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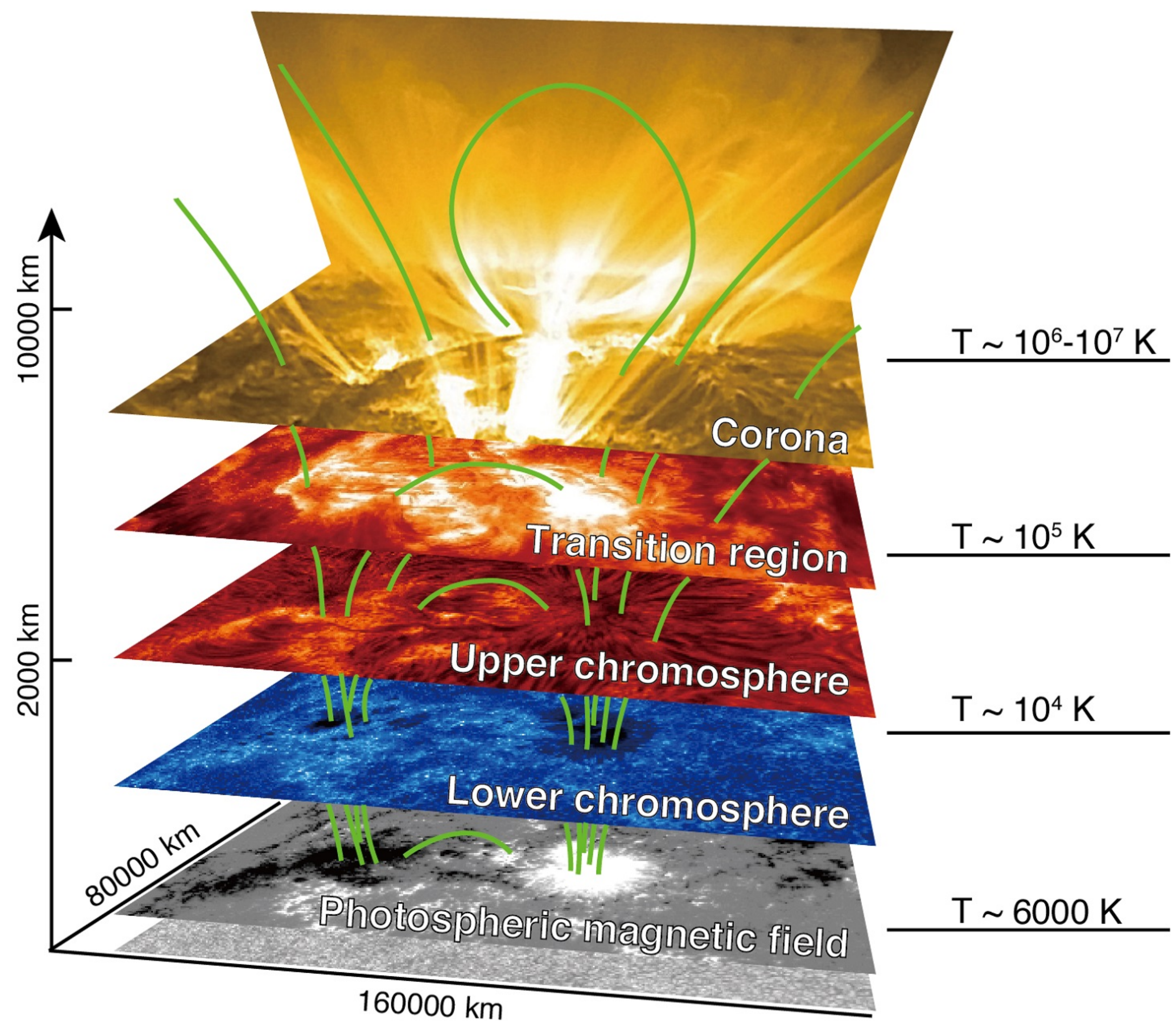
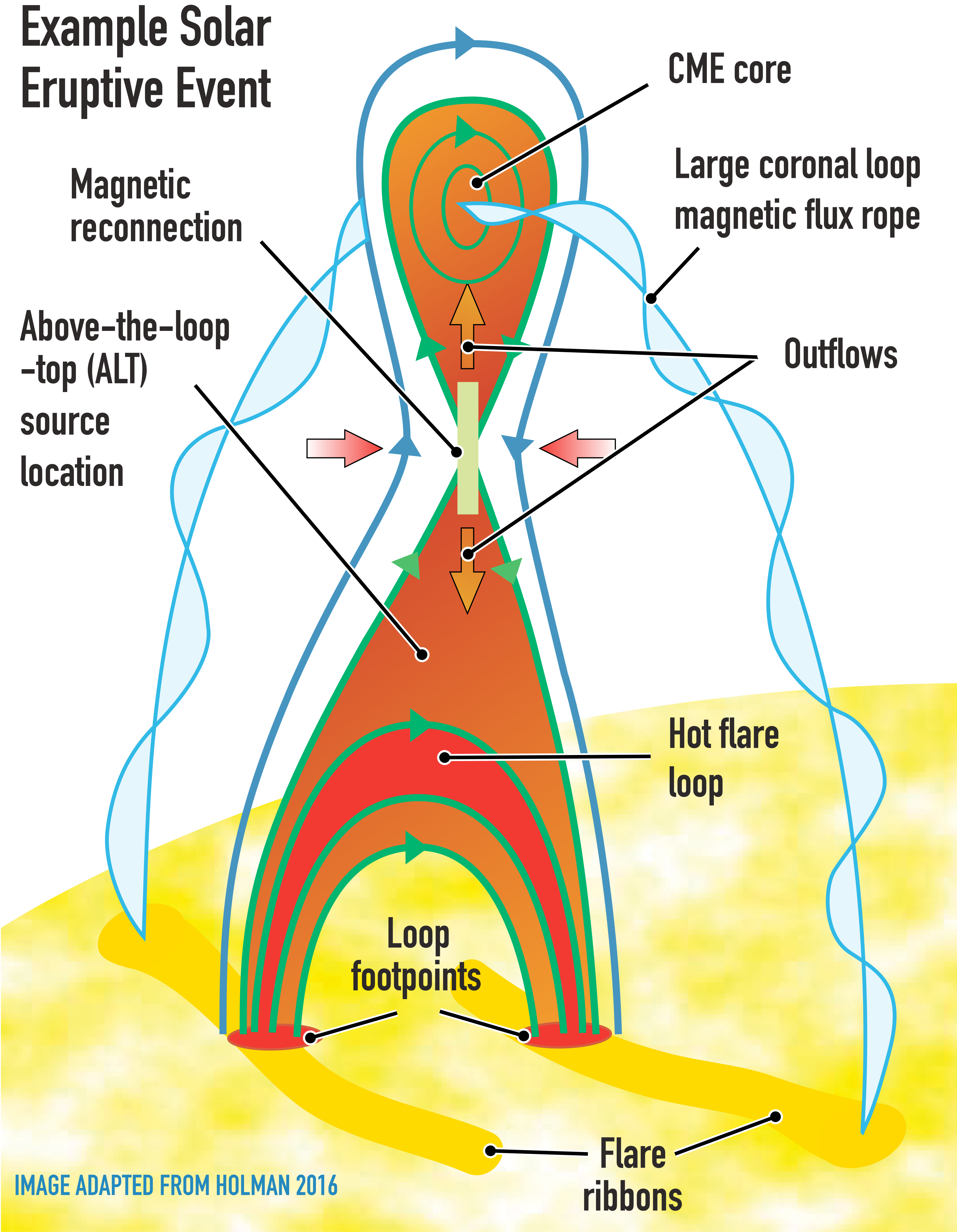
SOLAR FLARE RIBBON FRONTS: THE CHROMOSPHERE'S WINDOW ON MAGNETIC RECONNECTION

