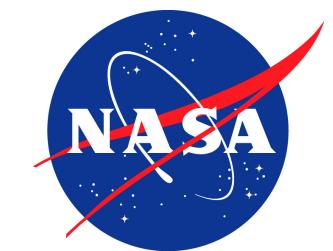


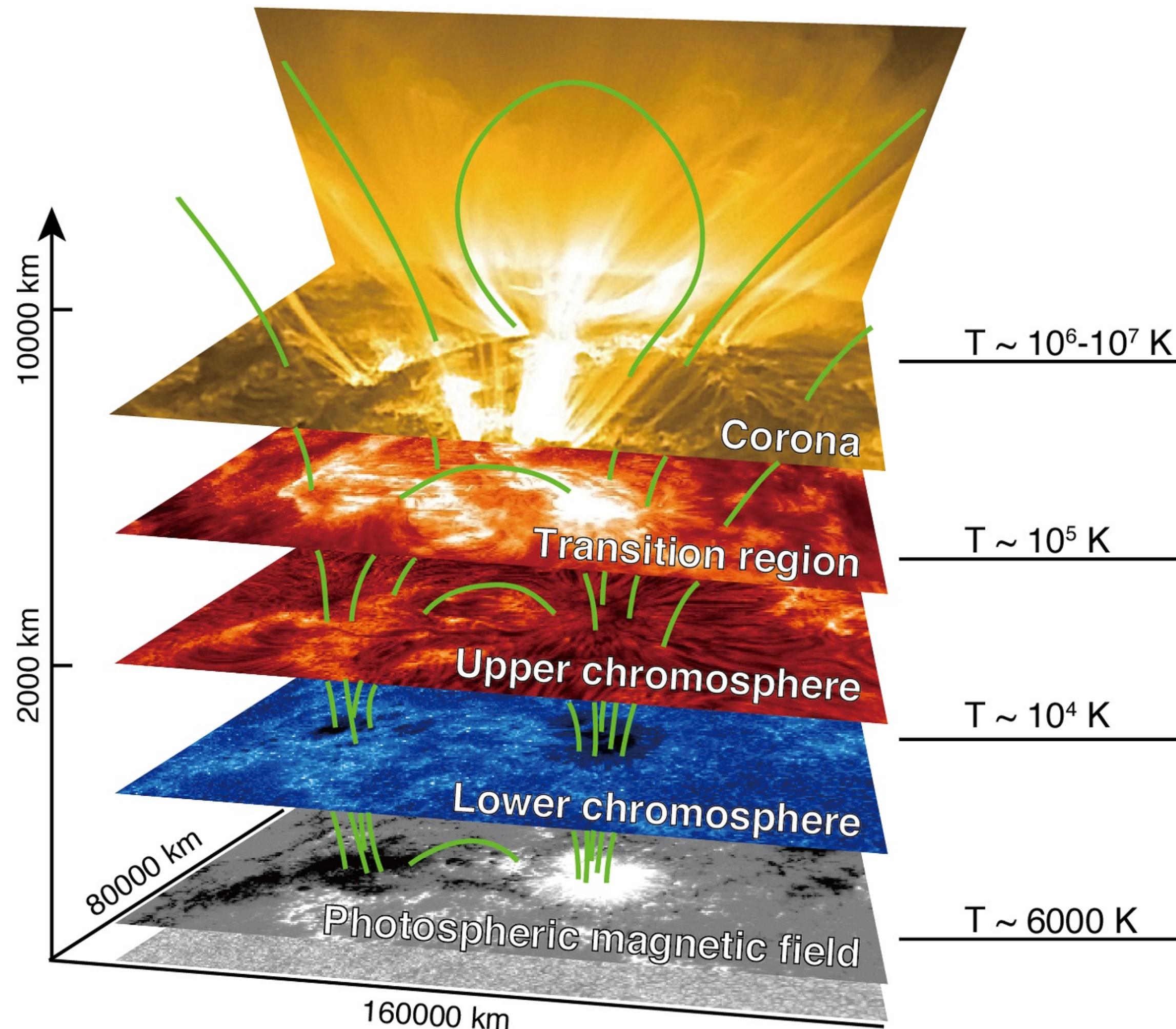
GRAHAM KERR (NASA/GSFC & CUA, HE/HIM)



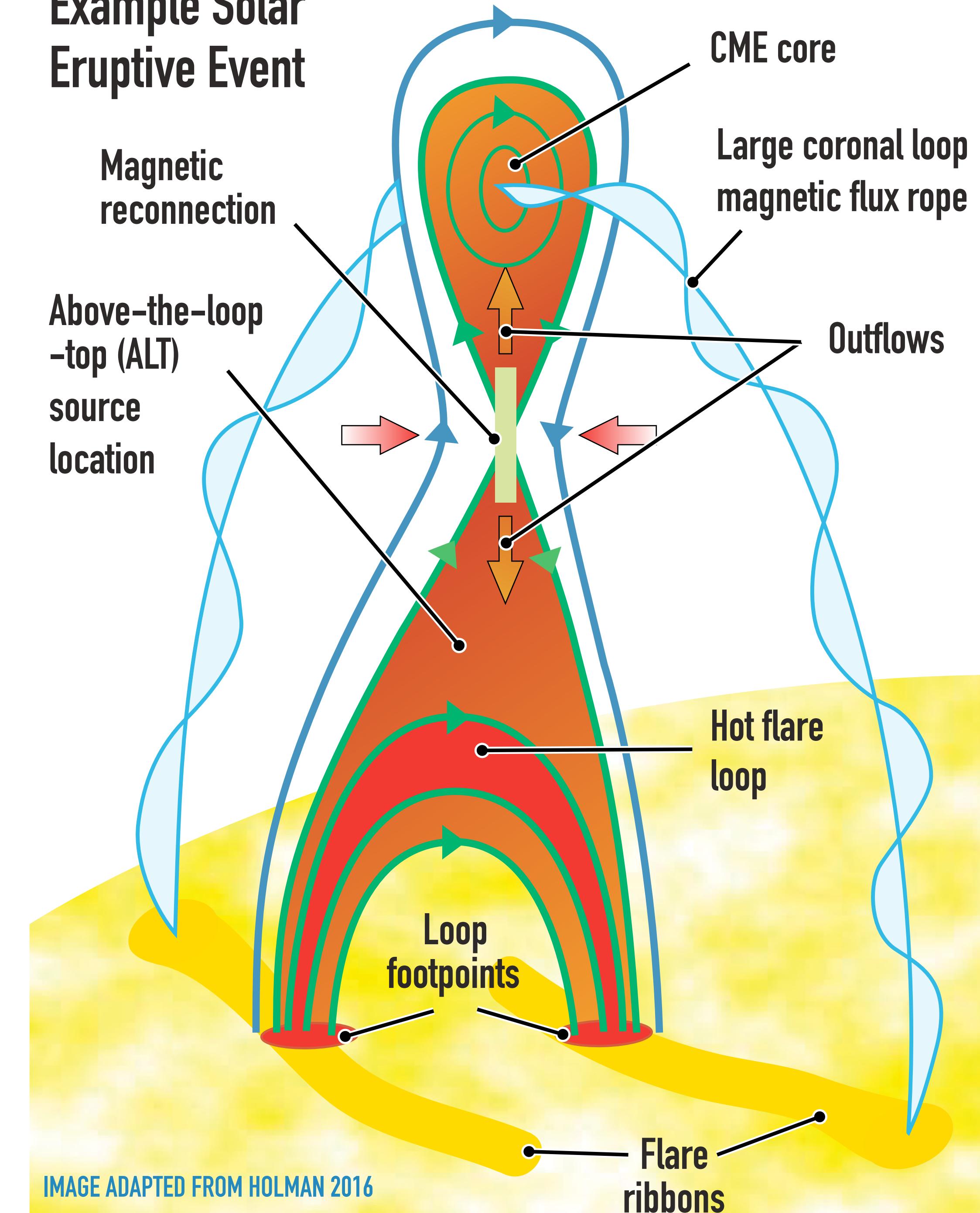
THE CATHOLIC
UNIVERSITY
OF AMERICA 

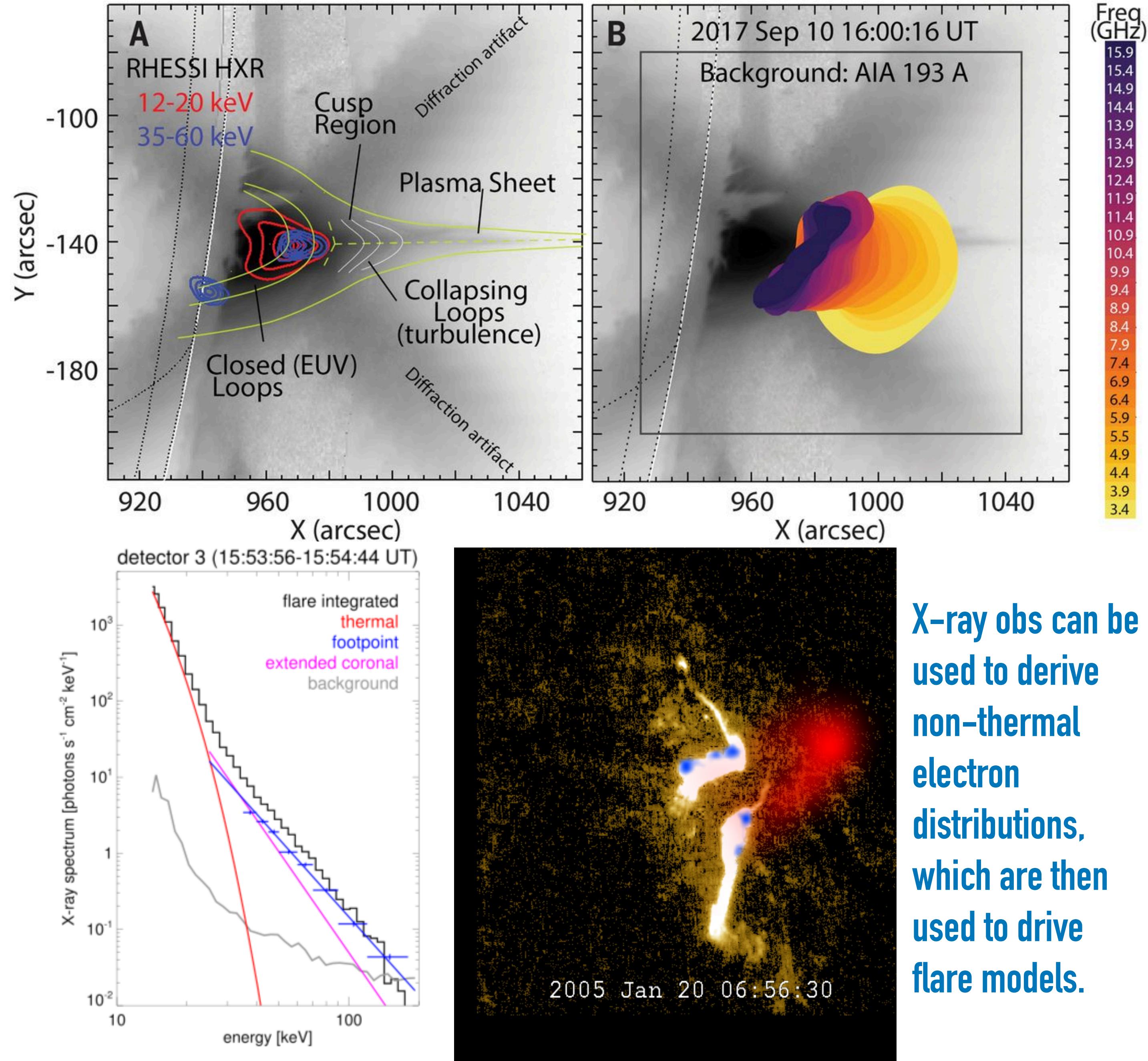
THE OPTICALLY THIN FLARING CHROMOSPHERE: NONTHERMAL LINE WIDTHS FROM A CHROMOSPHERIC CONDENSATION

SOLAR FLARES

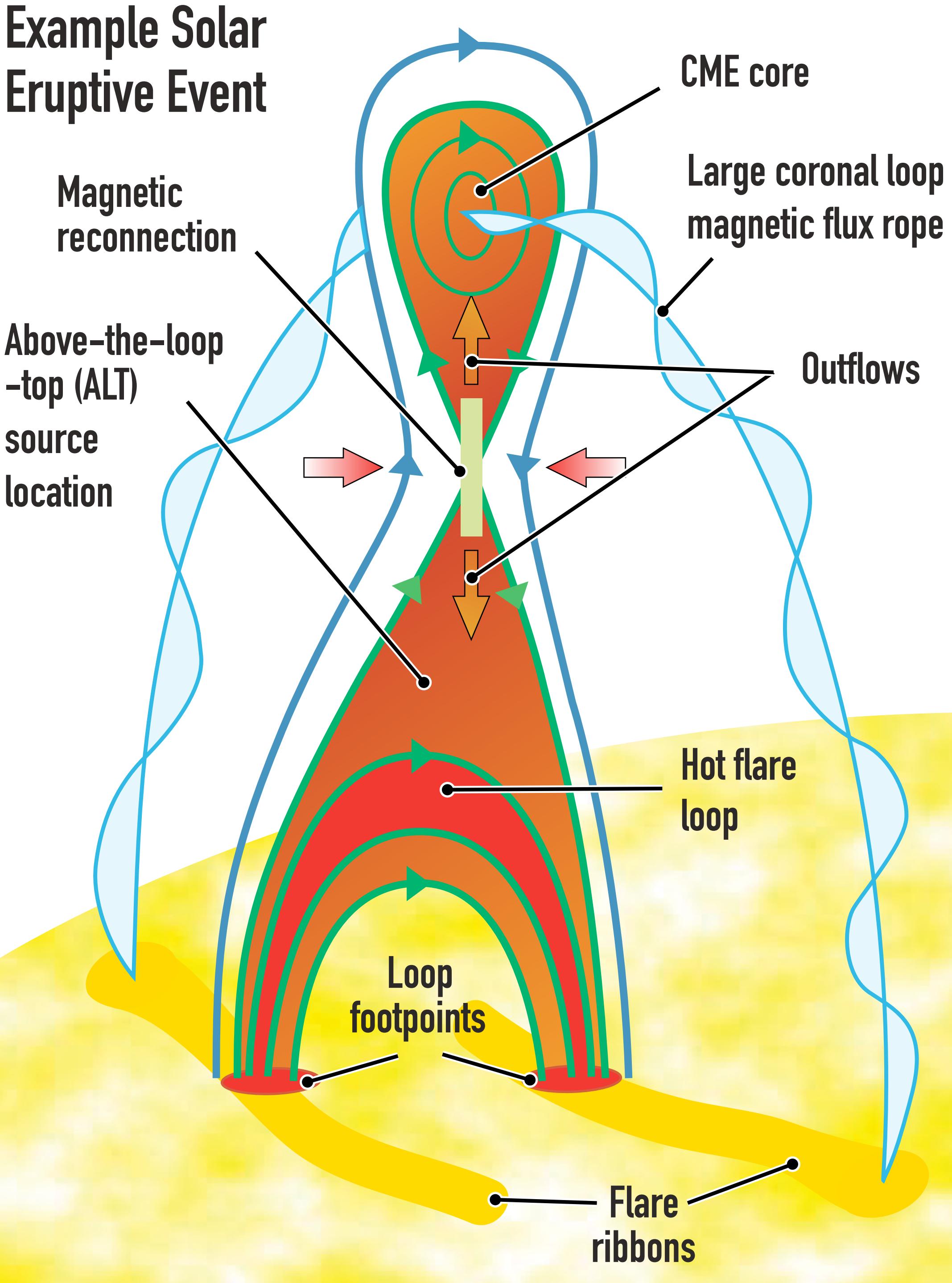


Example Solar Eruptive Event

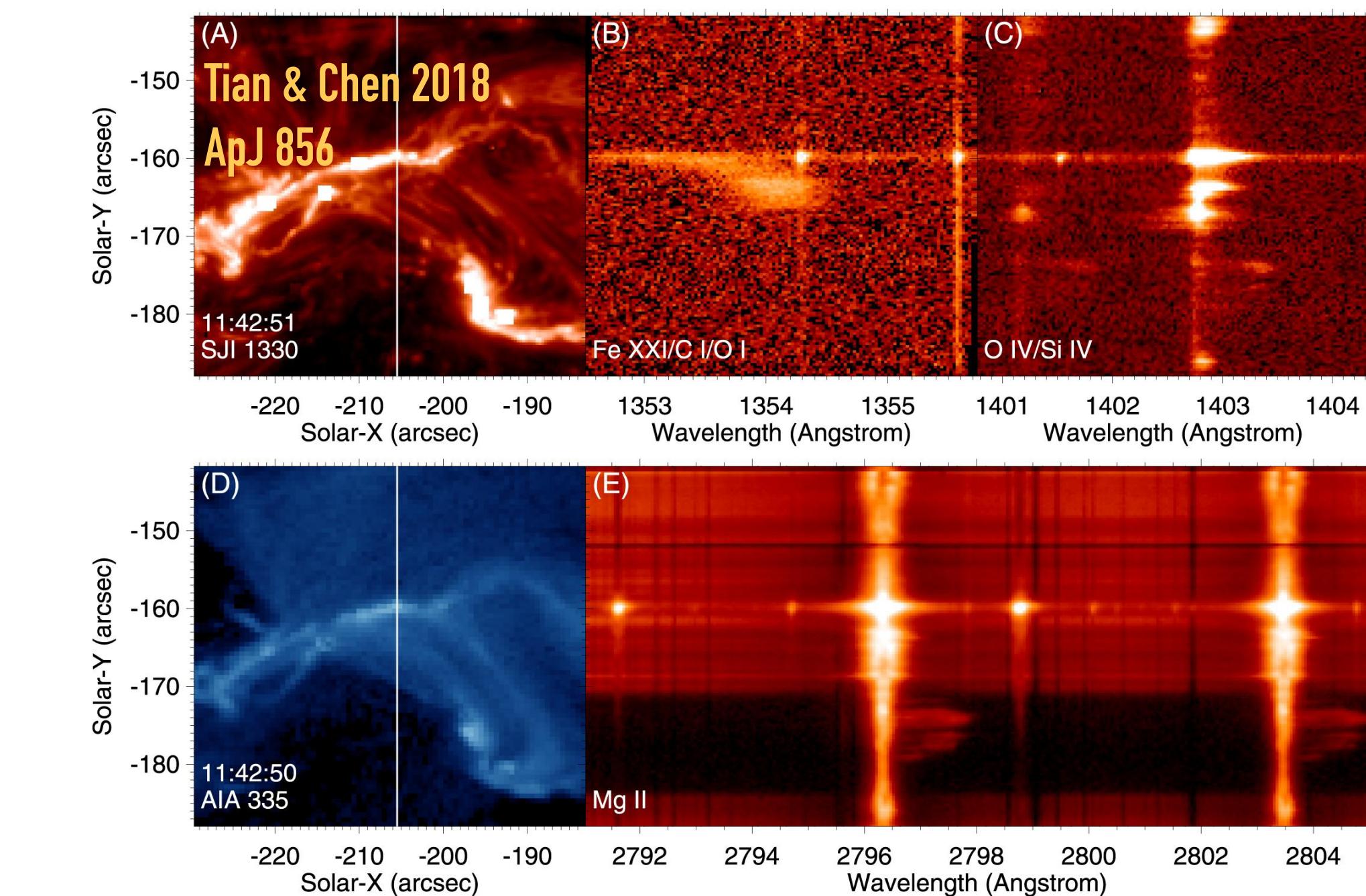
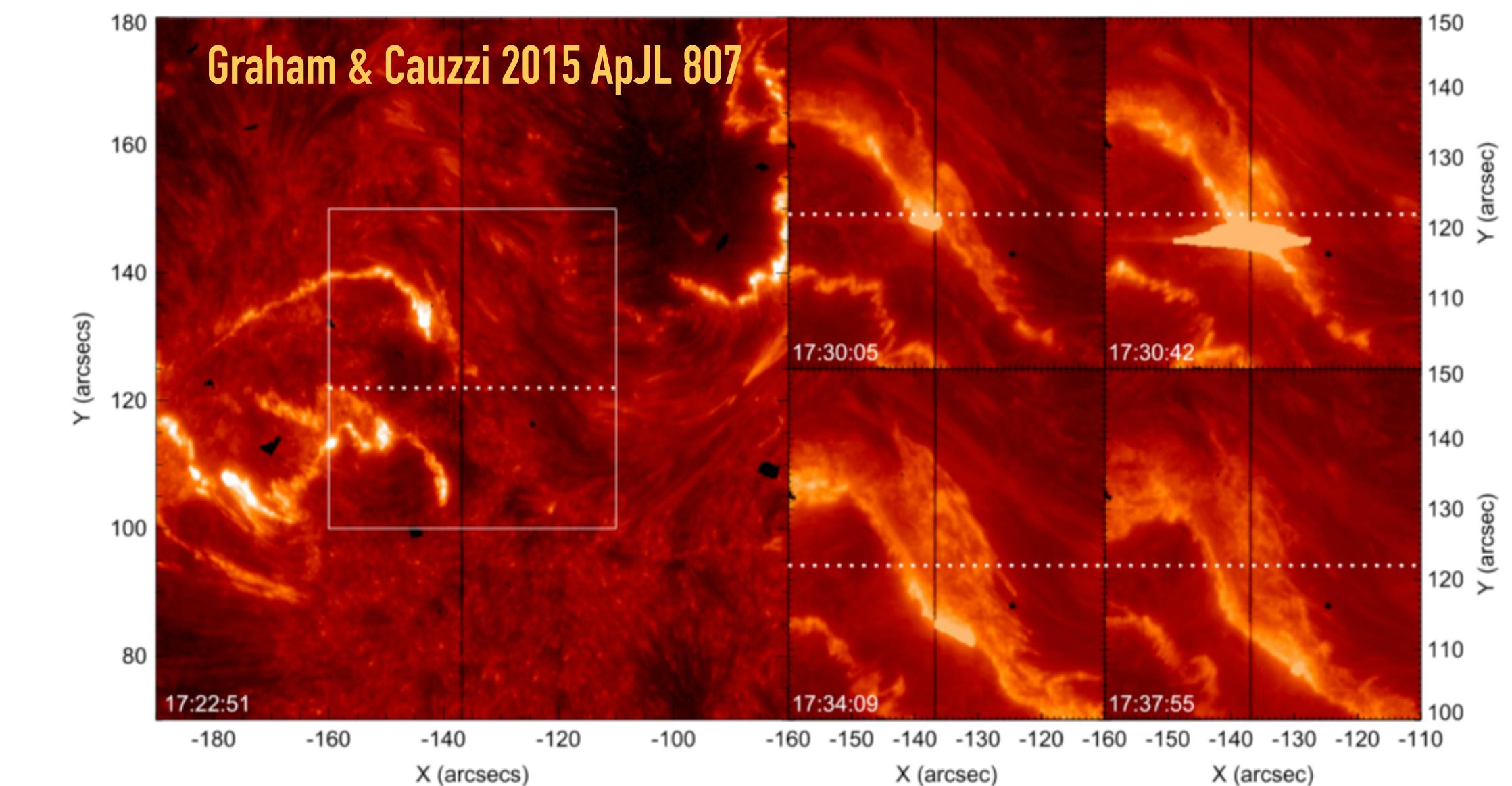
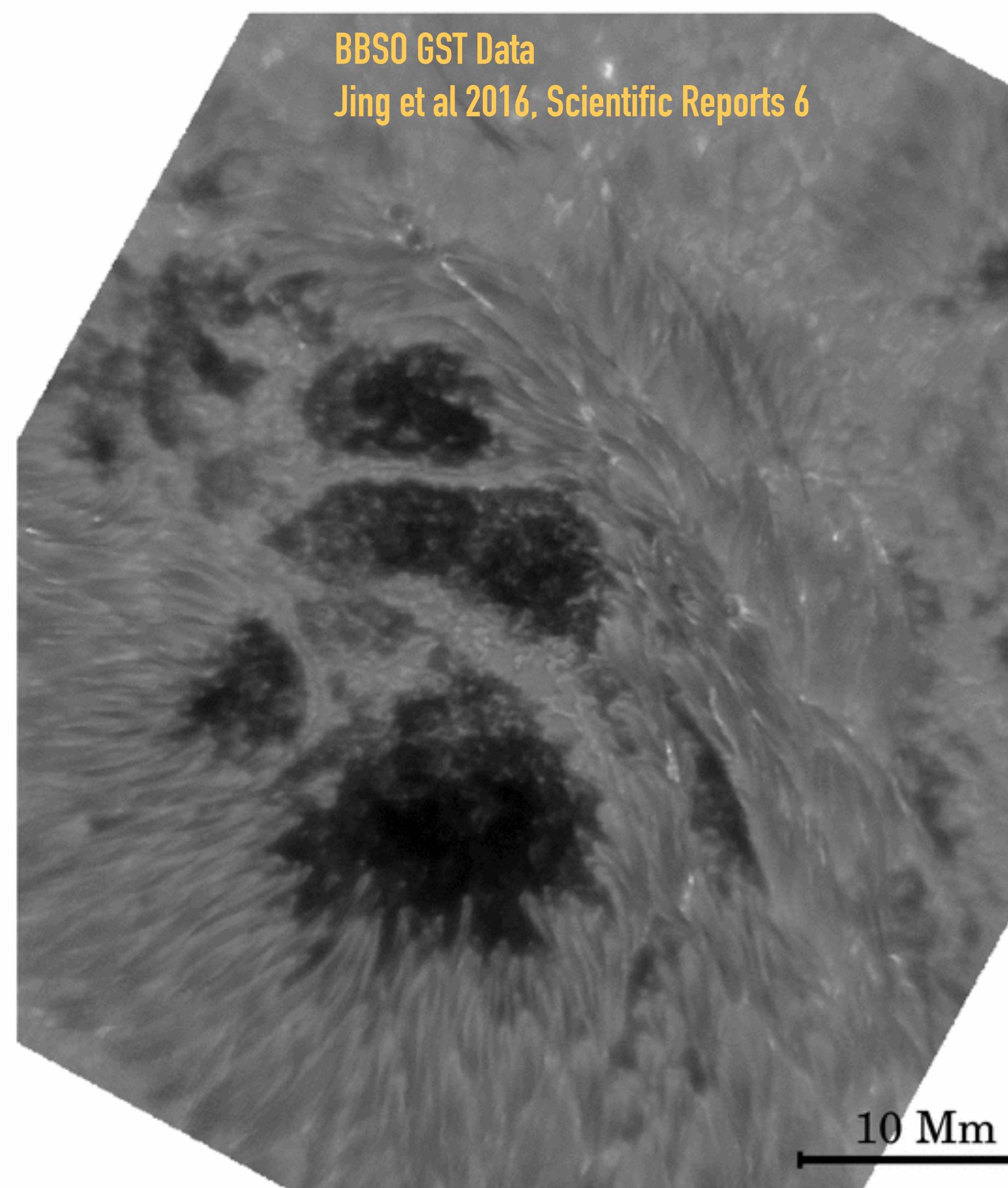
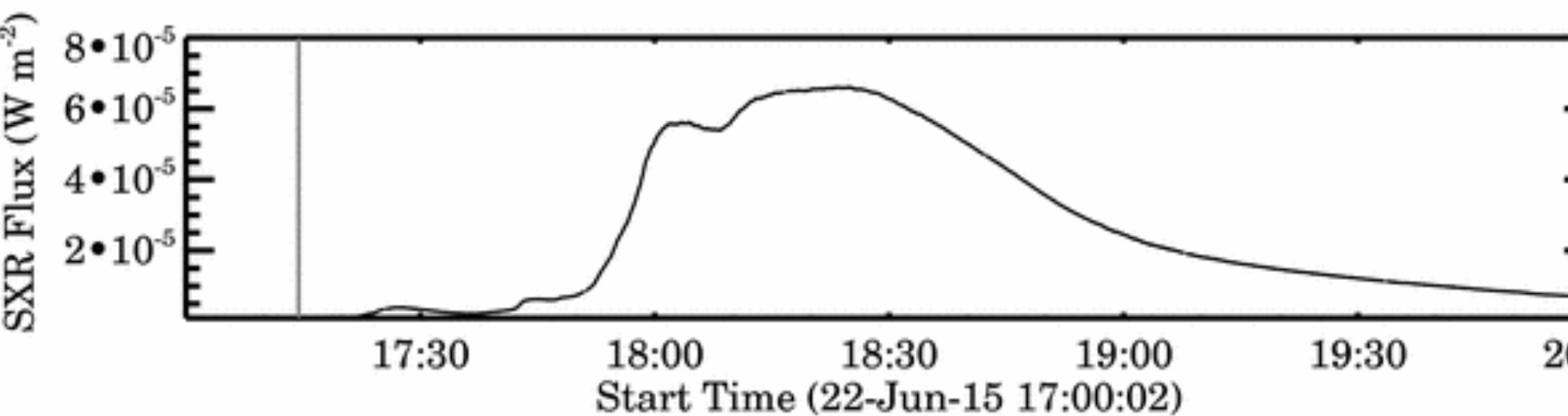




