

**GRAHAM S. KERR** (CUA / NASA GSFC)

# LYMAN LINE DECREMENT DURING SOLAR FLARES

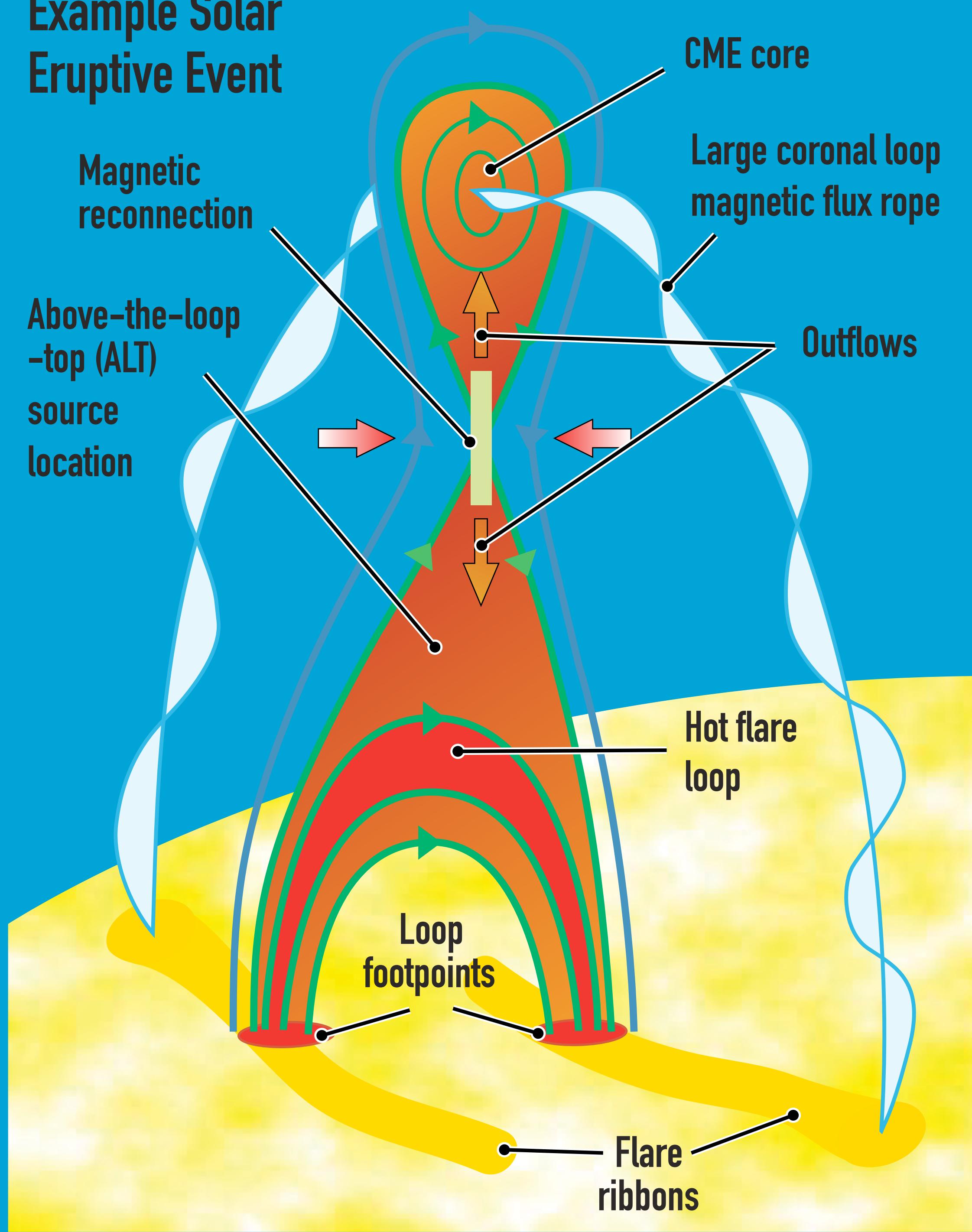
*A Model-data comparison between RHD models and Solar Orbiter SPICE observations*

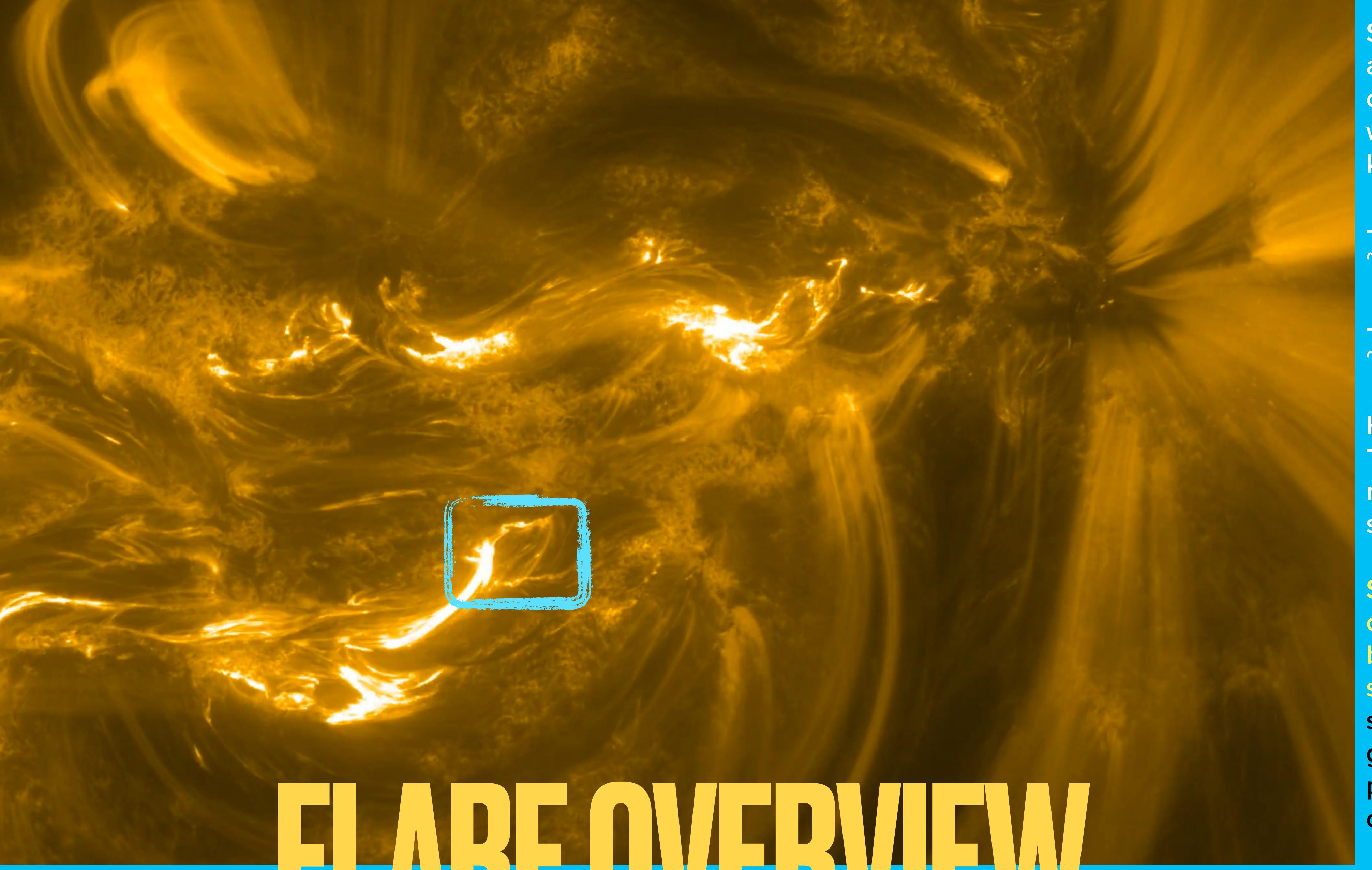
# OUTLINE

- Overview of SPICE observations of the 23rd March 2024 23:46UT M2.5 flare.
- Preliminary observational analysis:
  - ➔ No obvious Orrall-Zirker effect;
  - ➔ High cadence observations of a compact source;
  - ➔ Ly $\beta$  / Ly $\gamma$  ratio shows transient decrease;
- Preliminary RHD modelling of the event:
  - ➔ 12 electron beam simulations — heating upper chromosphere, or lower atmosphere, two different flare strengths;
  - ➔ 1 thermal conduction only simulation;
  - ➔ Synthesized Ly $\beta$  and Ly $\gamma$  lines, and studied formation properties;
  - ➔ Produced synthetic SPICE slit, including PSF;
  - ➔ Lyman decrement consistent with observations only in electron beam scenario, but observations miss structure in lightcurves;
  - ➔ Doppler motions strongly affected by PSF, but a slice through middle of source is sufficiently free of artifacts

Main takeaway — really nice high cadence observations of the EUV flare spectrum, but could really do with higher cadence!

# Example Solar Eruptive Event





# FLARE OVERVIEW

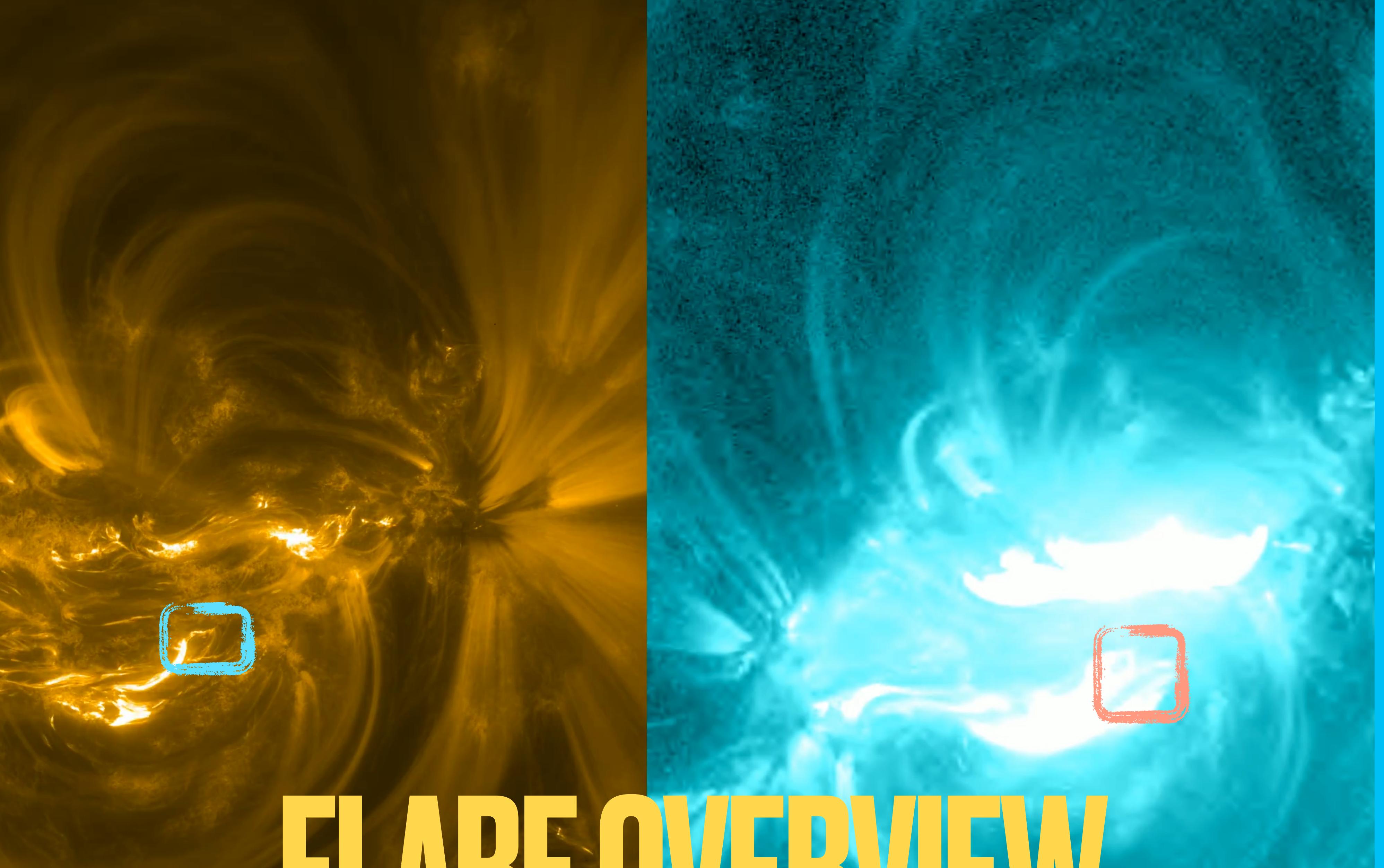
SPICE observed a series of sit-and-stare observations with 5s cadence during the major flare watch. So far there are two known events:

- M2.5 class 23rd March 2024  
~23:46UT

- C9 class 24th March 2024  
~01:00UT

Here I focus on the first event. This was a complex event with multiple ribbons and loop systems.

SPICE observed was a compact but intense brightening between larger sets of flare ribbons. The box shows a tentative, educated guess at where SPICE slit was positioned but need proper co-alignment.



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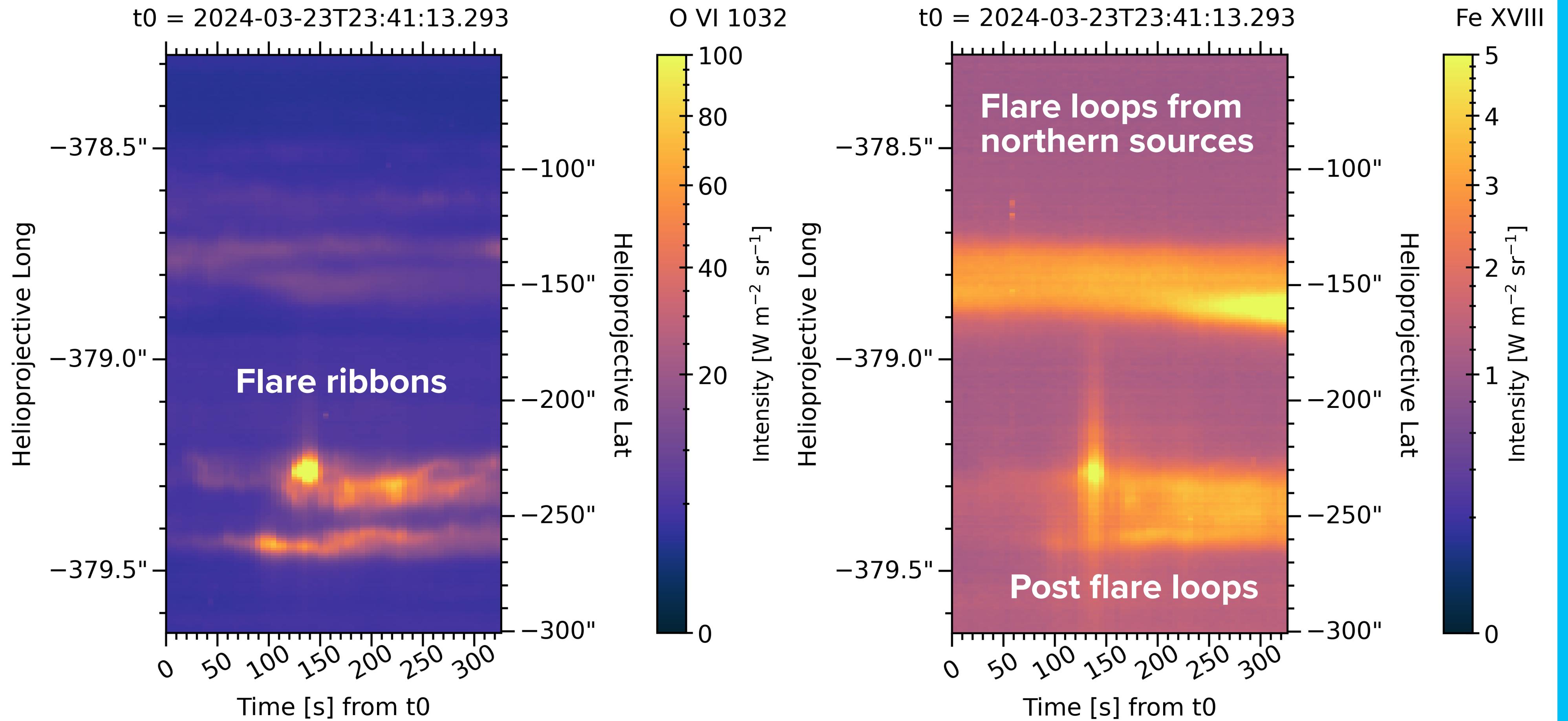
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\* Adapted from slide  
provided by P. Young



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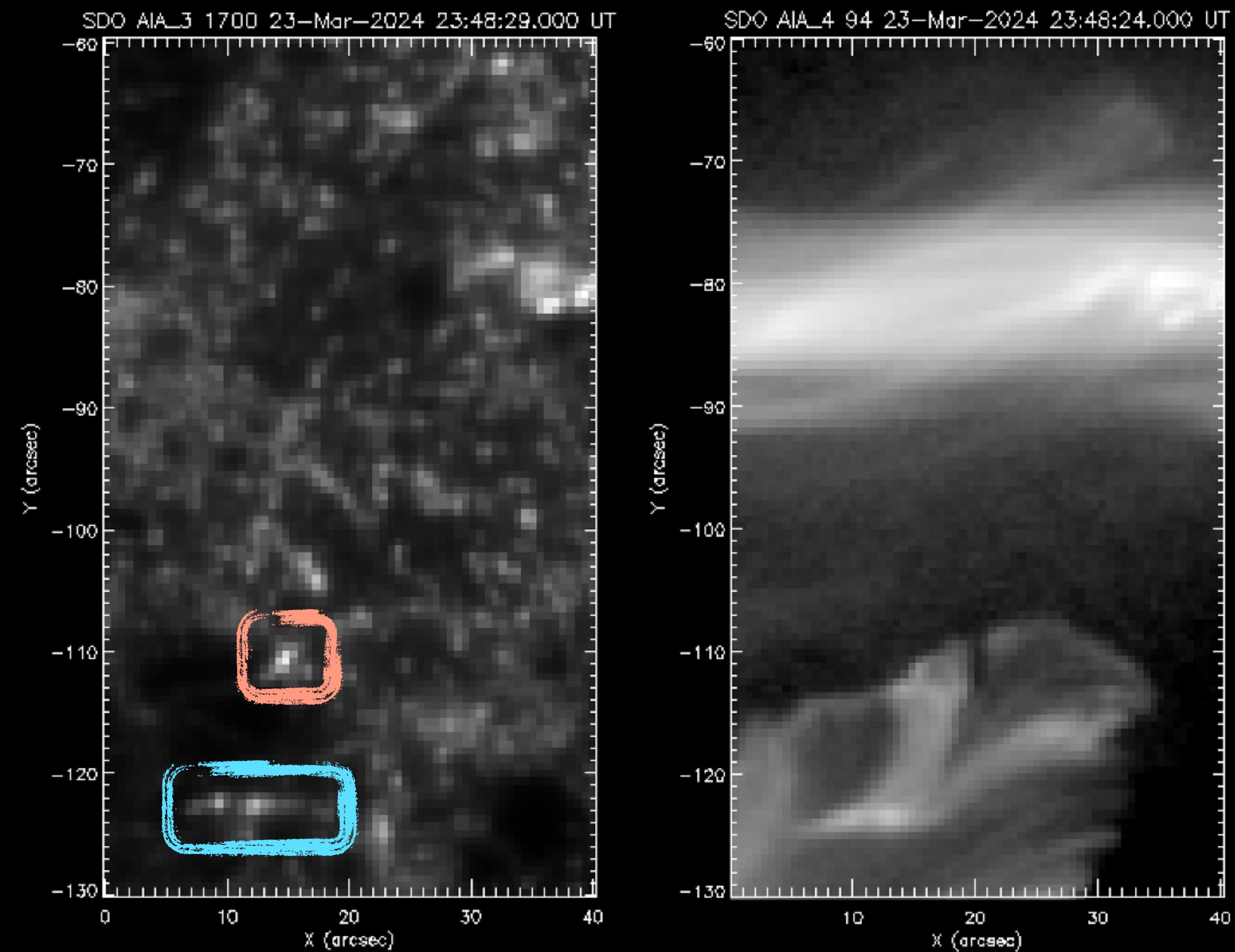
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Intense compact source.