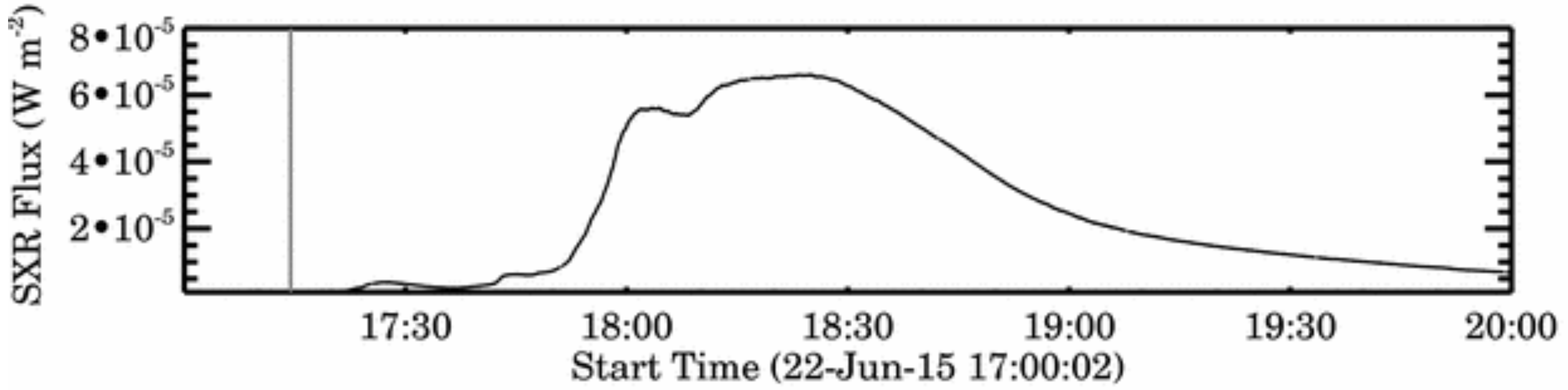
SOLAR FLARES

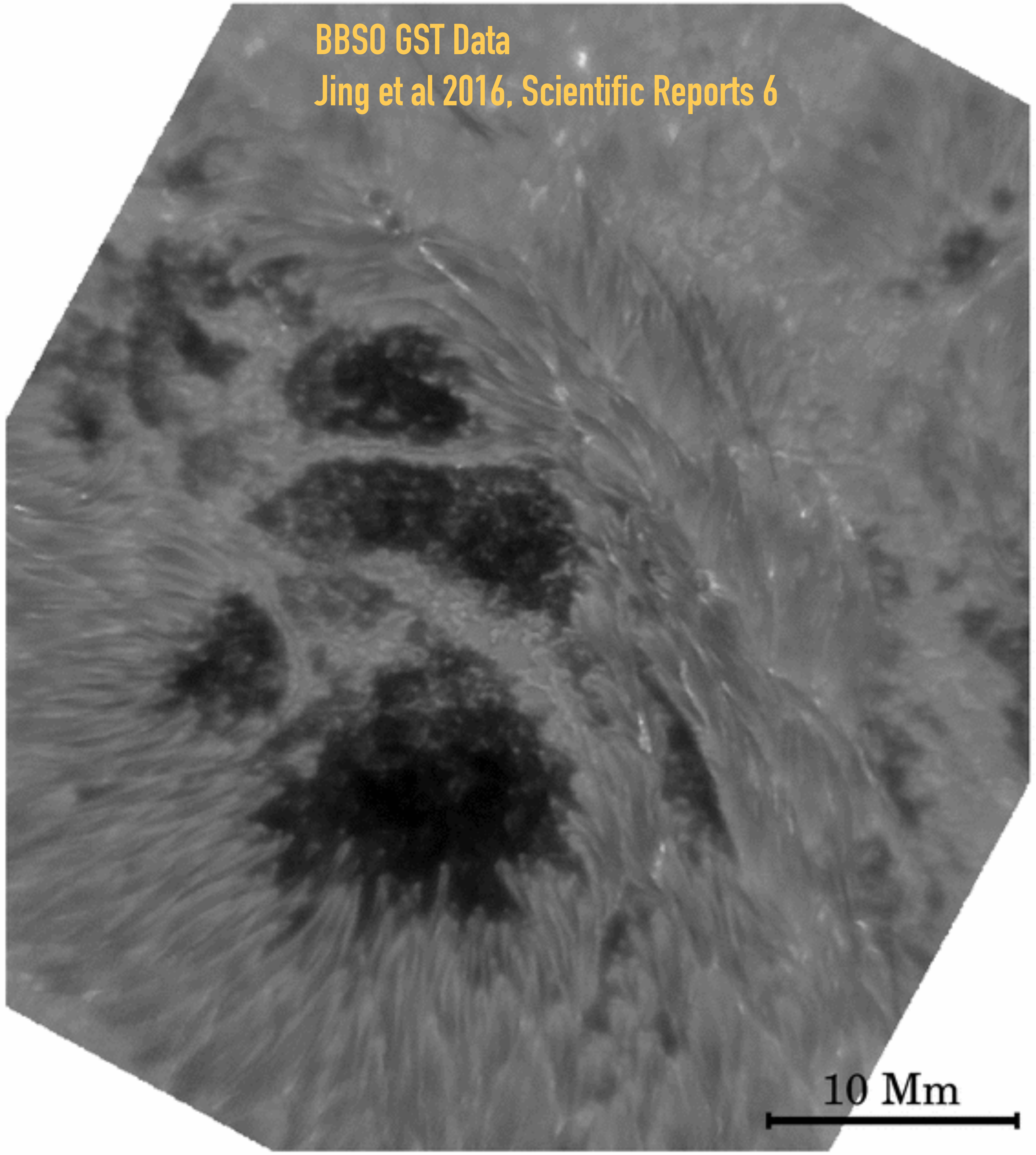


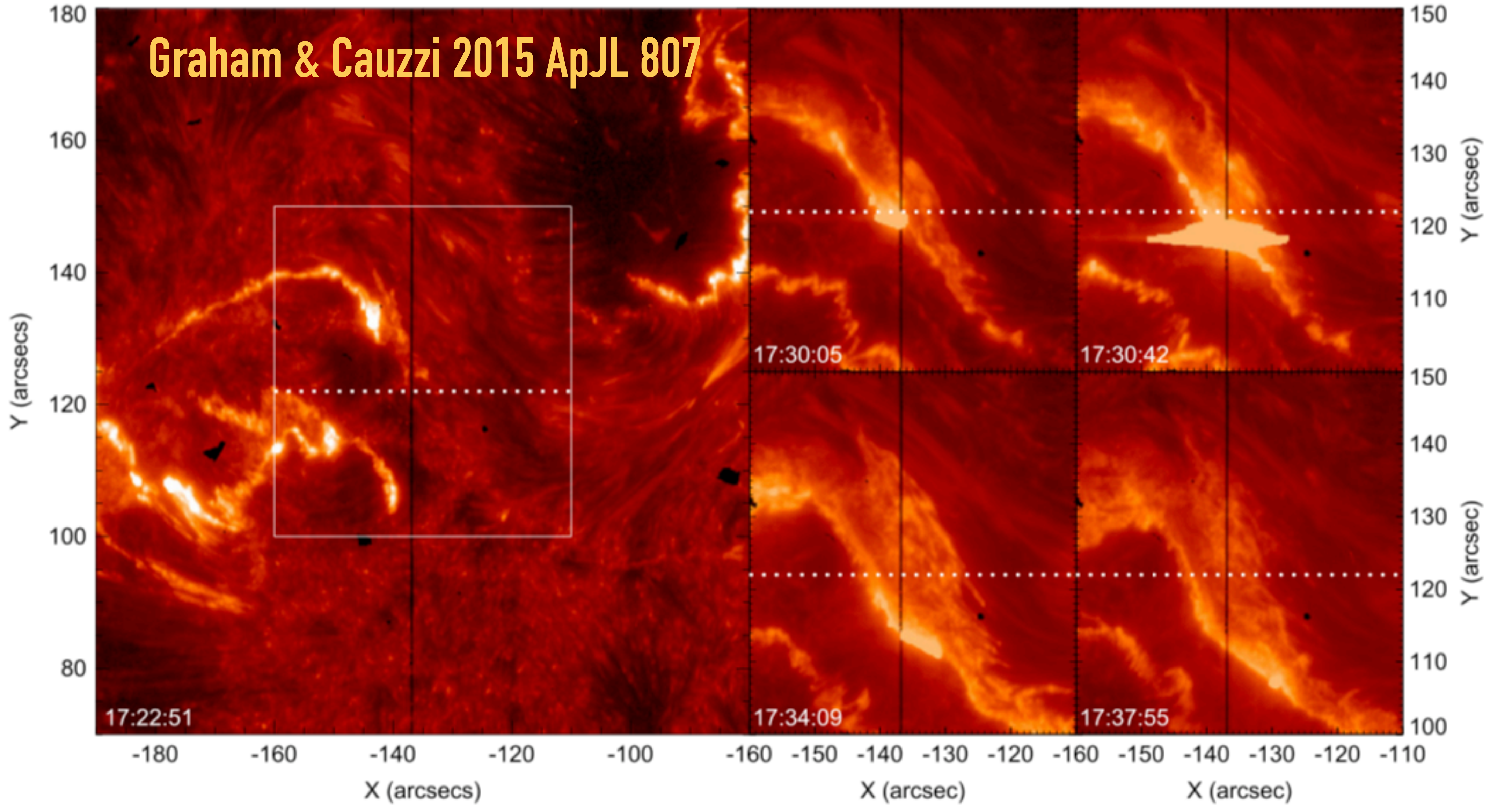


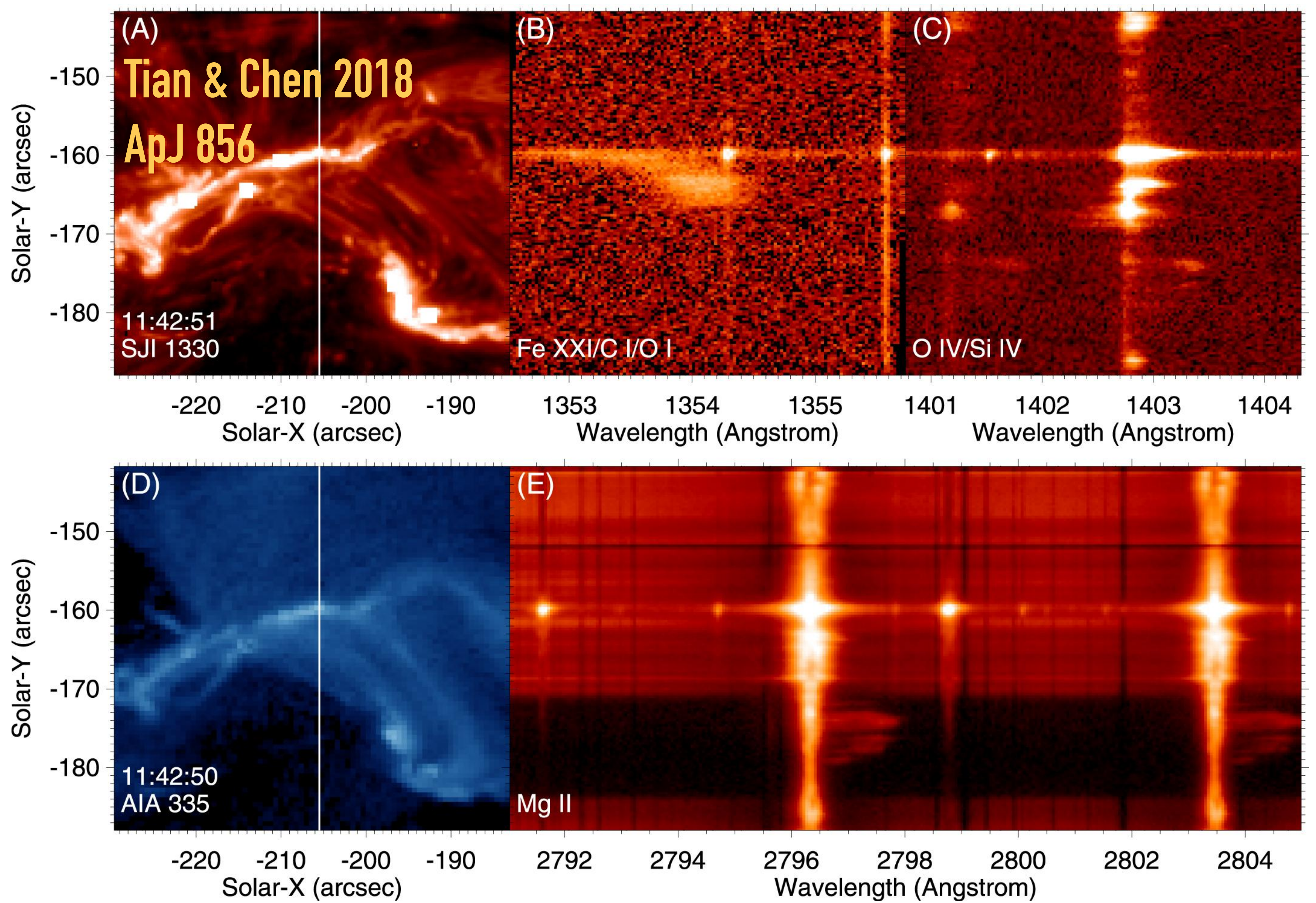
X1.6 CLASS FLARE 10TH SEPT 2014

SOLAR FLARES



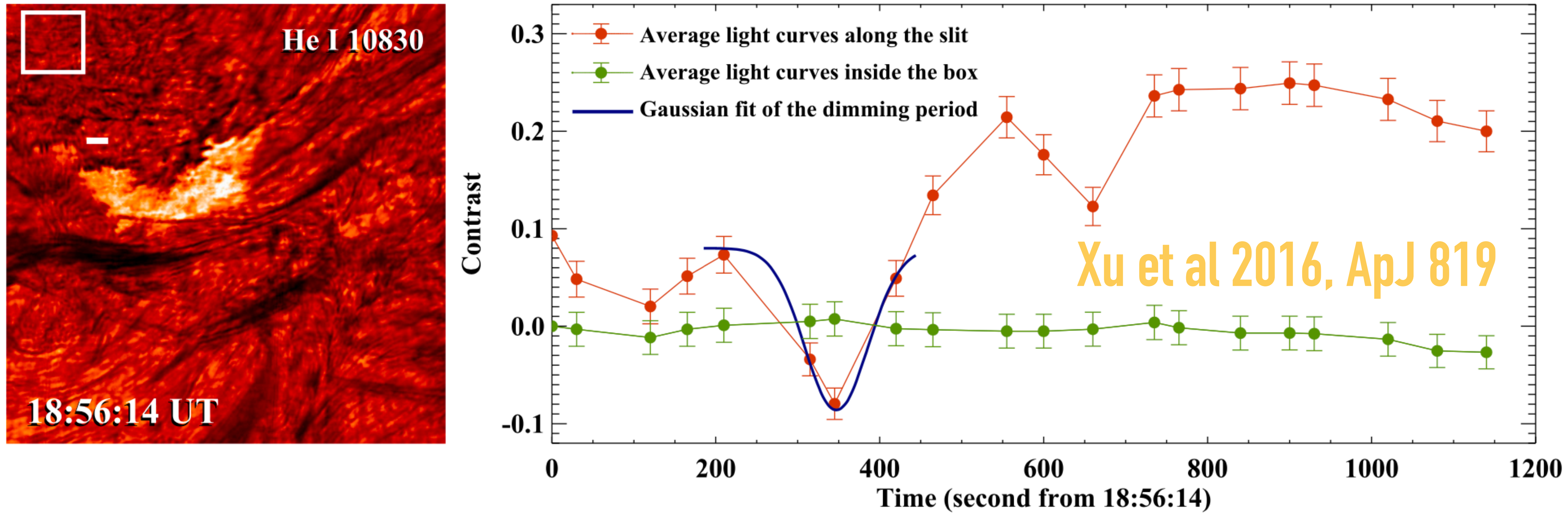




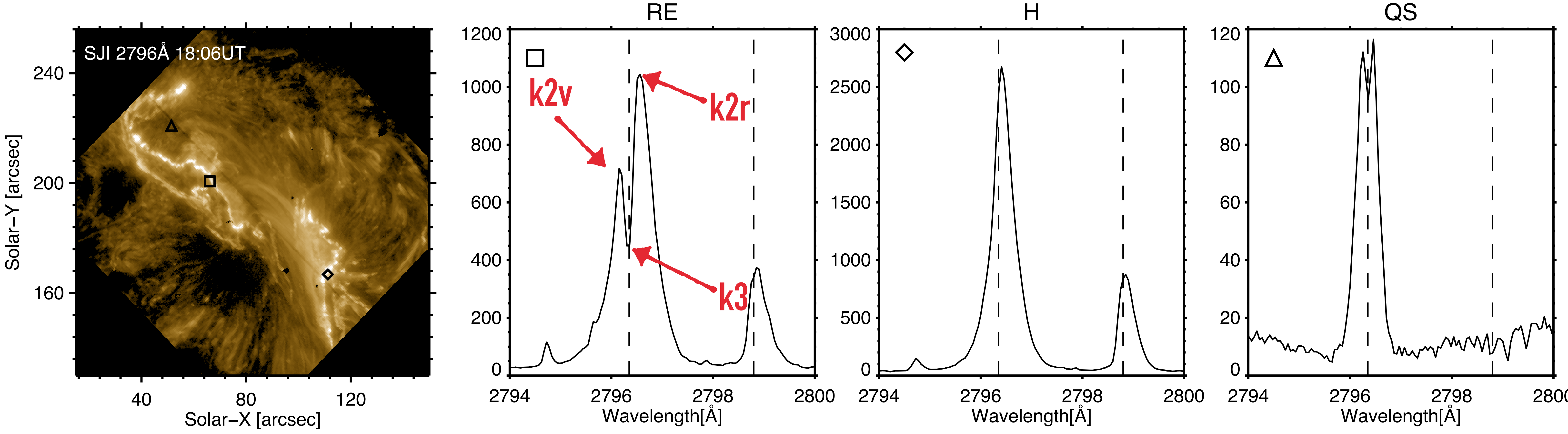


RIBBON FRONT BEHAVIOUR

- At ribbon fronts we see interesting spectral characteristics.
- He I 10830 dimming before brightening.
