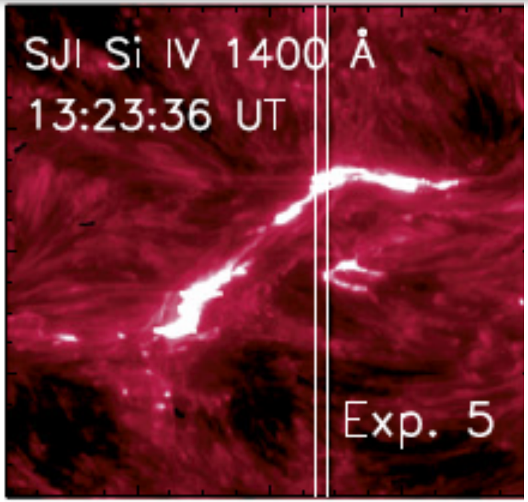
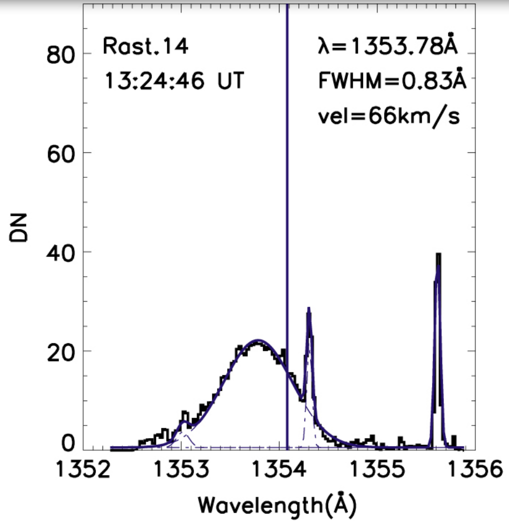
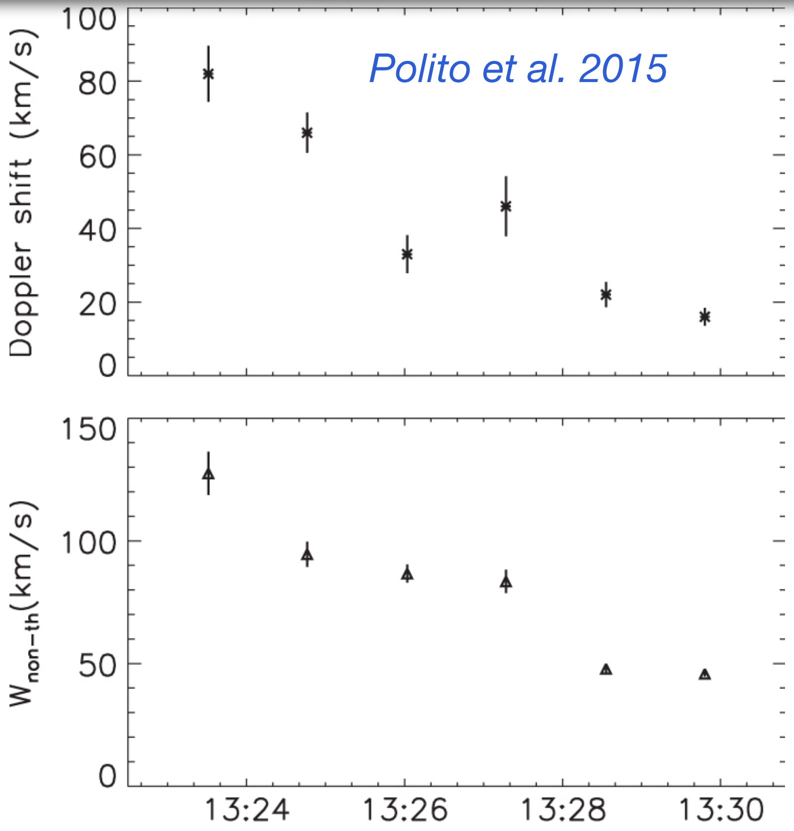
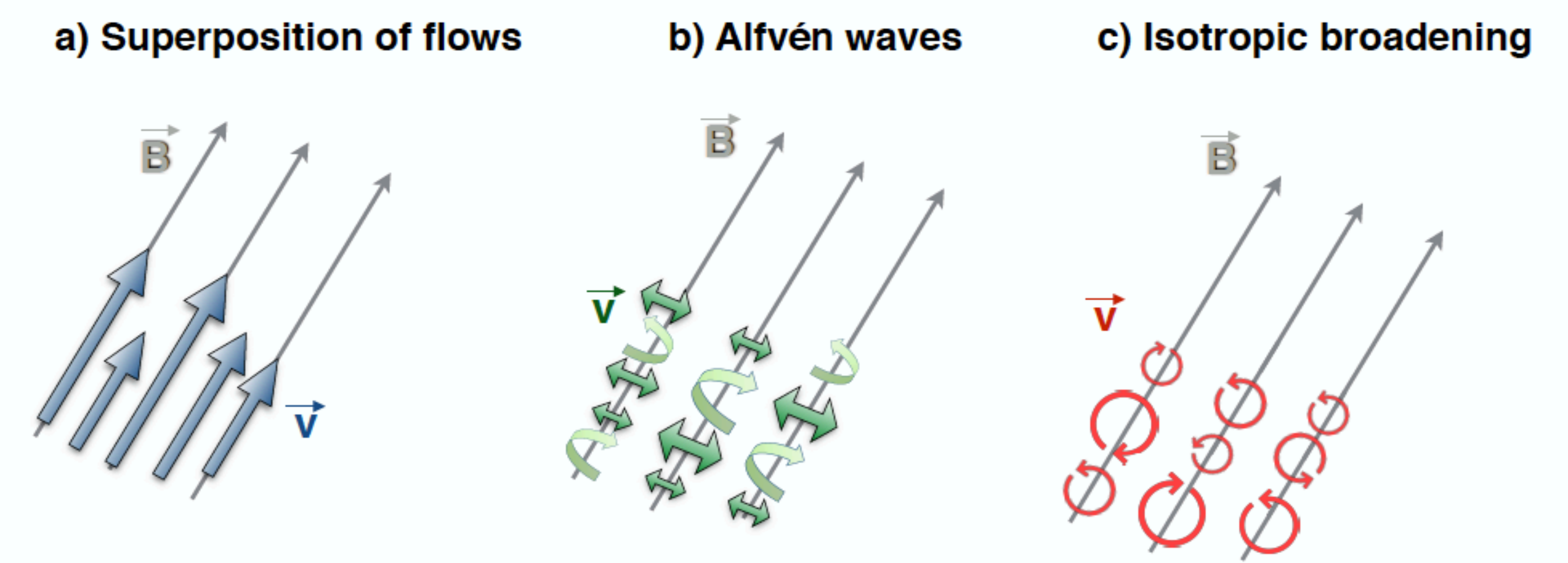