Weaker extended ribbon

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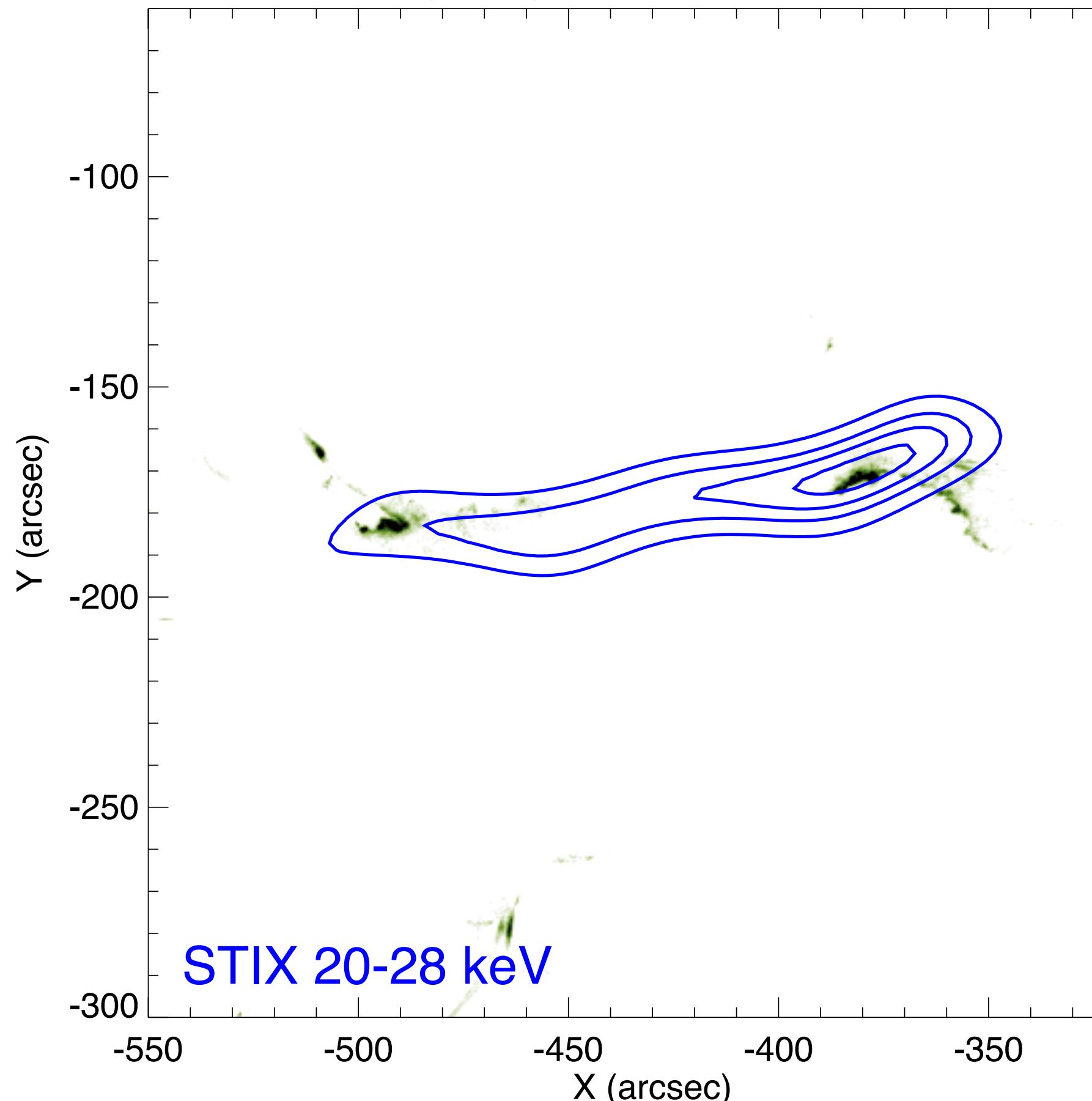
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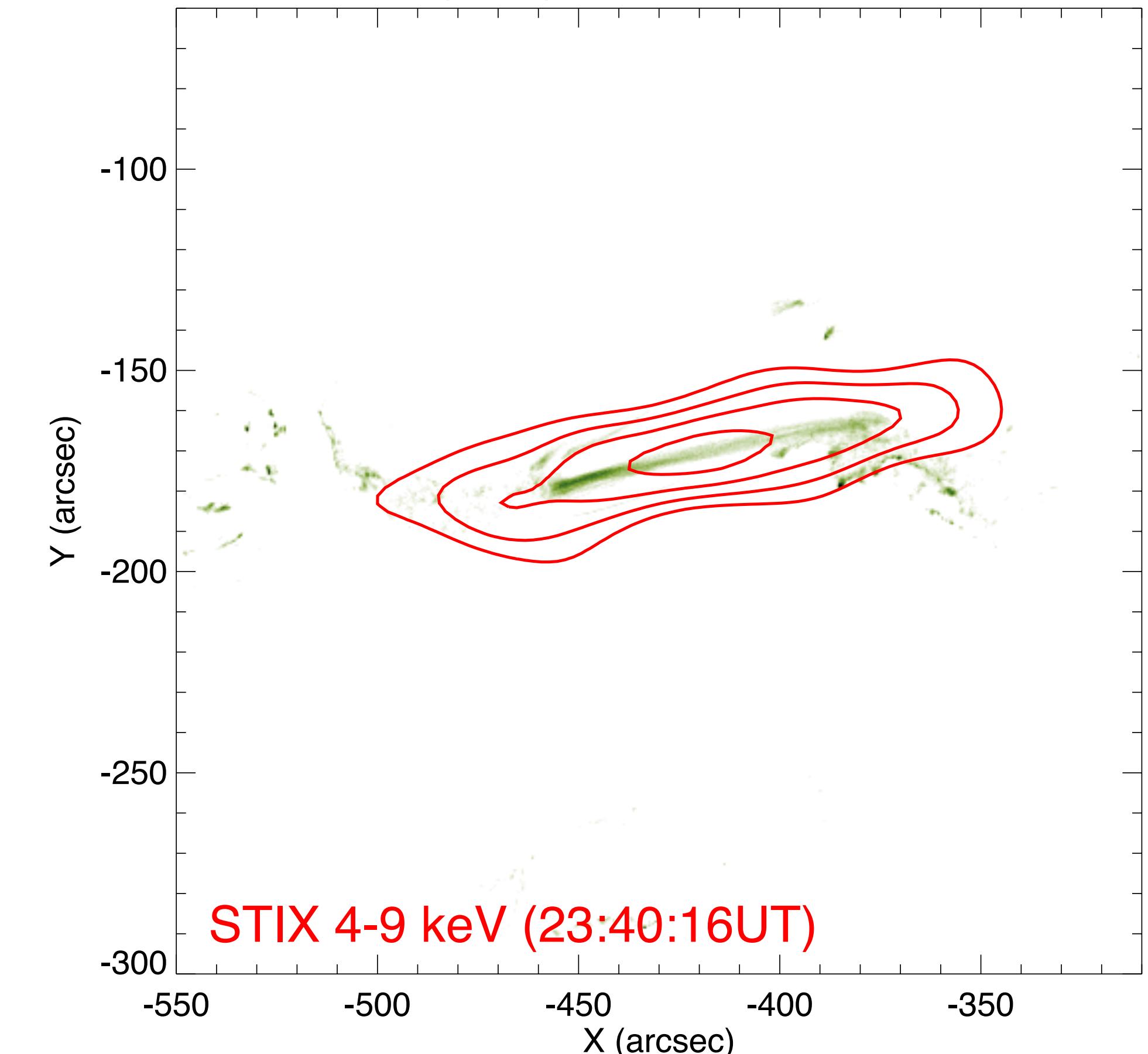
\* STIX Imaging by Säm Krucker and Dan Ryan

Dominant X-ray sources are to north of SPICE source, but needs proper co-alignment (STIX co-aligned with HRI in images below).

EUI/HRI 174A (short): 23-Mar-2024 23:40:16.247 UT



EUI/HRI 174A (short): 23-Mar-2024 23:42:40.247 UT



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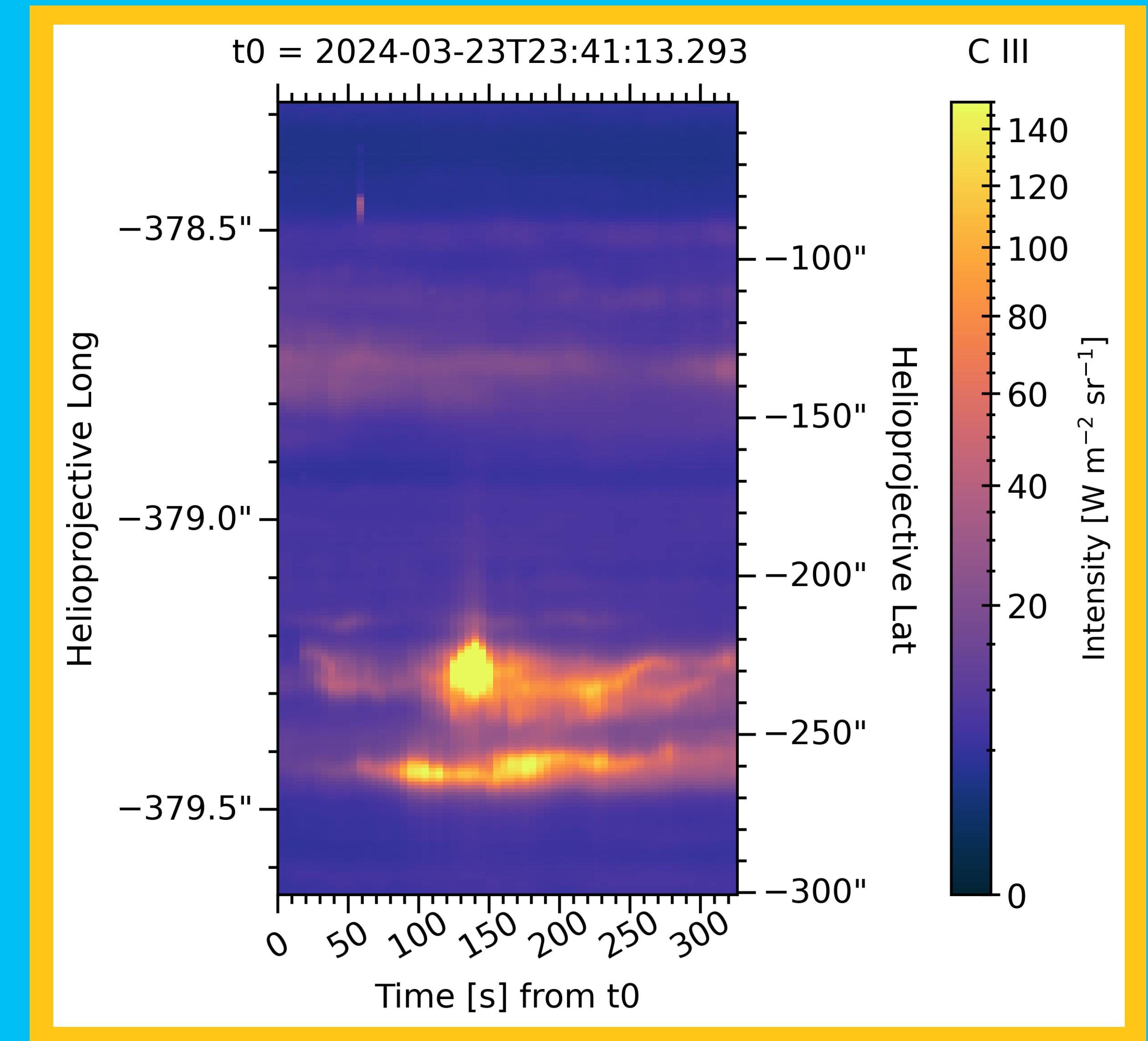
# FLARE OVERVIEW

# **OVERVIEW OF THE SPICE OBSERVATIONS**

**23RD MARCH 2024 23:46UT M2.5 CLASS FLARE**

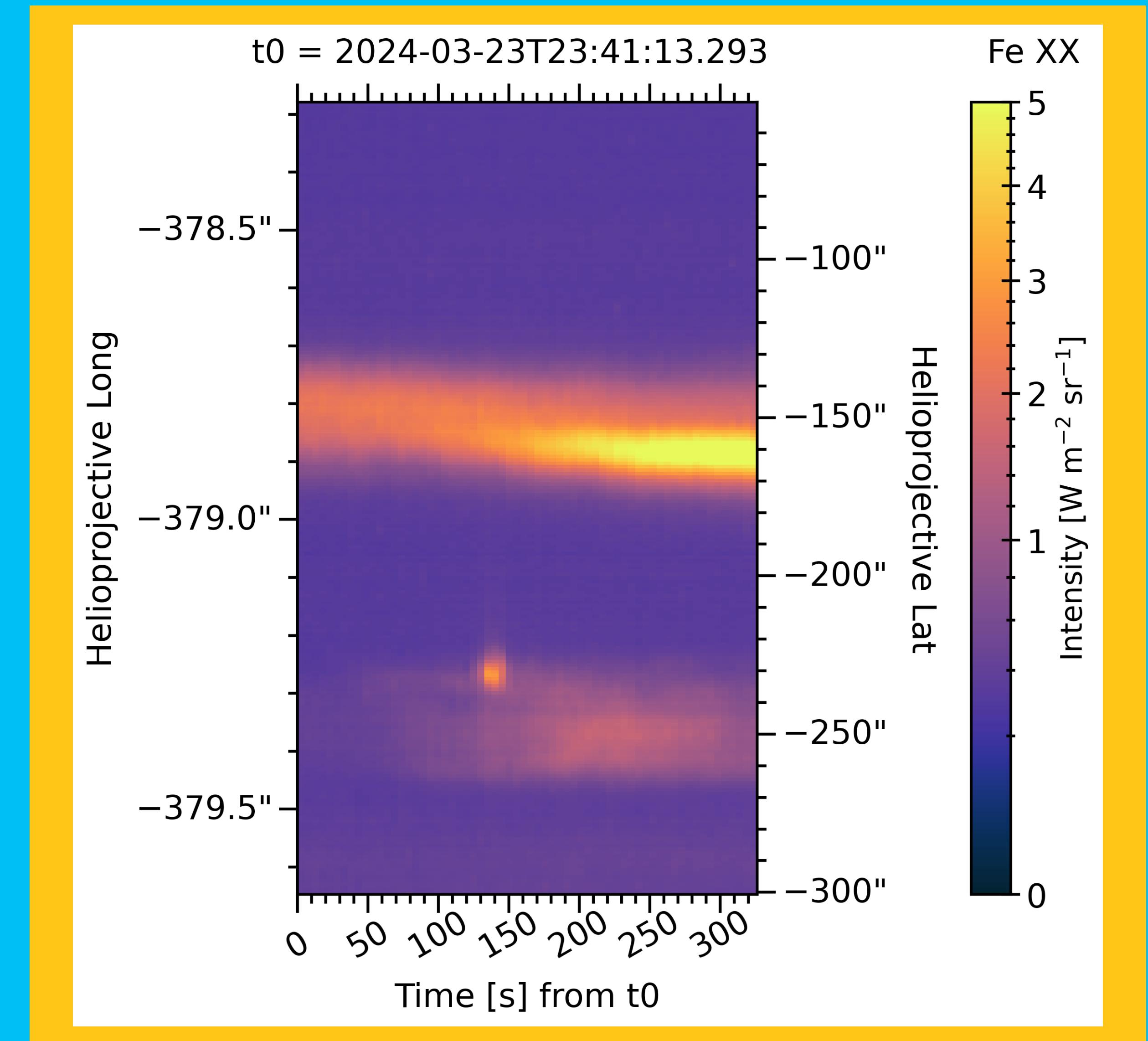
# SPECTRAL LINE LIST

- Many spectral lines were observed
  - ◆ C III  $\sim$ 97.7nm
  - ◆ Fe XVIII  $\sim$ 97.5nm
  - ◆ Fe XX  $\sim$ 72.1nm
  - ◆ Ly $\gamma$  & Ly $\beta$
  - ◆ Ne VIII  $\sim$ 77.0nm
  - ◆ N IV  $\sim$ 76.5nm
  - ◆ O II  $\sim$ 72.0nm
  - ◆ O III  $\sim$ 70.3nm
  - ◆ O VI  $\sim$ 103.2nm &  $\sim$ 103.7nm
  - ◆ ... maybe S III 101.2 – 101.6nm
- Covers a decent temperature range at 5s — one of highest cadence flare datasets.