- Mg II NUV spectra exhibit:
  - ➡Deep central reversals
  - ➡Blue shifted cores
  - ➡Asymmetric peaks
  - ➡Large line widths
  - ➡Subordinate line emission.



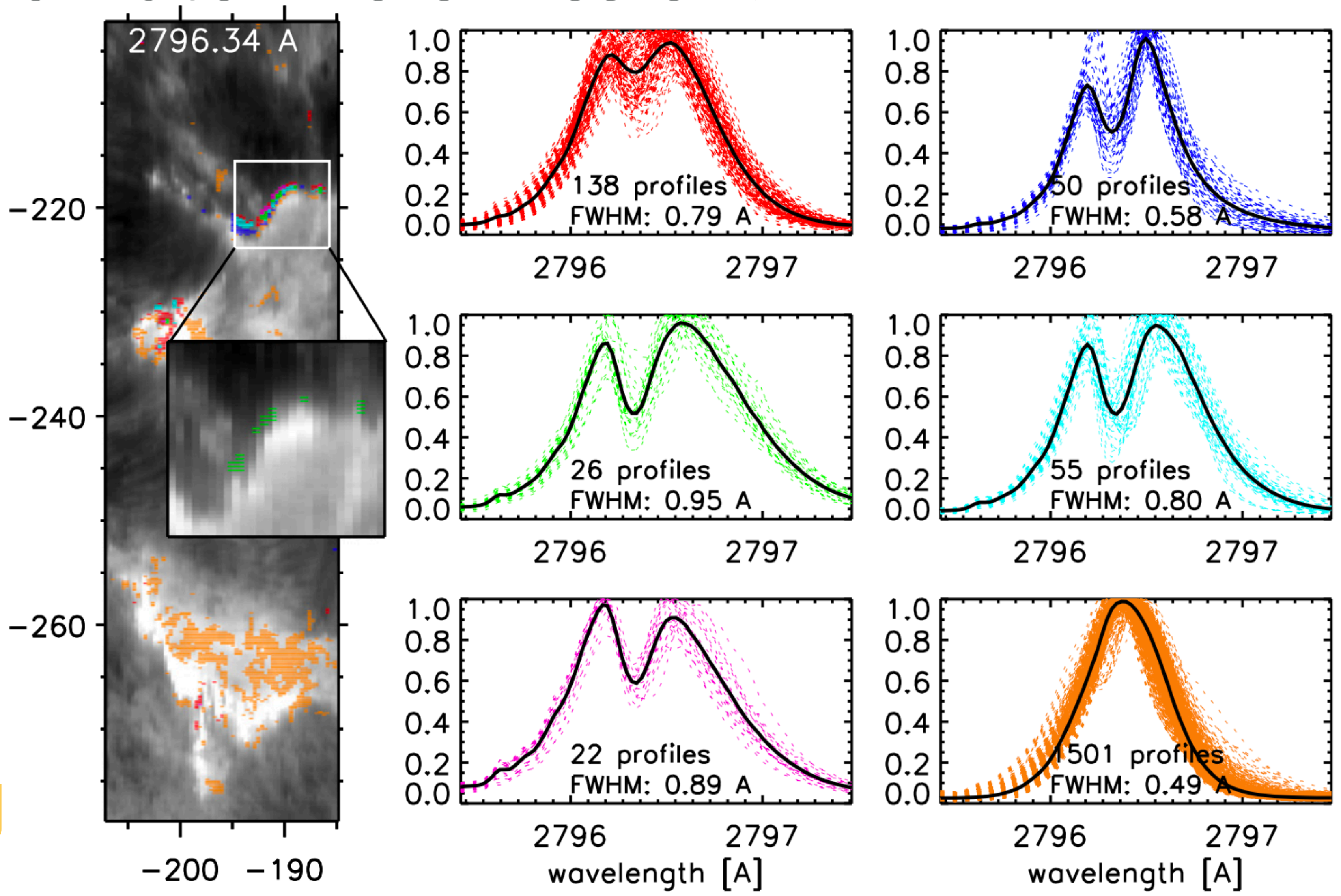
Xu et al 2016, ApJ 819



Polito, Kerr, in prep

See also Panos et al 2018,2021, ApJ

Xu et al 2016, ApJ 819

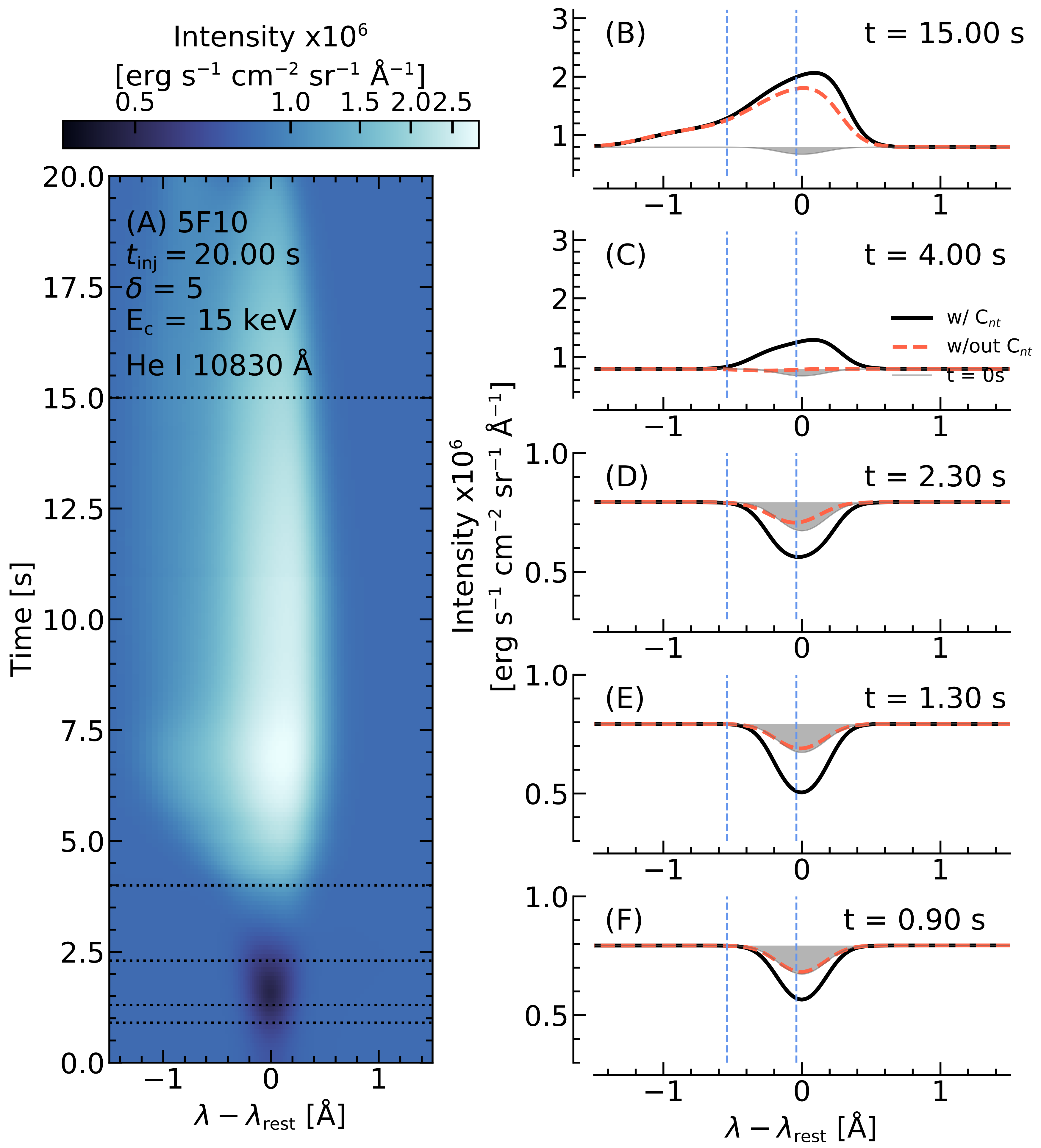


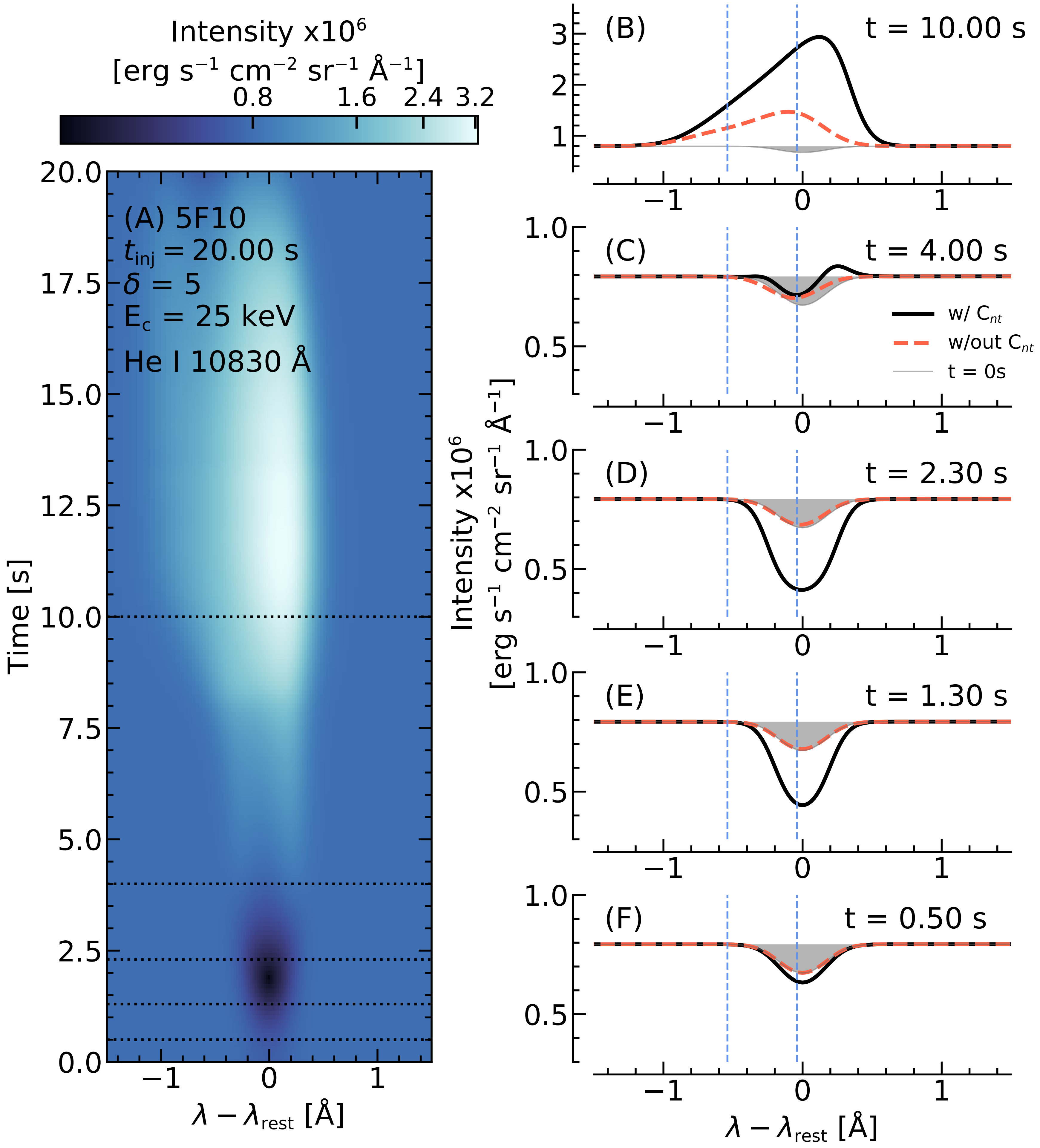
See also Huang et al 2020, ApJ

CAN WE MODEL HE I 10830Å NEGATIVE FLARES?