X-ray obs can be used to derive non-thermal electron distributions, which are then used to drive flare models.



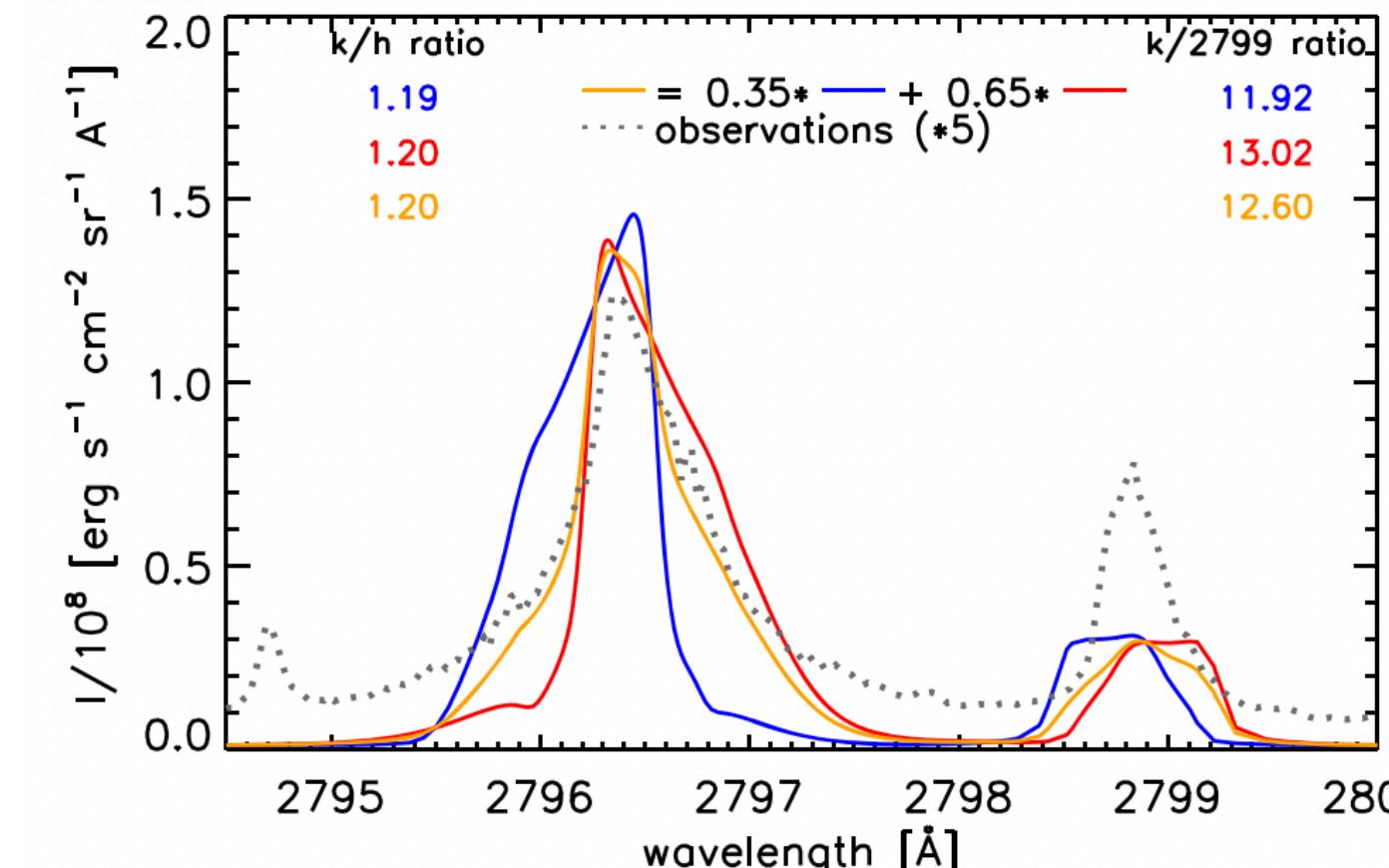
SOLAR FLARES



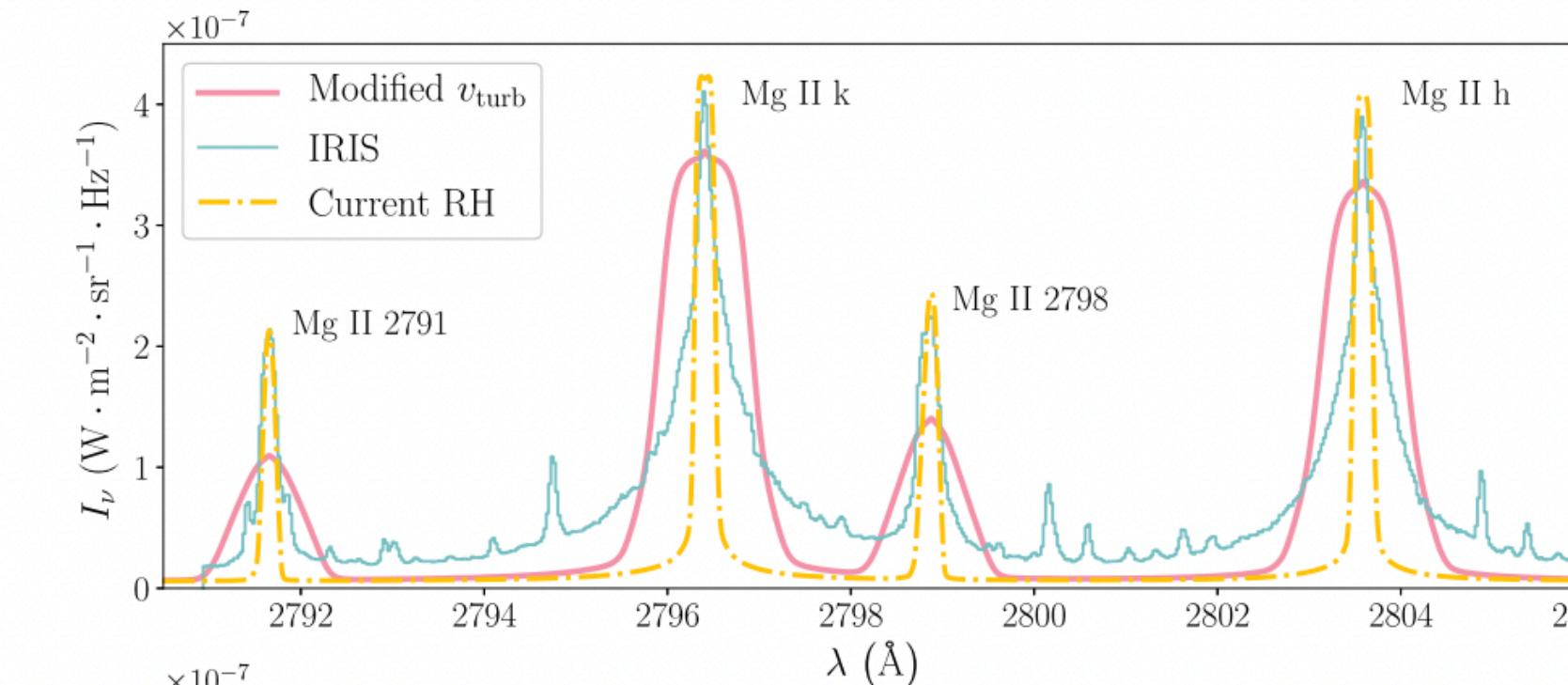
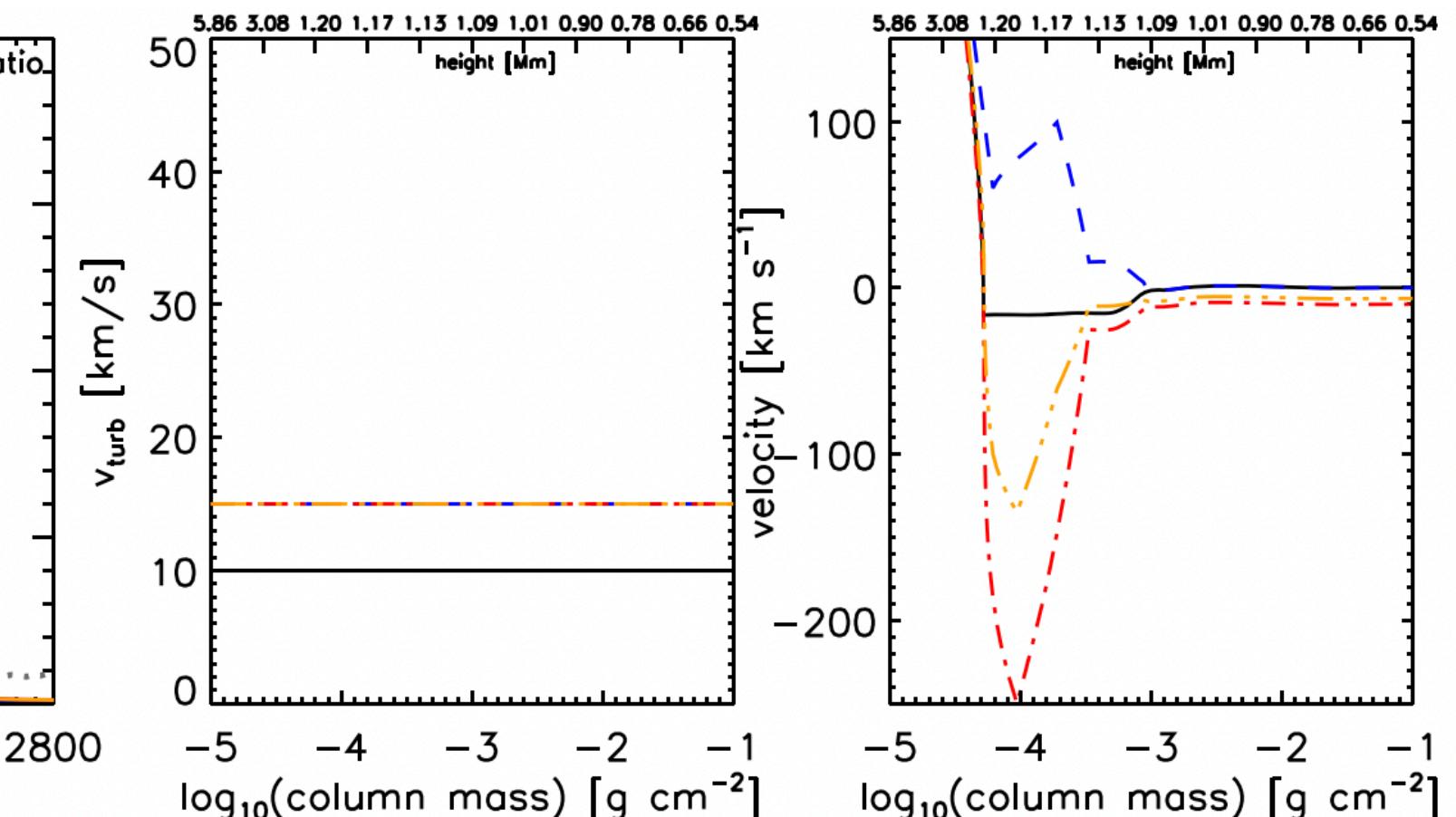
LINE WIDTHS ARE A PERENNIAL MODEL-DATA ISSUE

- ▶ Chromospheric and transition region lines are much broader in observations, than those forward modelled in flare simulations.

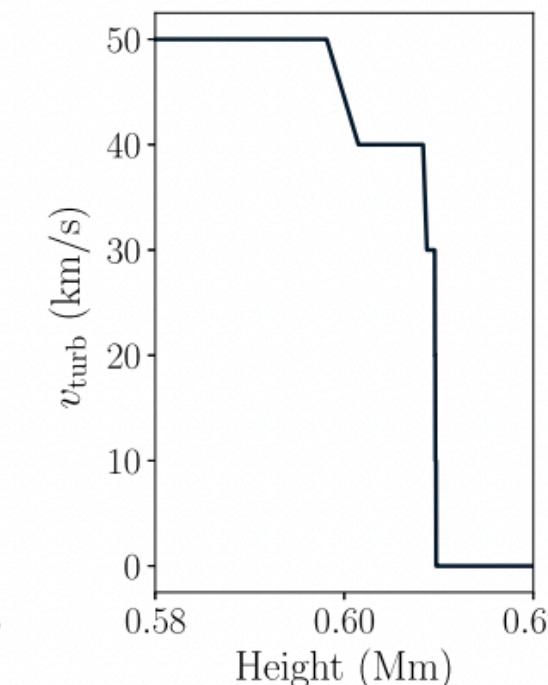
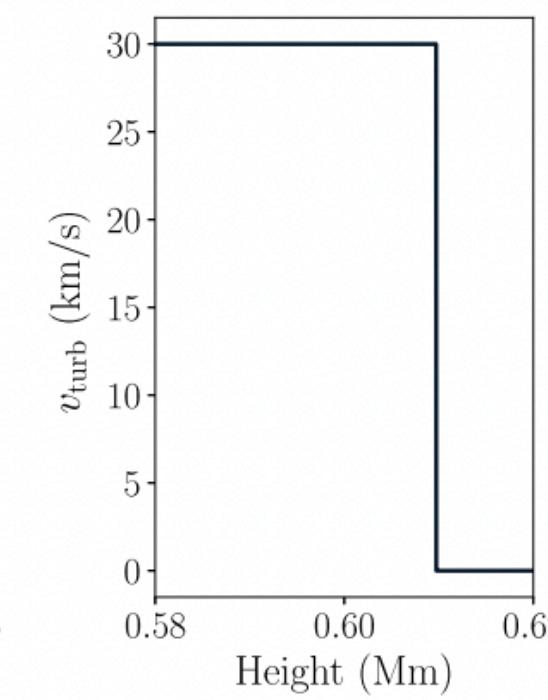
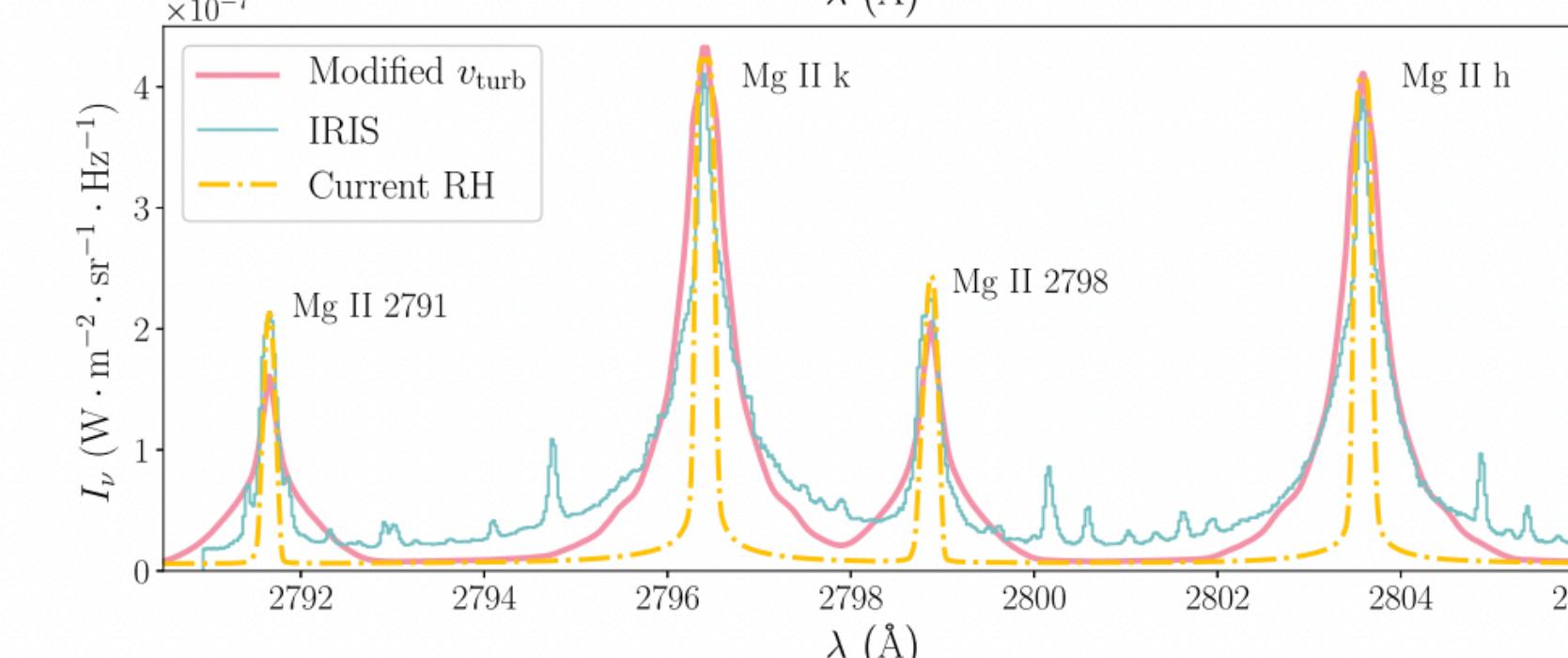
- ▶ Resolutions typical include exploring:
 - Extreme bi-directional flows (**any evidence?**).
 - Large amounts of microturbulent broadening, in the chromosphere, up to 30-50 km/s (**any evidence?**).
 - ... other?