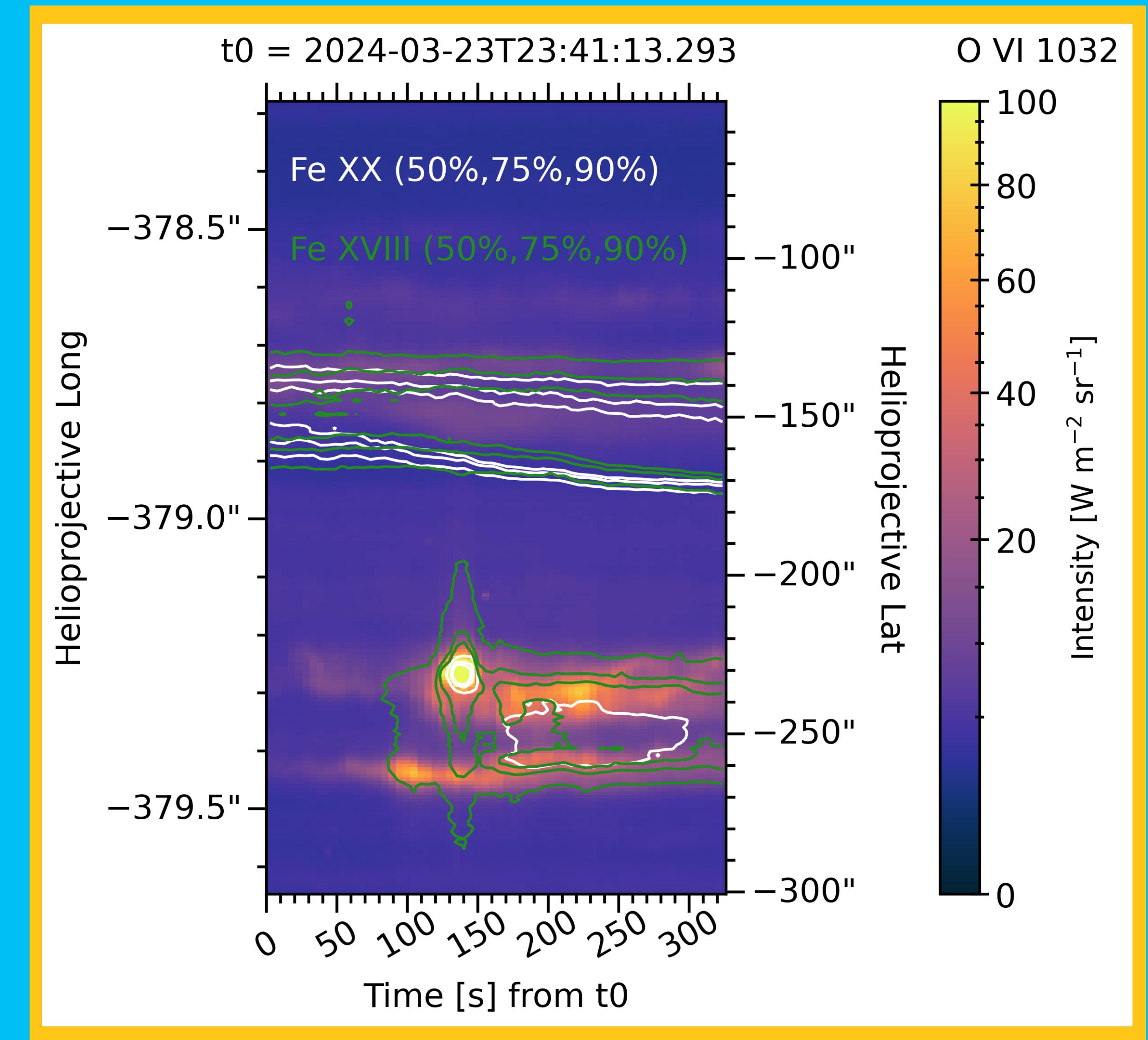
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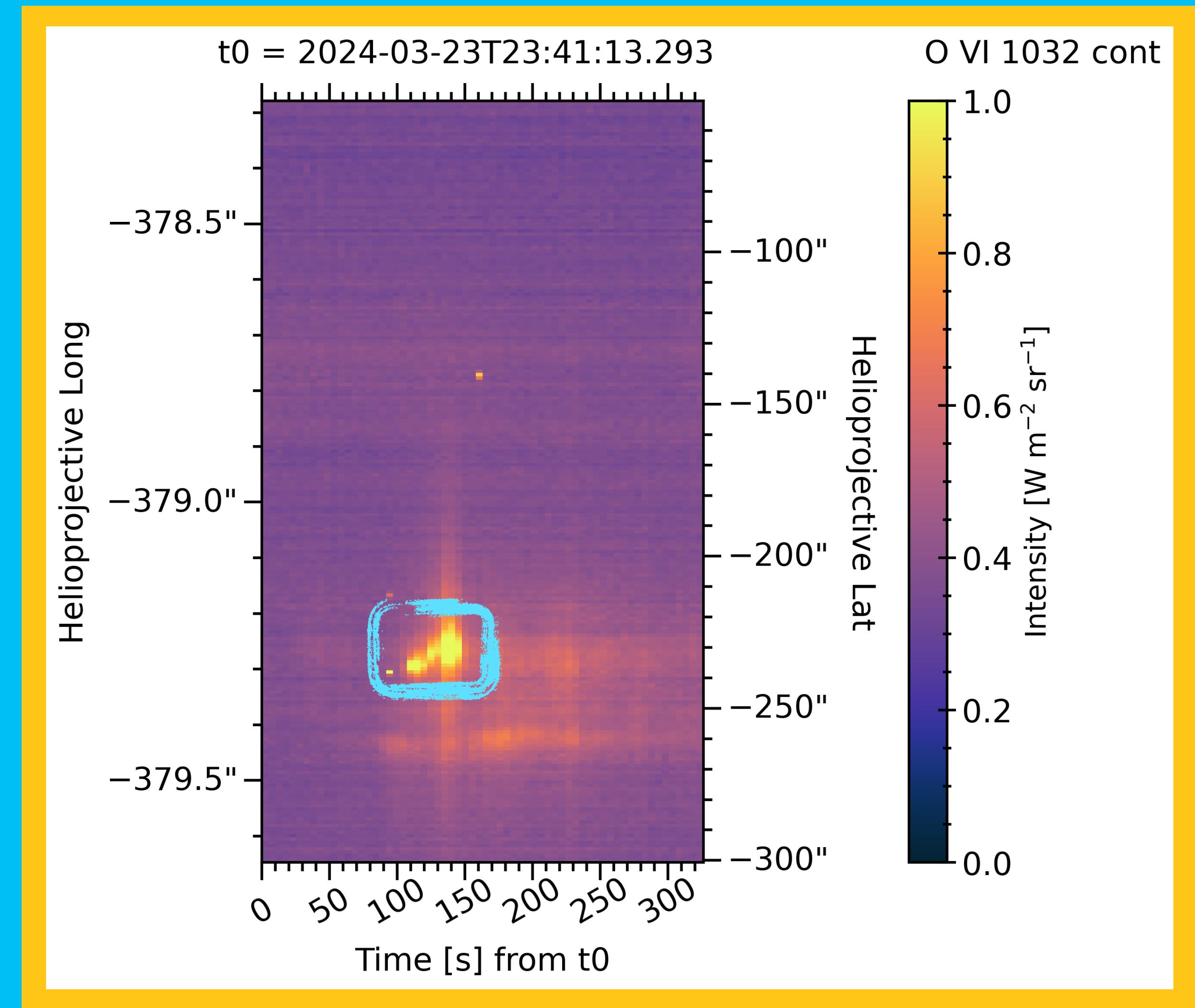
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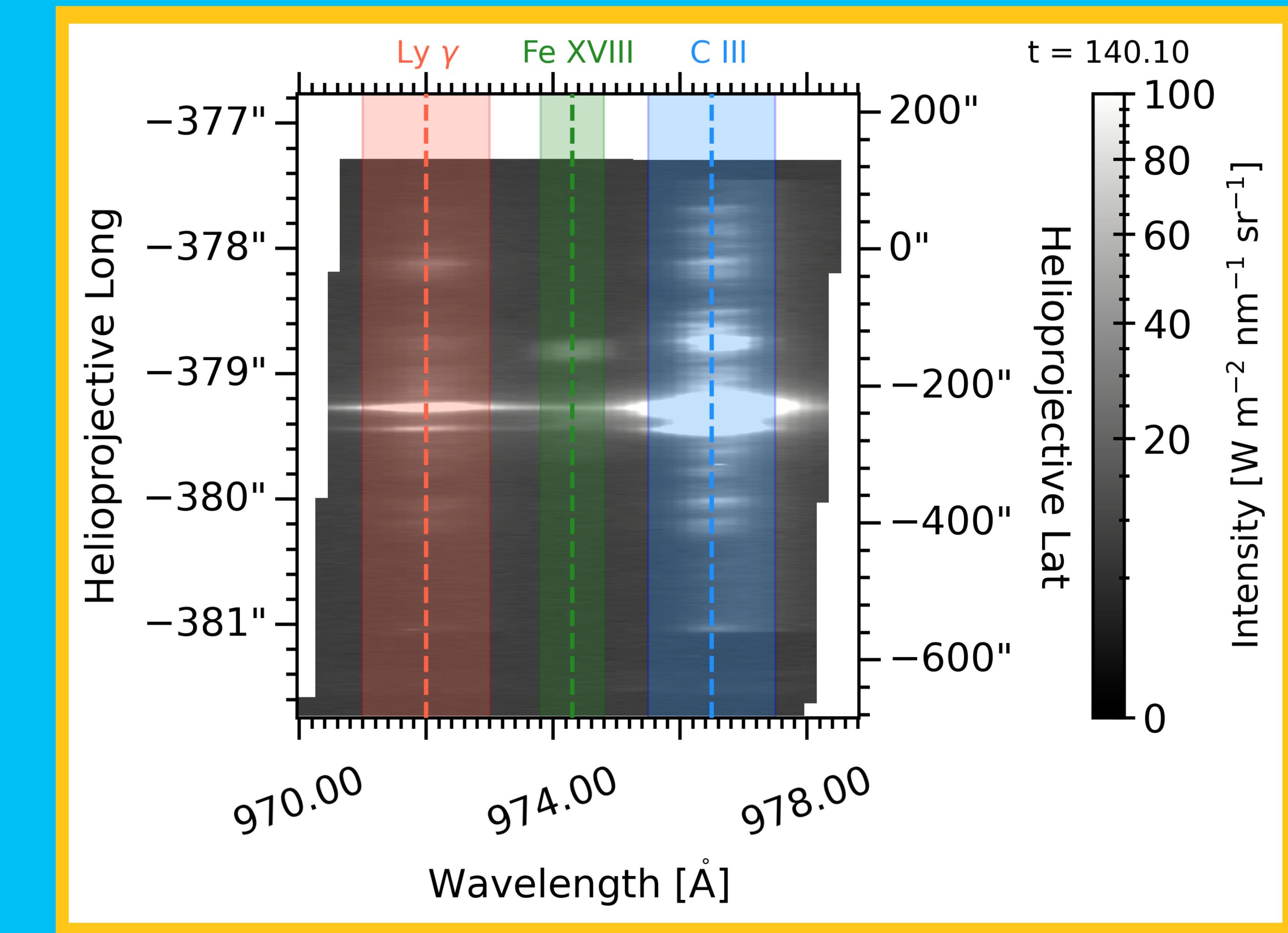
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Continuum brightens a little earlier in some locations!



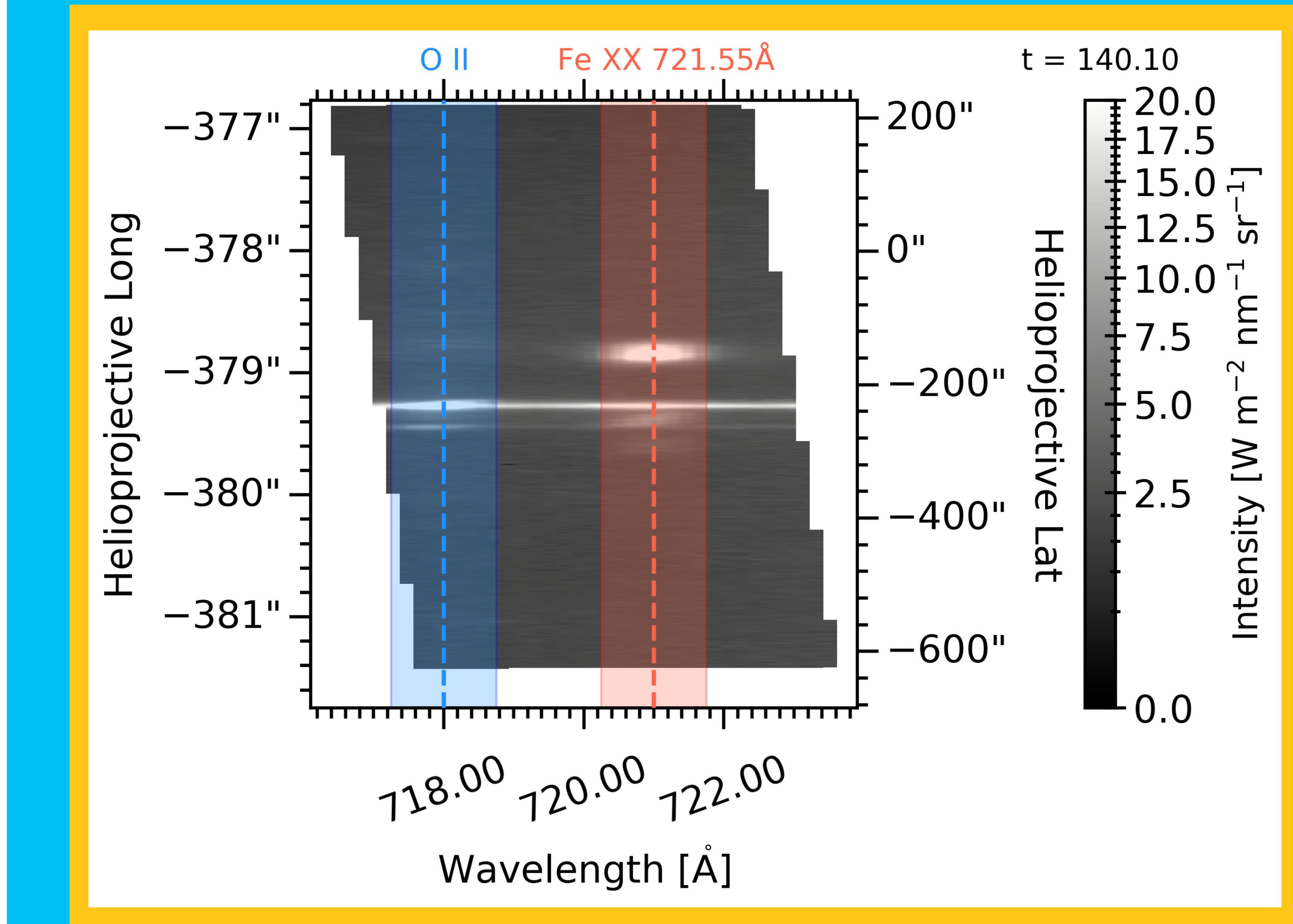
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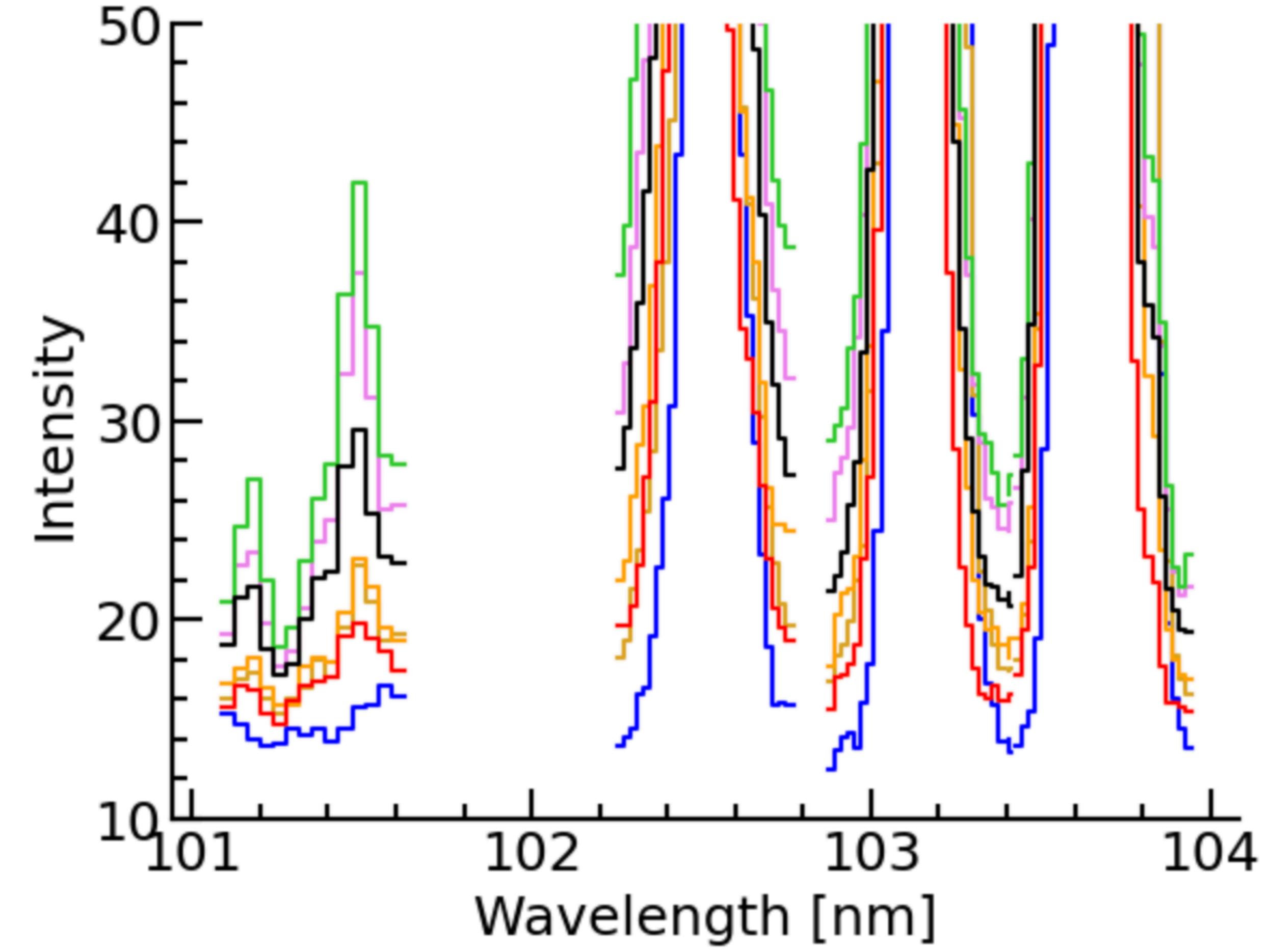
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# ORRALL-ZIRKER EFFECT?