- Yes! … but ONLY if we include He non-thermal collisional ionisations.
- There must be non-thermal electrons in the flare ribbon fronts.

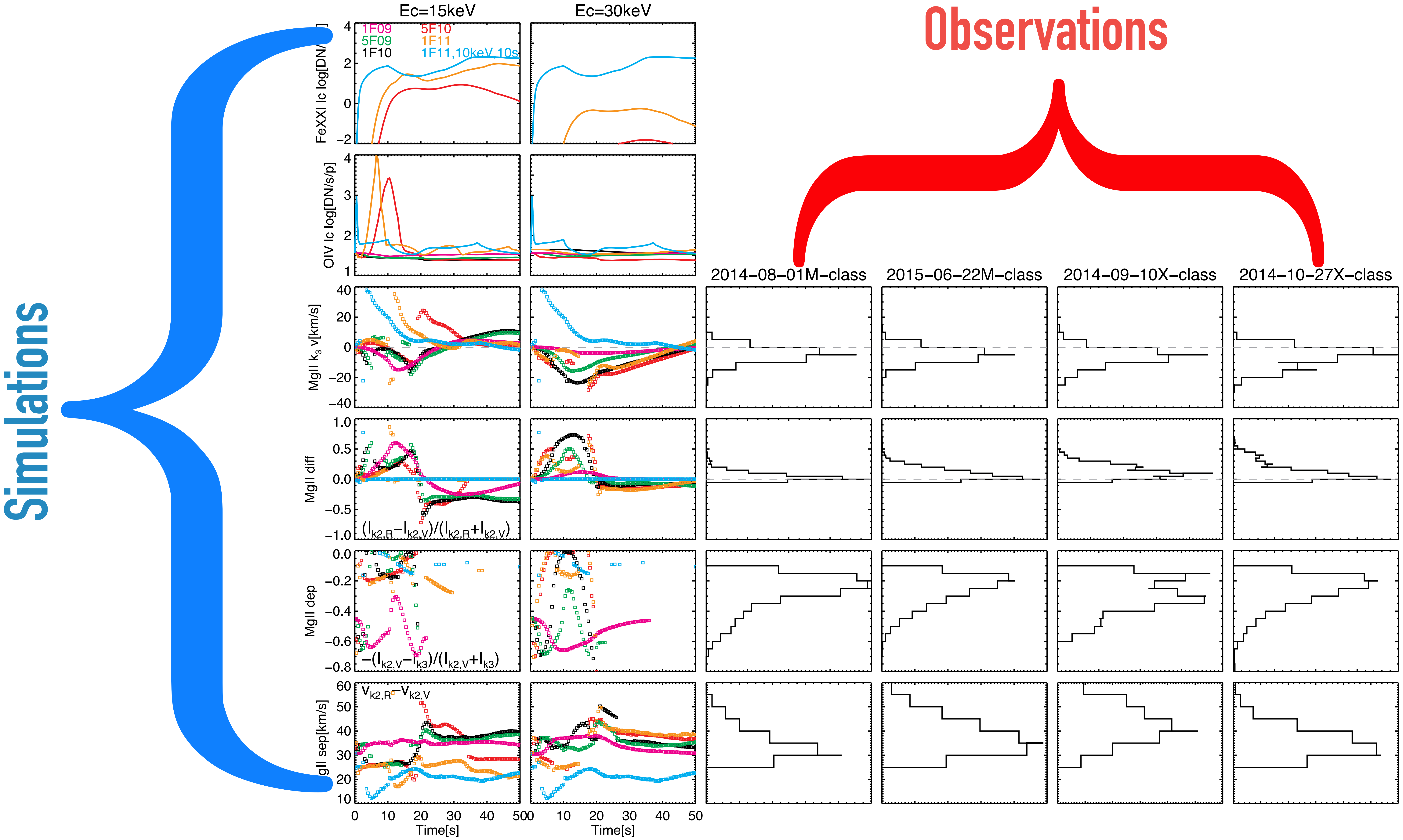
Kerr et al 2021, ApJ 912





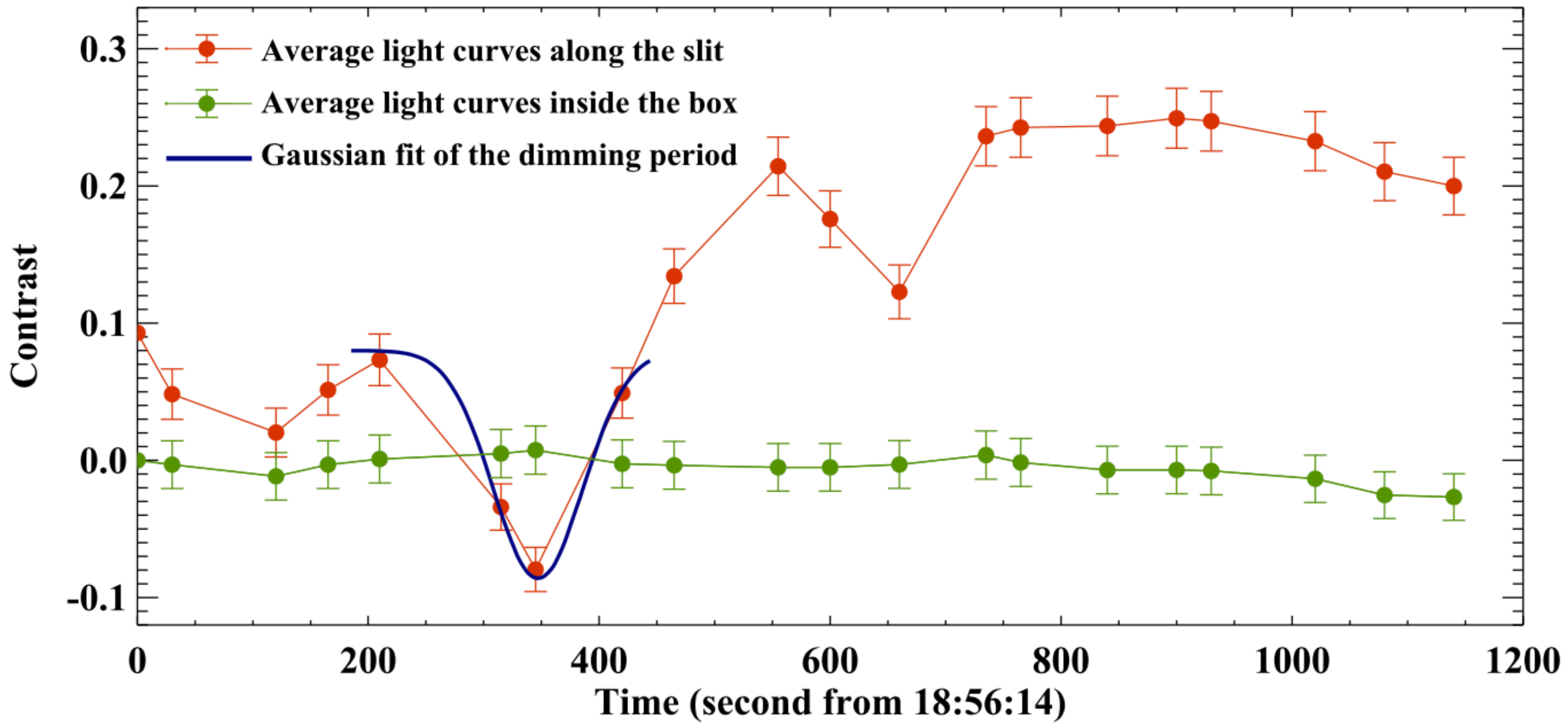
ARE THE SAME SIMULATIONS ALSO CONSISTENT WITH MG II RIBBON FRONTS?

- Simulations with **modest and gradual heating** are more consistent with observations of Mg II ribbon fronts.
- Those cases don’t drive explosive evaporation (we don’t see Fe XXI at ribbon fronts).
- Stronger heating can drive that evaporation and results in Mg II profiles more consistent with the brighter parts of the ribbon.

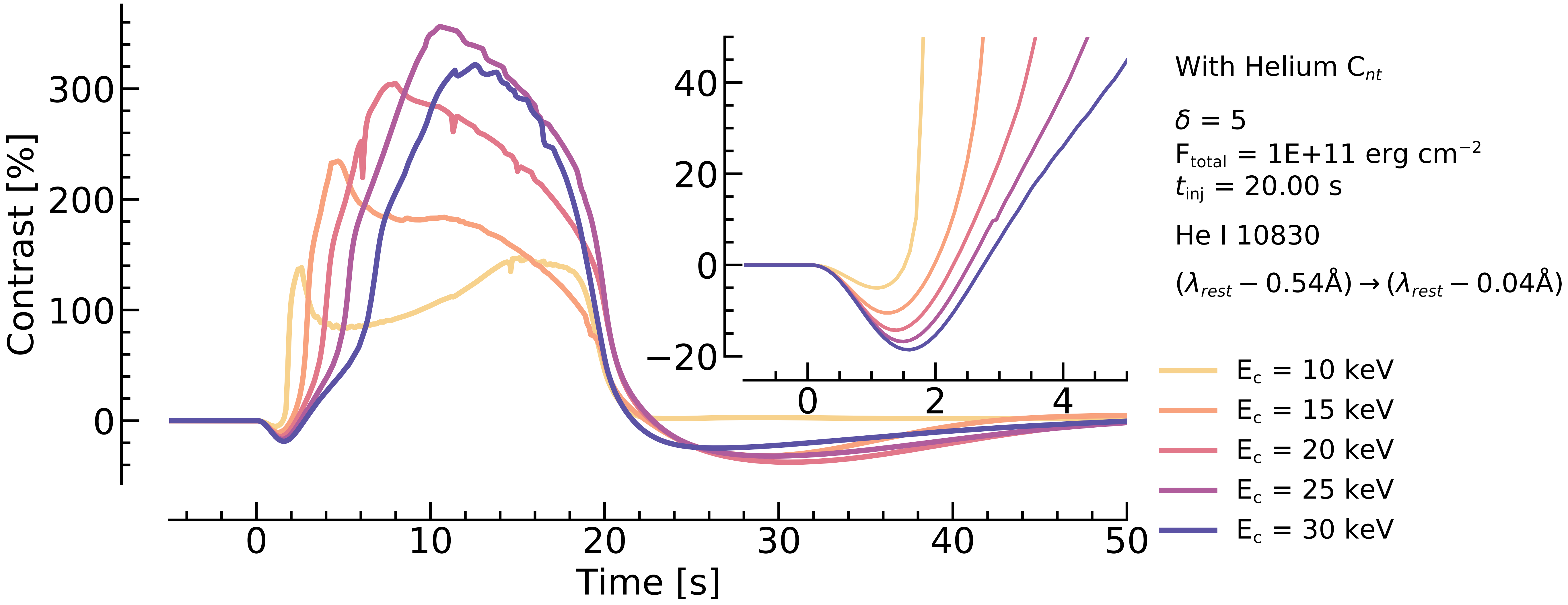


SIMULATIONS DIDN'T CAPTURE THE DURATION OF RIBBON FRONTS

- He I negative flare sources persisted for several dozen to 100s.
- Mg II ribbon fronts are variable, but on the order of ~1-3 mins.
- Naus et al 2021 also report offsets of ~30-120s between activation of ribbon front and a peak in the UV/HXR.