- *Completely blueshifted line in agreement with models* (See also e.g. Graham & Cauzzi 2015, Tian et al. 2015, Young et al. 2015, Li et al. 2015, Dudik et al. 2017, ...)
- The blueshifted lines are broadened and mostly symmetric (e.g. Graham & Cauzzi 2015).
- *Non-thermal broadening and Doppler shift decrease with time and are highly correlated over time*

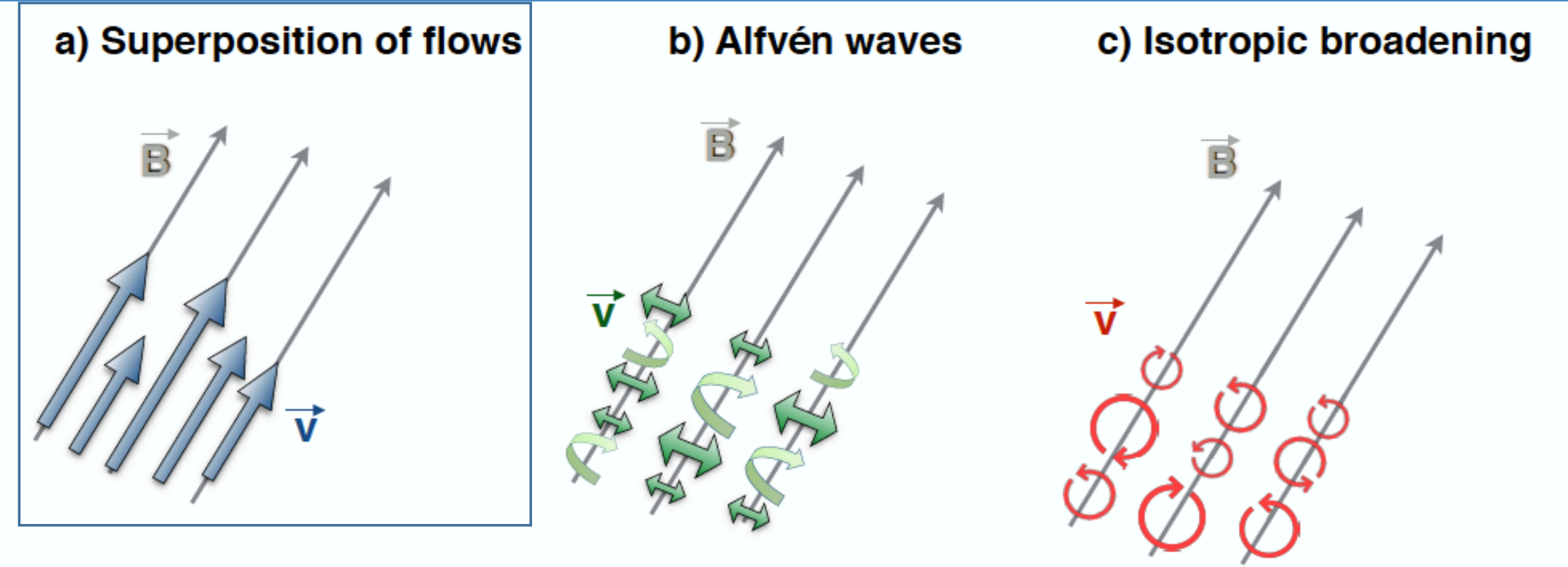
# Possible origin of line broadening




Different scenarios have been invoked