- Preliminary answer: **Not yet**
- ◆ See Kerr et al 2023 ApJ 945 for details.
- ◆ In brief, a potential diagnostic of accelerated protons, in which charge exchange results in enhanced continuum near Ly $\beta$  & O VI.

No clear enhancement of continuum on red side of Ly $\beta$  compared to blue.



S III + continuum

Ly $\beta$

O VI

O VI

# **LYMAN LINE DECREMENT**

**23RD MARCH 2024 23:46UT M2.5 CLASS FLARE**

**DUE TO SPICE PSF, COMPARING DOPPLER SHIFTS AND LINE WIDTHS TO MODELS IS NOT STRAIGHTFORWARD.**

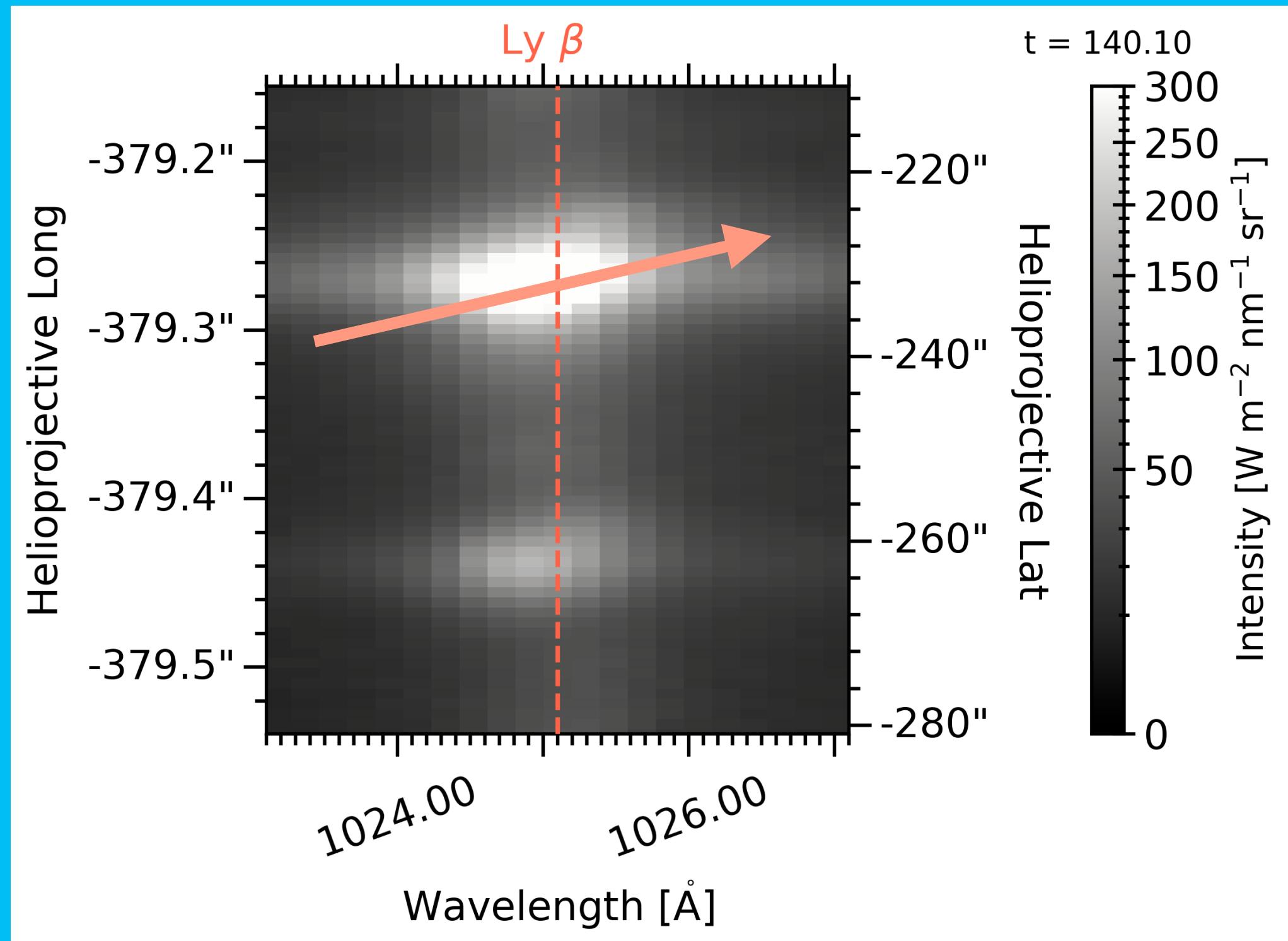
**AN EASIER, BUT POTENTIALLY STILL POWERFUL, METRIC IS THE LYMAN DECREMENT.**

**THIS CAN INFORM US ABOUT THE ATMOSPHERIC STRATIFICATION AND POTENTIALLY NONTHERMAL PROCESSES.**

# EFFECTS OF THE PSF

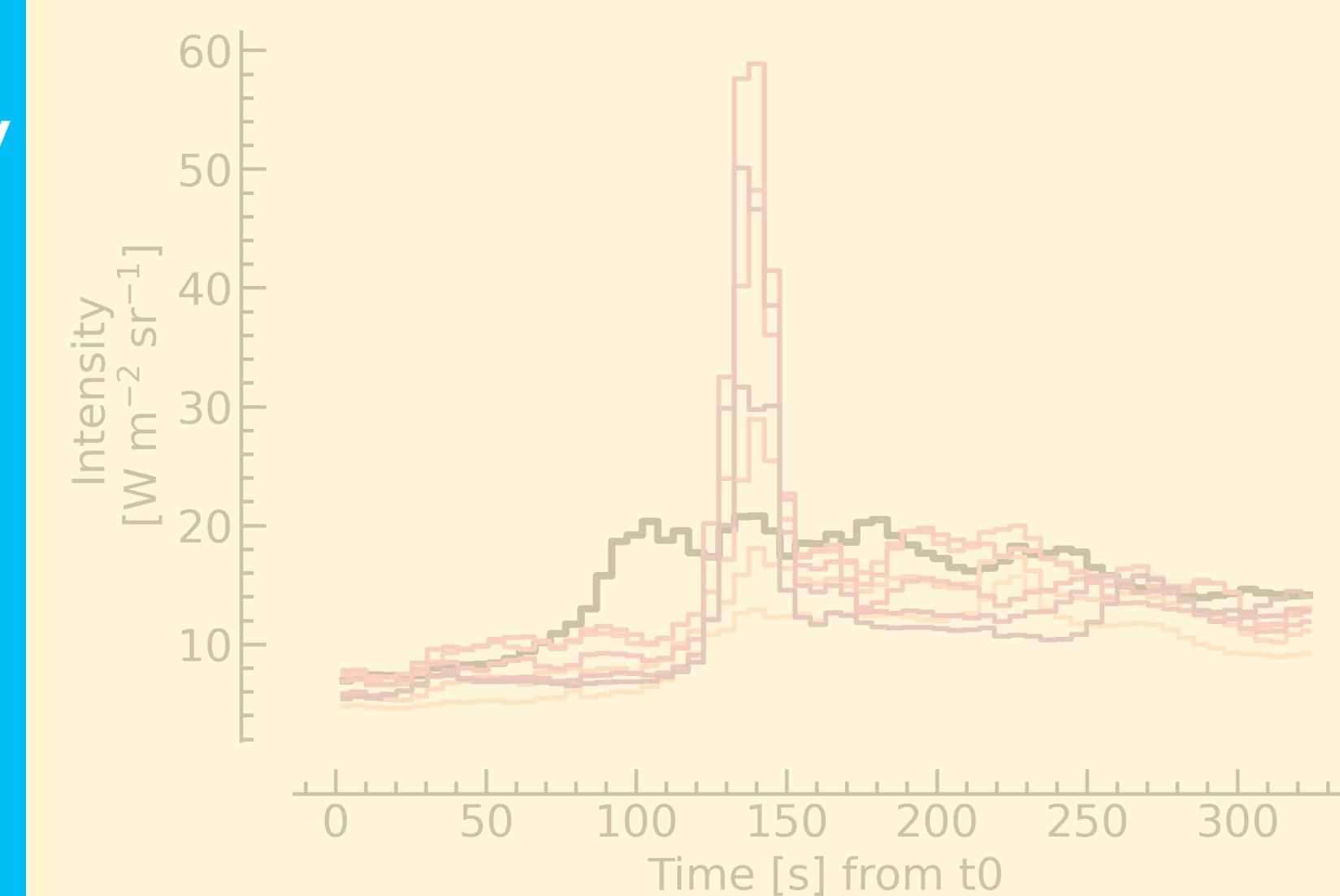
The tilted PSF means that inferring line widths or Doppler Shifts is non-trivial.

Need to remove PSF effects, but that takes time, so initially Lets do something simpler.



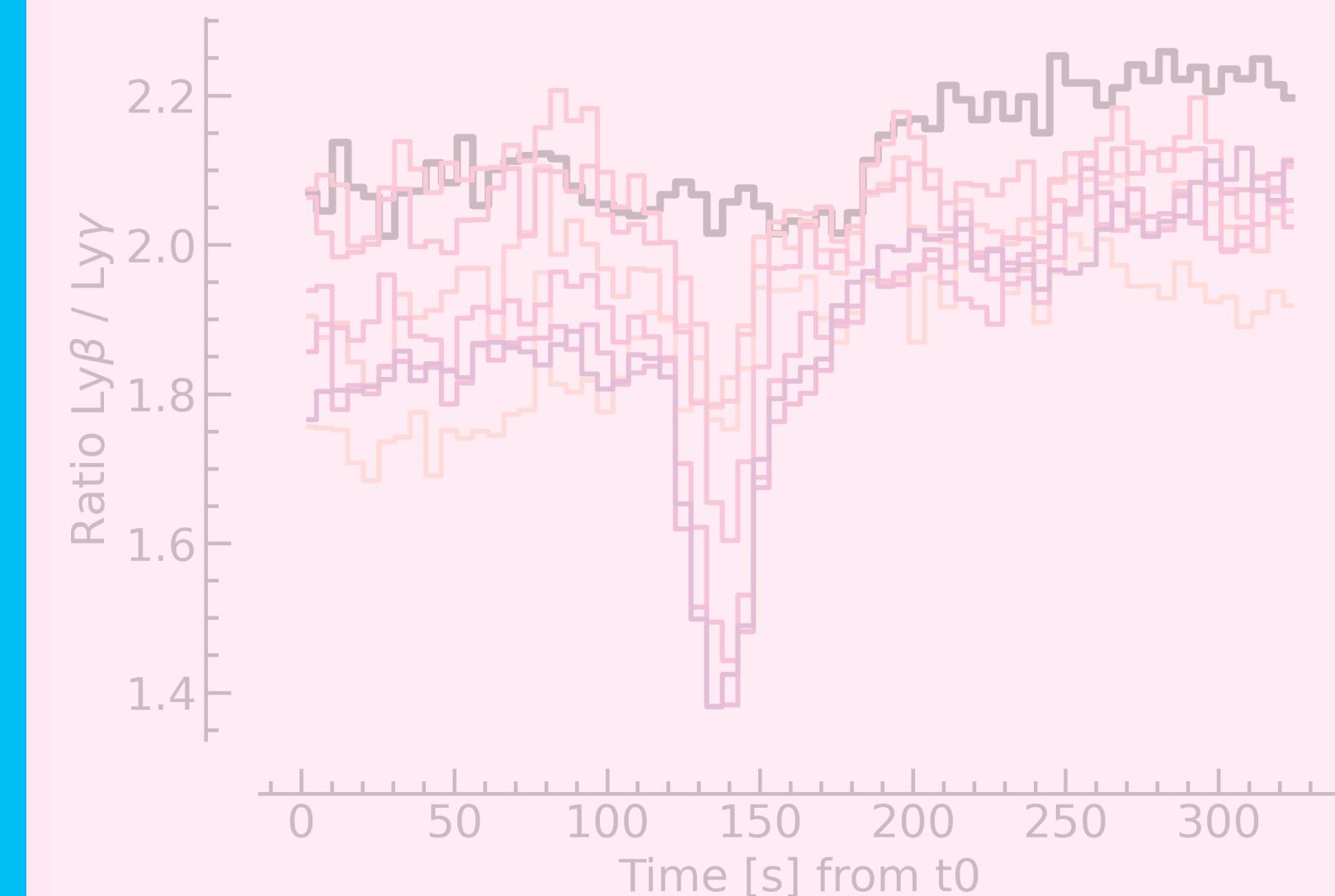
# INTENSITY INCREASE IS VERY TRANSIENT

$t_0 = 2024-03-23T23:41:13.293$



## LYMAN DECREMENT IN UPPER VS LOWER SOURCE

$t_0 = 2024-03-23T23:41:13.293$



Upper source much more intense, with a transient ( $\sim 30$ s) peak followed by slower decay to background.

Lower source (black curve) is much weaker and with less impulsive emission.

Ly $\gamma$  and other lines show same.

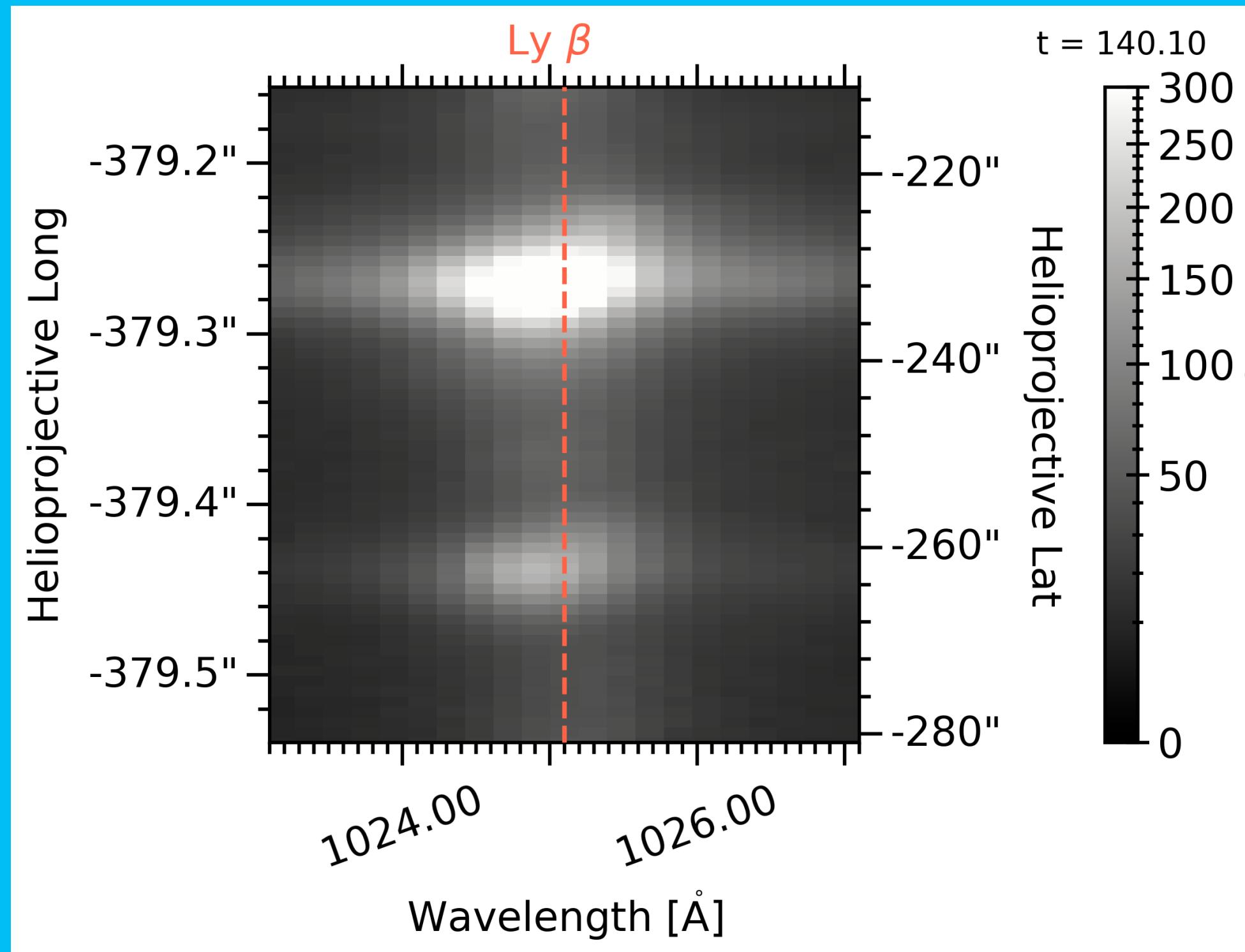
In the impulsive flare source the ratio decreases before returning to pre-flare values faster than the intensity of the line.

The lower source doesn't really show a meaningful change.