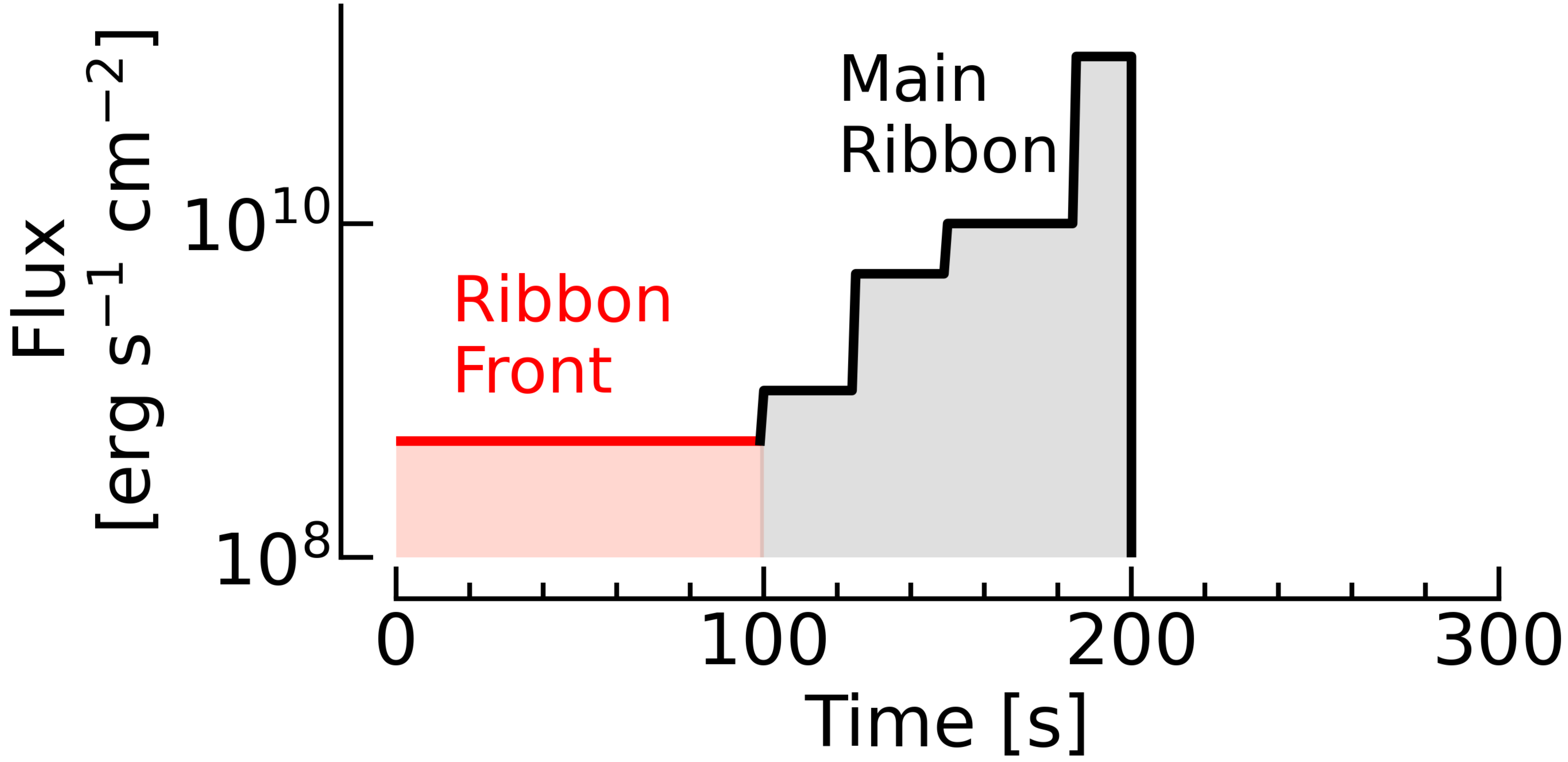
Observation



Simulations

WHAT IF WE INCLUDE AN EXTENDED PERIOD OF WEAK HEATING

- Ran a new set of RADYN experiments, which included an extended period of weak heating
  - **100s of 5×10^8 erg s^{-1} cm^{-2}** , followed by 100s of gradually ramping energy flux (latter part intended to study heating different regimes but is rather adhoc).
  - δ = [3,5,7] ; E_c = [10, 15, 20, 25, 30] keV



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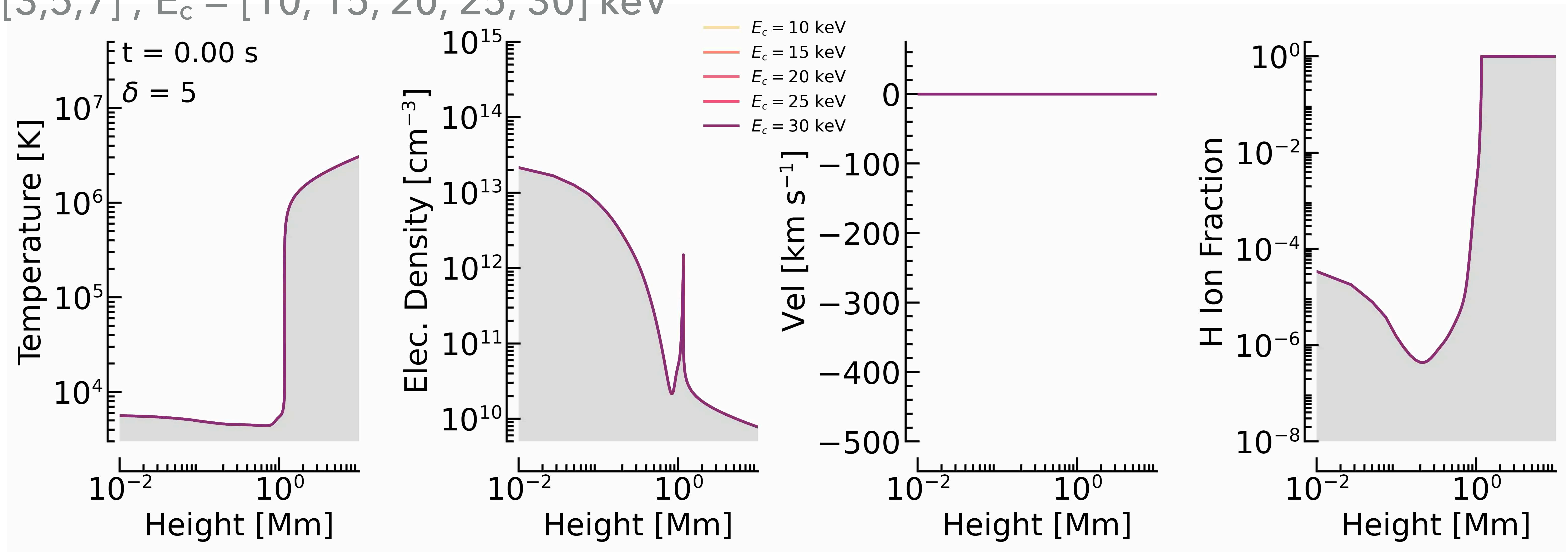
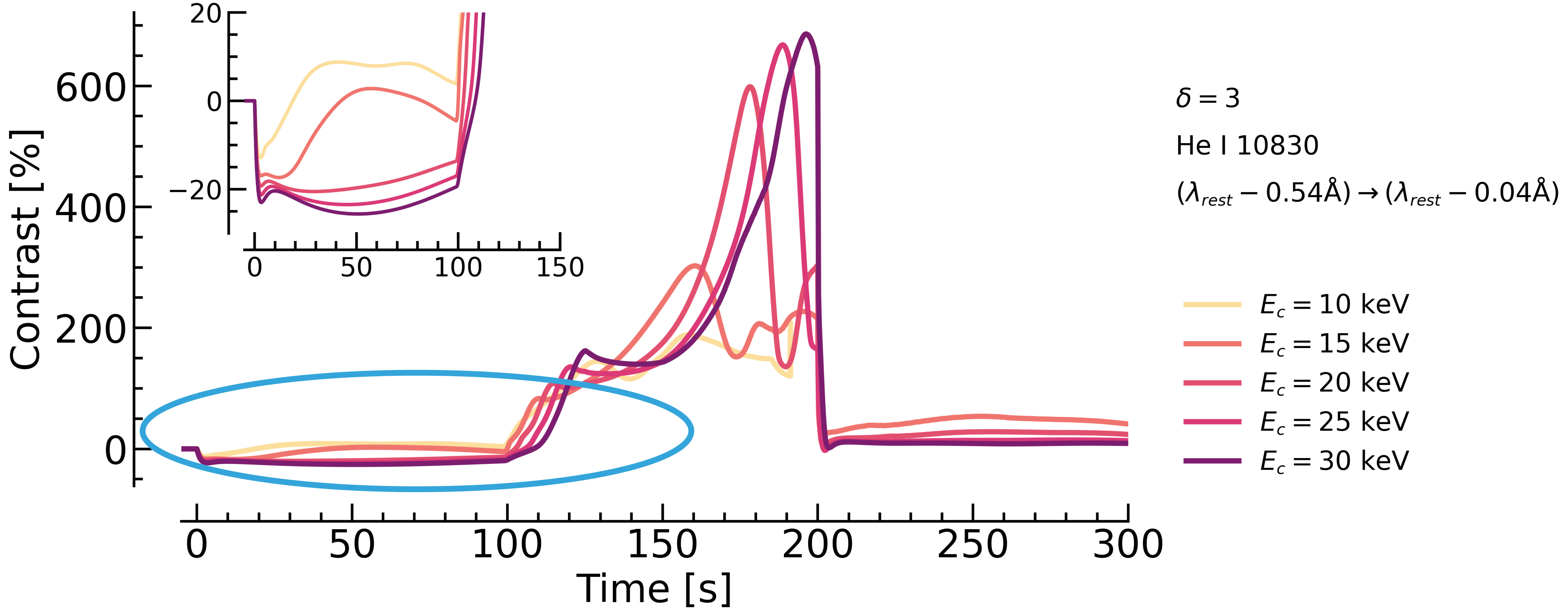


SUSTAINED HE I 10830 ENHANCED ABSORPTION

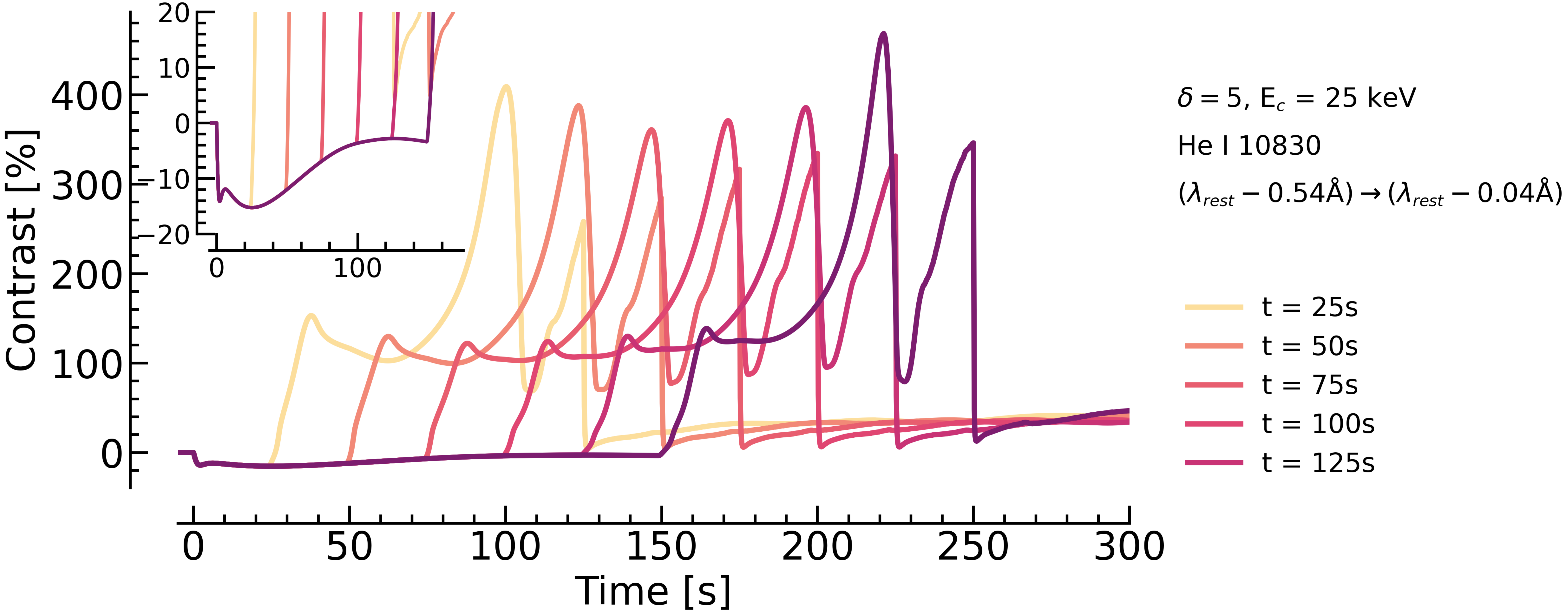
- We **CAN** extend the period of He I 10830 dimming to be consistent with observations by keeping the energy flux low.