to explain the large non-thermal widths in flare lines, each of which would produce distinct observational characteristics in the line profiles:

- superposition of unresolved flows along the line-of-sight (a)
- Alfvénic turbulence (b)
- isotropic broadening (c, e.g. very large ion temperature, turbulence)

# Possible origin of line broadening

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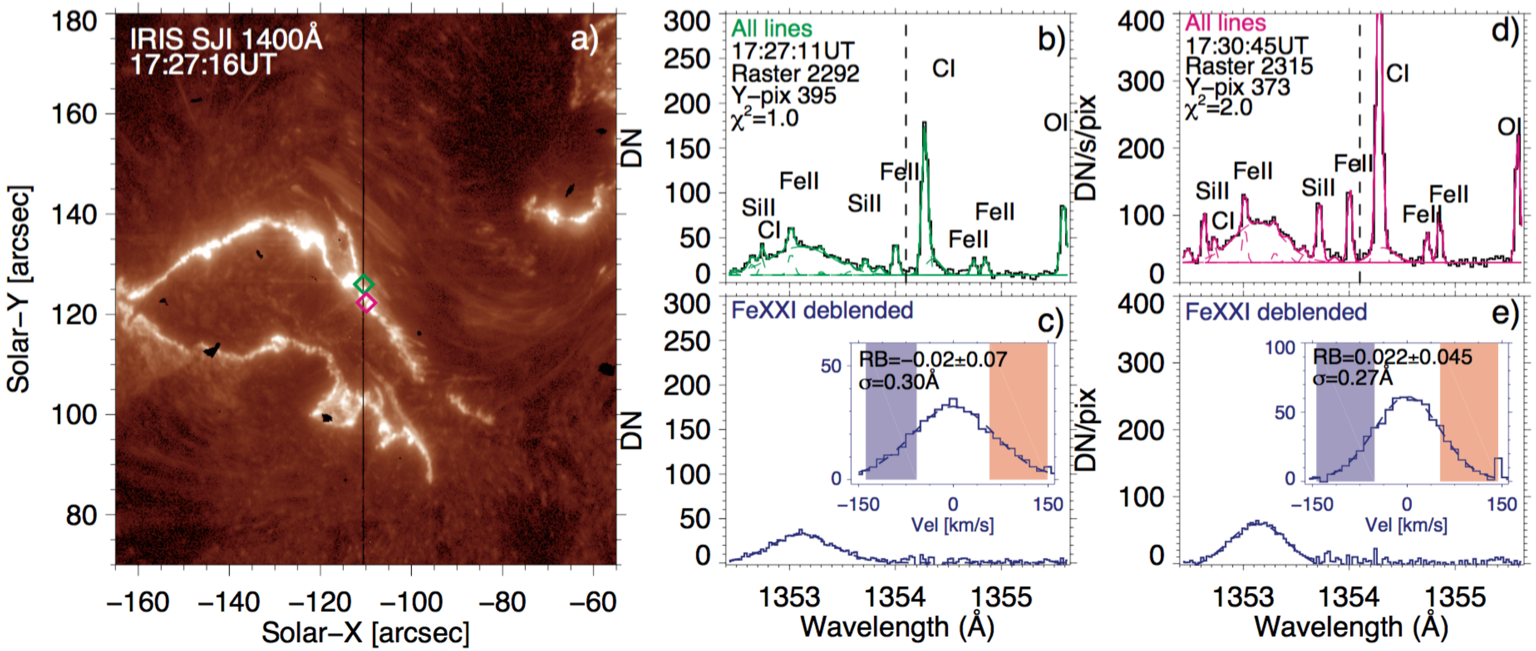
# Broadening and symmetry of Fe XXI