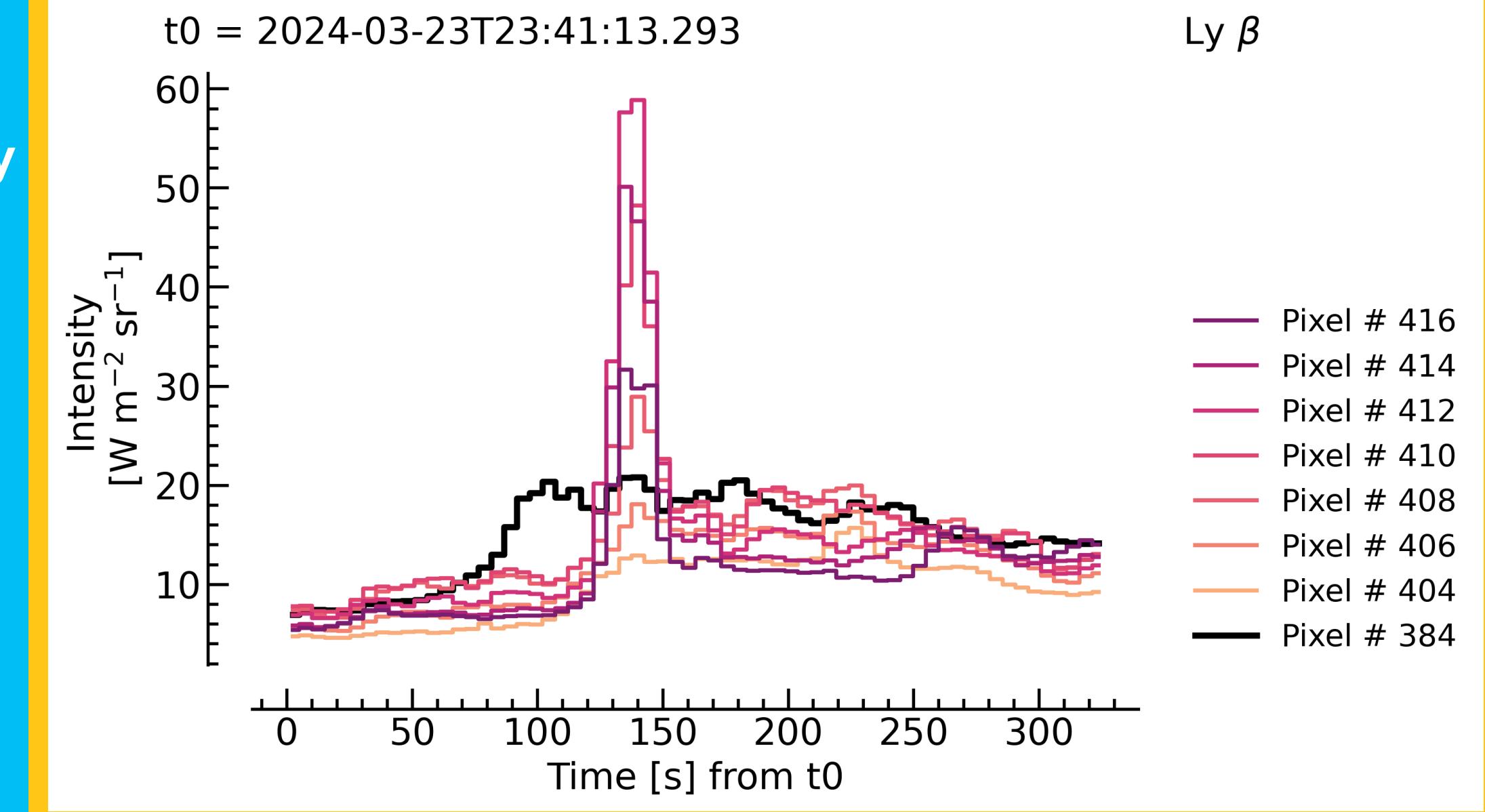
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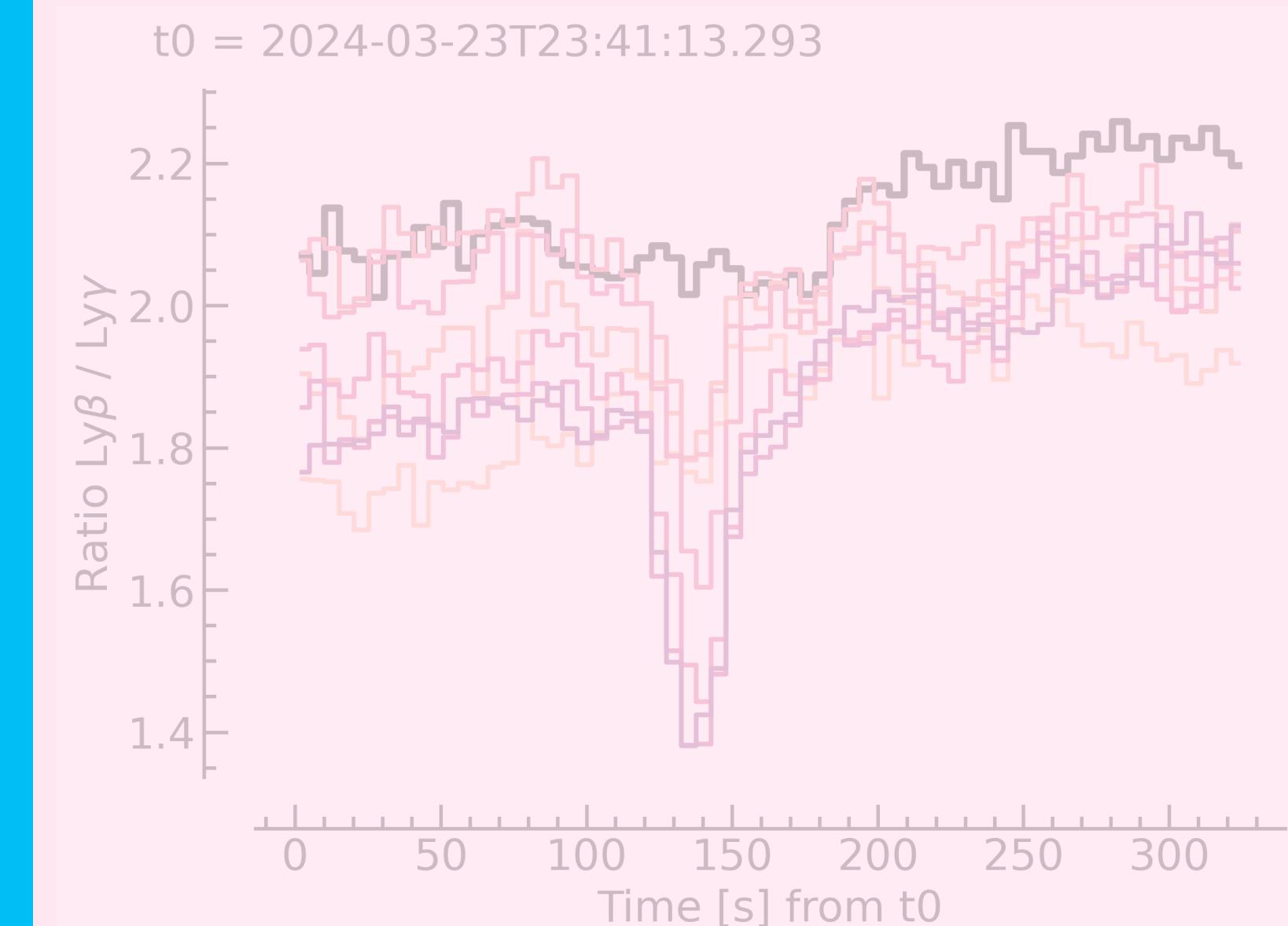
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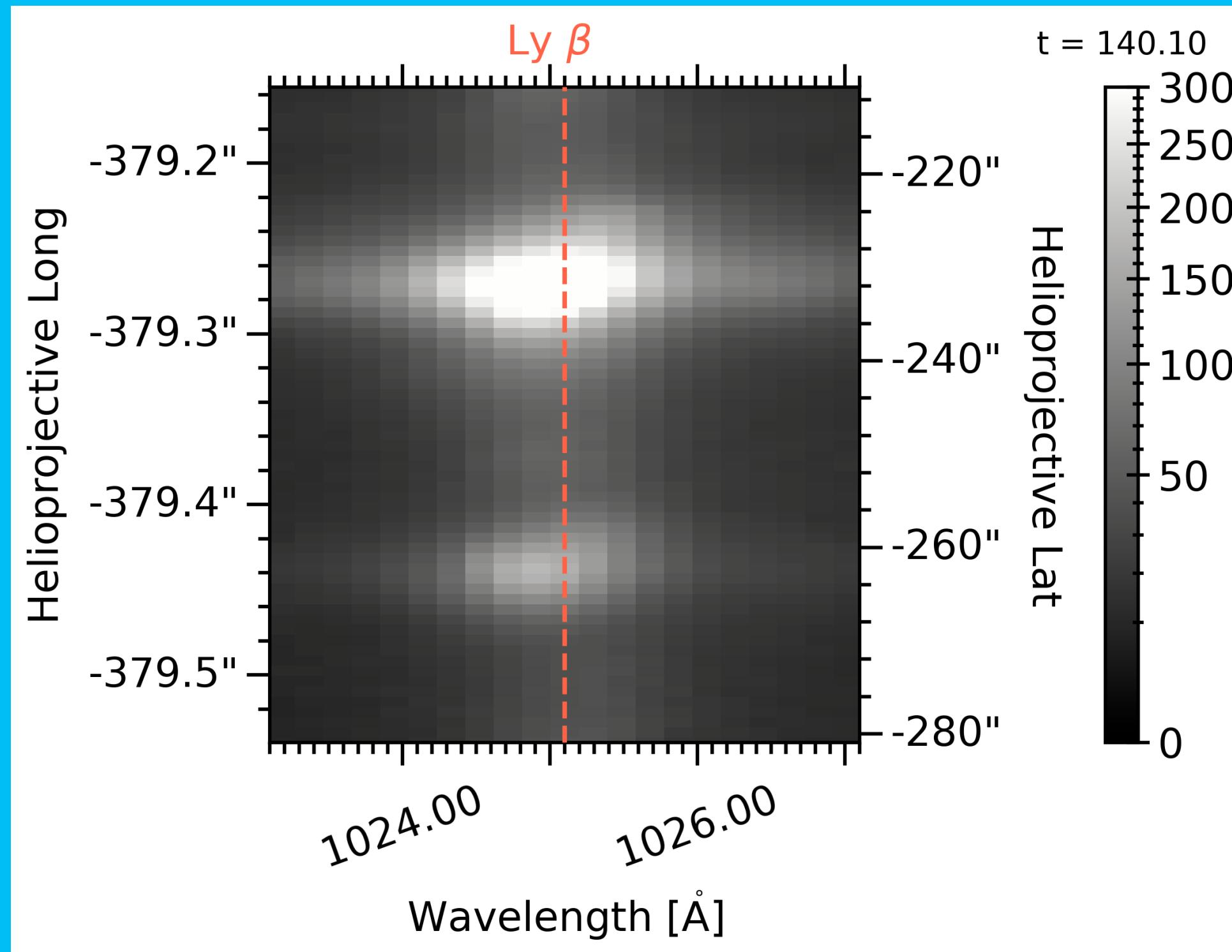
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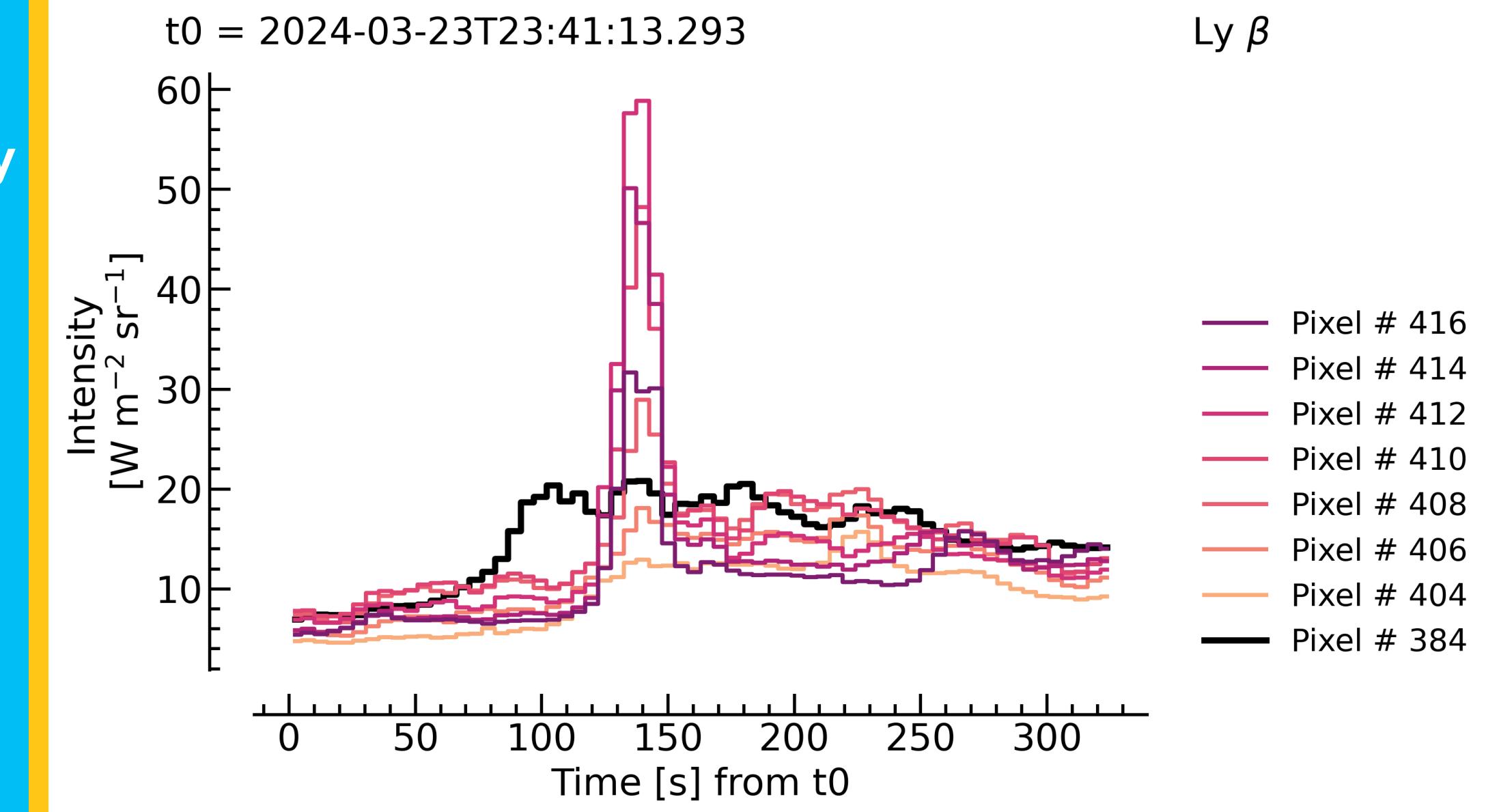
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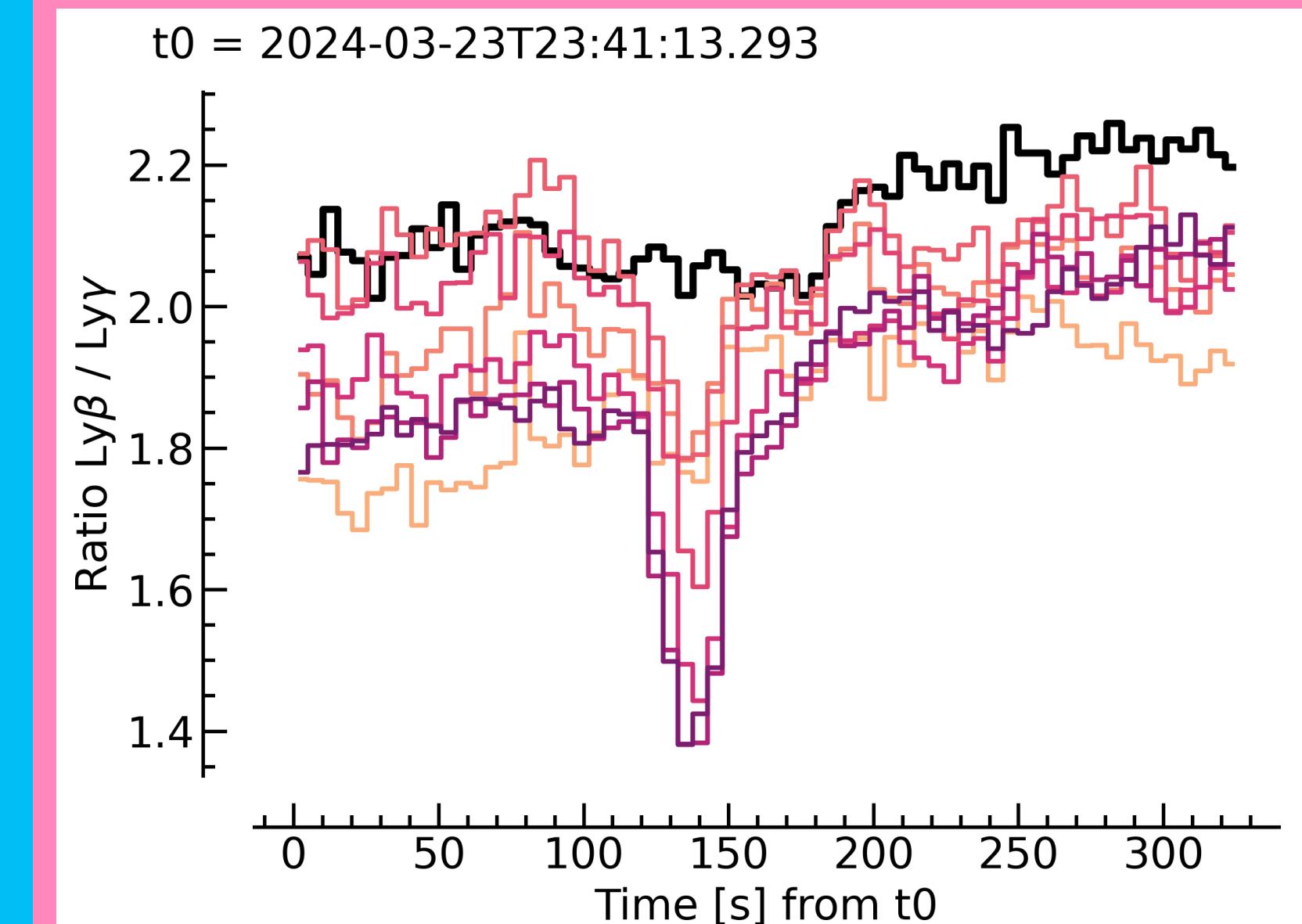