Rubio da Costa & Kleint 2017



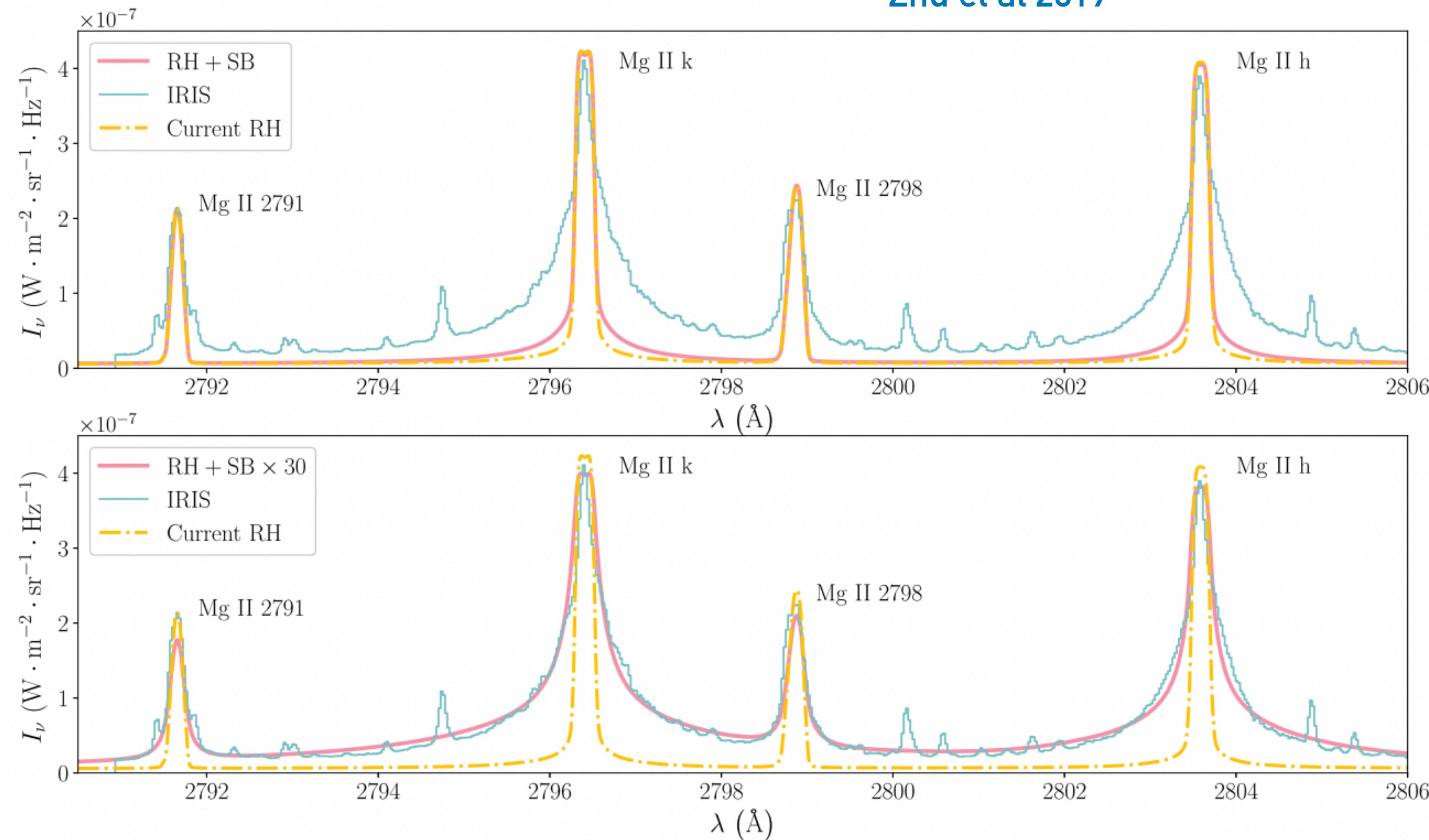
Zhu et al 2019



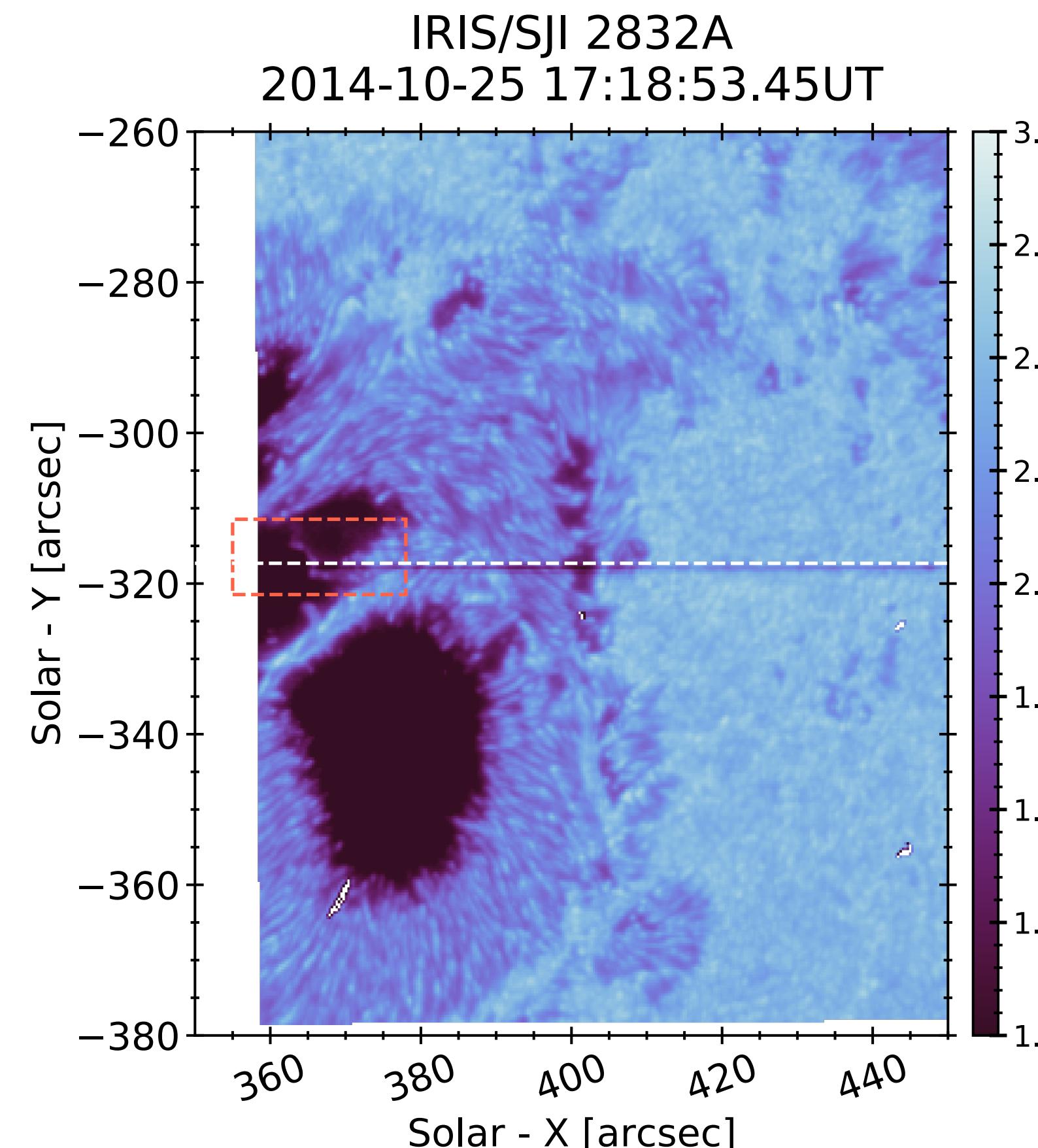
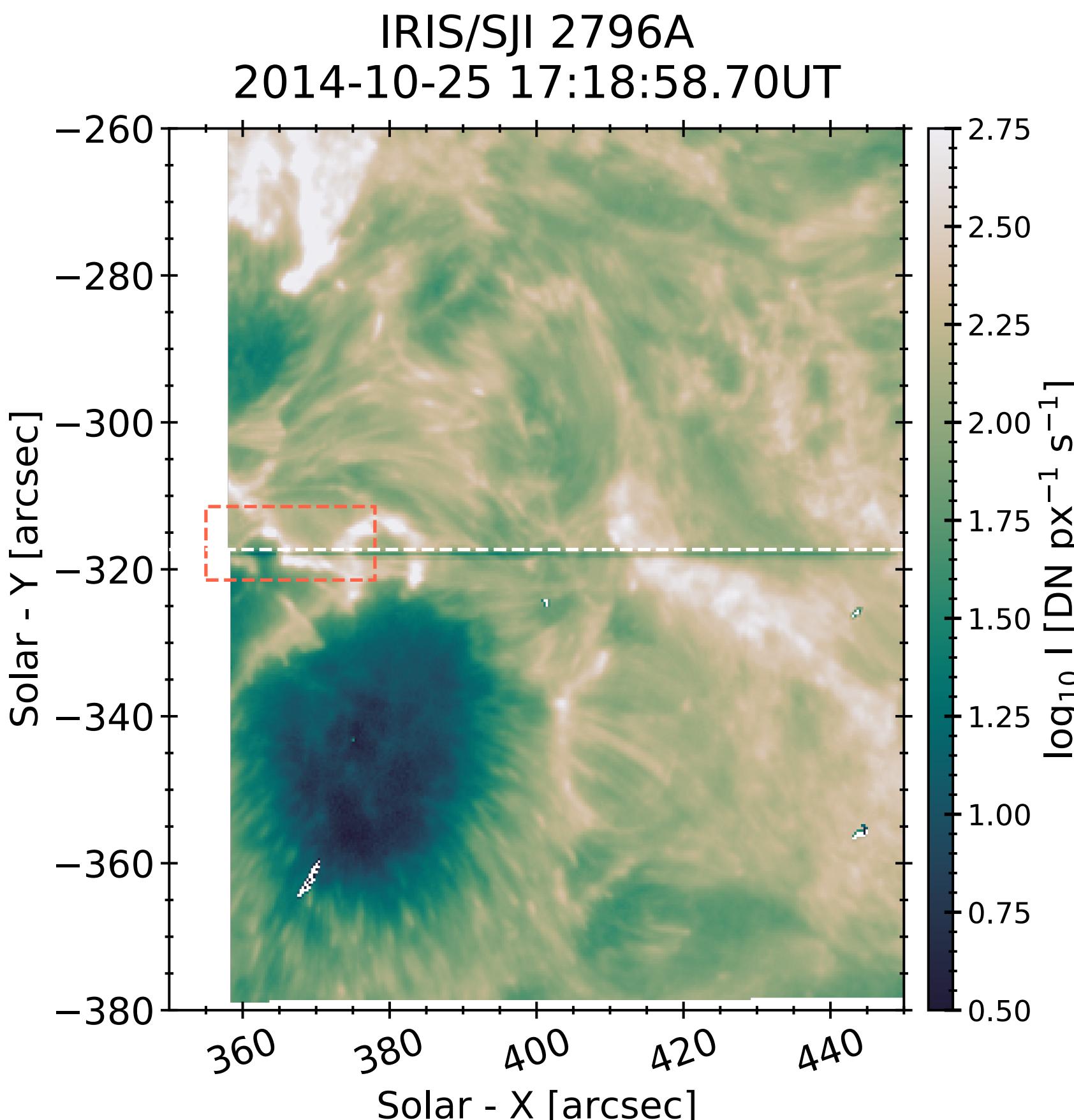
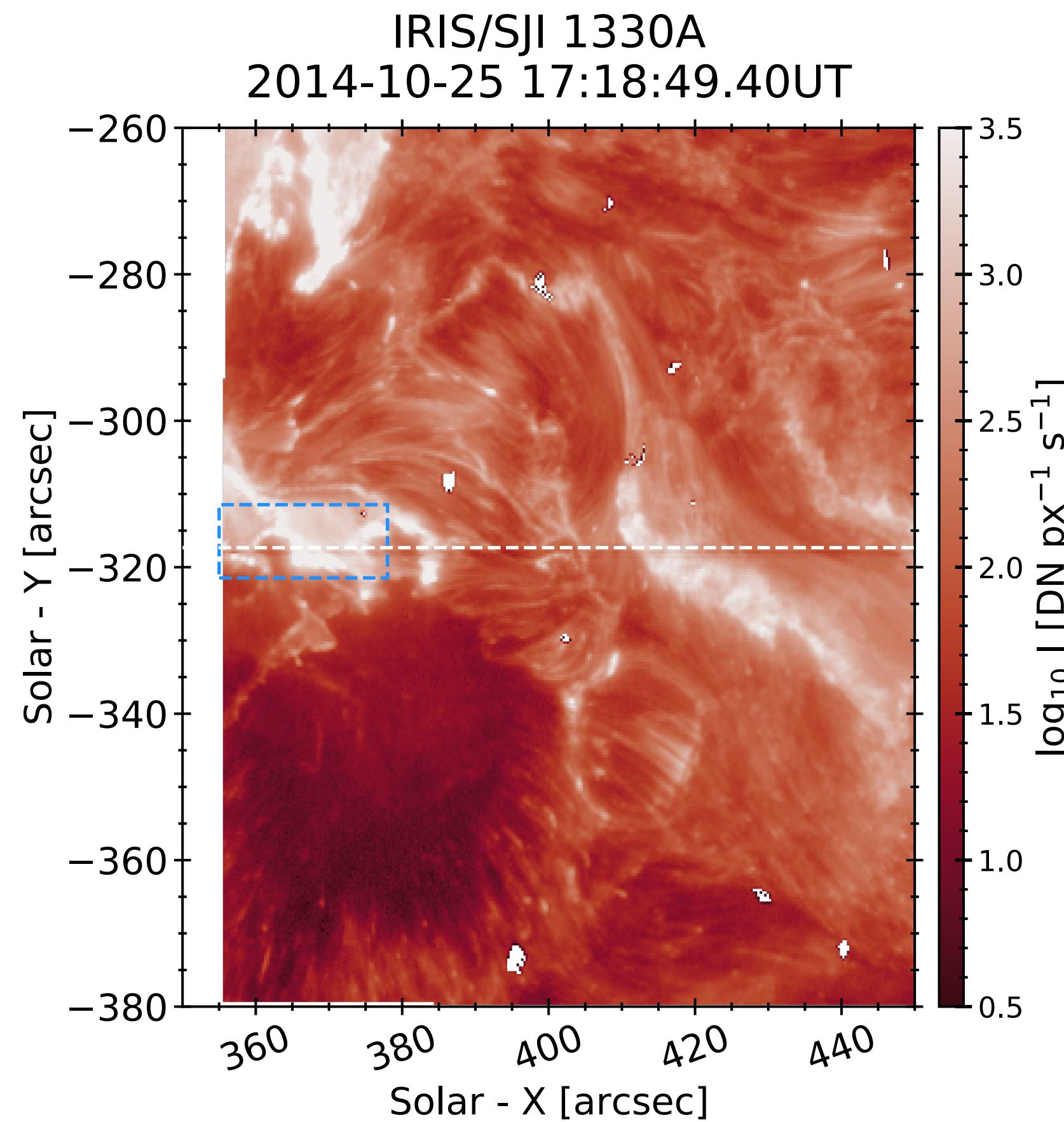
LINE WIDTHS ARE A PERENNIAL MODEL-DATA ISSUE

Zhu et al 2019

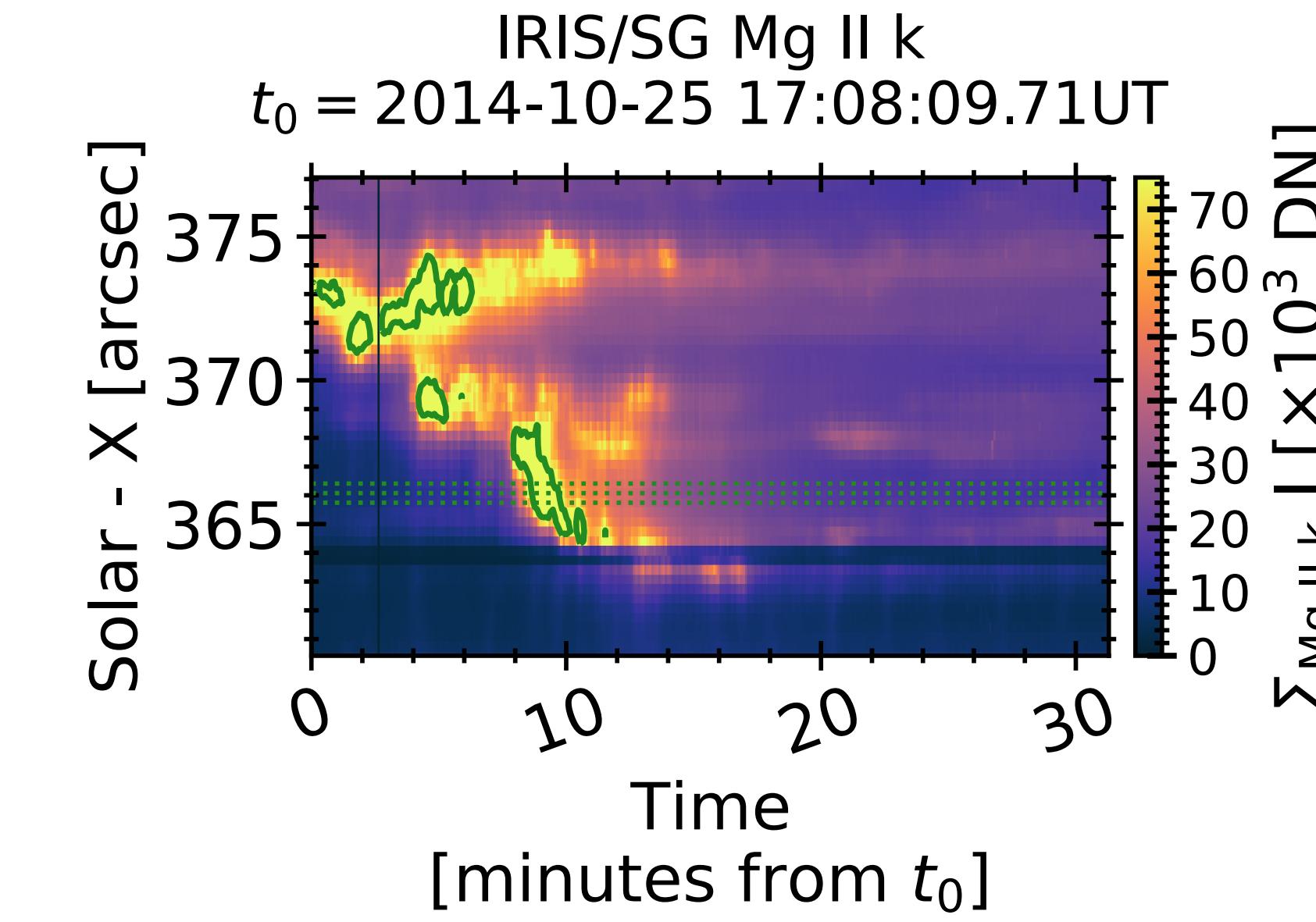
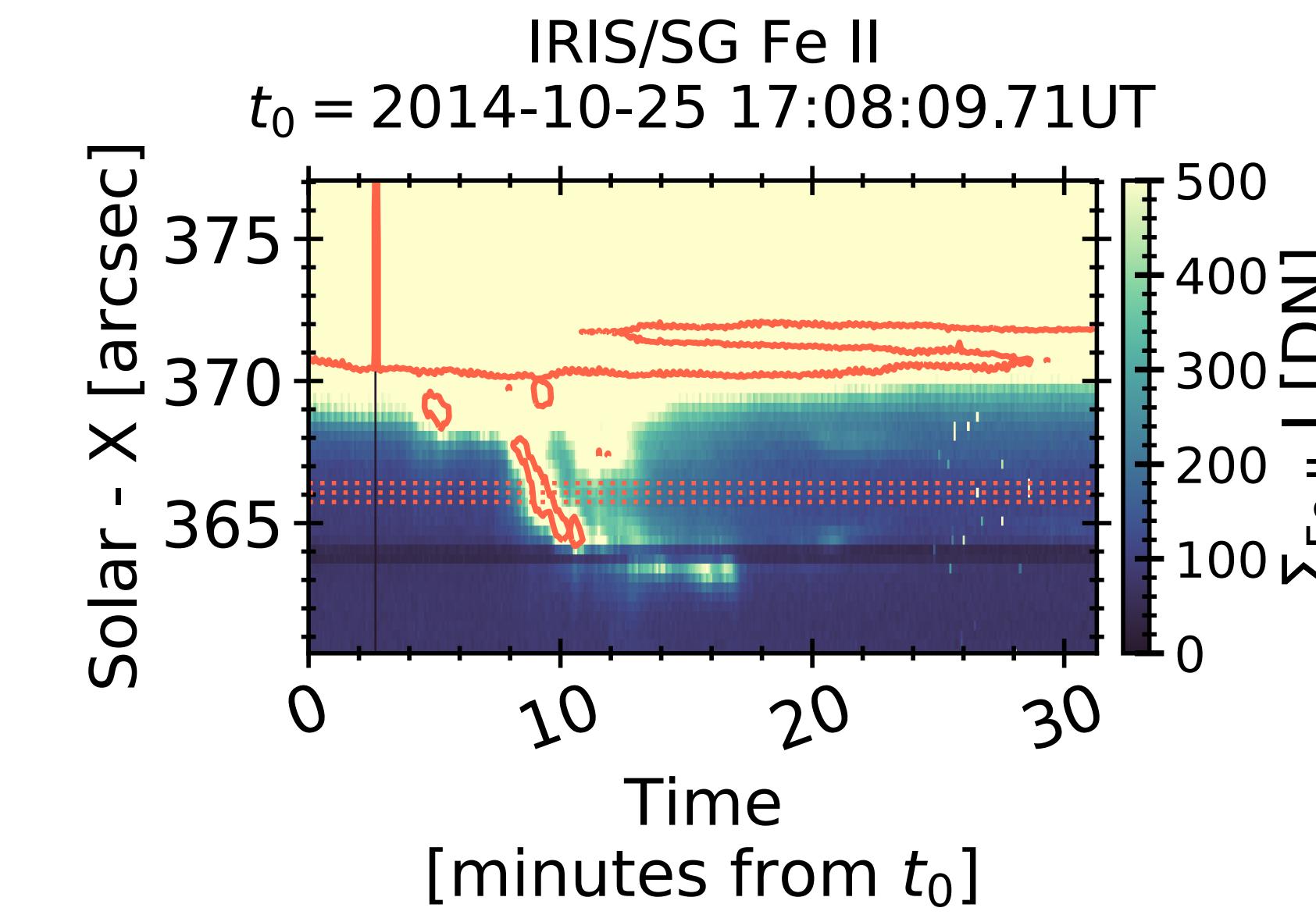
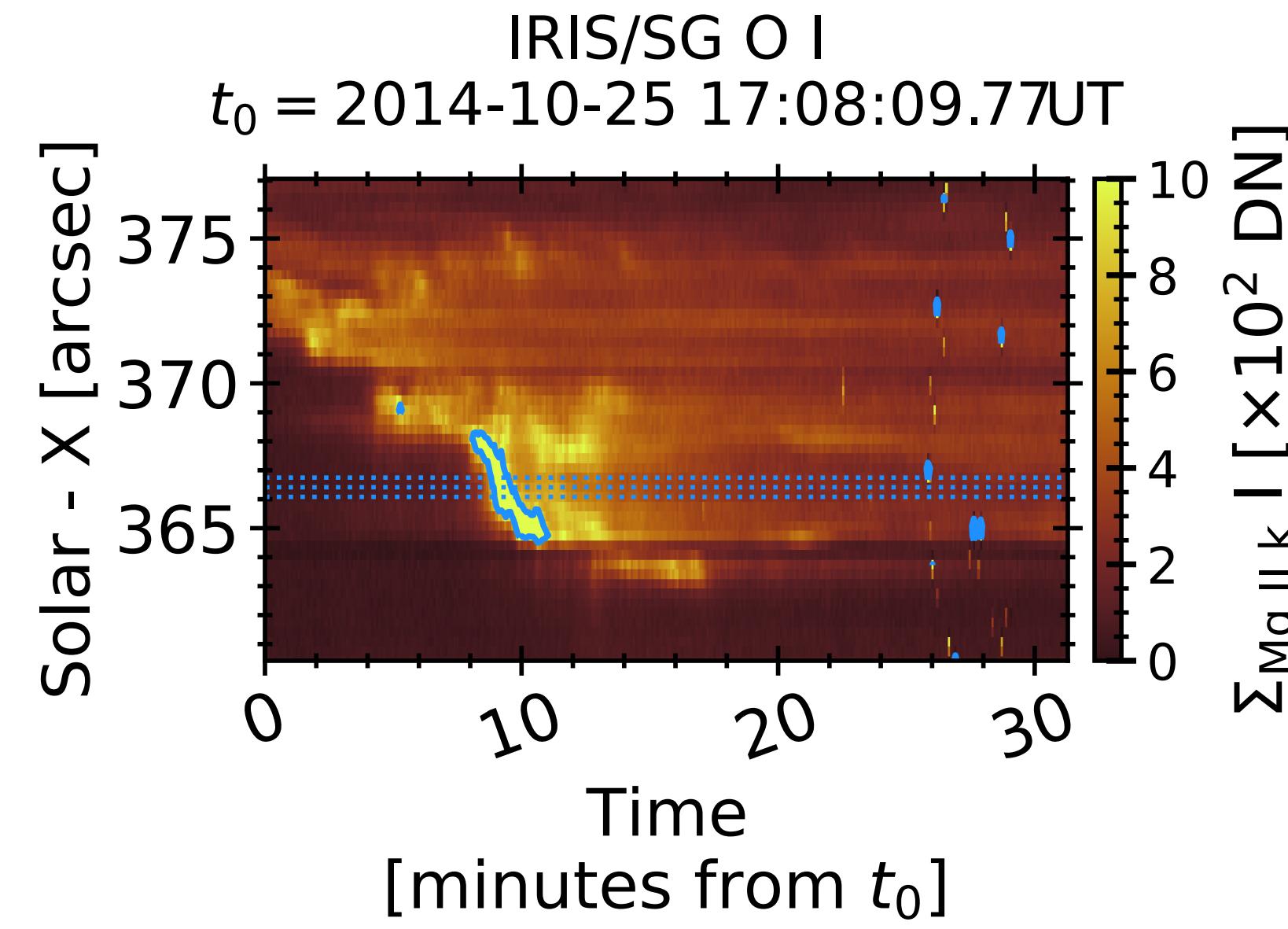
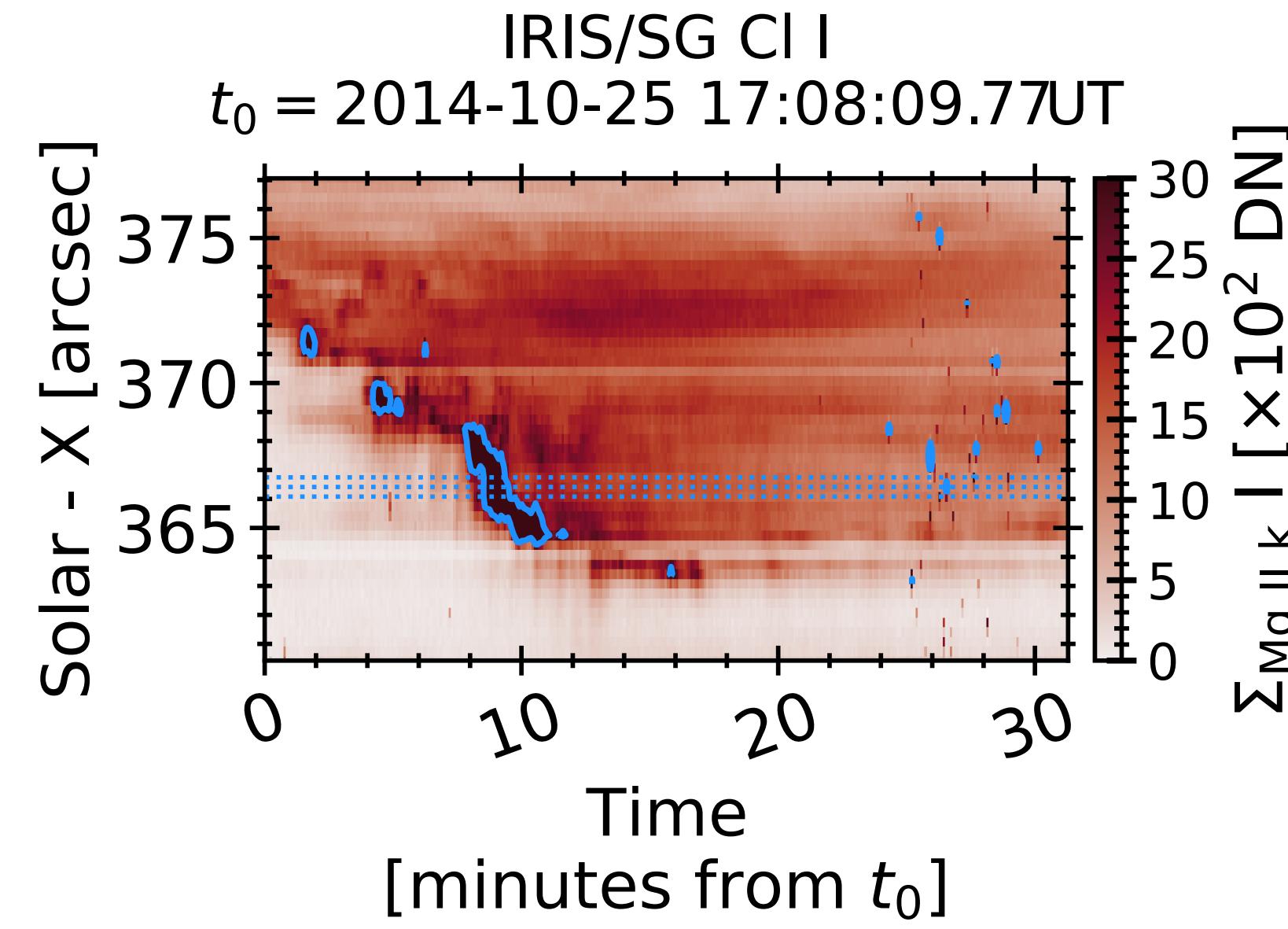
- ▶ Improved the treatment of Stark broadening for Mg II, using the STARK-B database broadens the lines but still not enough –**another factor of 30x was needed!**
- ▶ One possibility is that we are not heating the lower atmosphere sufficiently.