- This is strongly dependent on the spectral properties of the non-thermal electron distribution – softer energy spectra heat and raise the density of the upper chromosphere more easily so drive the line into emission quickly, despite the low energy flux.



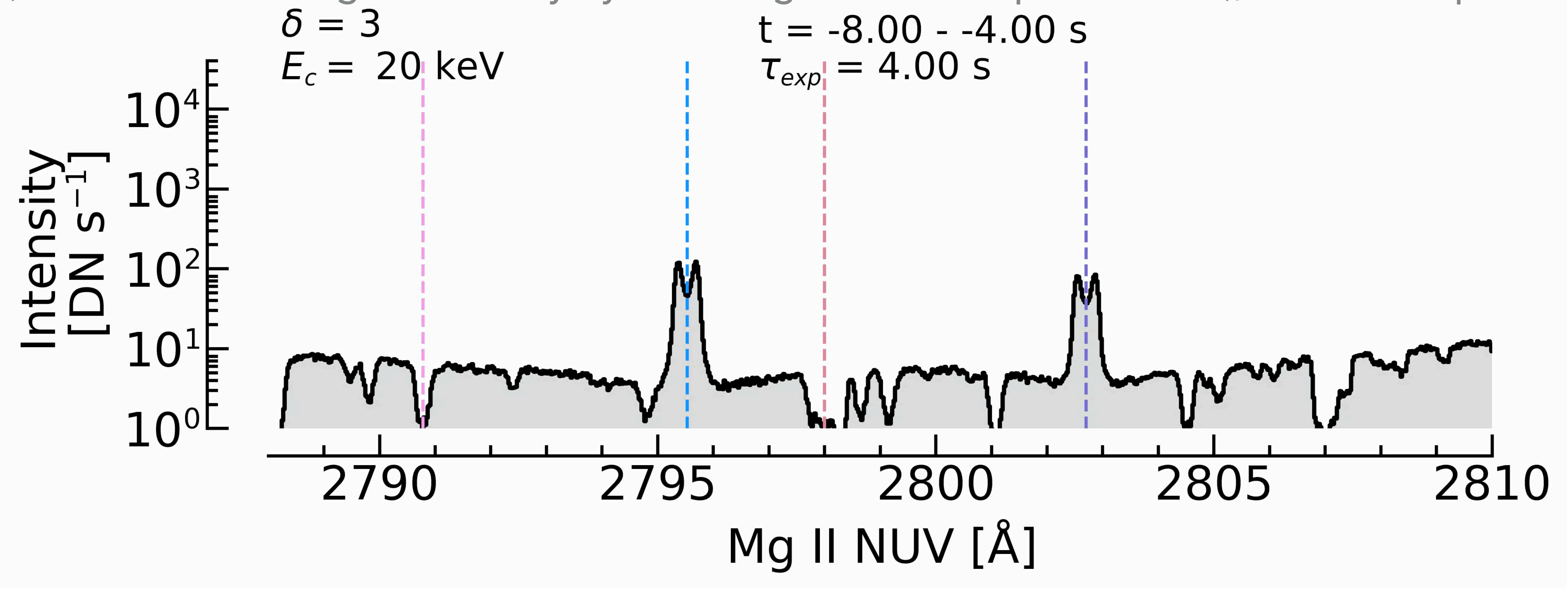
SUSTAINED HE I 10830 ENHANCED ABSORPTION

- Varying the period of weak heating can shorten or extend the period of absorption.



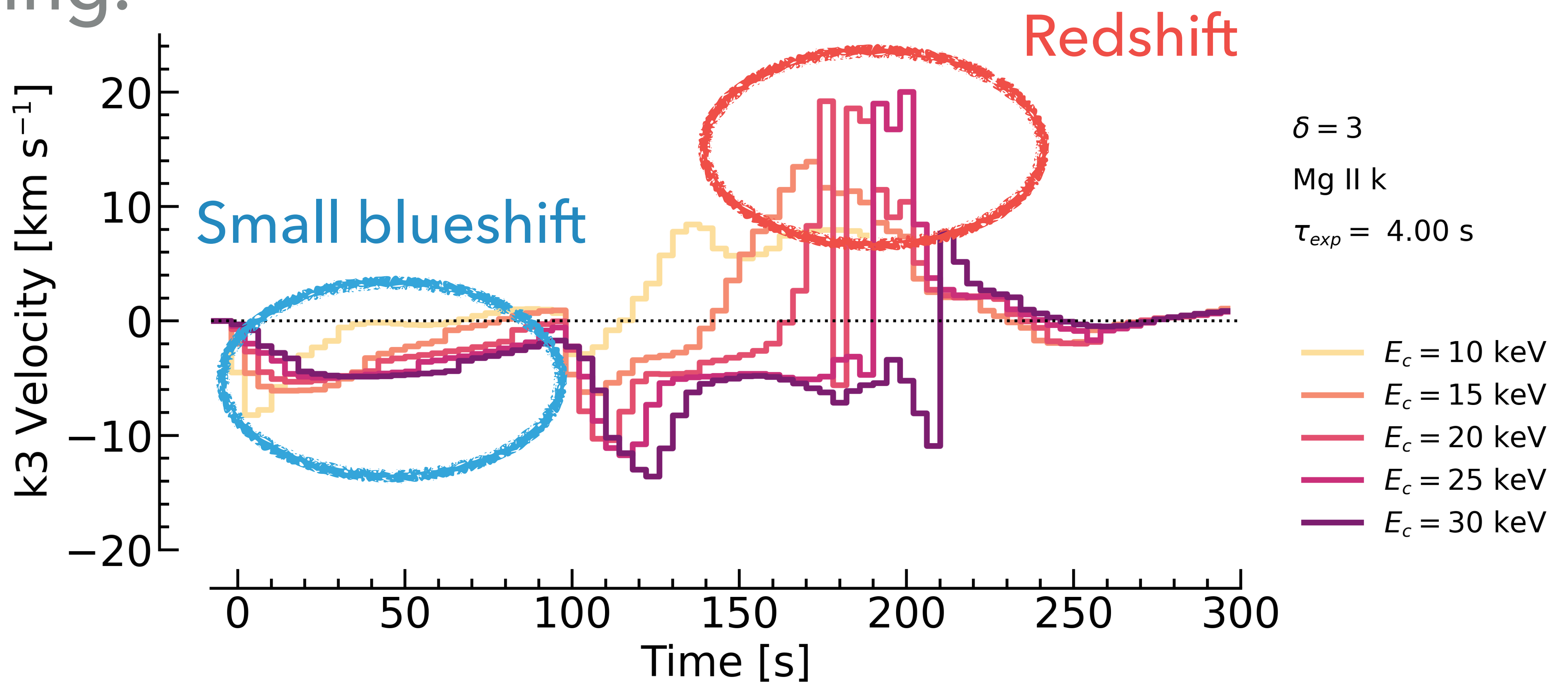
SUSTAINED MG II RIBBON FRONT PROFILES

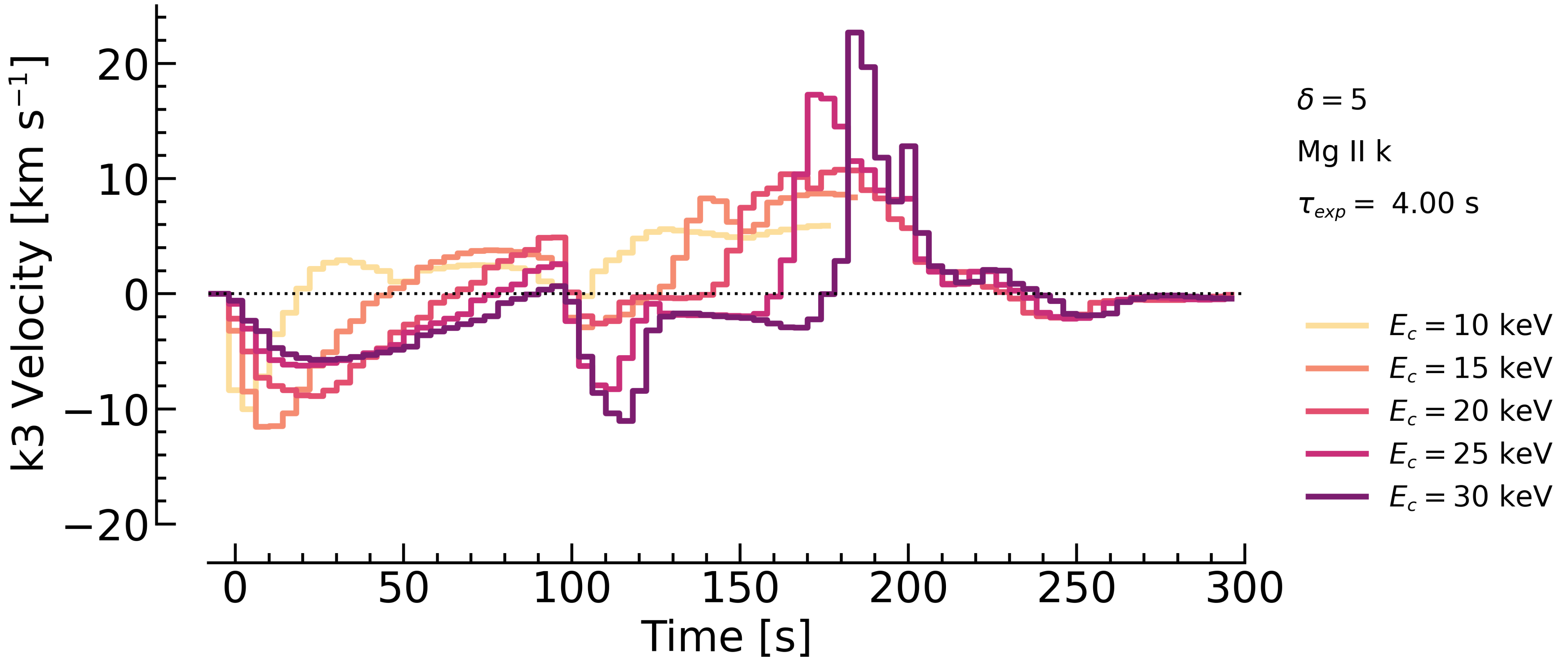
- Using our RADYN simulations we produced Mg II NUV spectra using a modified version of RH15D.
  - Also forward modelled several other lines, including the He I D3 lines, Ly α,β, plus IRIS observables.
- Folded the Mg II data through the IRIS response, degraded to IRIS resolution, assumed a typical exposure time of 4s (results didn't change drastically by assuming a smaller exposure time), and added poisson noise.