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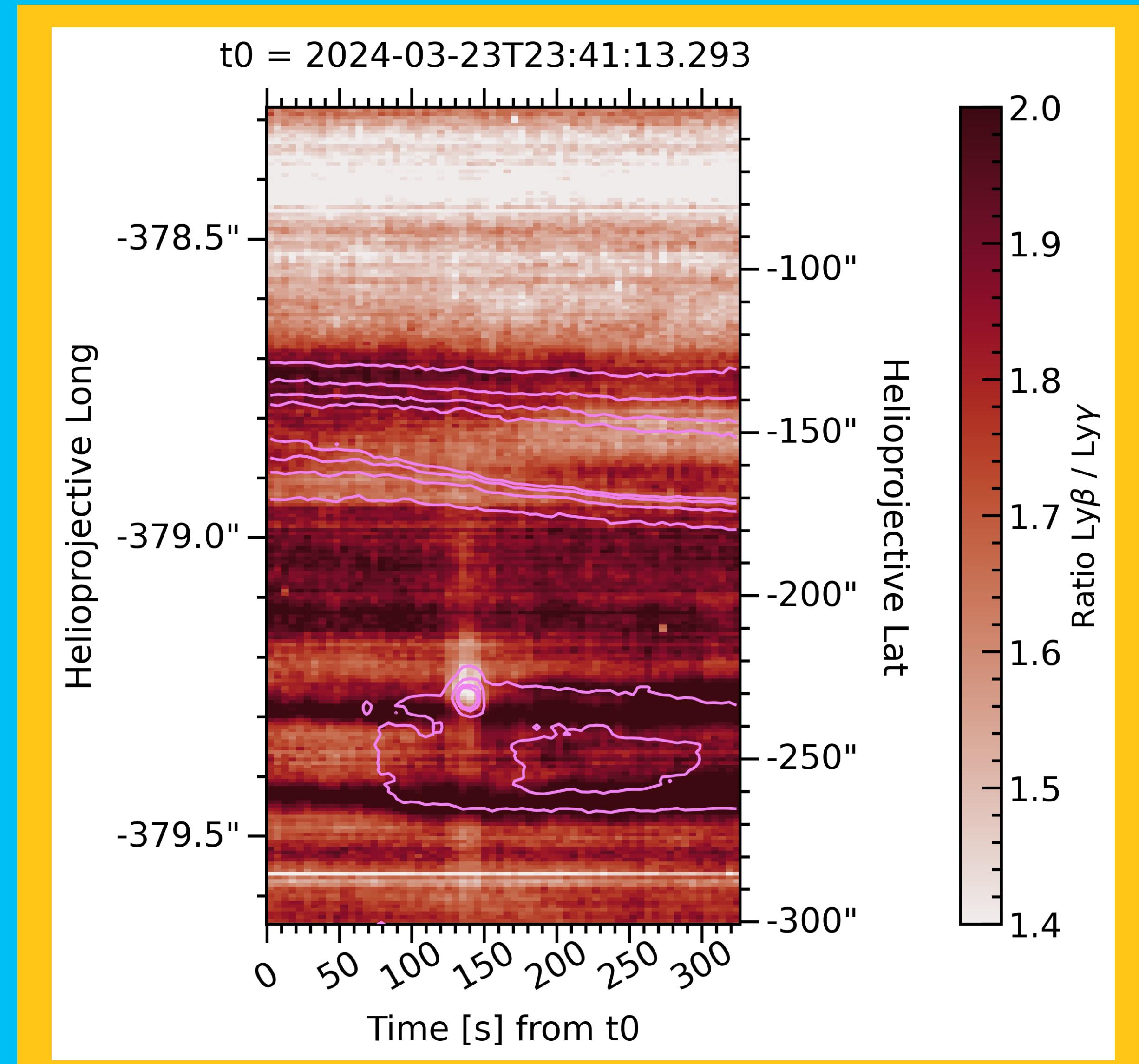
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# LYMAN DECREMENT MAP

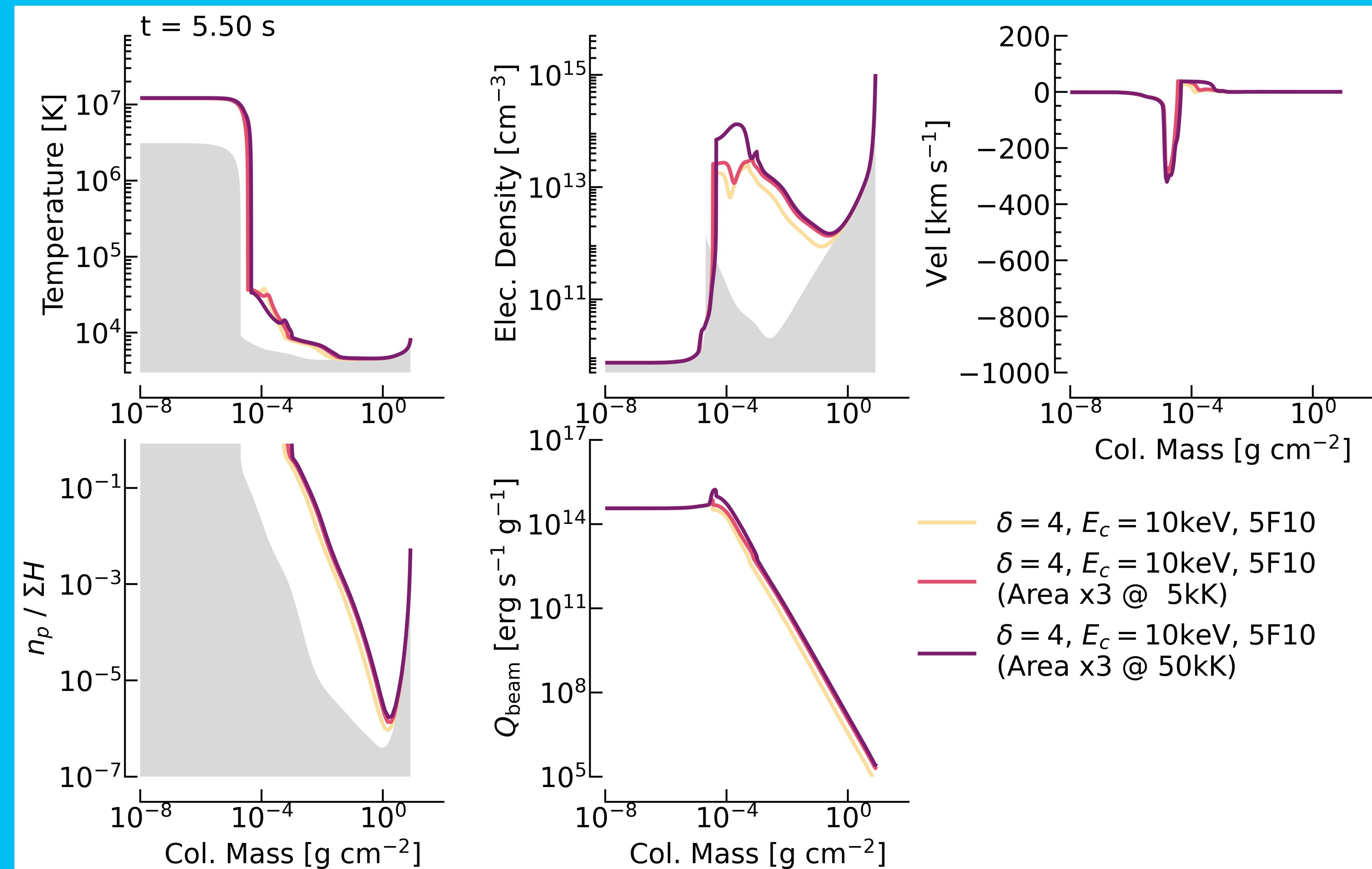
- Map shows transient decrease of ratio. and rapid return to pre-flare, in upper source.
- Lower source doesn't really vary.
- Note that in upper portion of field-of-view (away from the flare region) the ratio is lower. So, the ratio tells us about the relative change during the flare, but a low ratio doesn't just occur in flares.

Contours are Fe XX



# COMPARING TO RHD MODELS

RAN SEVERAL LOOP MODELS, INCLUDING AREA EXPANSION. NOT GOING TO DISCUSS THE VARIOUS DIFFERENCES IN DETAIL HERE.



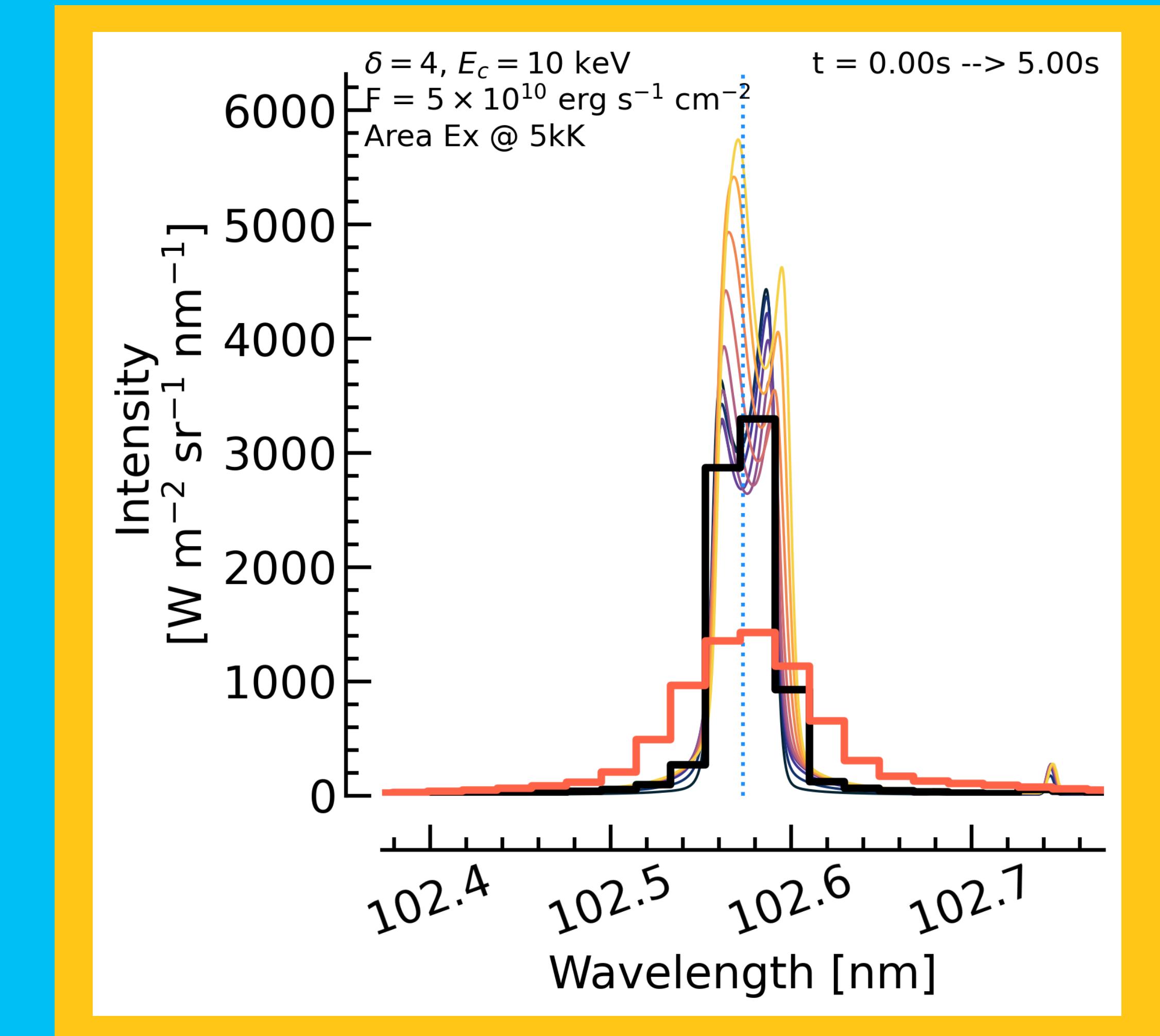
Coloured lines are spectra appearing in this exposure.

Black is the SPICE spectra, without PSF.

Red is with PSF applied (see later).

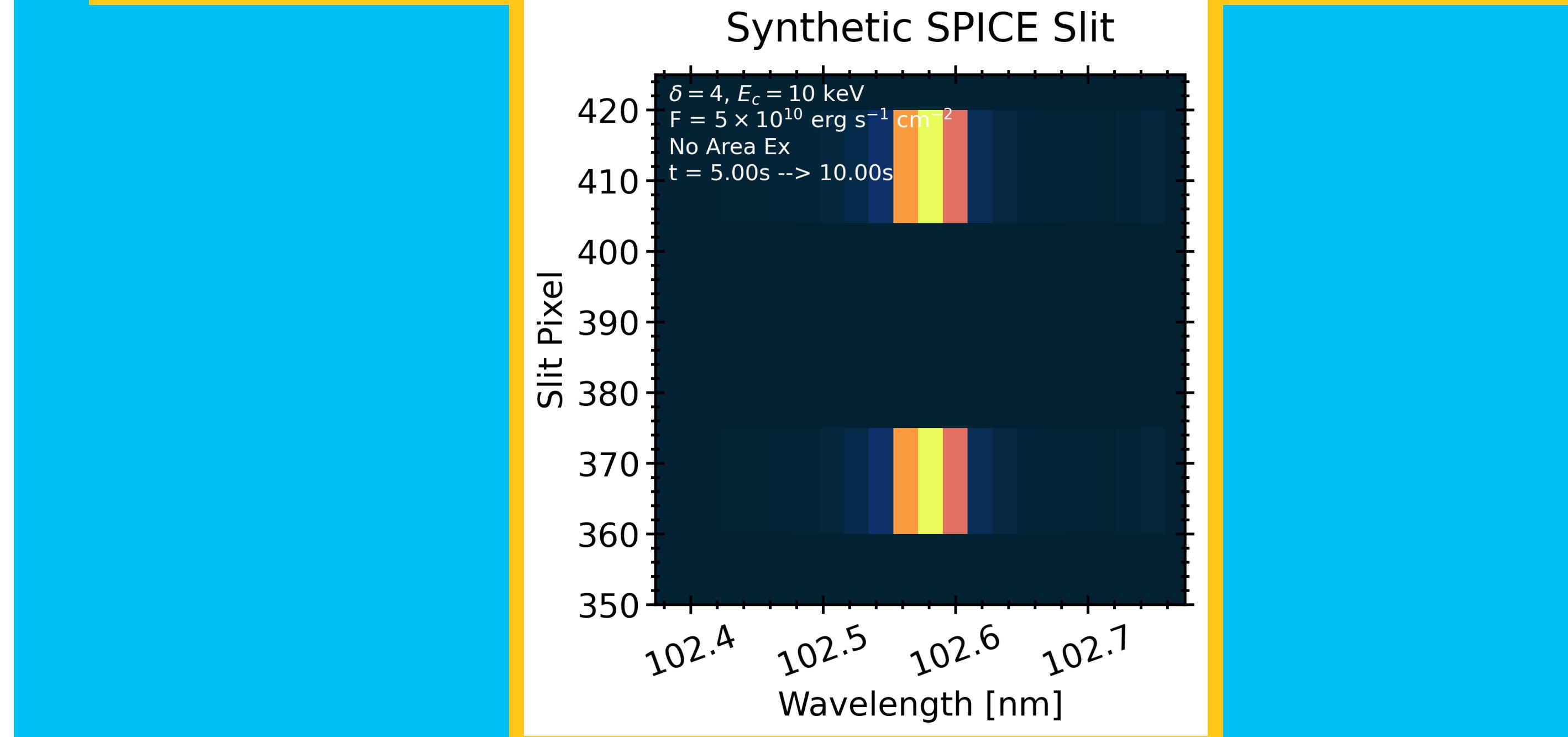
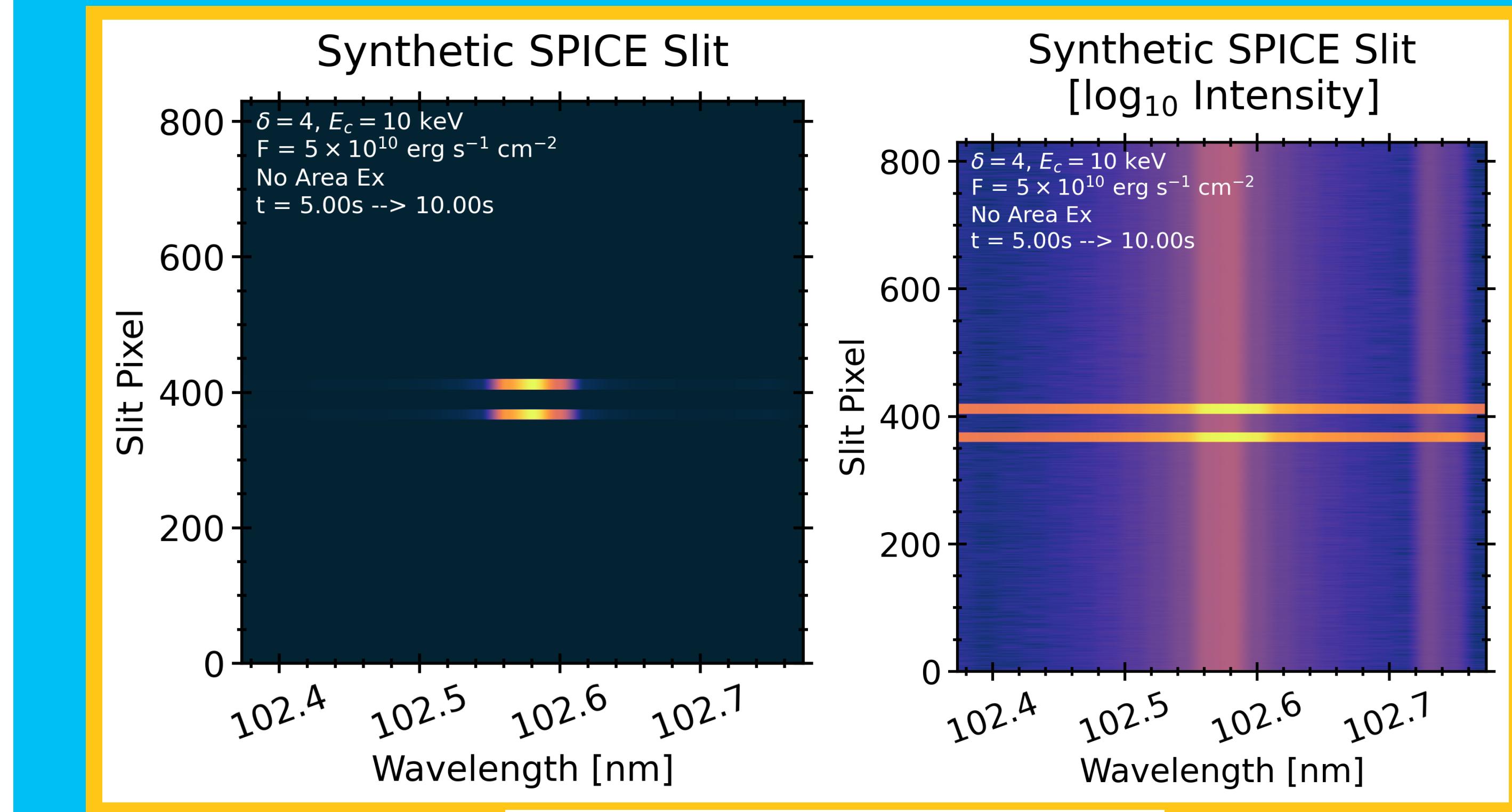
# MODEL → SYNTHETIC SPICE

- Model output was converted to a synthetic SPICE flare by:
  - Recasting to SPICE plate scale;
  - Converted to photon number;
  - Folding through SPICE effective area;
  - Summed through exposure time and readout time;
  - Added Poisson noise;
  - Converted back to physical units.