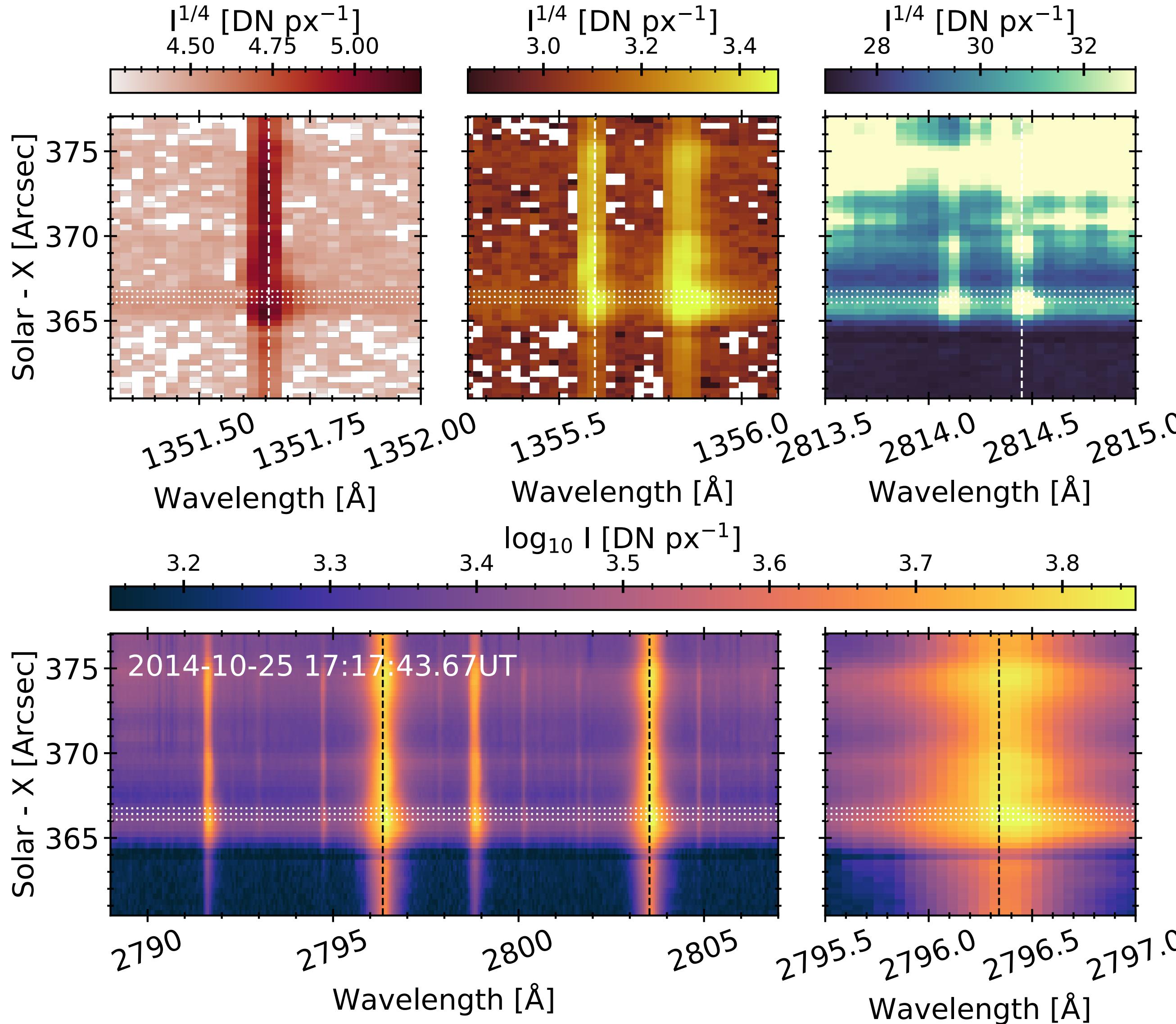
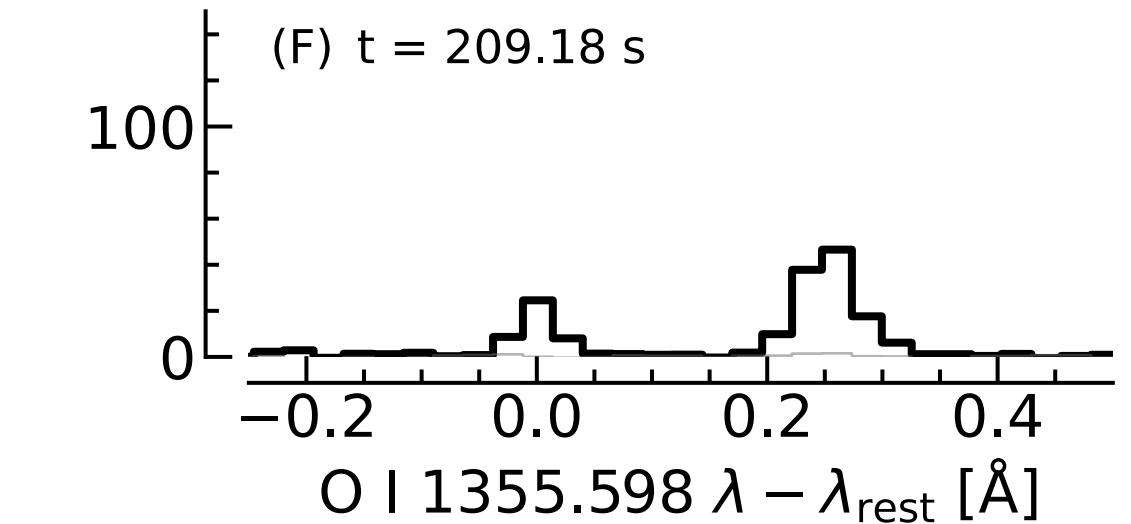
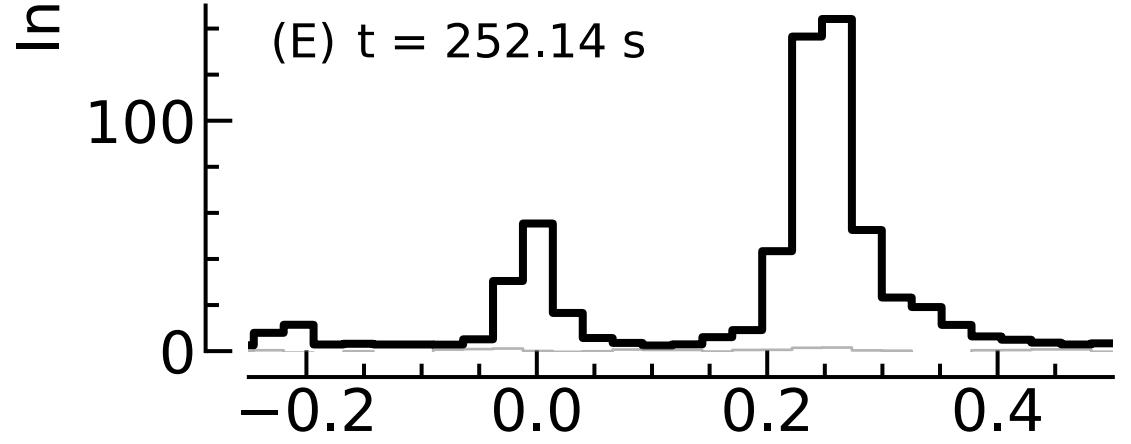
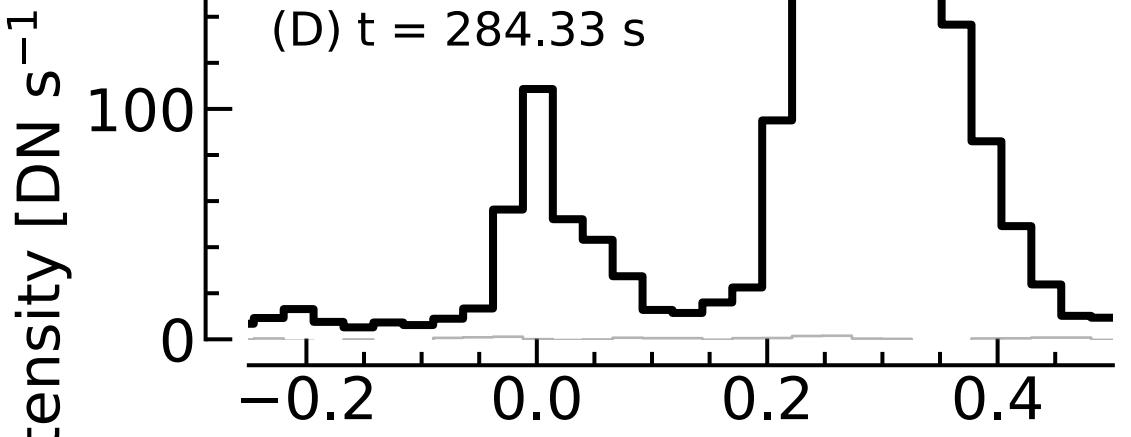
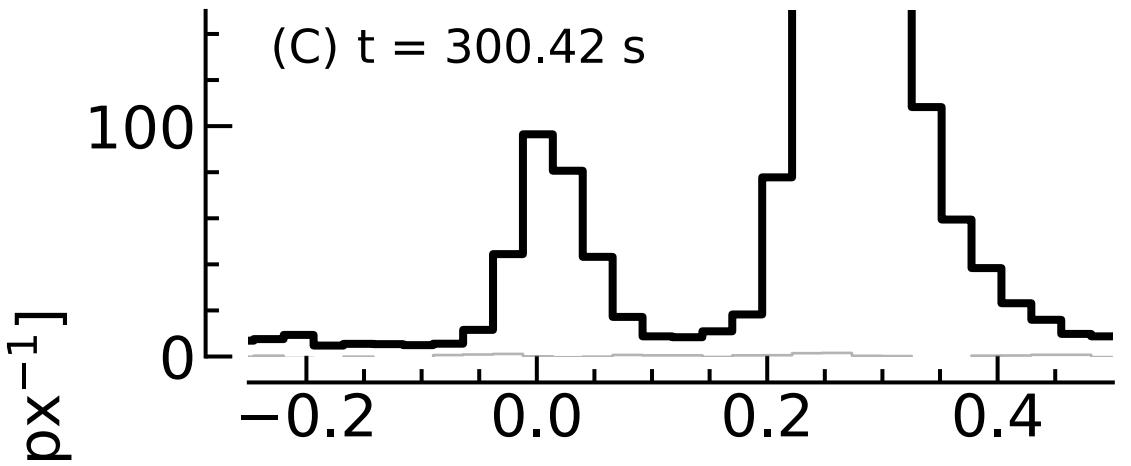
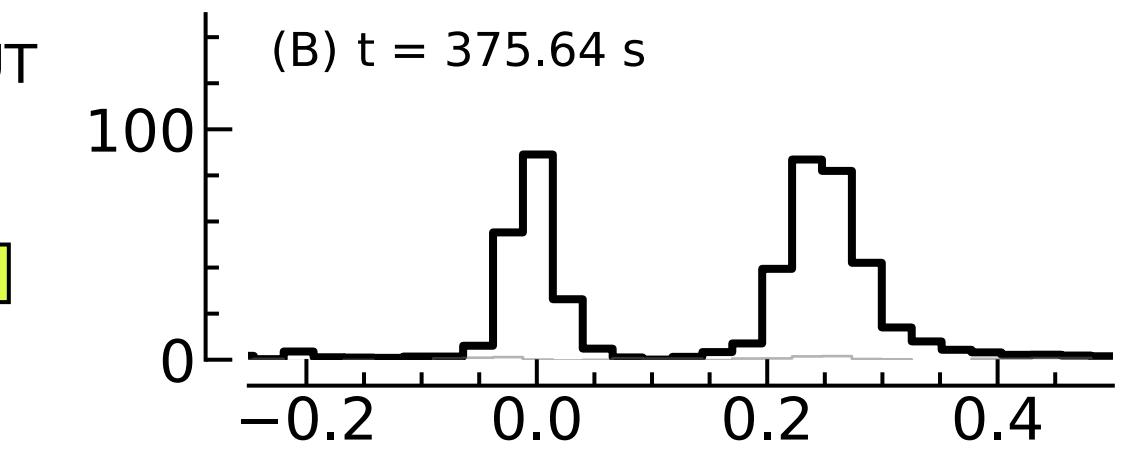
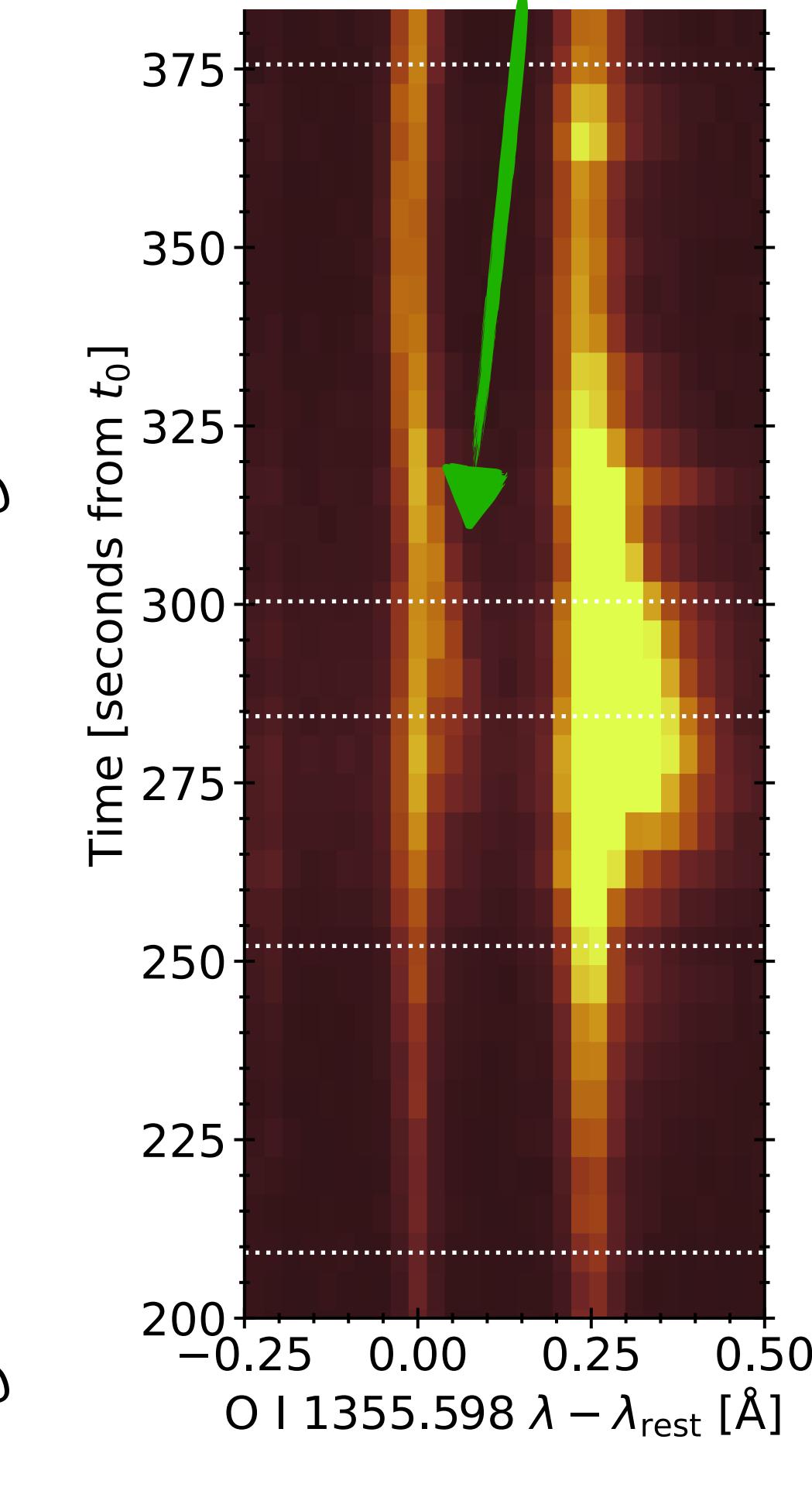
2014-OCTOBER-25 X1 CLASS FLARE



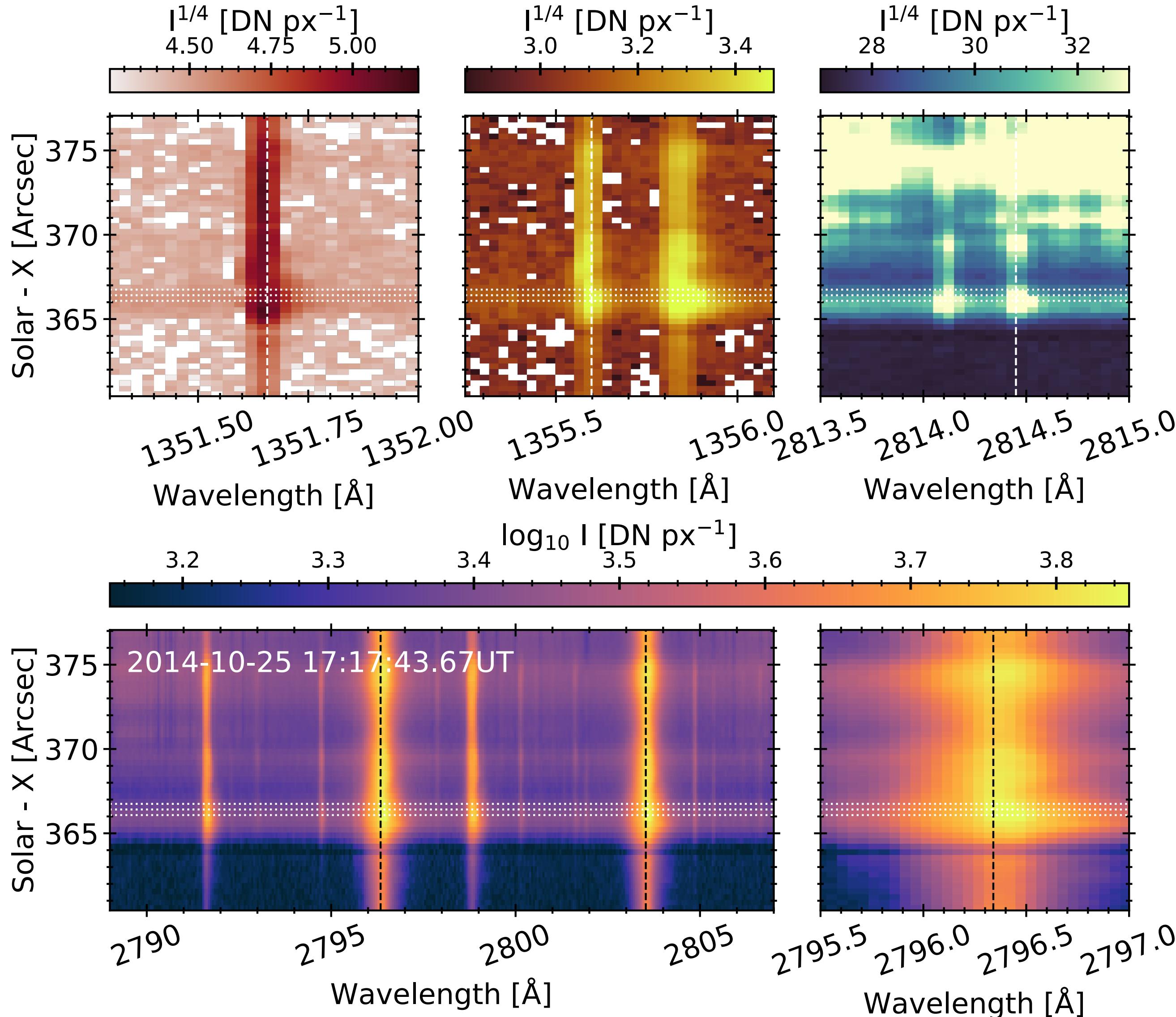
2014-OCTOBER-25 X1 CLASS FLARE



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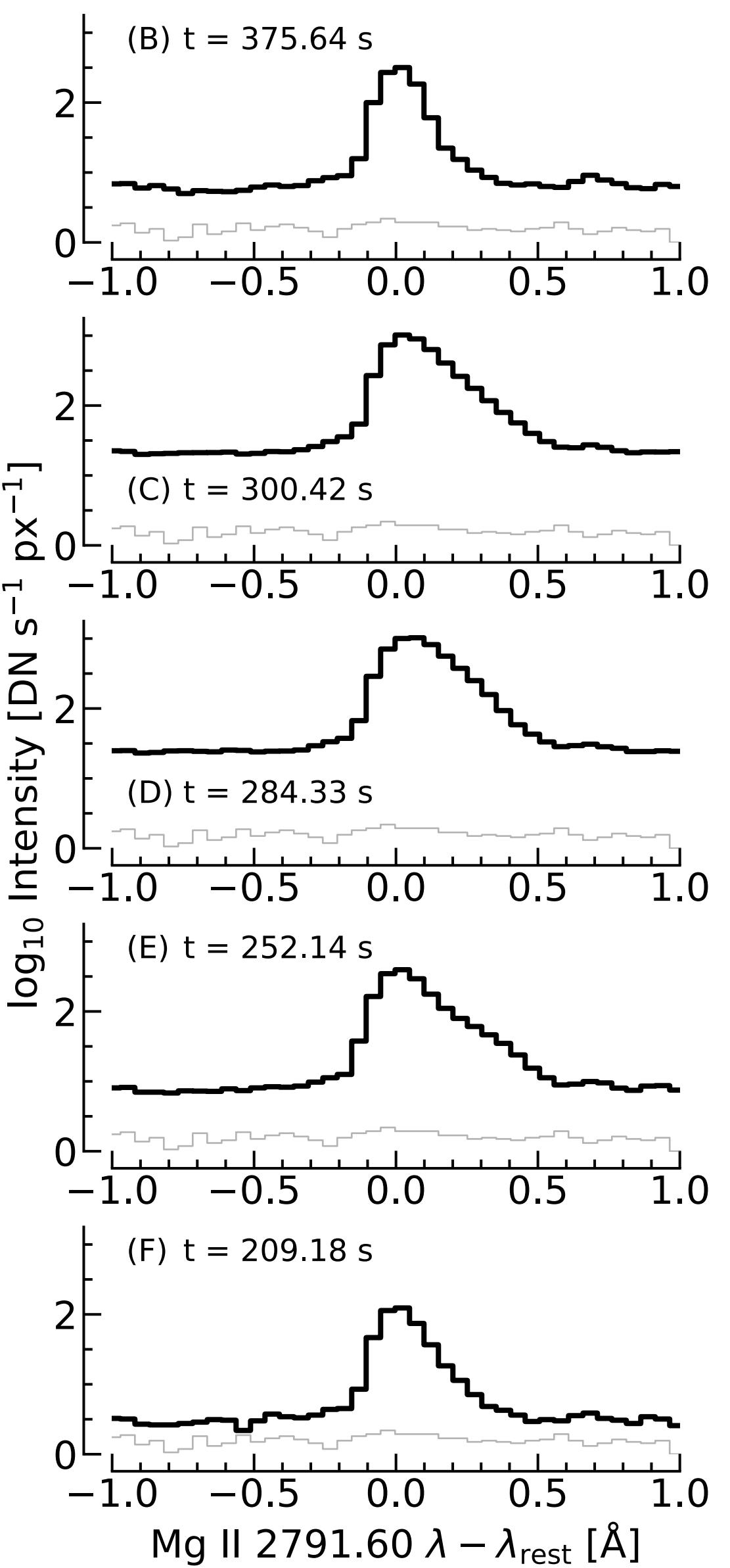
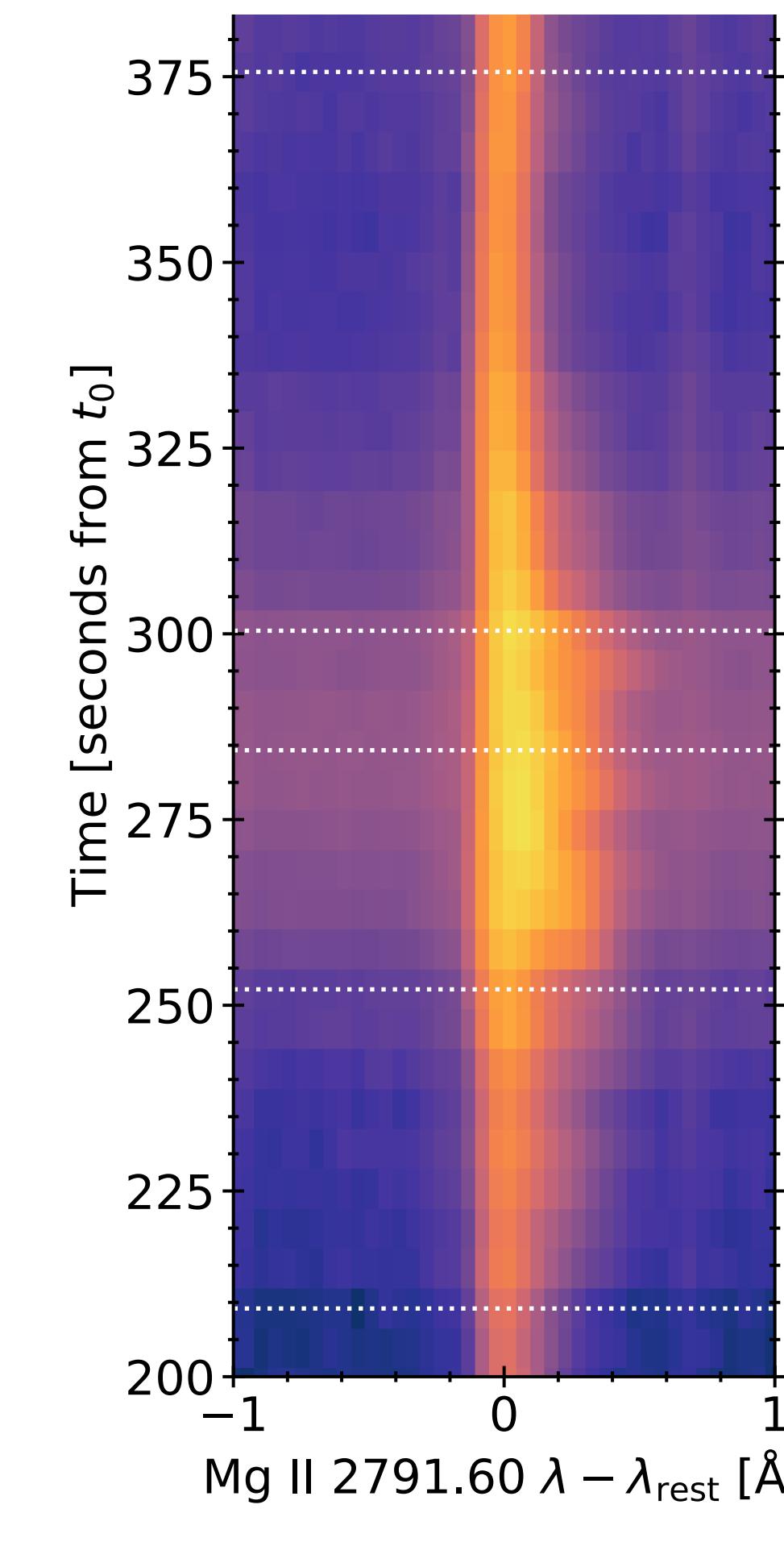
 $t_0 = 2014-10-25 17:12:37.94 \text{ UT}$ Intensity $[\text{DN s}^{-1} \text{ px}^{-1}]$ **O I 1355.598 Å**