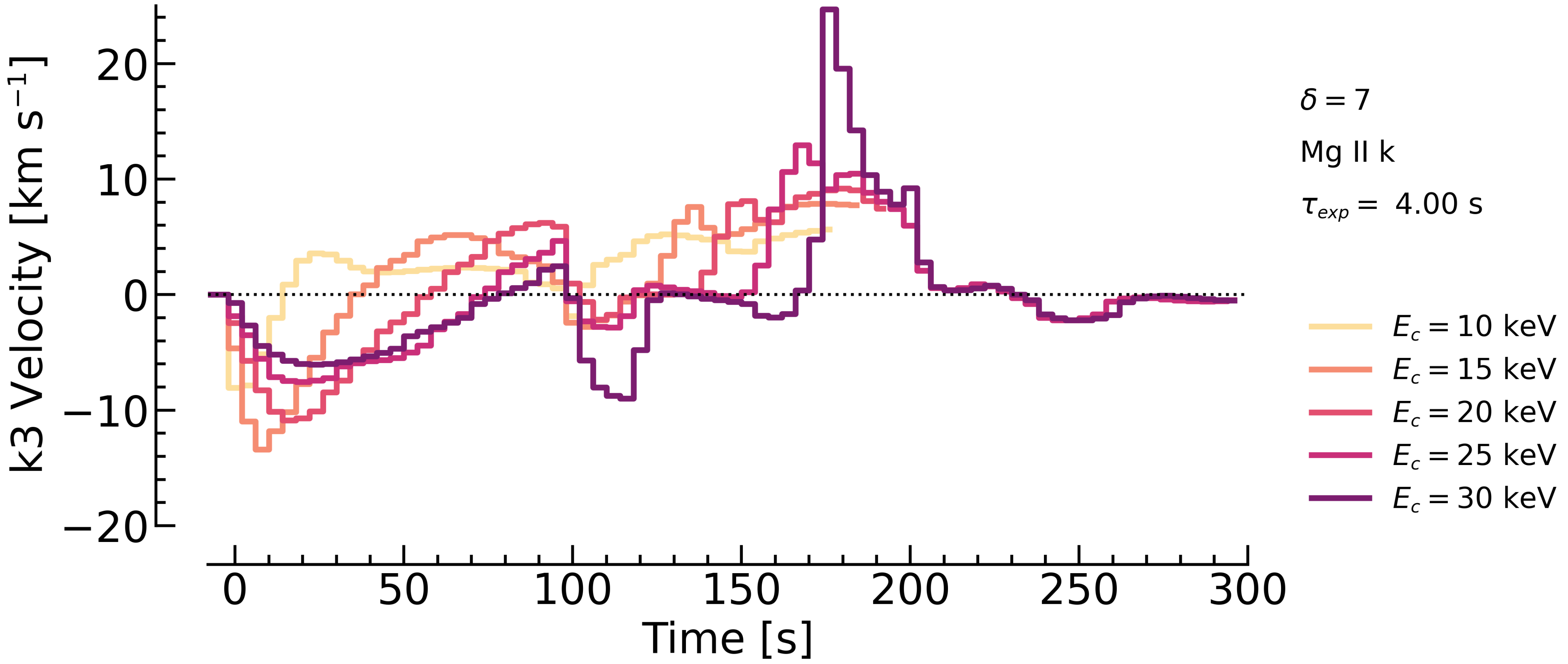


MG II DOPPLER SHIFTED CORE

- Mg II k3 component initially blueshifted, before chromospheric condensation either redshifts the core or produced a strong red wing.





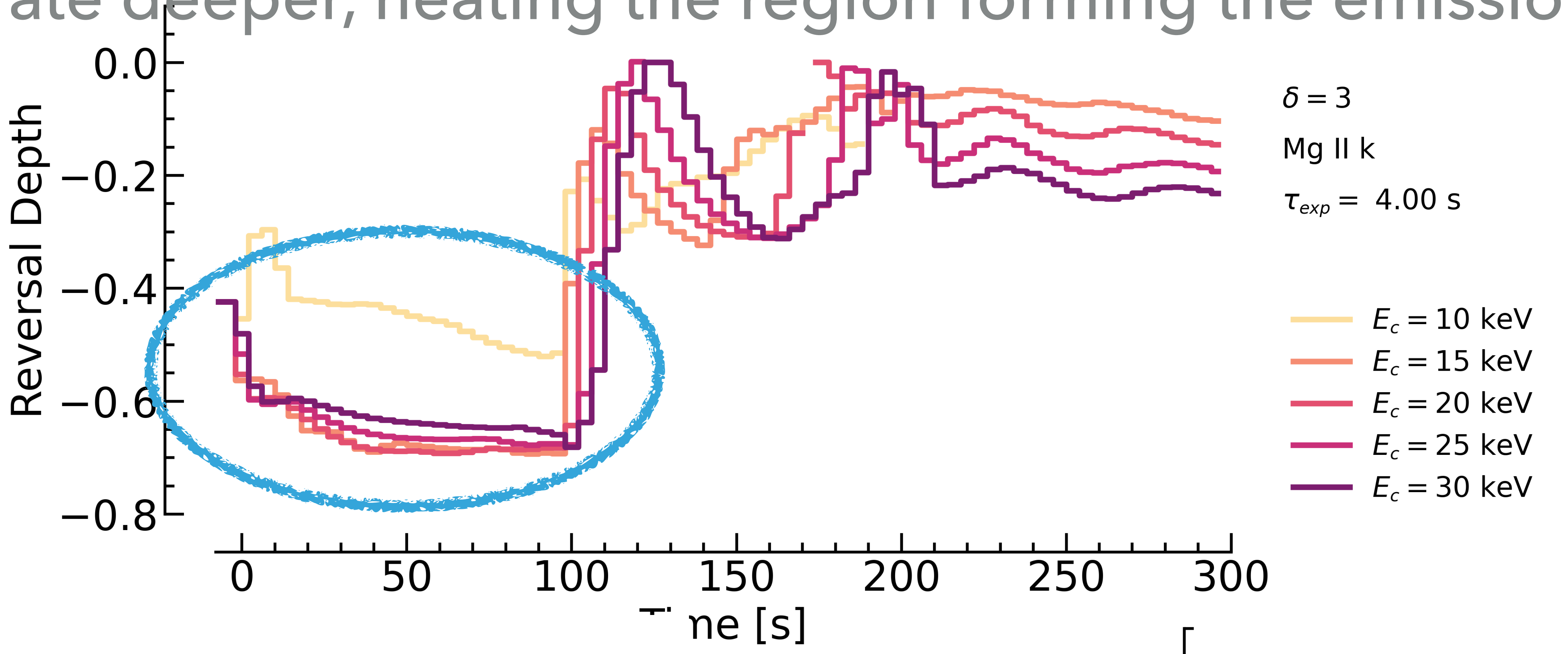


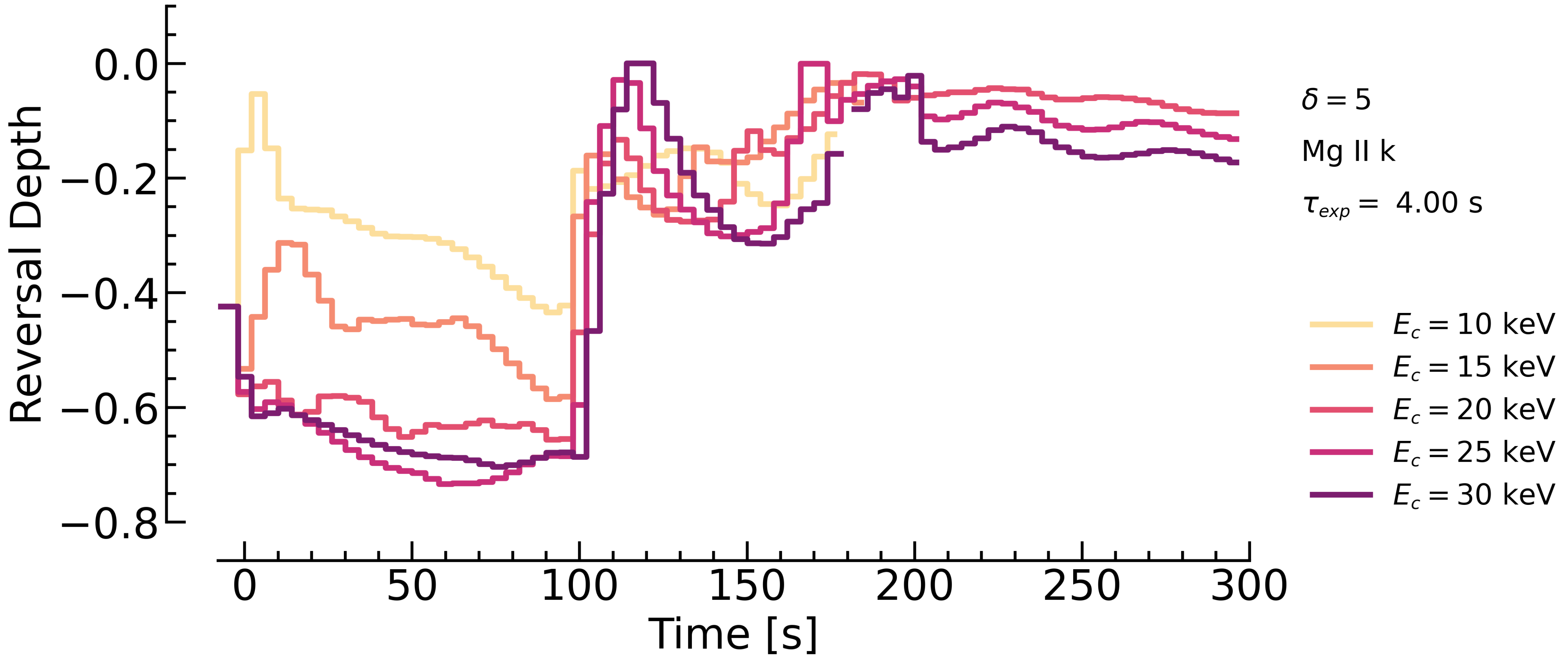
MG II DEEP CENTRAL REVERSAL

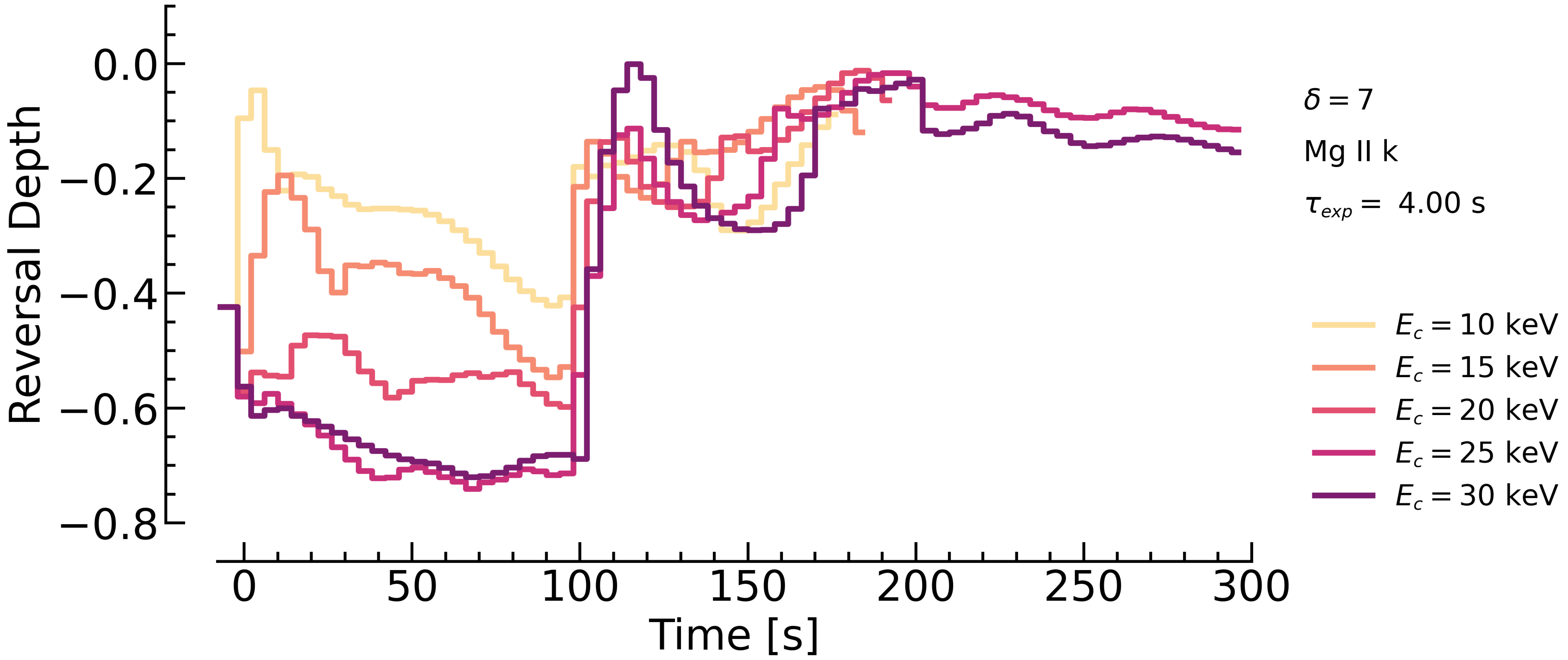
- Mg II central reversal deepens during the period of weak heating, before becoming more shallow when energy flux is increased.