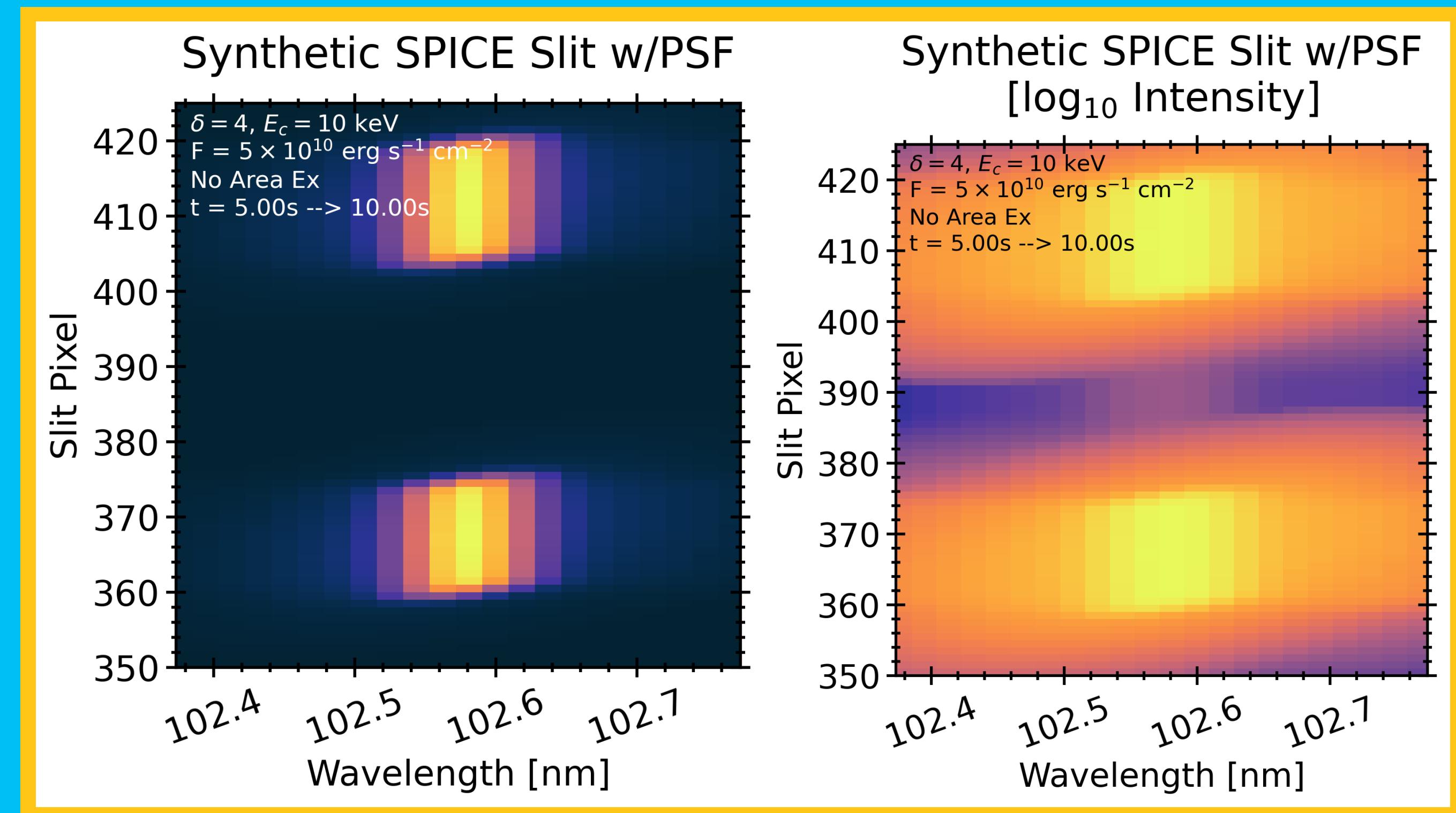
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- Then an artificial sit-and-stare observation was created, very ad-hoc for now (can be more creative in future). Wavelength and spatial dimensions guided by observations.
- This was passed through J. Plowman's SHARPPEST tools to apply a titled PSF.



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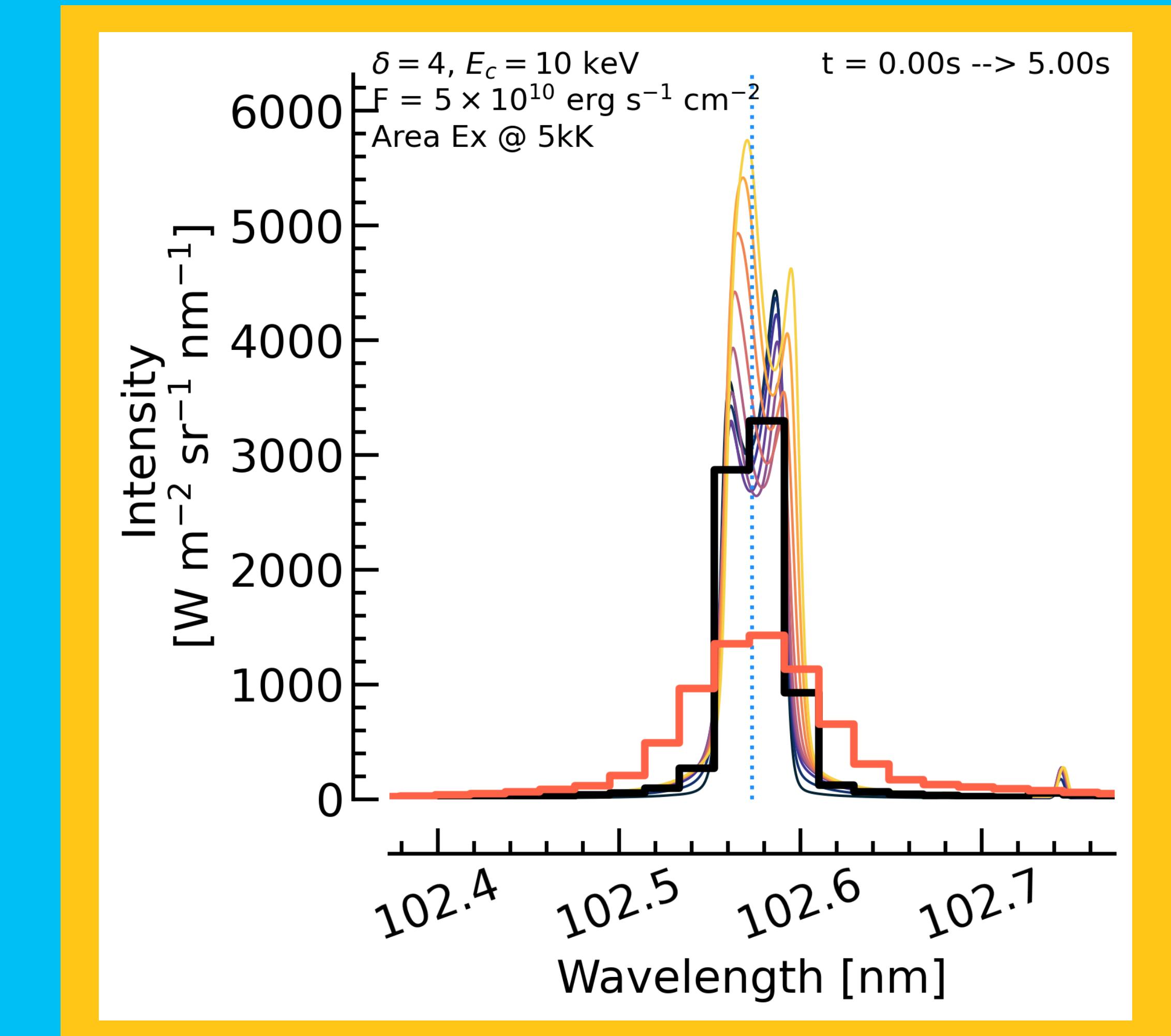
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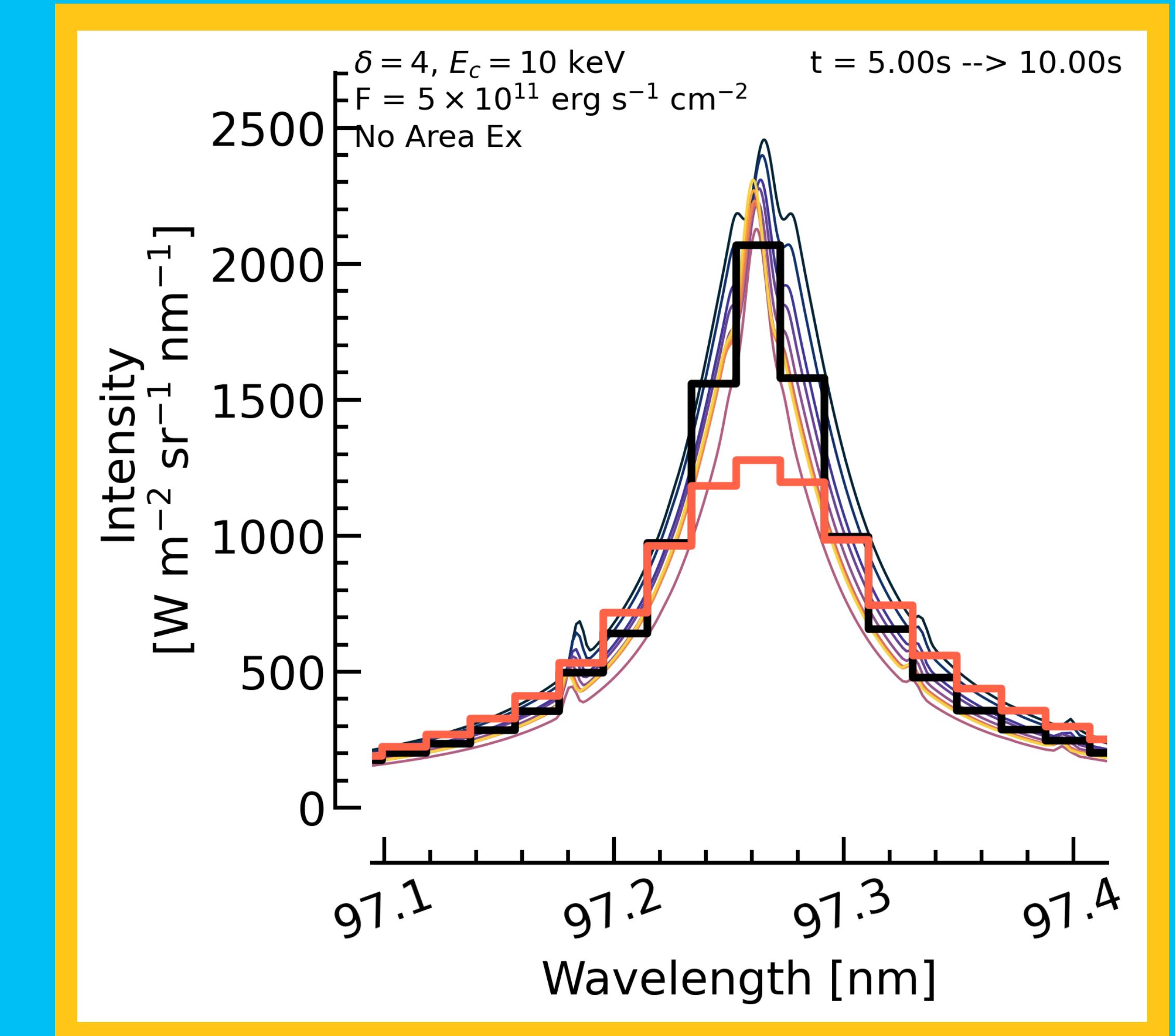
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- PSF (red) results in a broader profile... though in some stronger sims it isn't so bad!



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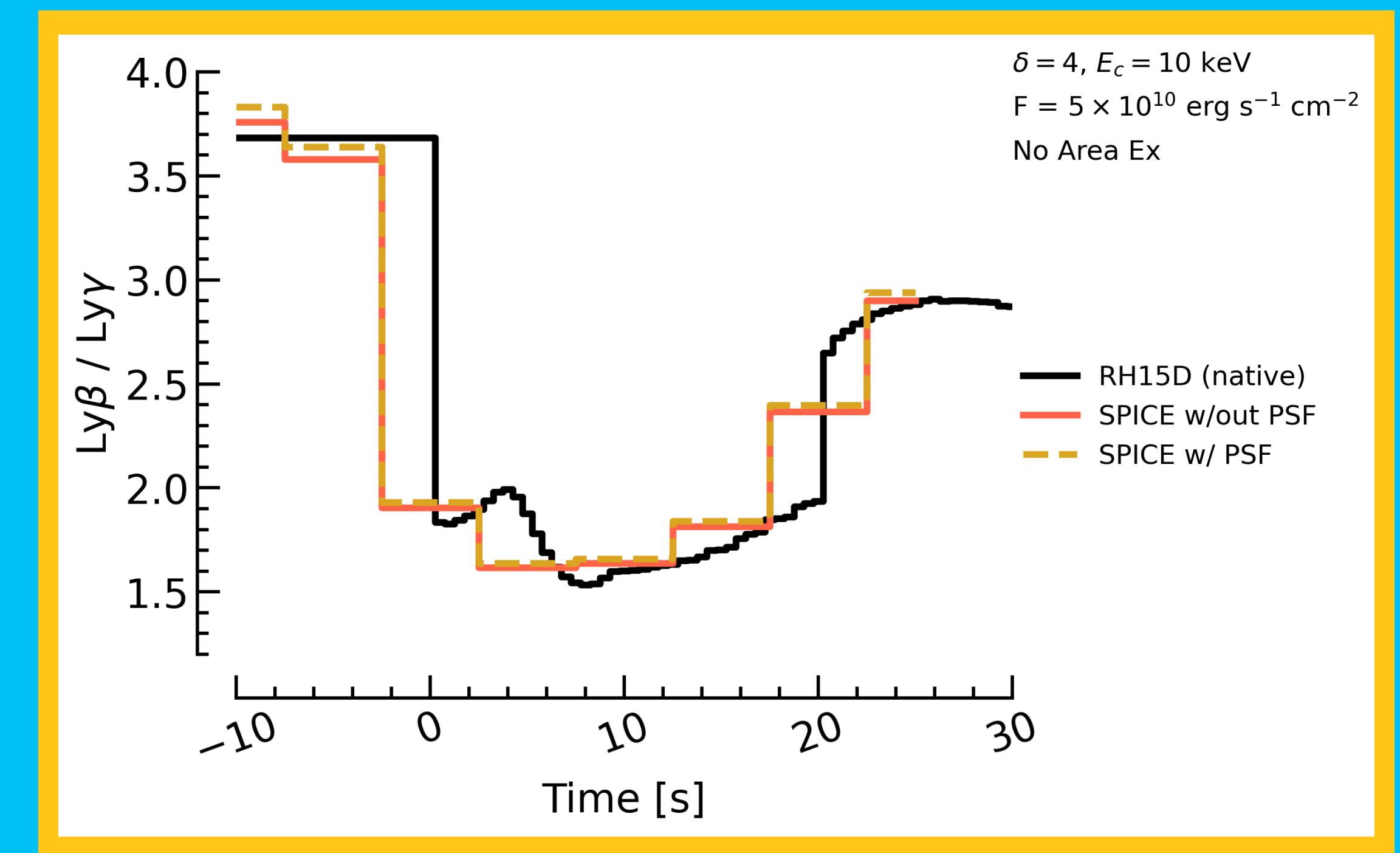
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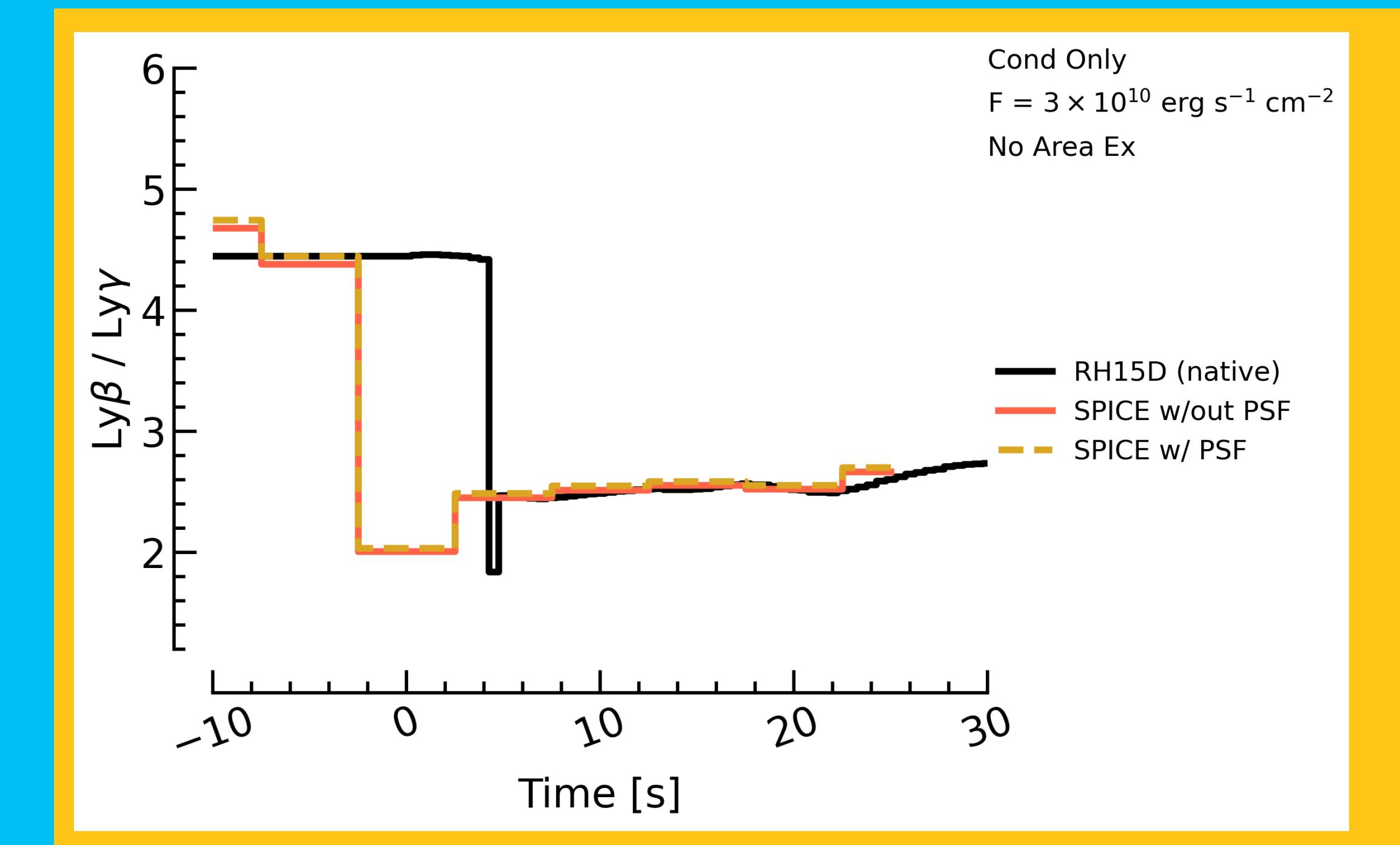
# MODELLED LYMAN DECREMENT