*Polito, Testa & De Pontieu 2019*

- Calculate the RB asymmetry of the unblended line (e.g. De Pontieu et al. 2009, Tian et al. 2011):

$$RB = \frac{I_R - I_B}{I_p} \qquad I_{R/B} = \sum_{+/-v_1}^{+/-v_2} \frac{lp}{n_{bins}}$$

$lp$ = line profile

$I_p$ = line peak

$v_{1-2}$ = 50 – 150 km s$^{-1}$

- Very little asymmetry (less than ~8%)

# Comparison with modeling: RADYN

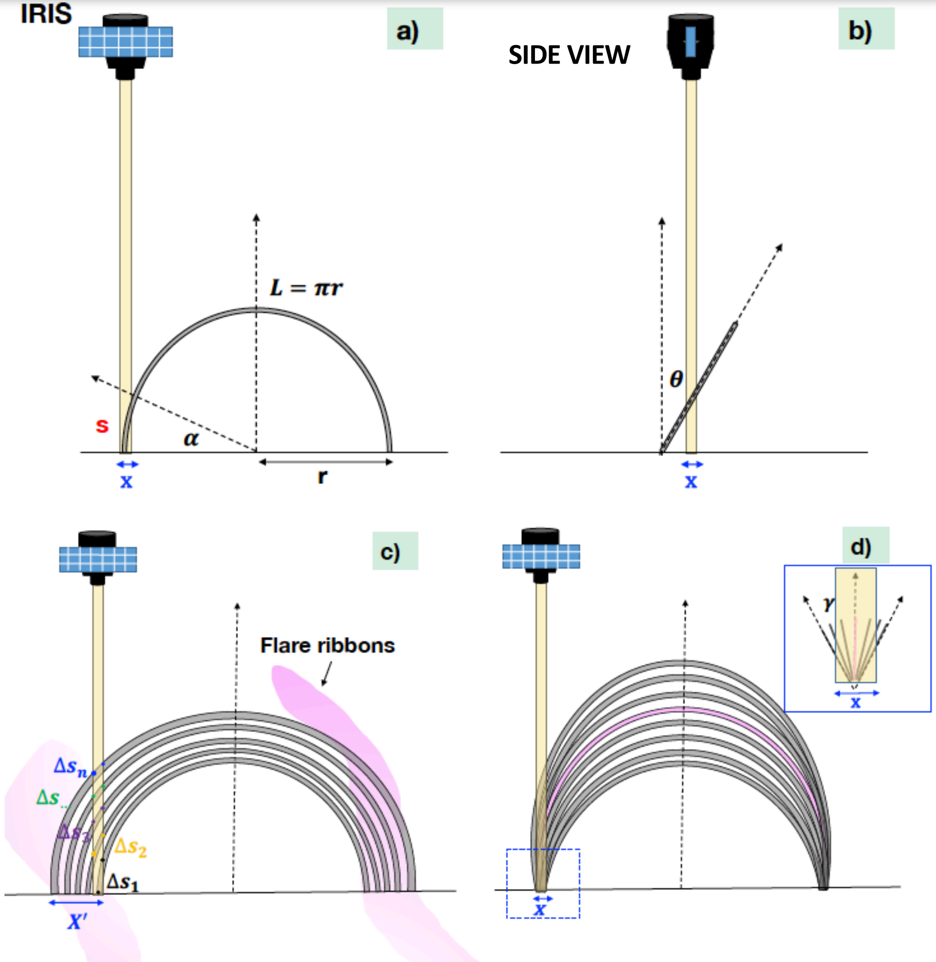
*RADYN* (Carlsson & Stein 1992, 1995, Allred et al. 2005, 2015) 1D radiation hydrodynamics code