2014-OCTOBER-25 X1 CLASS FLARE

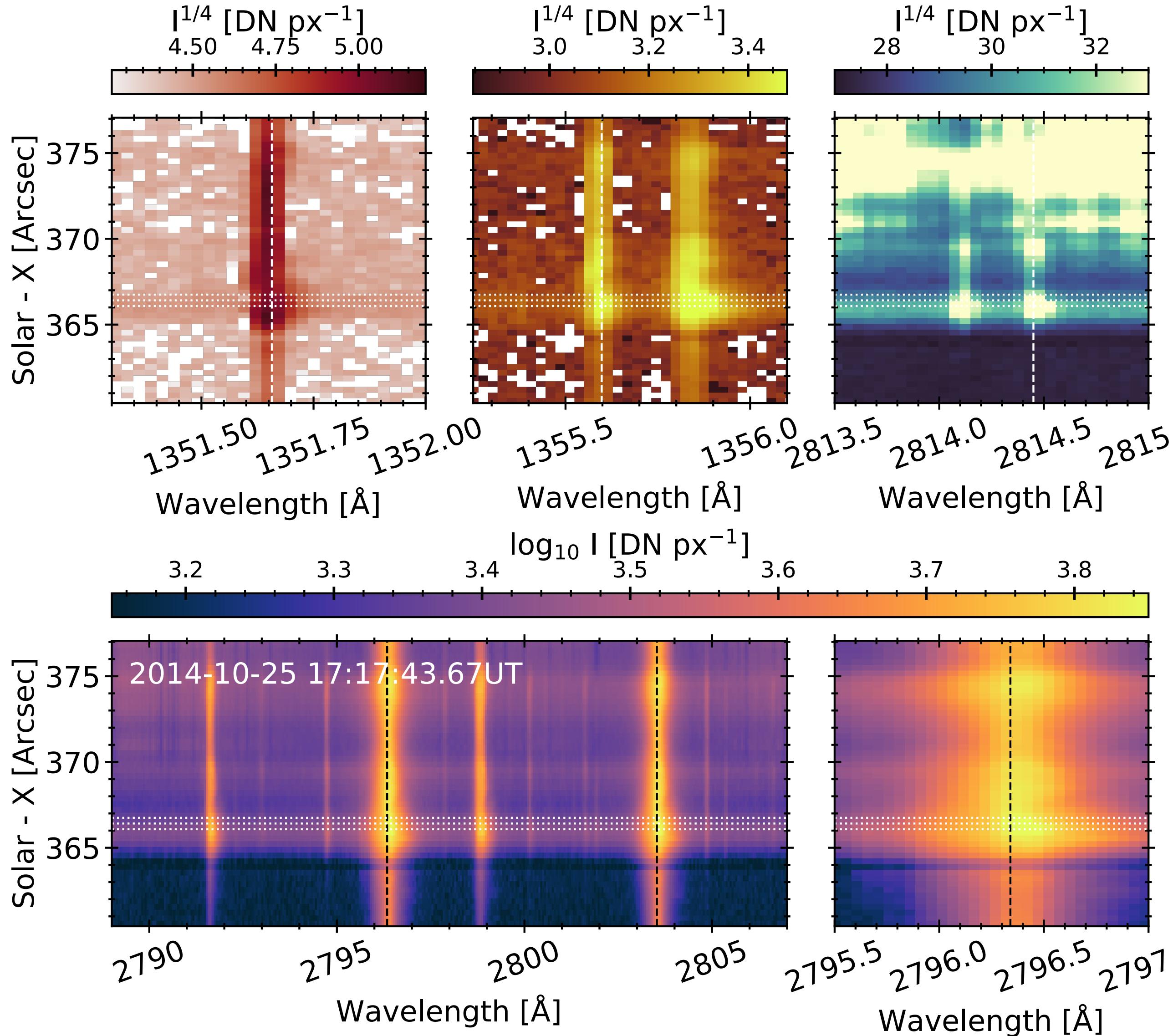


$t_0 = 2014-10-25 17:12:37.87 \text{ UT}$
 $\log_{10} \text{ Intensity } [\text{DN s}^{-1} \text{ px}^{-1}]$

Mg II 2791.6 Å

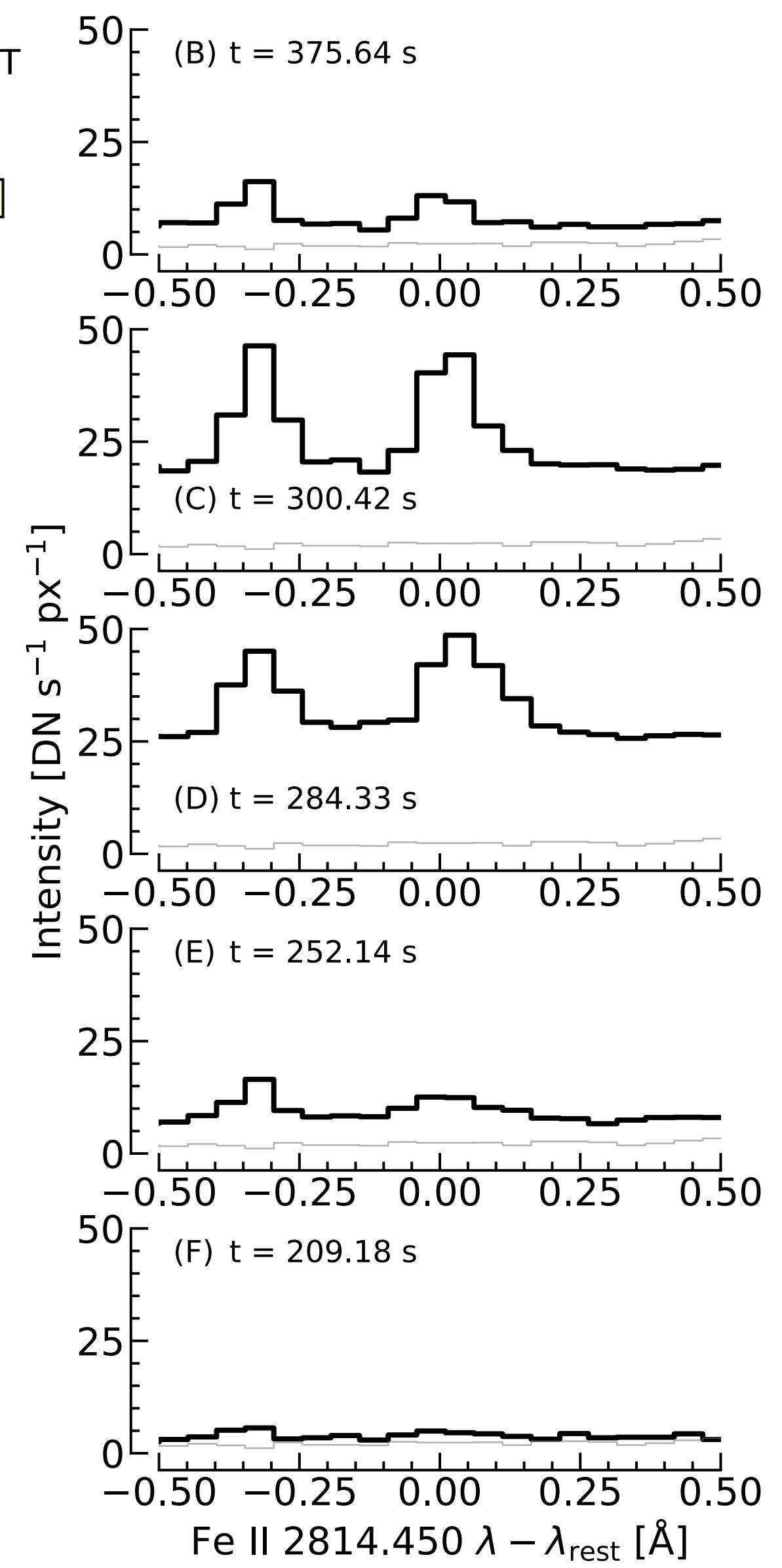
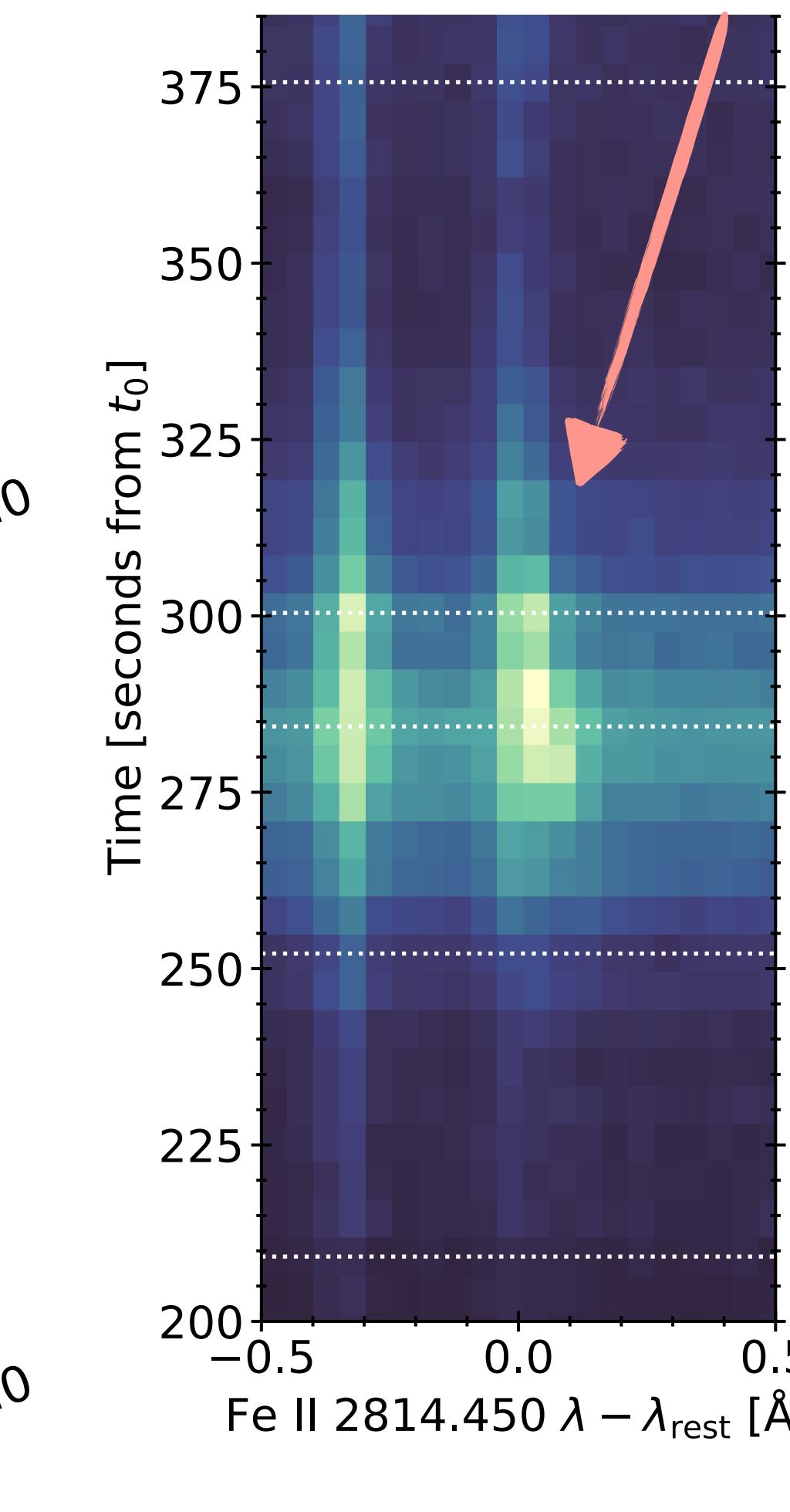


2014-OCTOBER-25 X1 CLASS FLARE

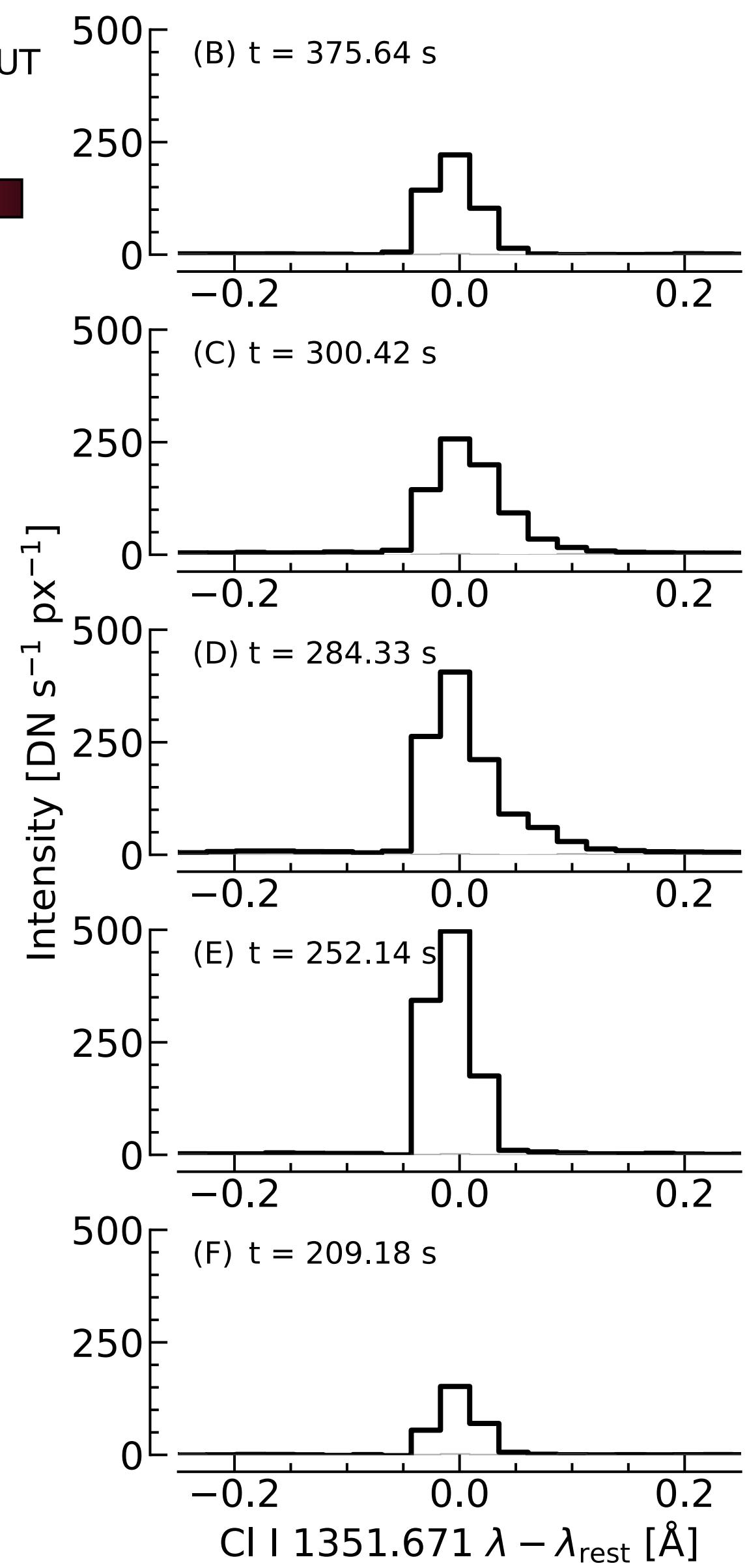
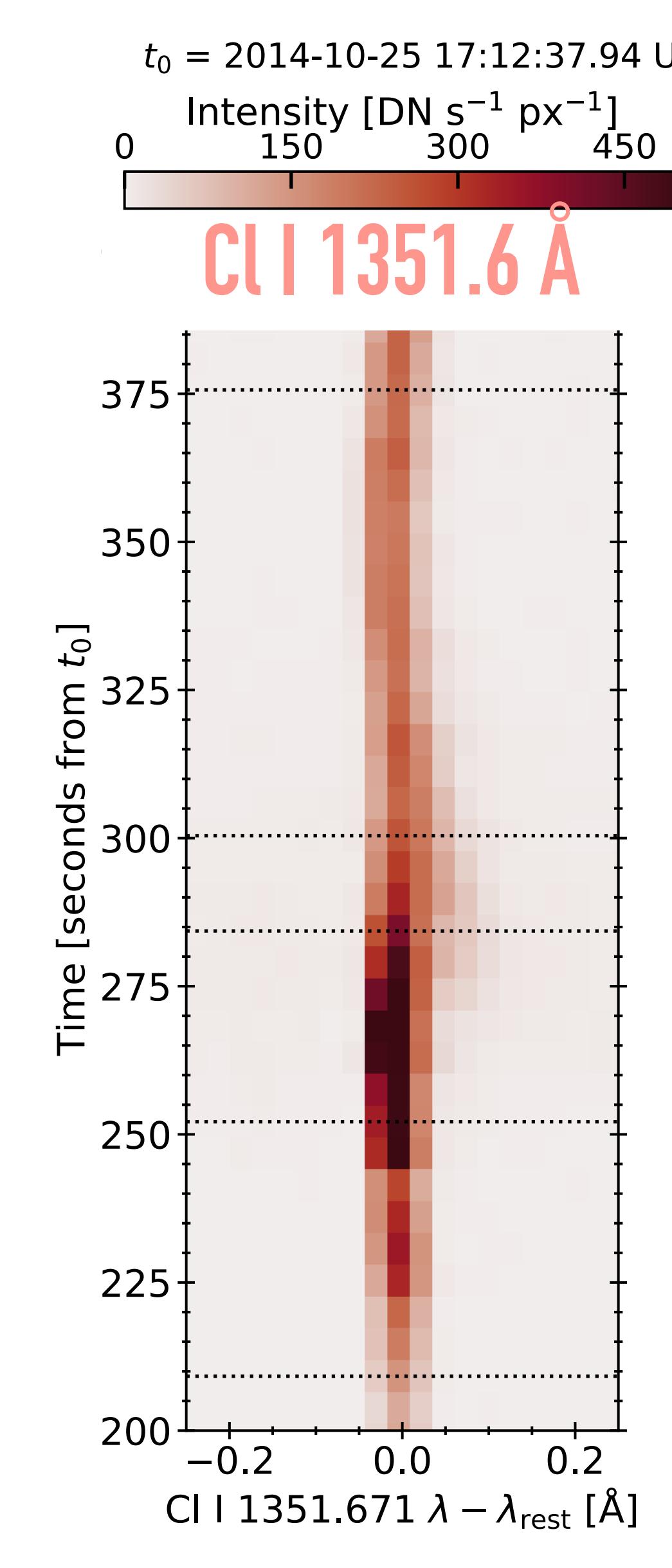
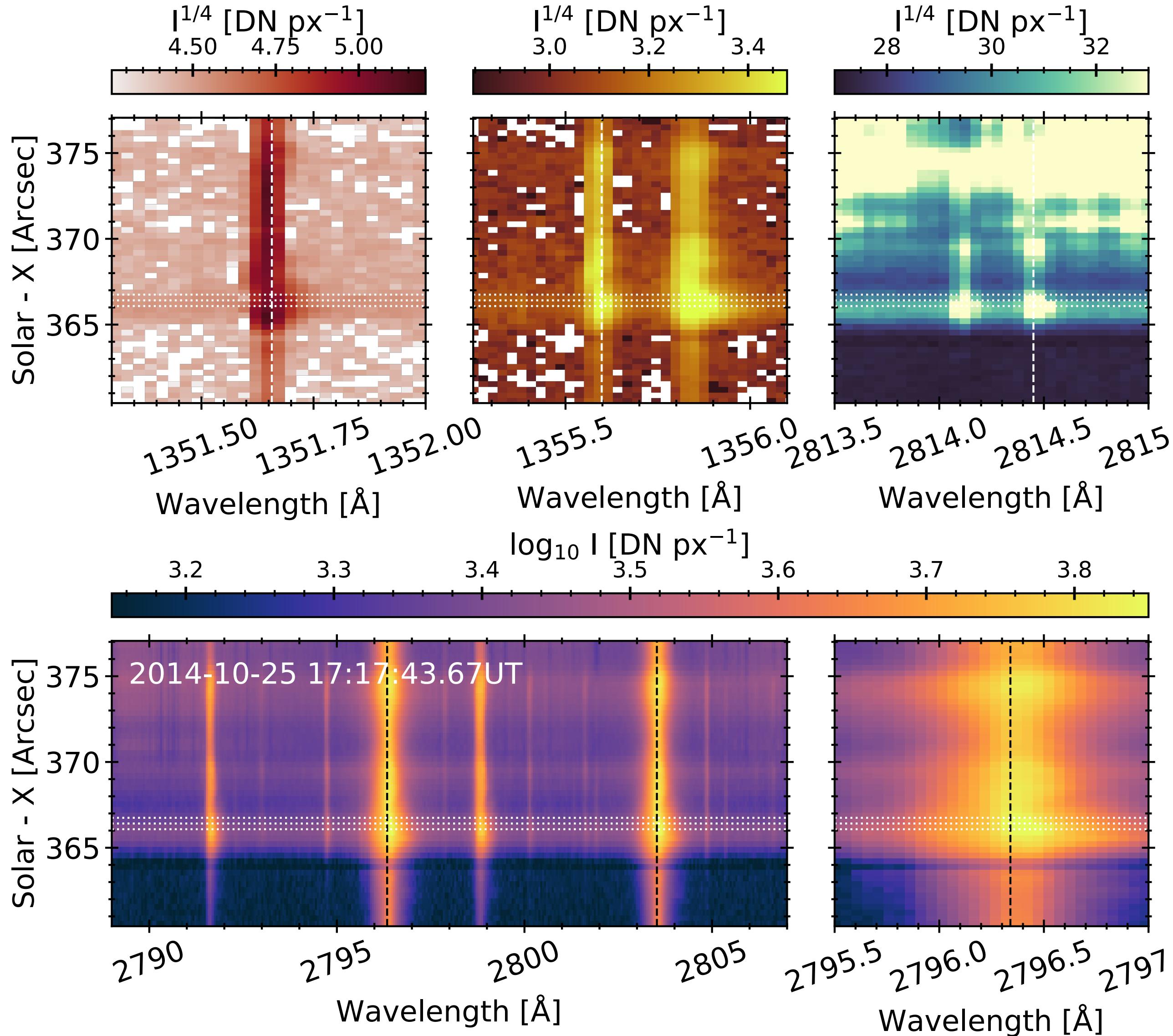