- Harder electron spectra penetrate deeper, heating the region forming the emission peaks more than the core.

Central reversal gets deeper

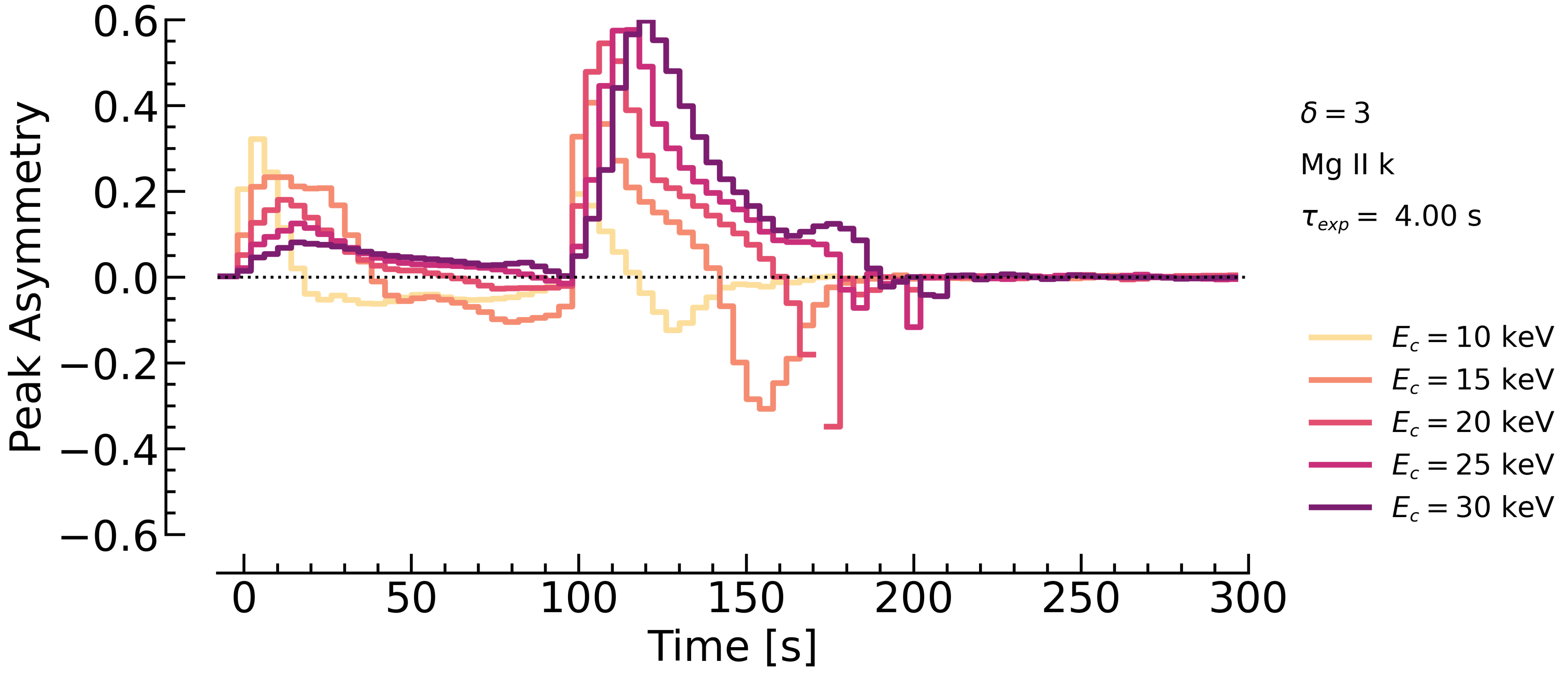


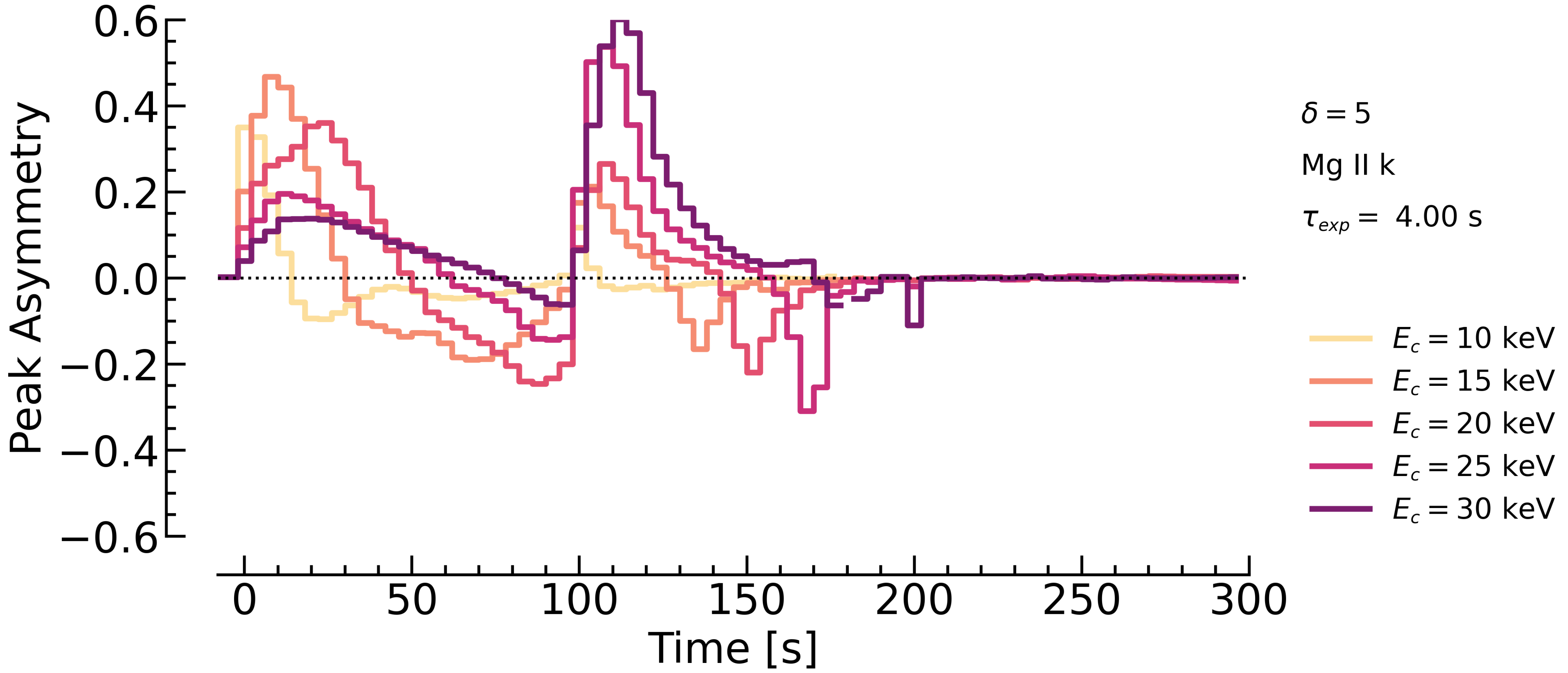


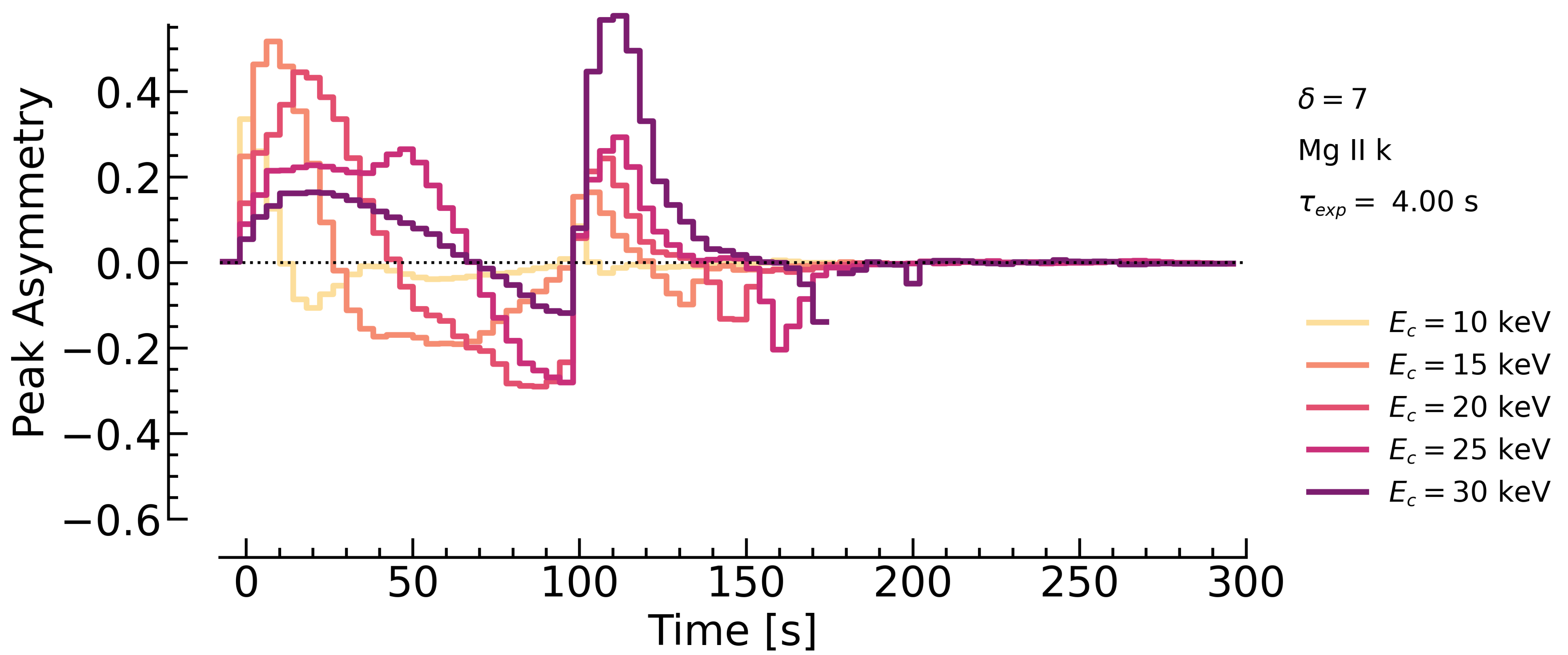


MG II PEAK ASYMMETRY

- The red peak (k2r) becomes stronger than the blue peak (k2v) during the period of weak heating, before flipping when energy flux is increased – makes sense, considering the line formation and relation to atmospheric flows (upflow = blue shifted absorption profile, and weaker blue peak).







Summary

- ▶ Chromospheric observations of flare ribbons carry important information about fundamental flare processes.

- ▶ We have identified an explanation for both He I 10830 negative ribbons and Mg II ribbon front spectra.

    - ❖To achieve consistency between the behaviour and duration of both He I 10830 absorption, and Mg II ribbon front profiles, an extended period of weak heating by a hard non-thermal electron spectrum ***into each footpoint*** is required.