- Electron beam models produce Lyman decrements that are mostly consistent with observations!
- They are transient, and have similar values.
- Importantly, the pre-flare ratio is too high in our models, indicating that the pre-flare atmosphere isn't ideal.
- Can track atmospheric properties to see what this might mean... early indications suggest the lines form closer together and at similar temperature/electron density.

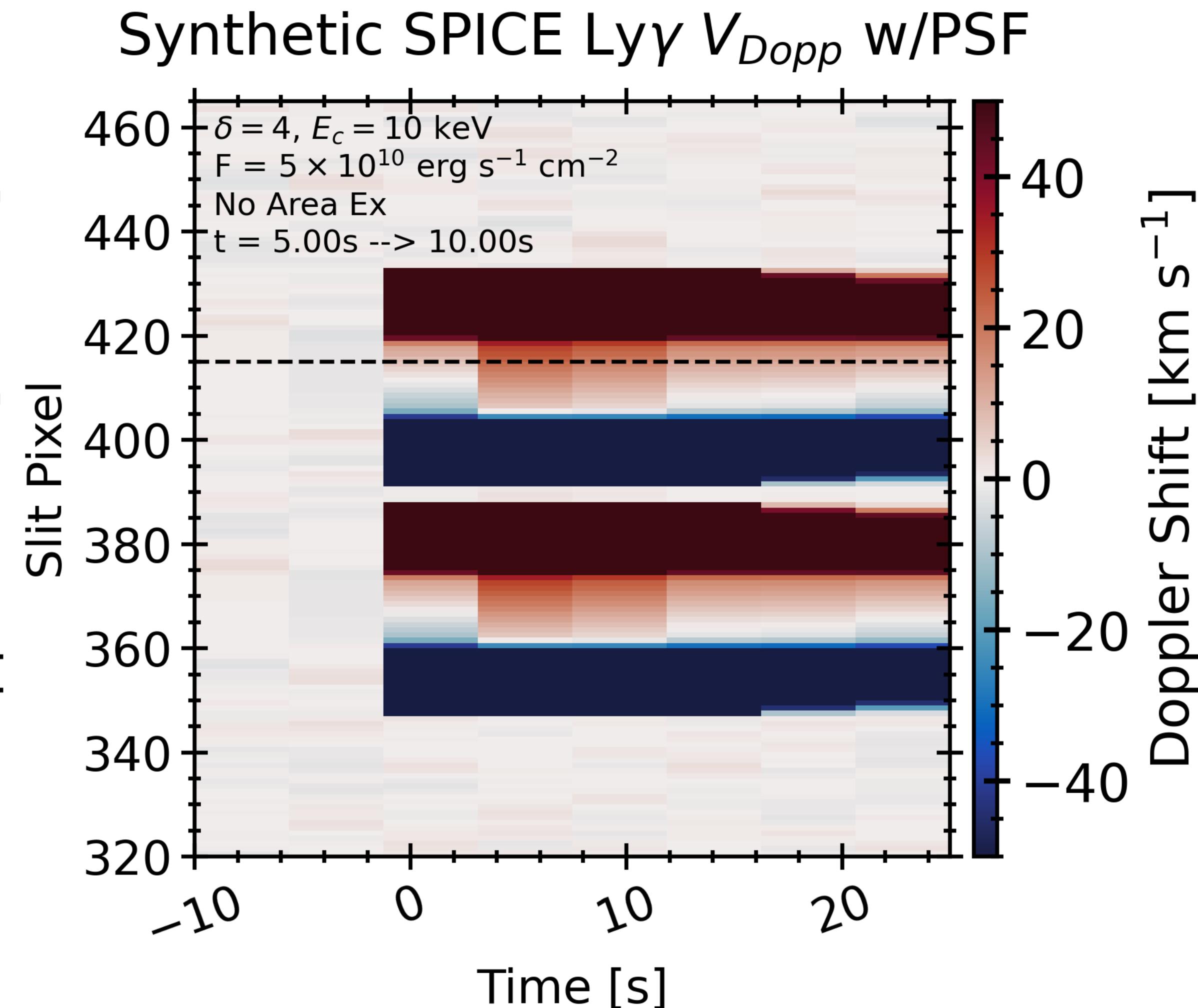
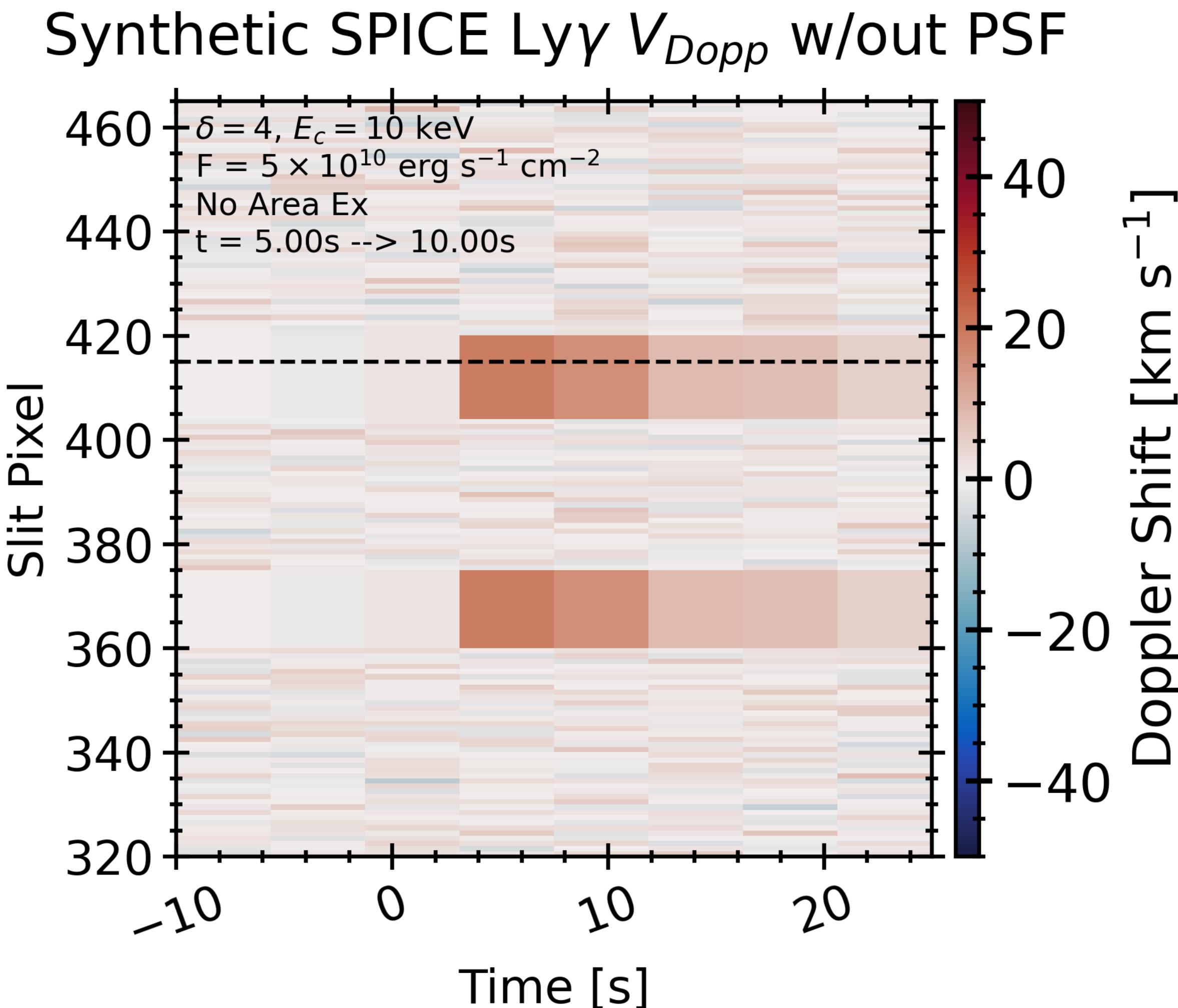


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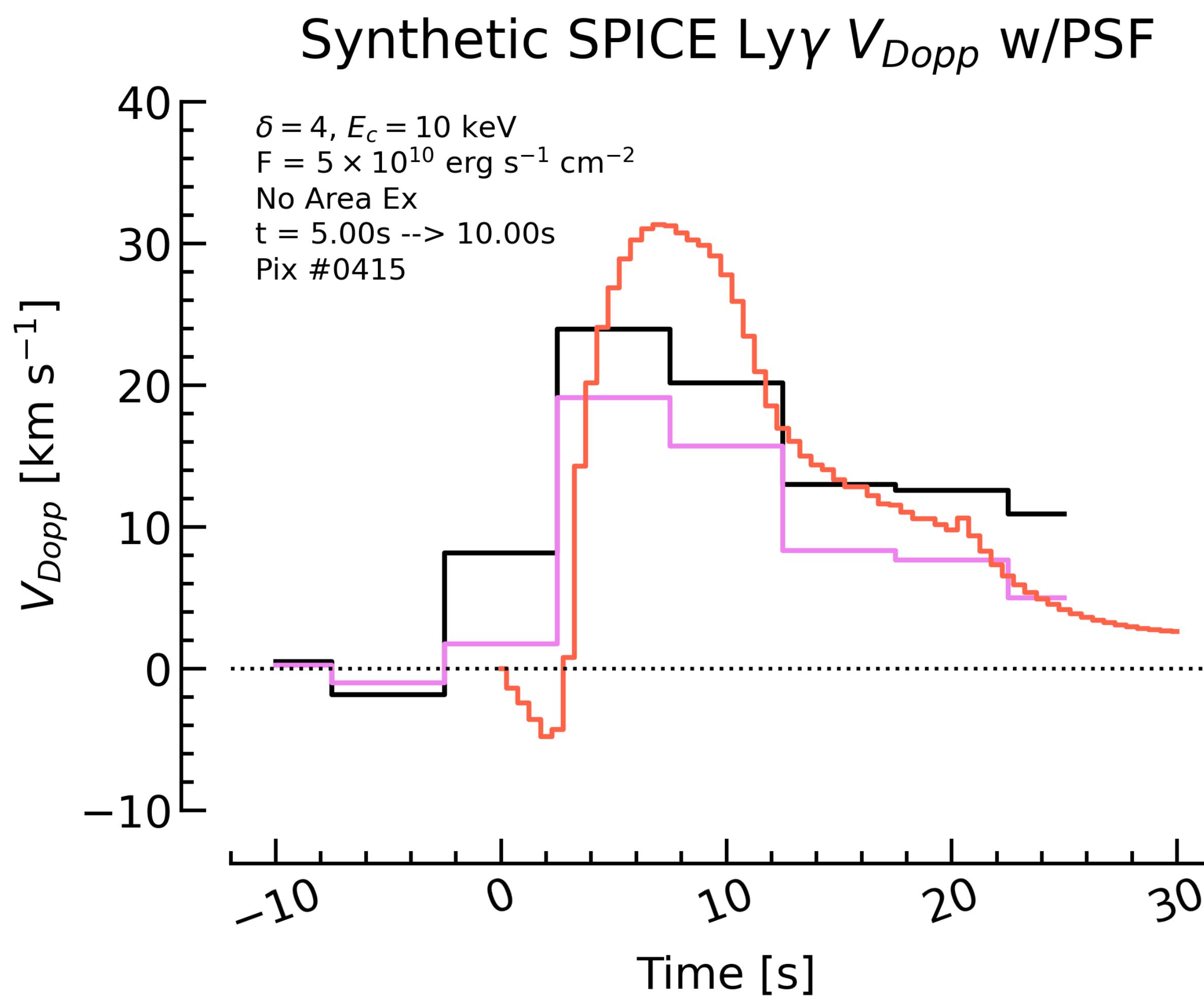
- Thermal conduction models *do not* show a deep enough decrease in the ratio.
- Perhaps this means that the stronger ribbon is primarily non thermal electron-beam driven and the lower is not.
- Could be related to lack of non thermal collisional excitation ... more work needed.



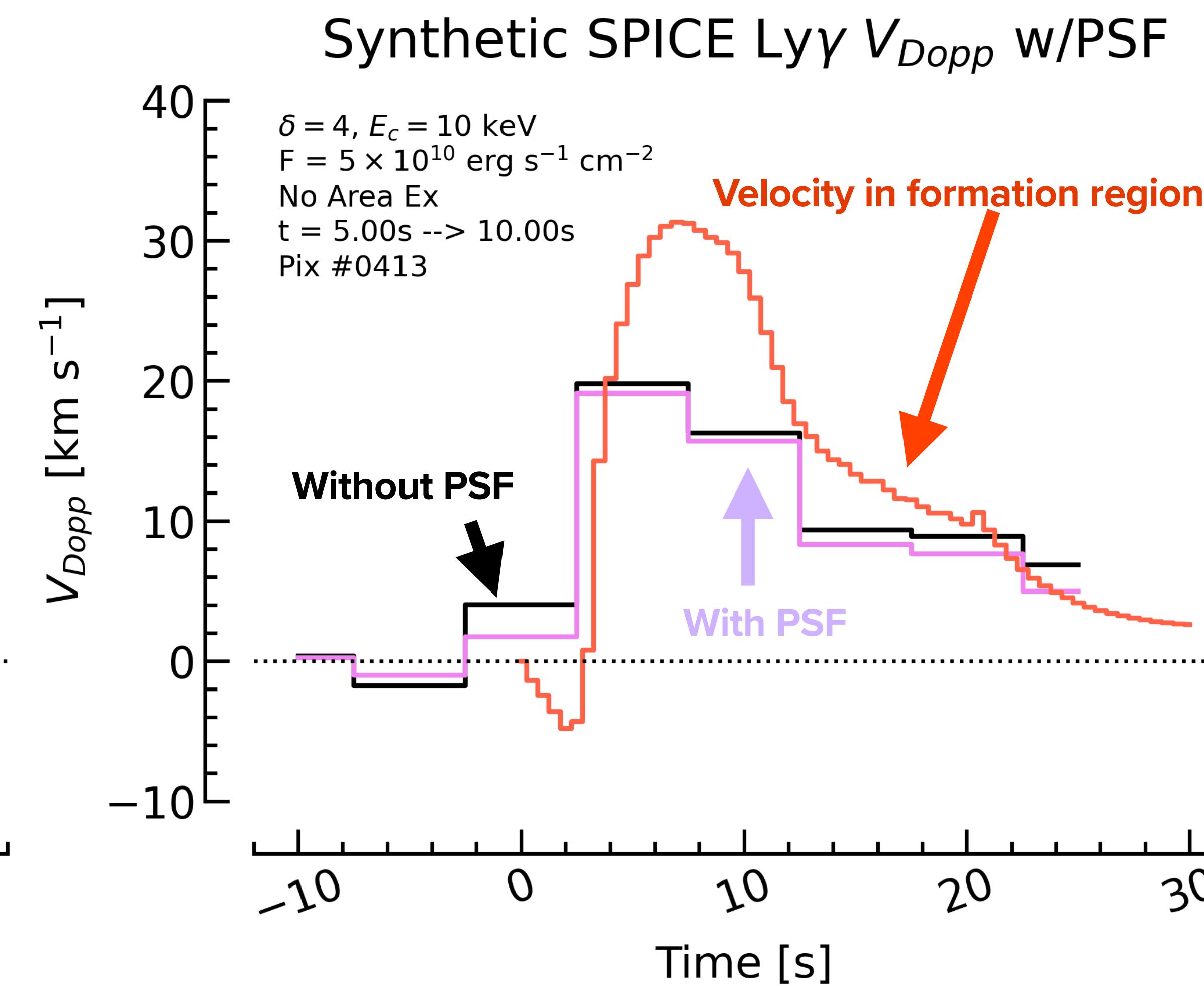
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Edge of flare source



Middle of flare source

# SUMMARY

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Main takeaway — really nice high cadence observations of the EUV flare spectrum, but could really do with higher cadence!