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Intensity $[\text{DN s}^{-1} \text{ px}^{-1}]$

Fe II 2814.45 Å

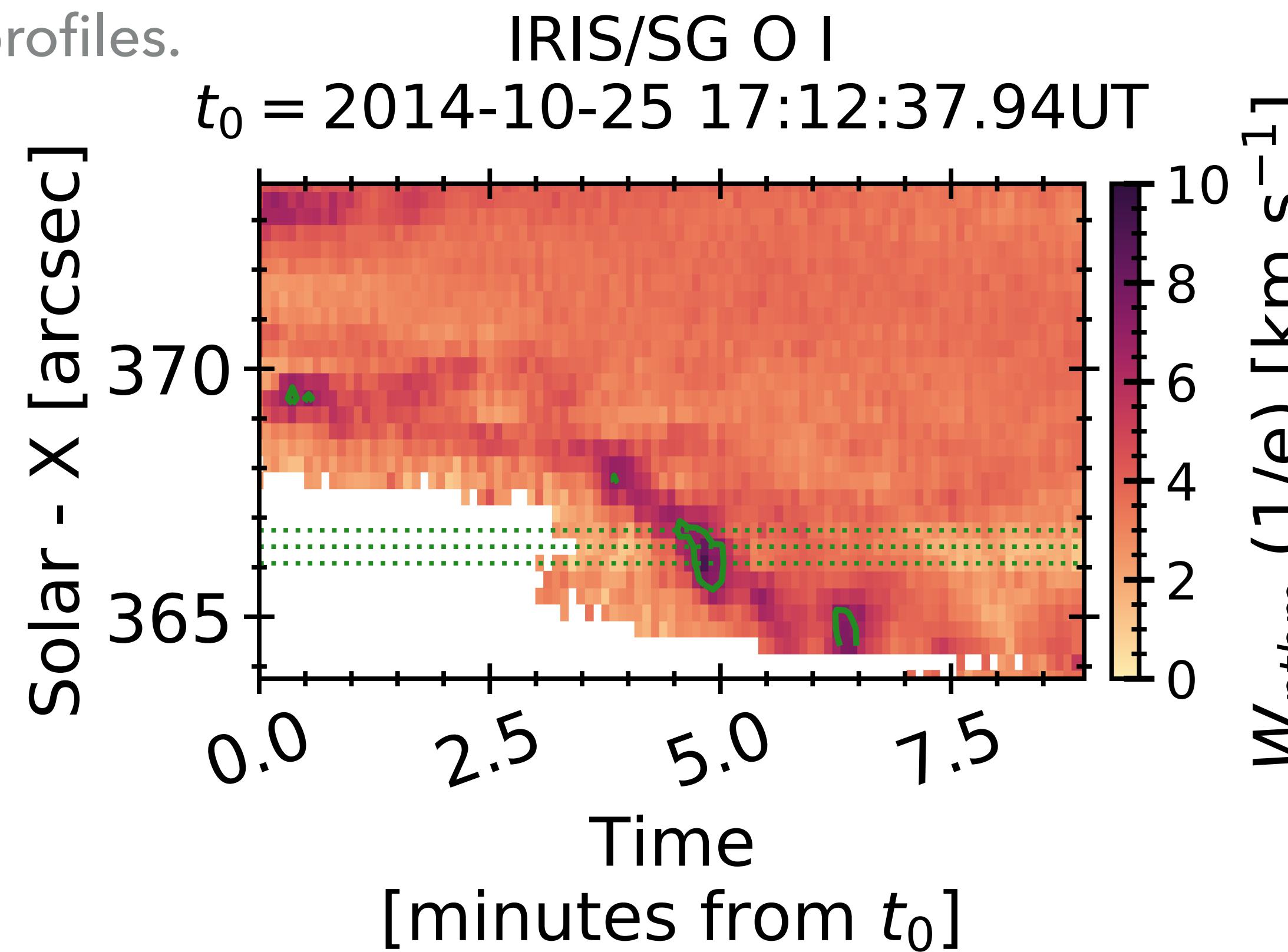


2014-OCTOBER-25 X1 CLASS FLARE

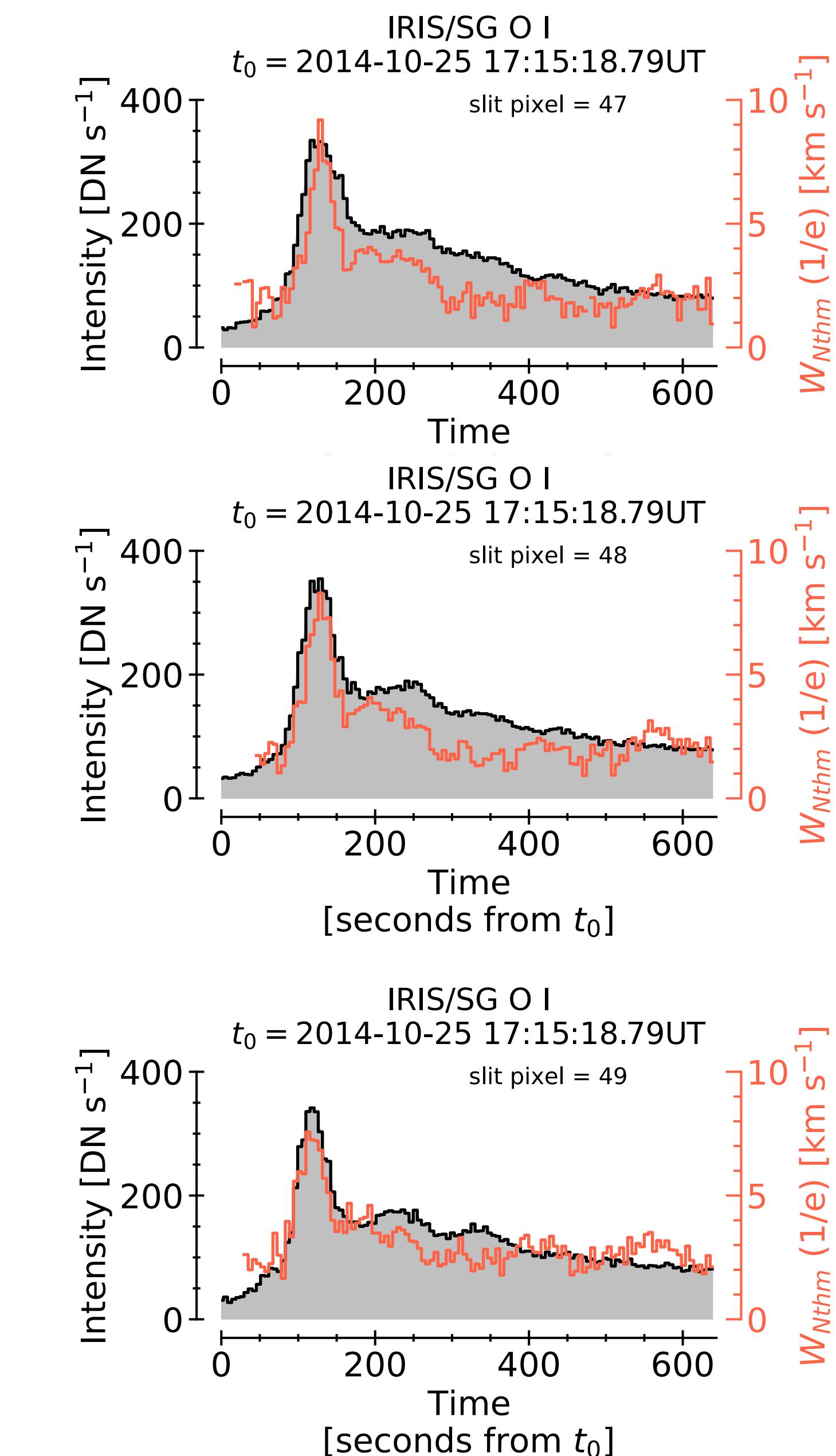


WHAT IS THE OBSERVED v_{TURB} ?

- Background values of $v_{N\text{thm}} \sim 2 - 3.5 \text{ km/s}$.
- Short lived ($\sim 30\text{-}90\text{s}$) broadening, co-spatial with bright profiles.

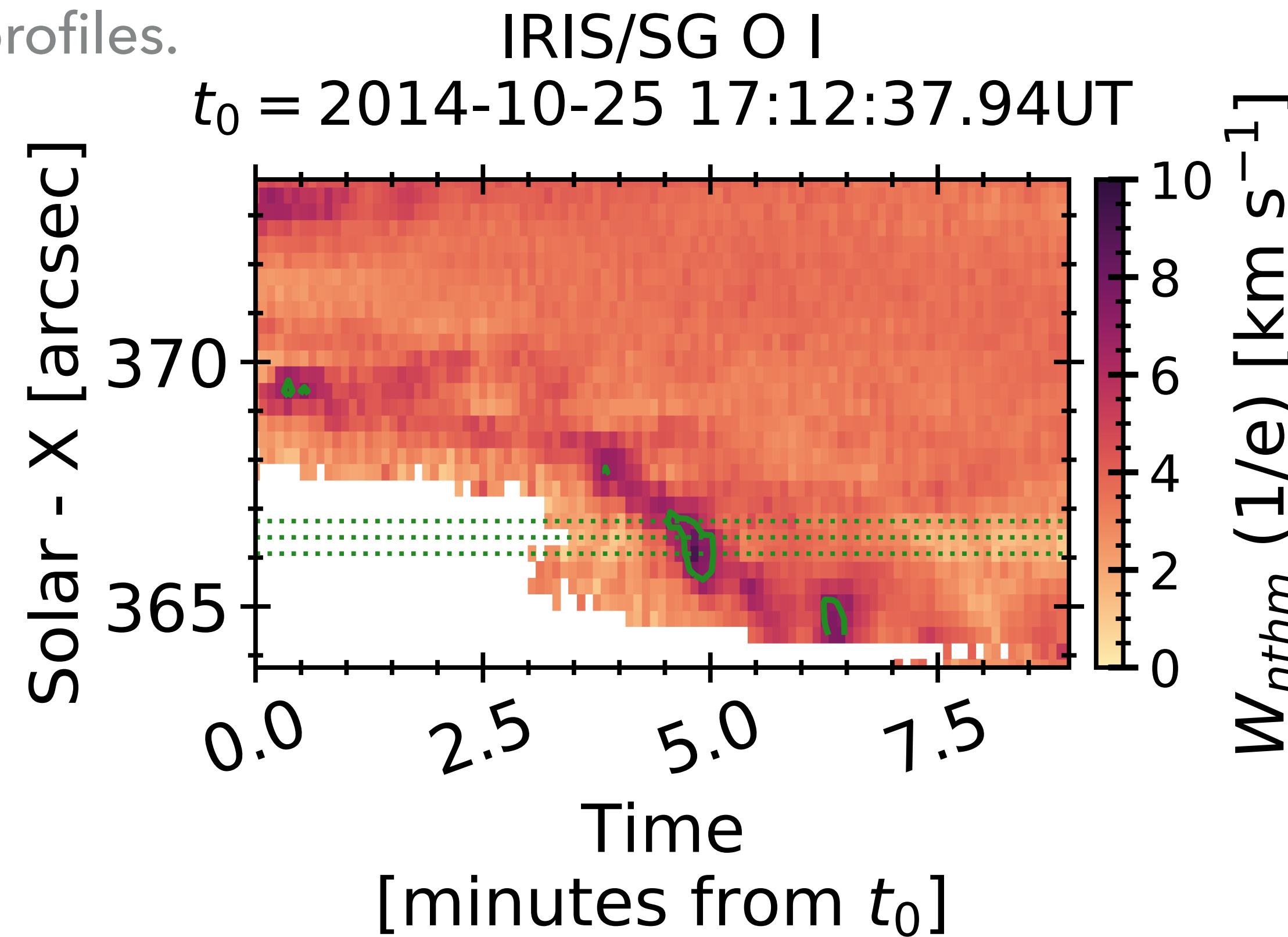


- Not shown here: background values of $v_{N\text{thm}} \sim 4.5 - 6 \text{ km/s}$ in plage, but with flare sources of comparable $v_{N\text{thm}}$ as the umbra.

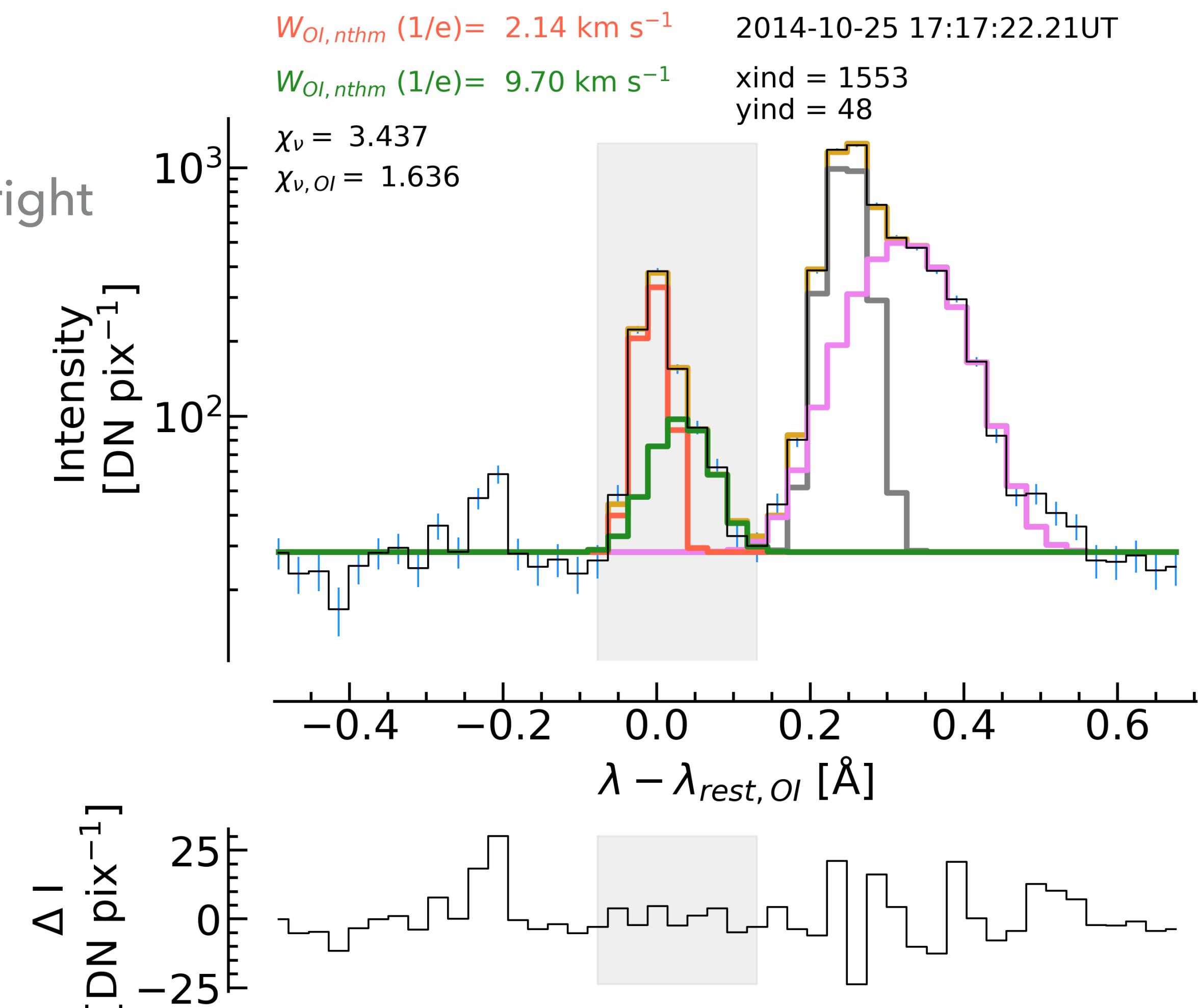


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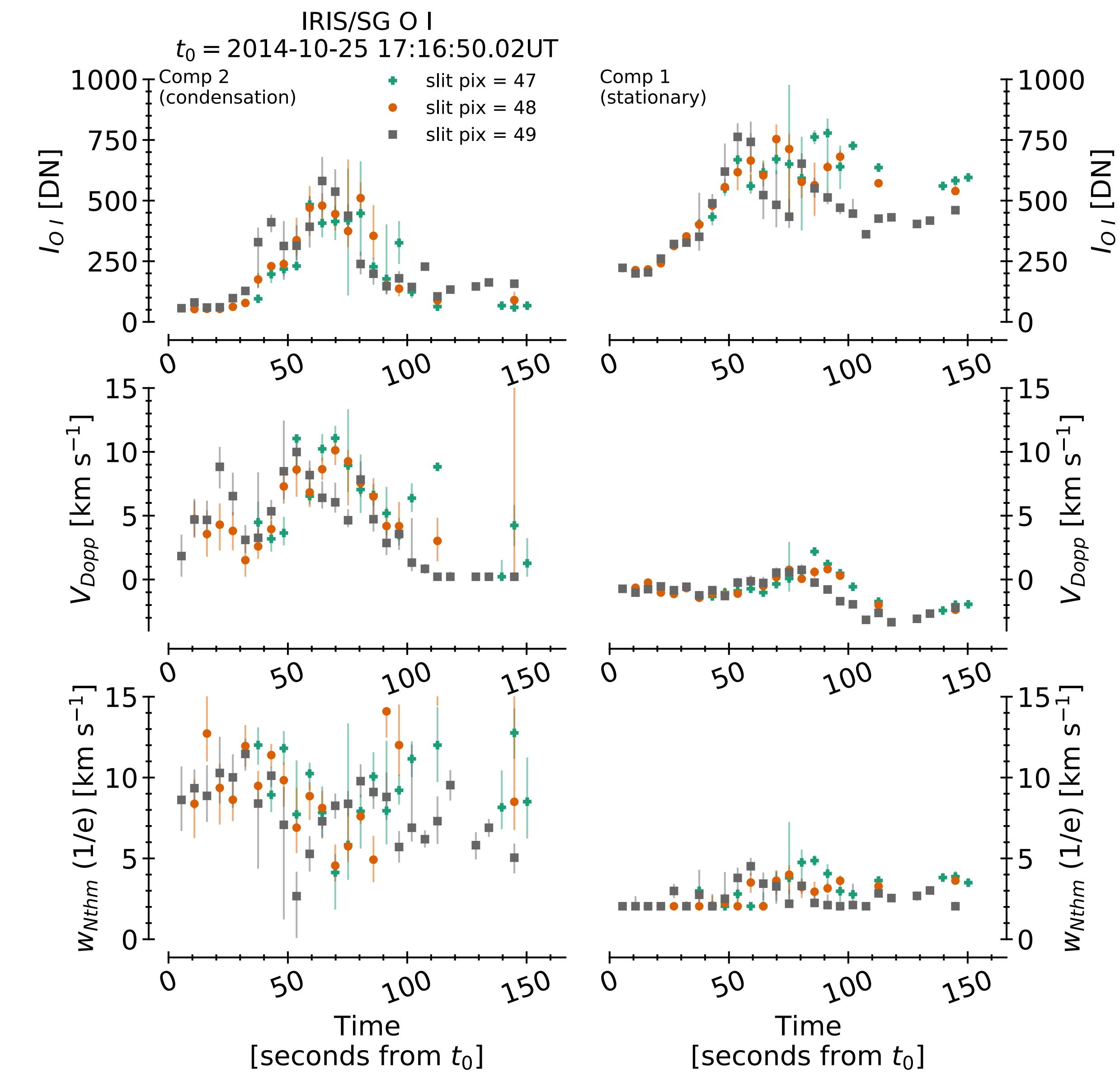


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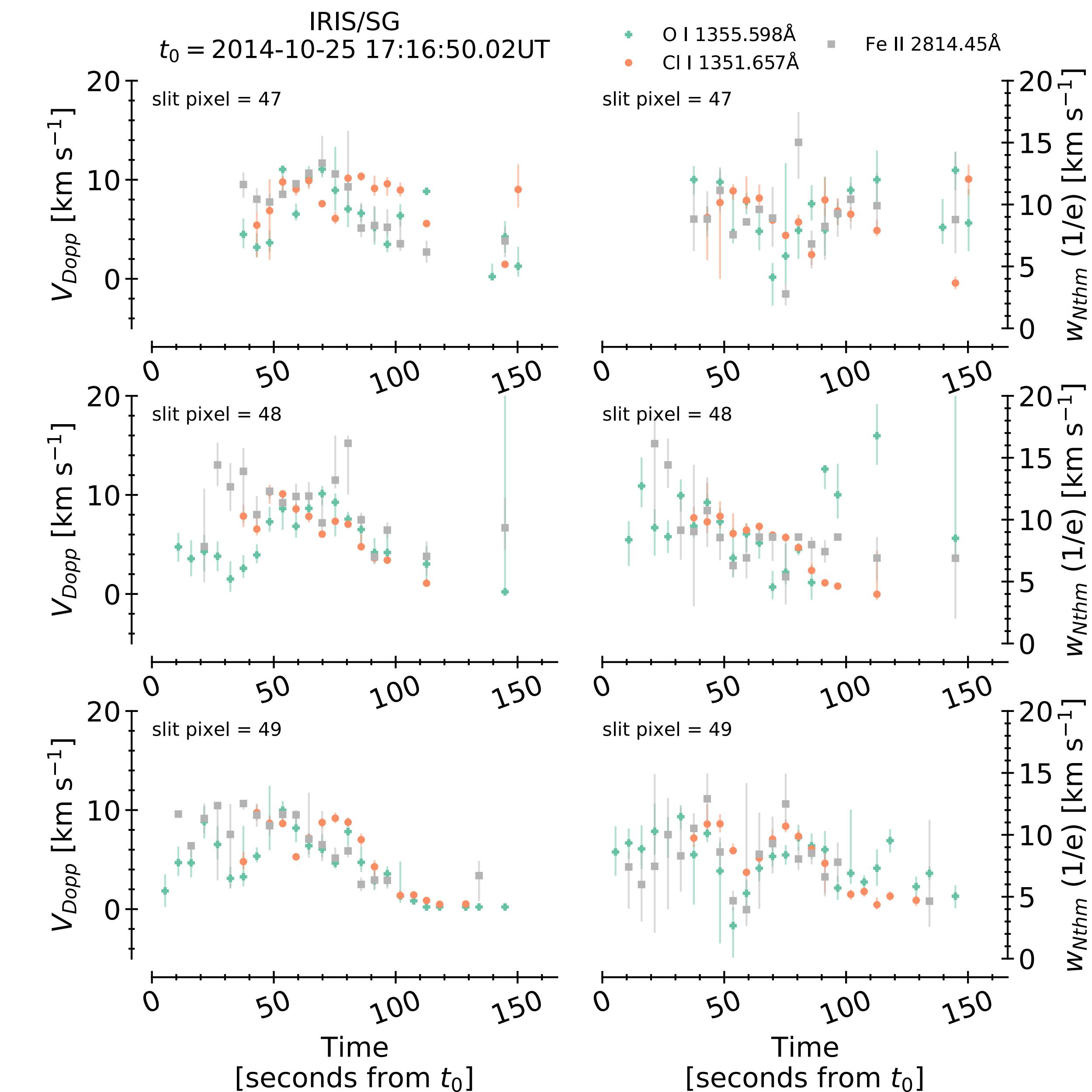
WHAT IS THE OBSERVED V_{TURB} ?

- ▶ Moderately redshifted second component; stationary component exhibits small red and blue shifts.
- ▶ Observed nonthermal width in the red wing component is $\sim 5\text{-}12 \text{ km/s}$ (typically 10 km/s).
- ▶ True for each of our assumed optically thin lines (Cl I, O I, Fe II).
- ▶ Stationary components only show very minor, if any, broadening – no strong broadening below the condensation?