Our experiment:

- Heating *by a beam of accelerated electrons with power law distribution* :
  - F=1.2x$10^{11}$ ergs $cm^{-2}$ $s^{-1}$ (F11), $E_C$ = 20 keV and $\delta = 5$, typical of large class flares.
  - Constant heating for 60s, following Reep, Polito et al. 2018, L/2= 50 Mm
  - (different input parameters also assumed: F =0.8-2F11, t=10s, L/2=15Mm)

- Synthesize Fe XXI emission in a single loop simulation using density, temperature and bulk velocity from the simulations and atomic data from CHIANTI v. 8
- Create a multi-strand loop bundle (e.g. Bradshaw & Klimchuk 2011)

# Comparison with modeling: superposition of flows




**Model a):**

- Co-spatial loops with inclination angle $\theta = 0°$

**Model b):**

- Co-spatial loops with $\theta = 30°, 45°$

**Model c):**

- Superposition of *not co-spatial* loops,

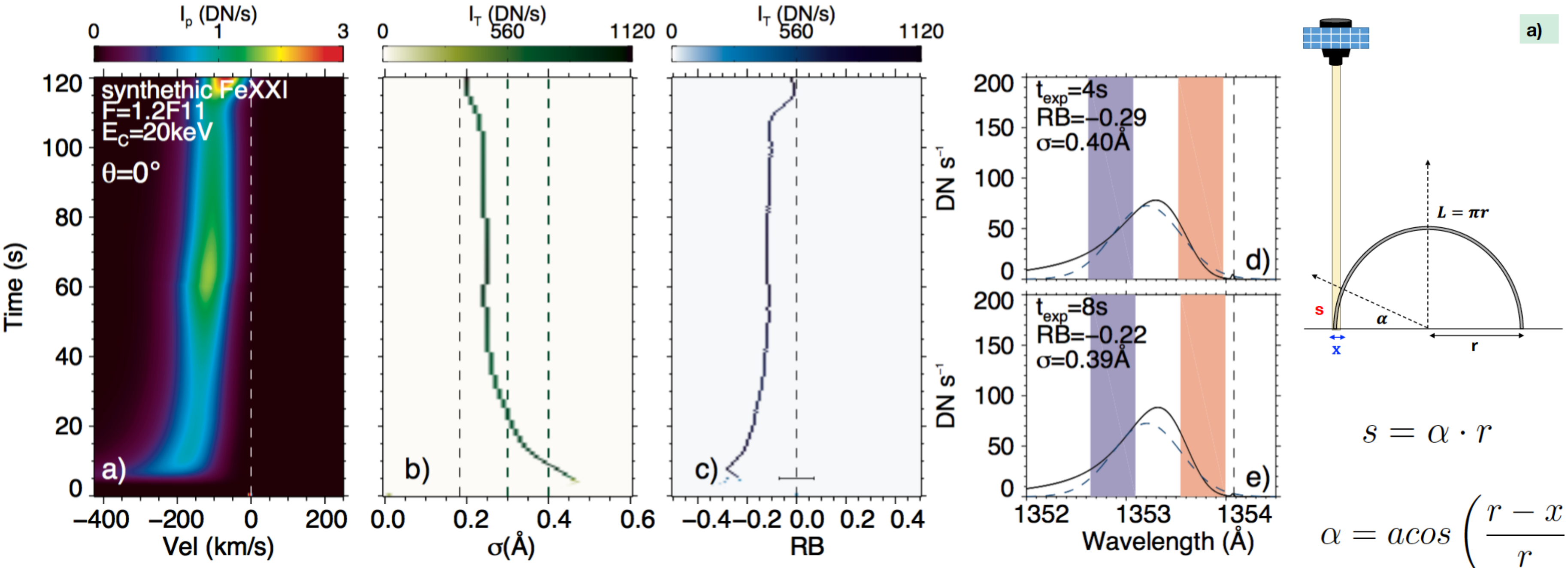
$\theta = 30°, 45°$ and different assumptions:

1. Loops activated at random times
2. Loops activated progressively over time (i.e. “slipping reconnection”)
3. Cases in between

**Model d):**

- Expanding cross section of loops bundle
- $\gamma$ normally distributed between $\pm 20°$
- $\theta = 0°, 30°, 45°$

# Comparison with modeling: superposition of flows



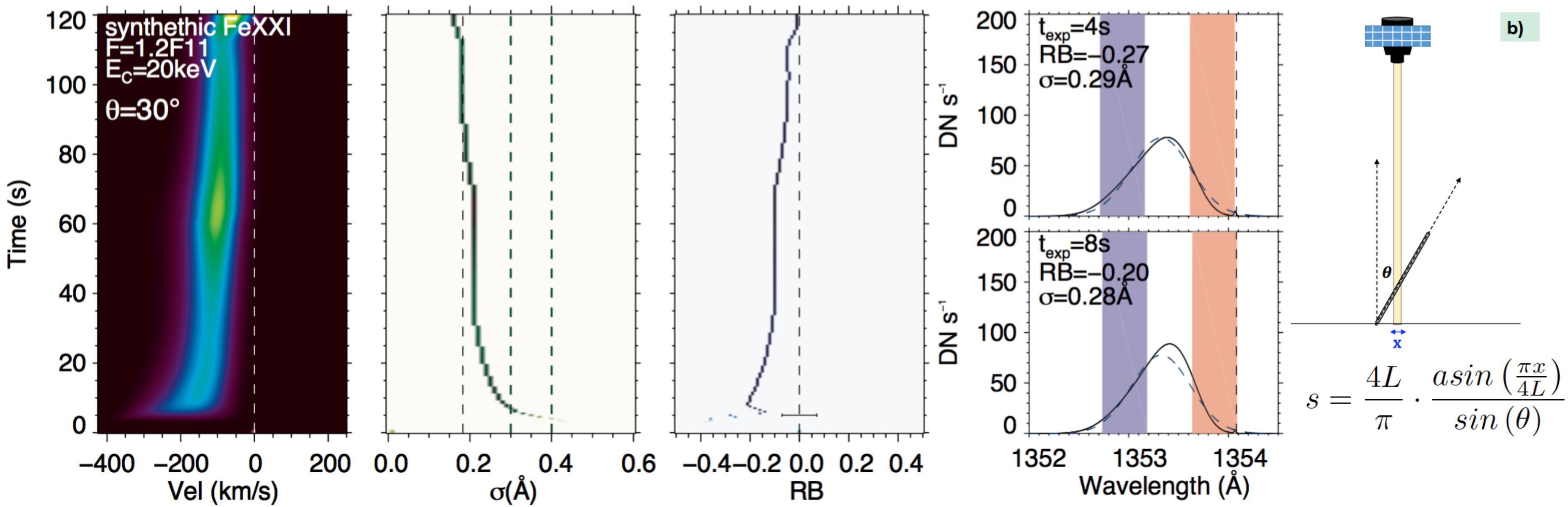

$$s = \alpha \cdot r$$

$$\alpha = acos\left(\frac{r-x}{r}\right)$$

*Polito, Testa & De Pontieu 2019*

- Broad profiles with blue asymmetry up to ~30% of the peak

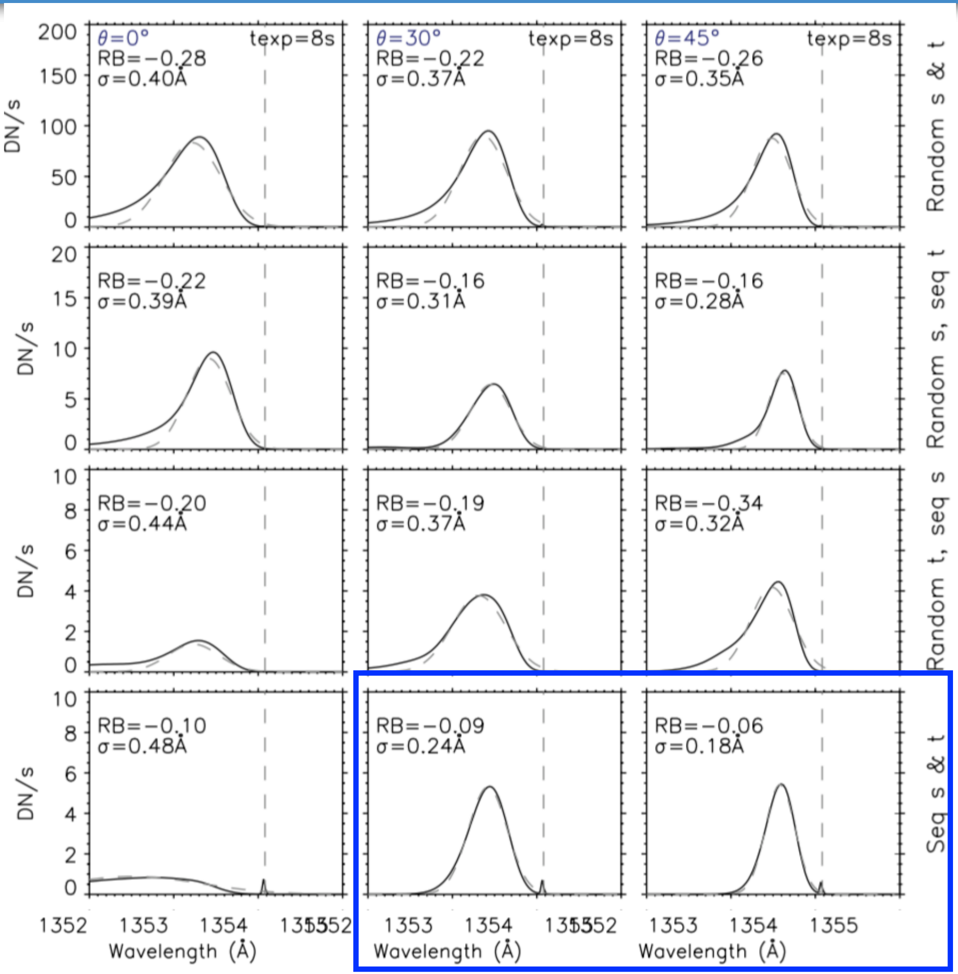
# Comparison with modeling: superposition of flows

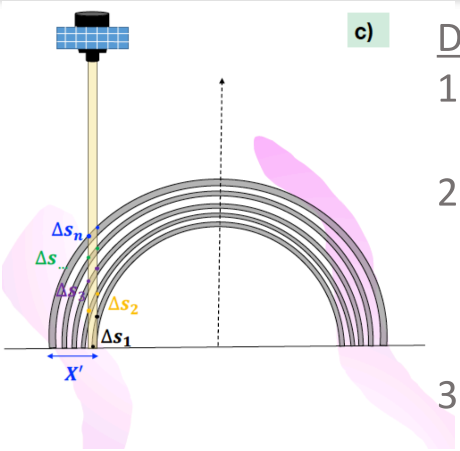



$$s = \frac{4L}{\pi} \cdot \frac{asin\left(\frac{\pi x}{4L}\right)}{sin\left(\theta\right)}$$

- Both broadening and RB smaller than in the $\theta = 0°$ case, but RB still 20-27 % of the peak

# Comparison with modeling: superposition of flows




Different assumptions:

1. Loops activated at random times
2. Loops activated progressively over time, (i.e. "slipping reconnection")
3. Cases in between

- Only narrow synthetic profiles show RB values compatible with observations
- All the other cases show RB of ~20% of the peak
- Similar results for model d (not shown here)

# Outline & future work

- Anti-correlation between broadening and symmetry : broader profiles are always asymmetric