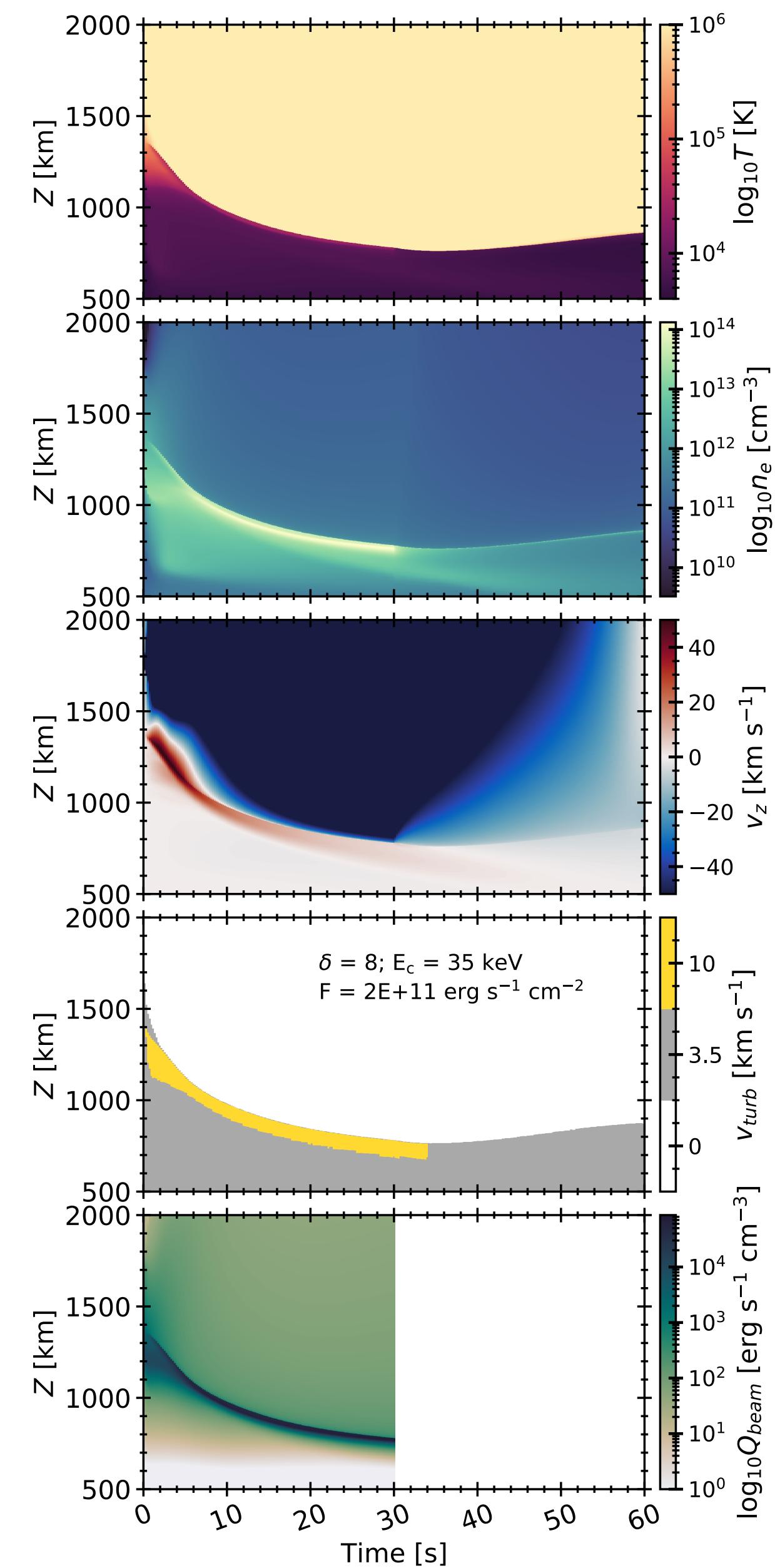
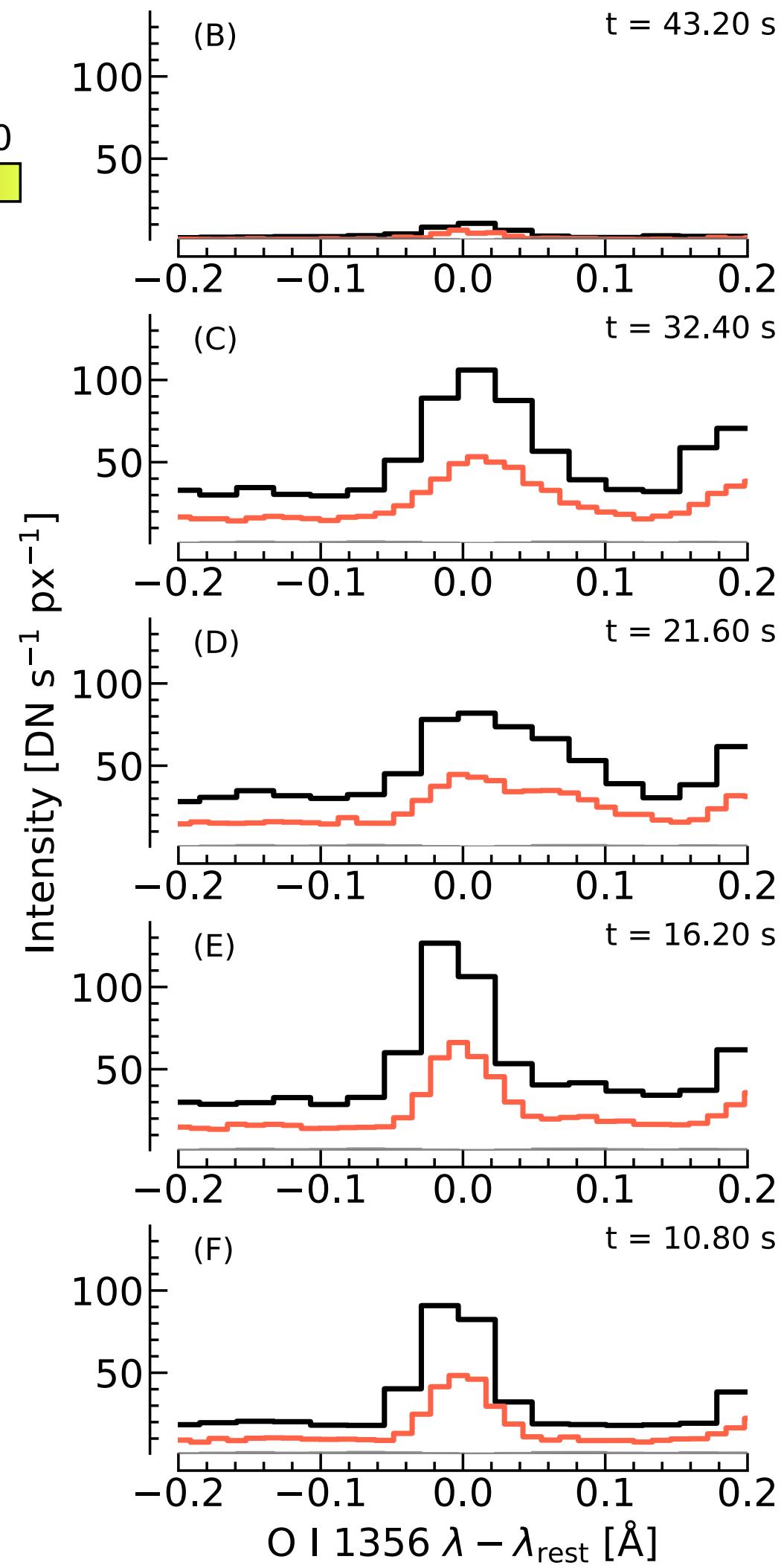
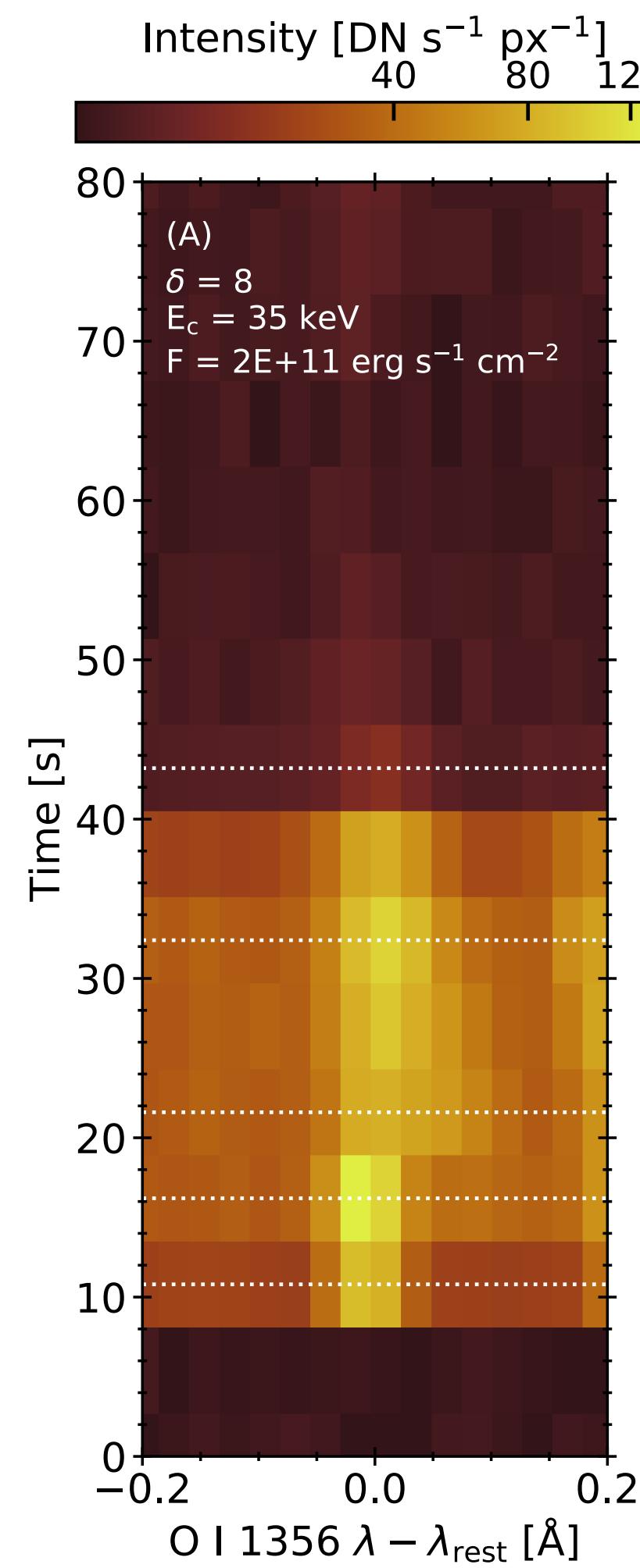
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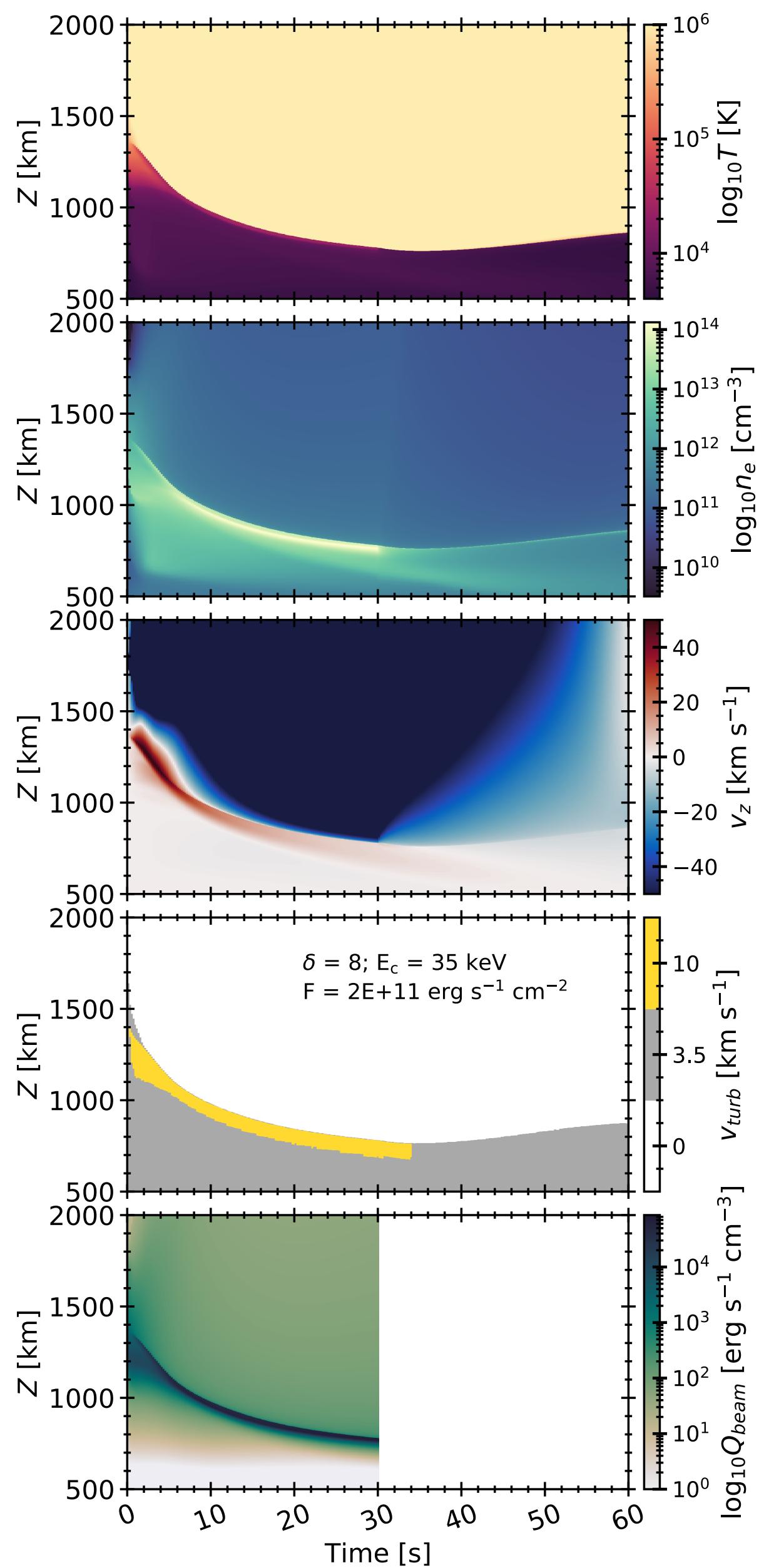
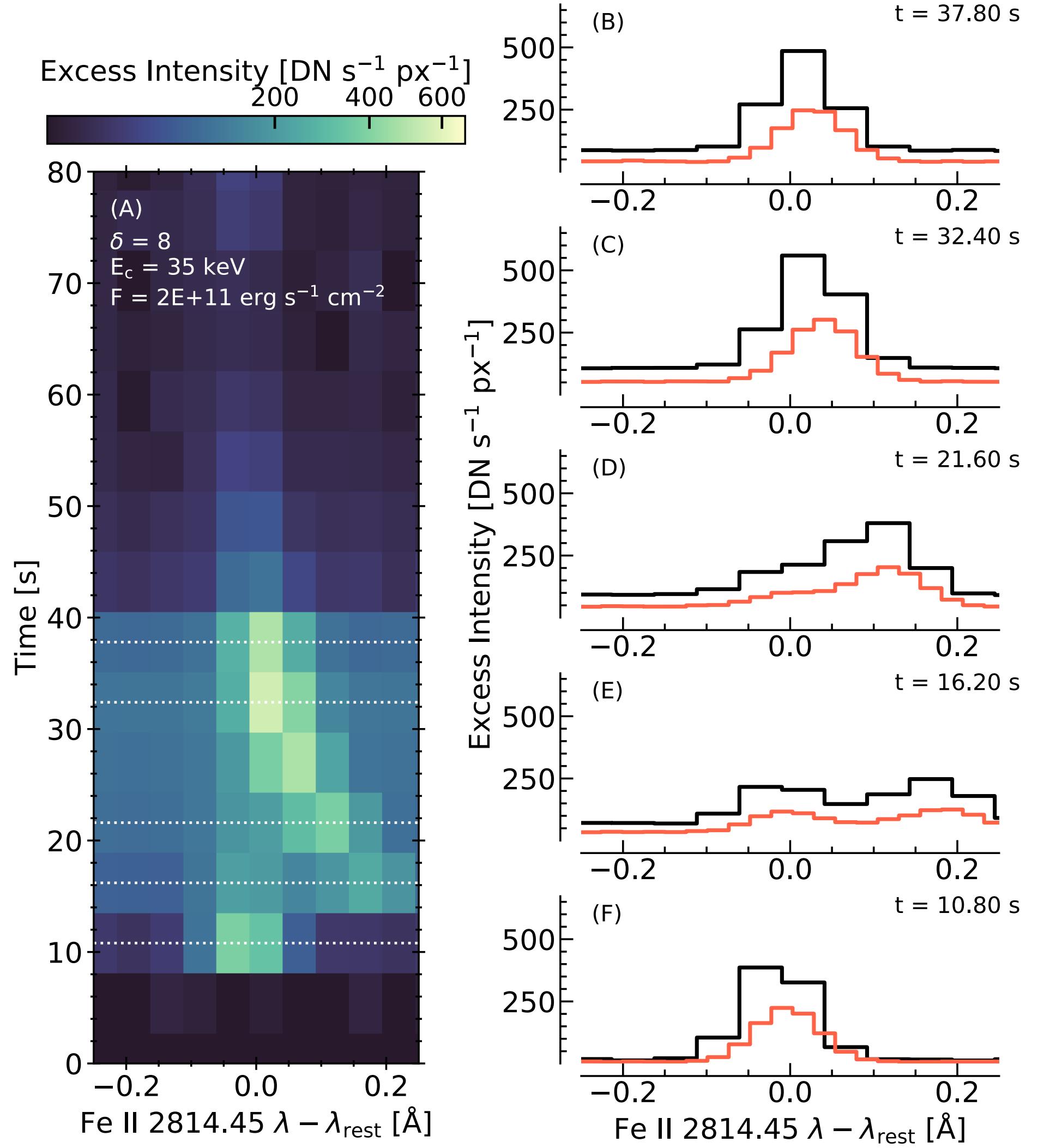
DATA-INSPIRED RADIATION HYDRODYNAMICS MODELLING

- ▶ Ran two RADYN flare simulations, with e-beam input from *Fermi* HXR analysis (only showing one of those here).
- ▶ When synthesizing IRIS lines with RH15D, imposed a micro-turbulence of 10 km/s within the condensation, guided by observations (assumes they form near Mg II).
- ▶ In the stronger flare both Fe II and O I exhibited prominent red wing components.