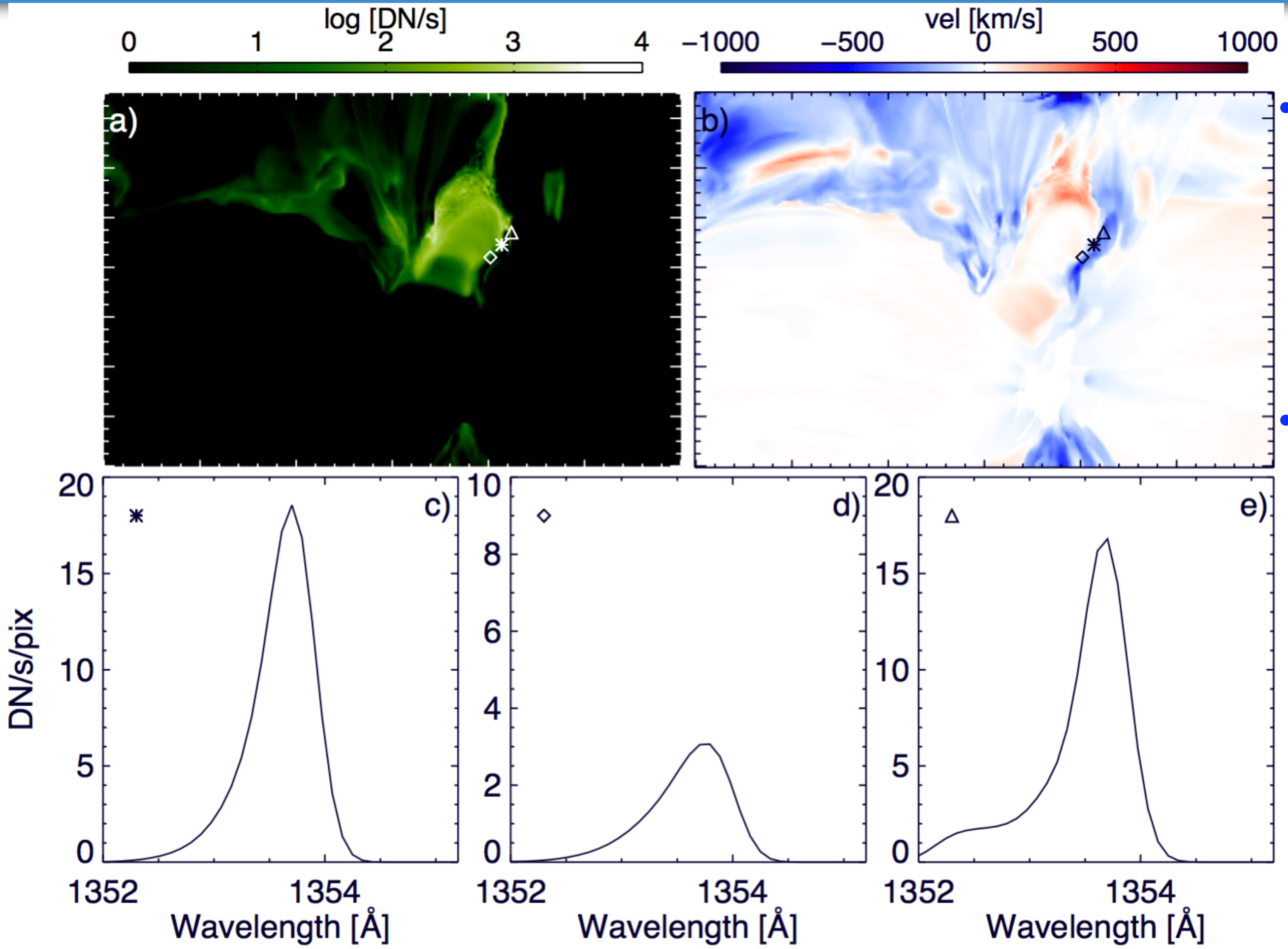
- Most of the models show that the RB asymmetry of the synthetic profiles is significant larger (~ 20 % of the peak) than that in the observed spectra (~ less than 8% of the peak including error estimates)

- It is very difficult to produce both broad and symmetric profiles with superposition of flows alone. Other processes-such as: *very large ion temperatures (40-60MK), isotropic turbulence or Alfven waves turbulence* may be required to explain the observations

Work in progress:

- Statistical study of Fe XXI spectral characteristics for all IRIS flares
- More investigation with 3D models (see also Graham Kerr's talk this afternoon)

# Work in progress: application to 3D MHD models




- *Top panels:* Intensity (a) and velocity (b) 2D maps of *IRIS* Fe XXI synthetic emission for the 3D MHD simulation of Cheung et al. (2019)
- *Bottom panels:* Fe XXI synthetic spectra obtained by integrating the Fe XXI emission along the LOS.