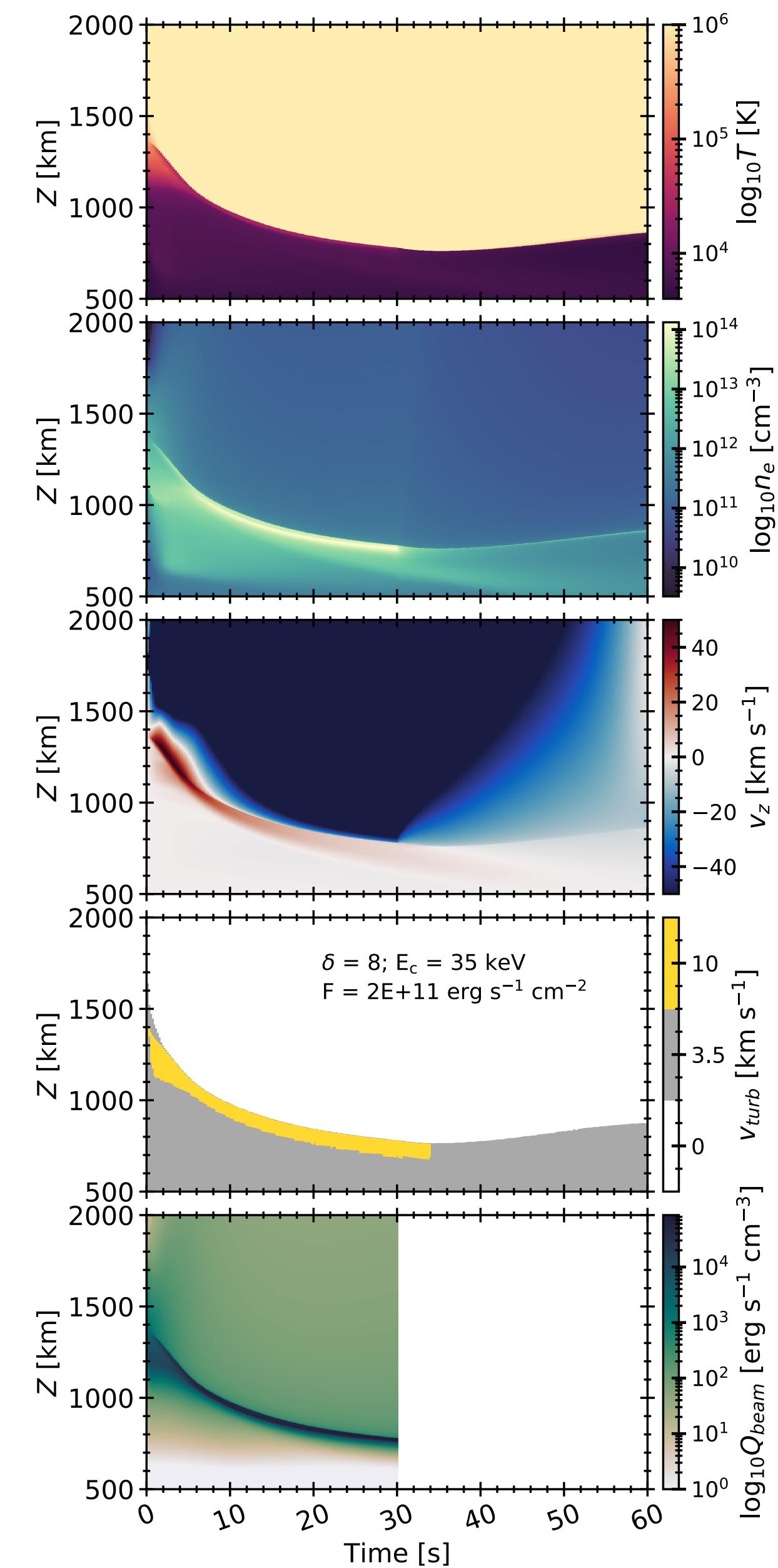
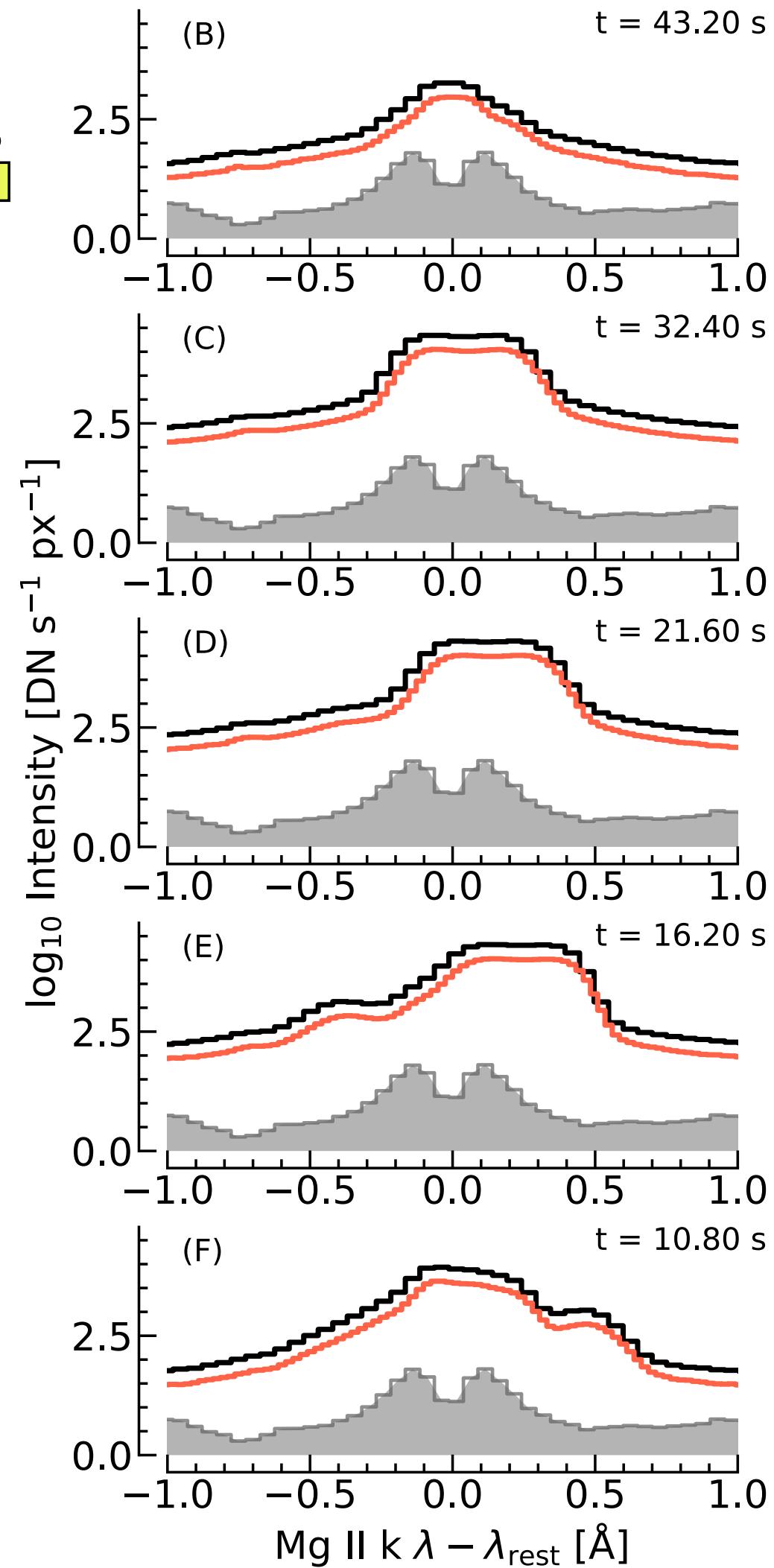
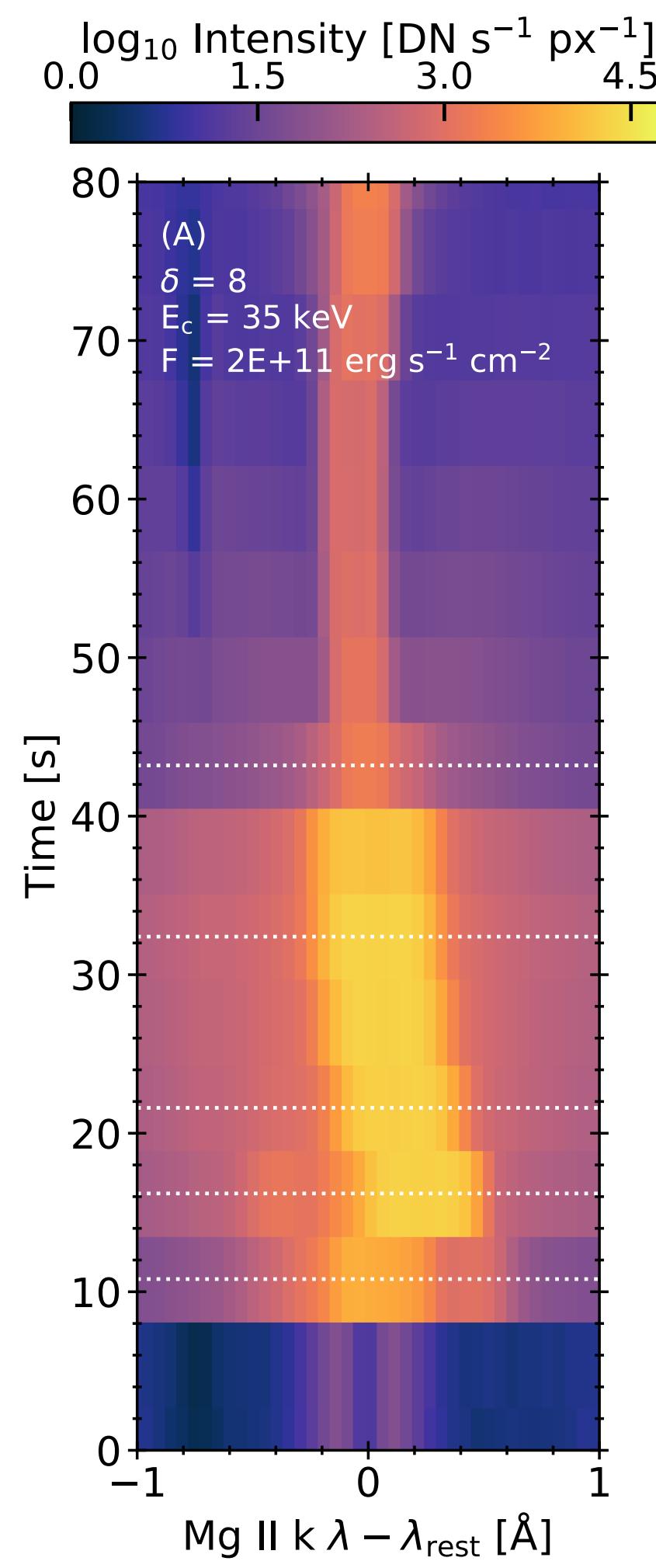
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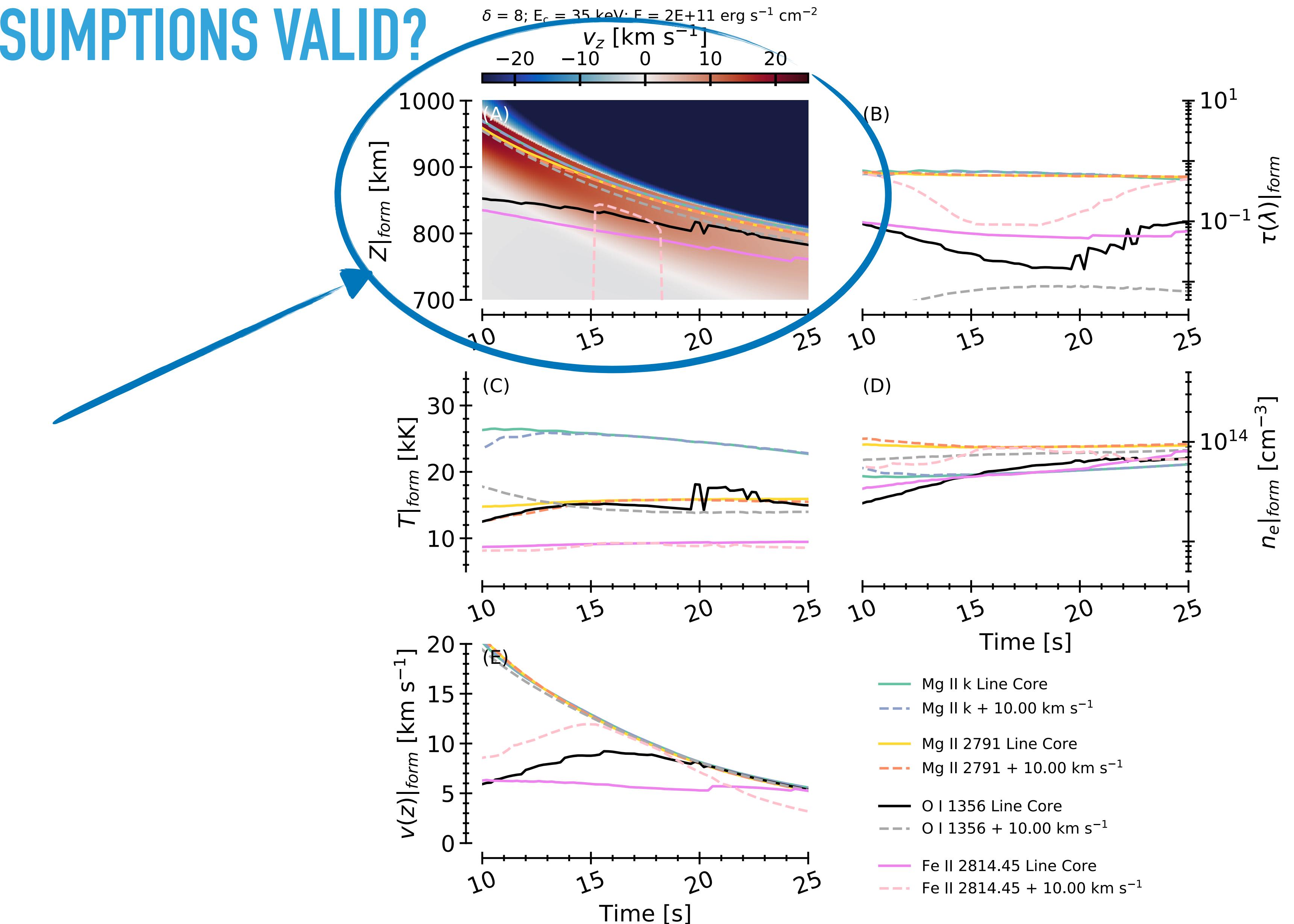
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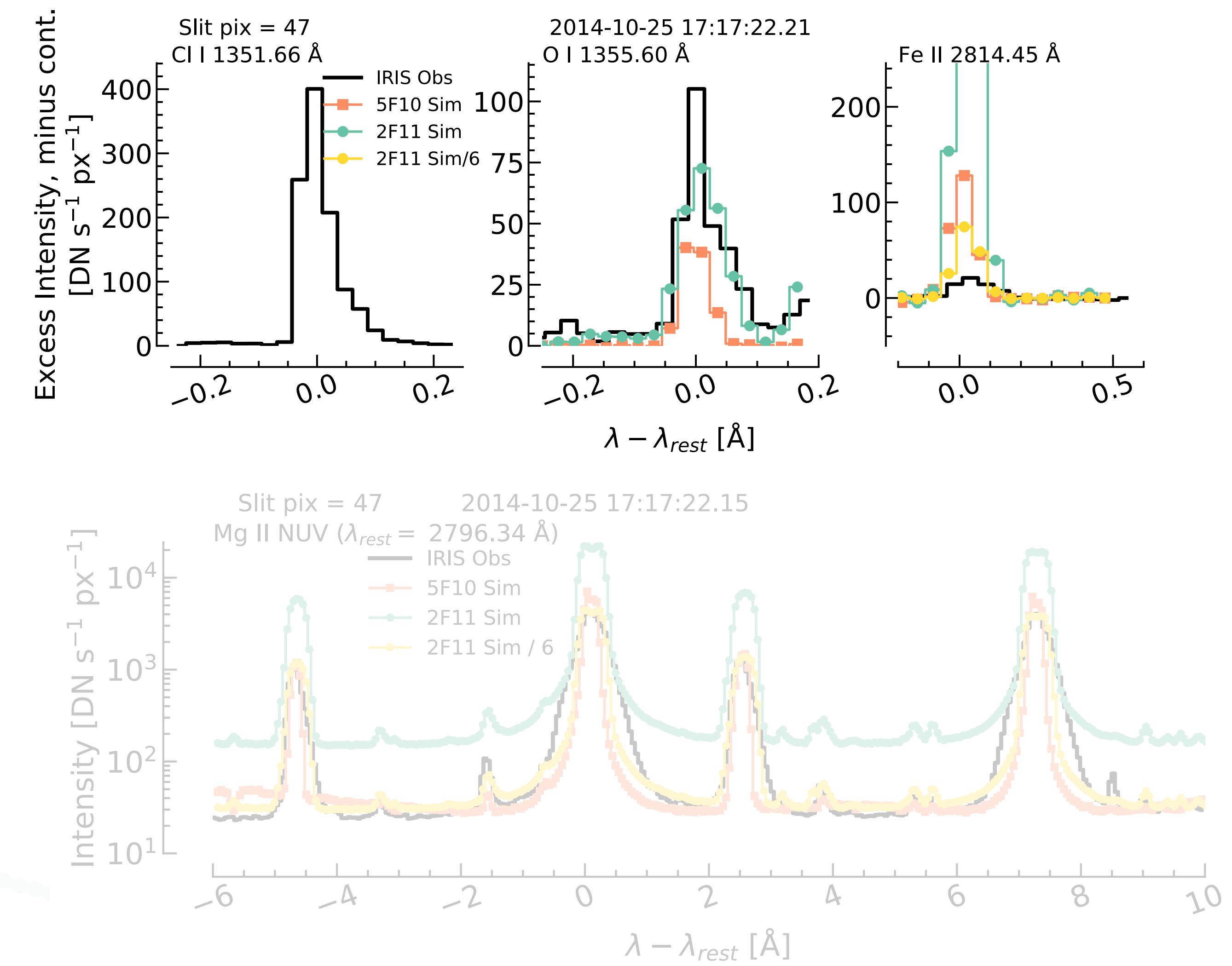
ARE OUR ANALYSIS ASSUMPTIONS VALID?

- ▶ O I line core and shifted component optically thin throughout.
- ▶ Fe II shifted component optically thin throughout, but core does suffer from some optical depth effect.
- ▶ Red wing components of both lines form nearby Mg II h & k lines, within the chromospheric condensation.



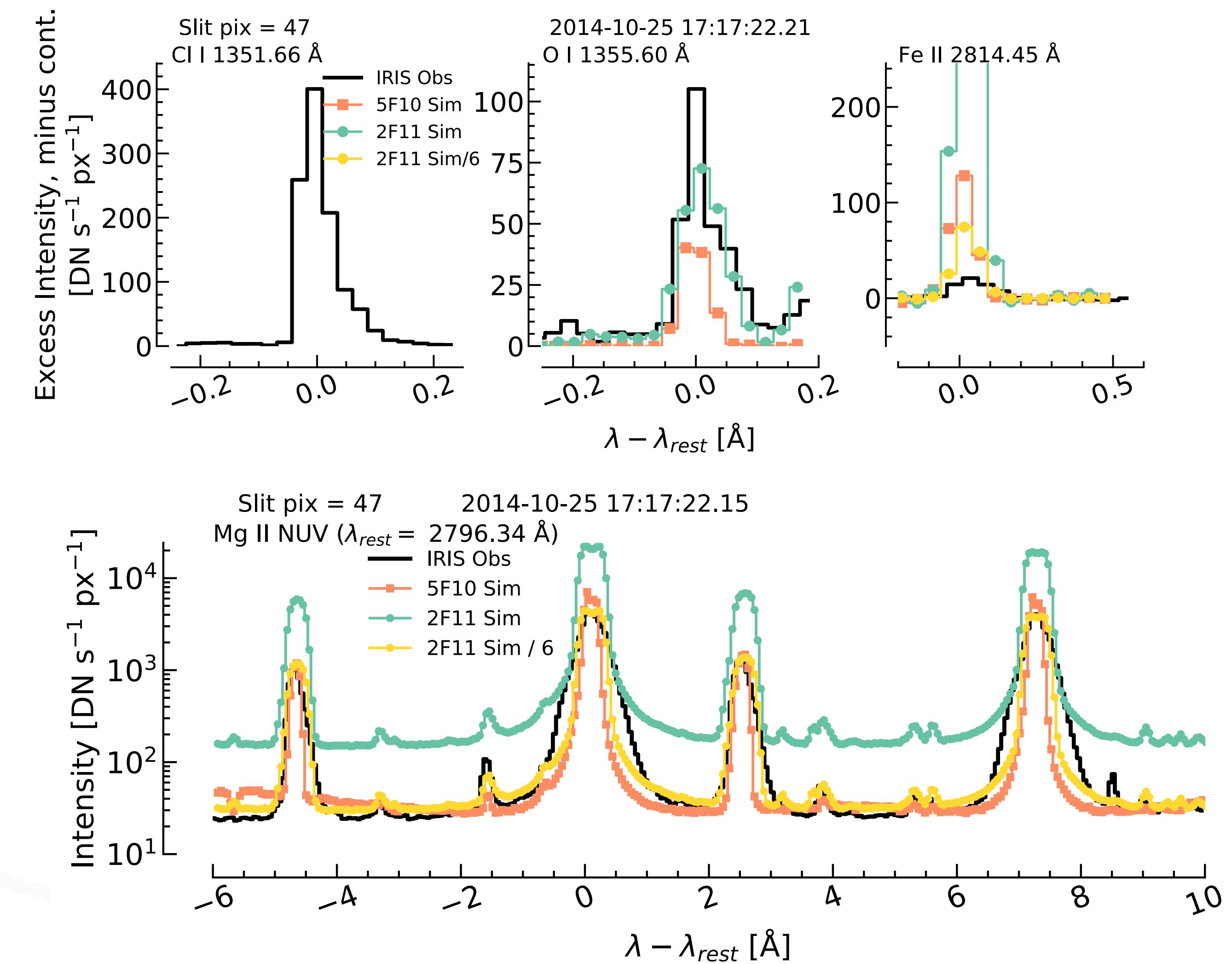
O I MODEL-DATA COMPARISON

- ▶ O I synthesis is pretty good!
- ▶ Fe II line core is too intense.
- ▶ Mg II NUV spectra's general shape is good, but too intense (x6).
- ▶ Mg II Line wings still too narrow, but we can't increase microturbulence deeper since we would see that in the O I line core.



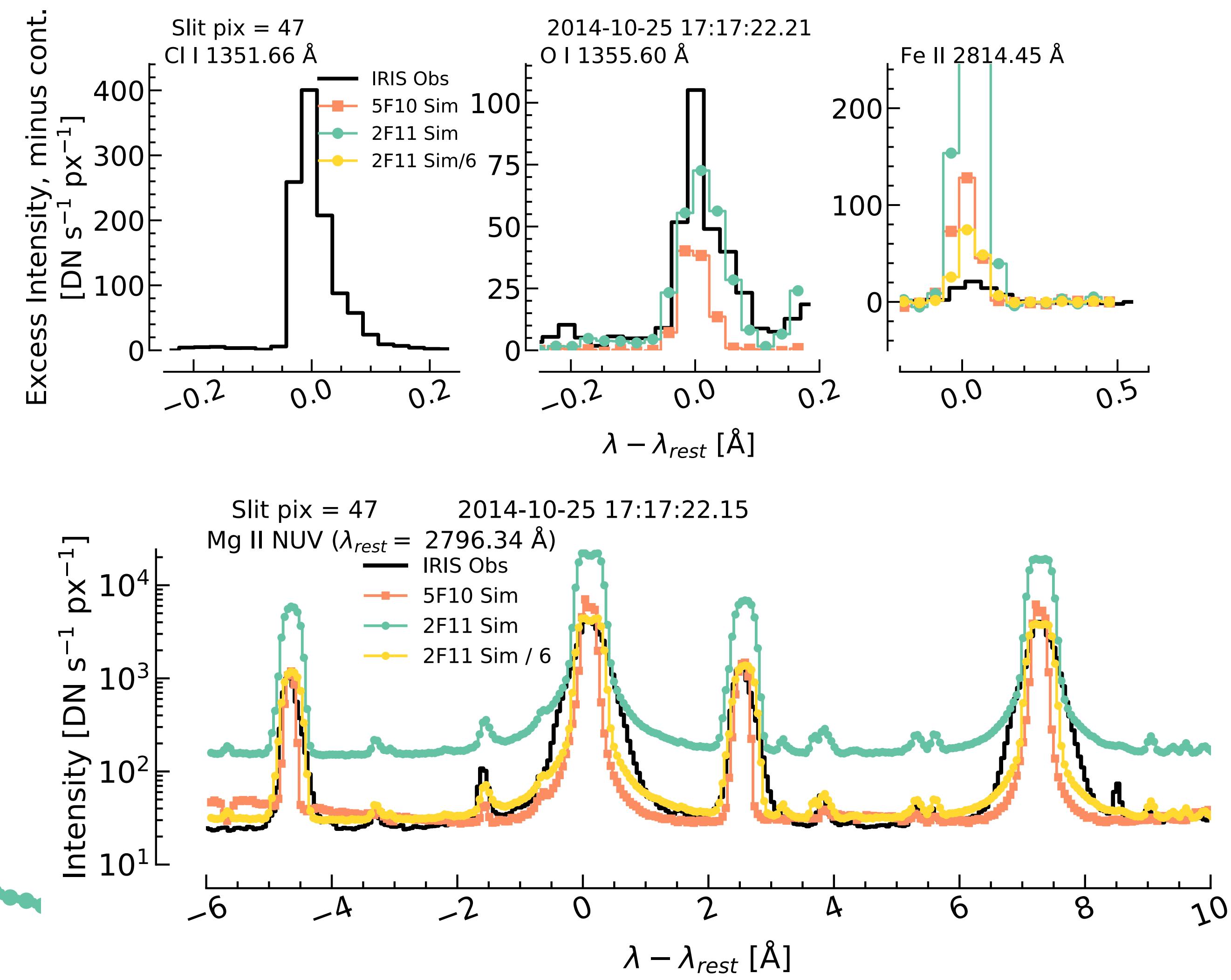
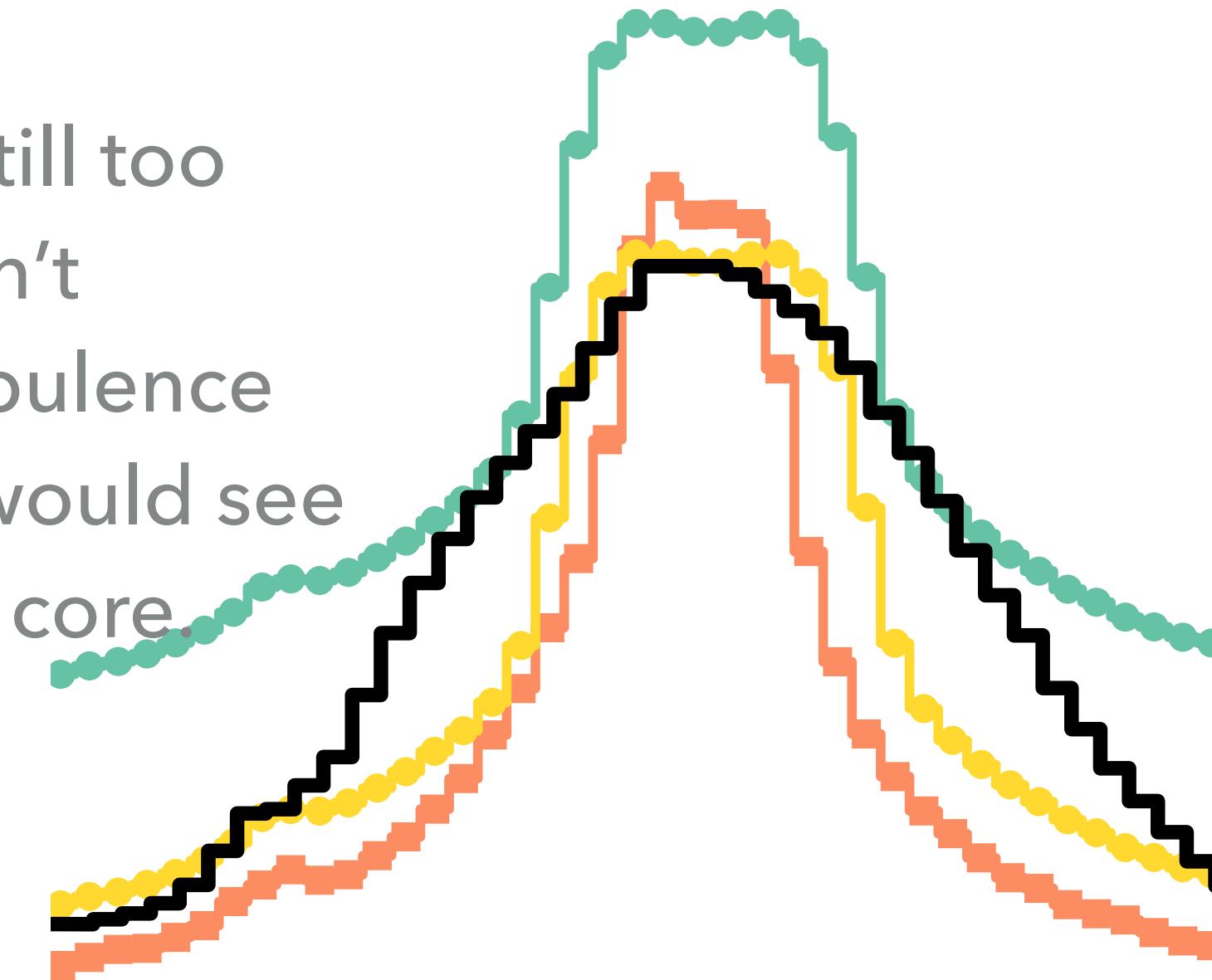
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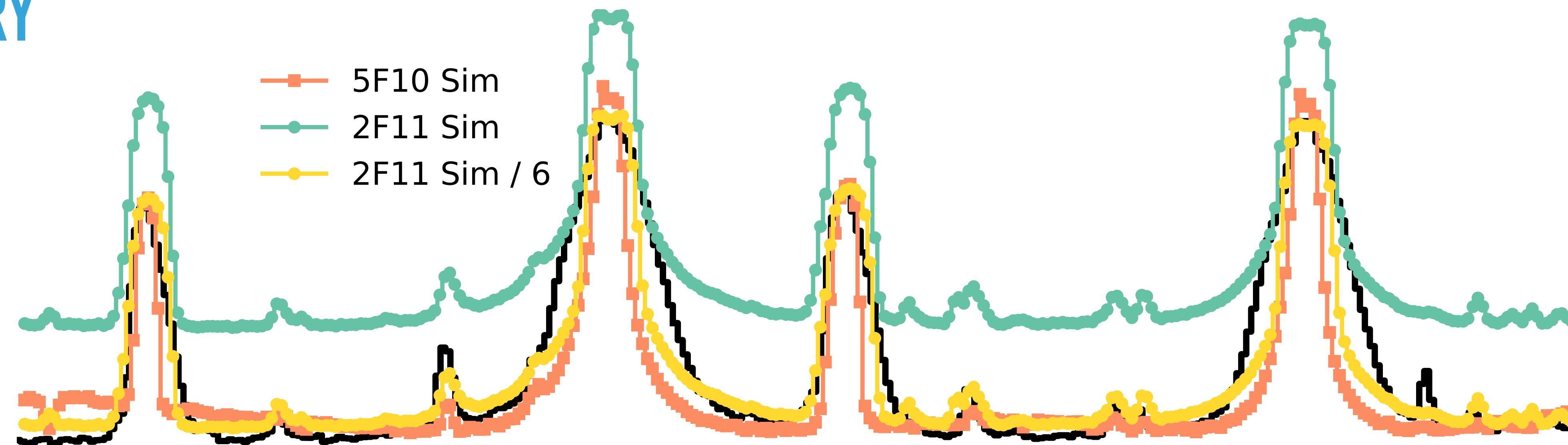


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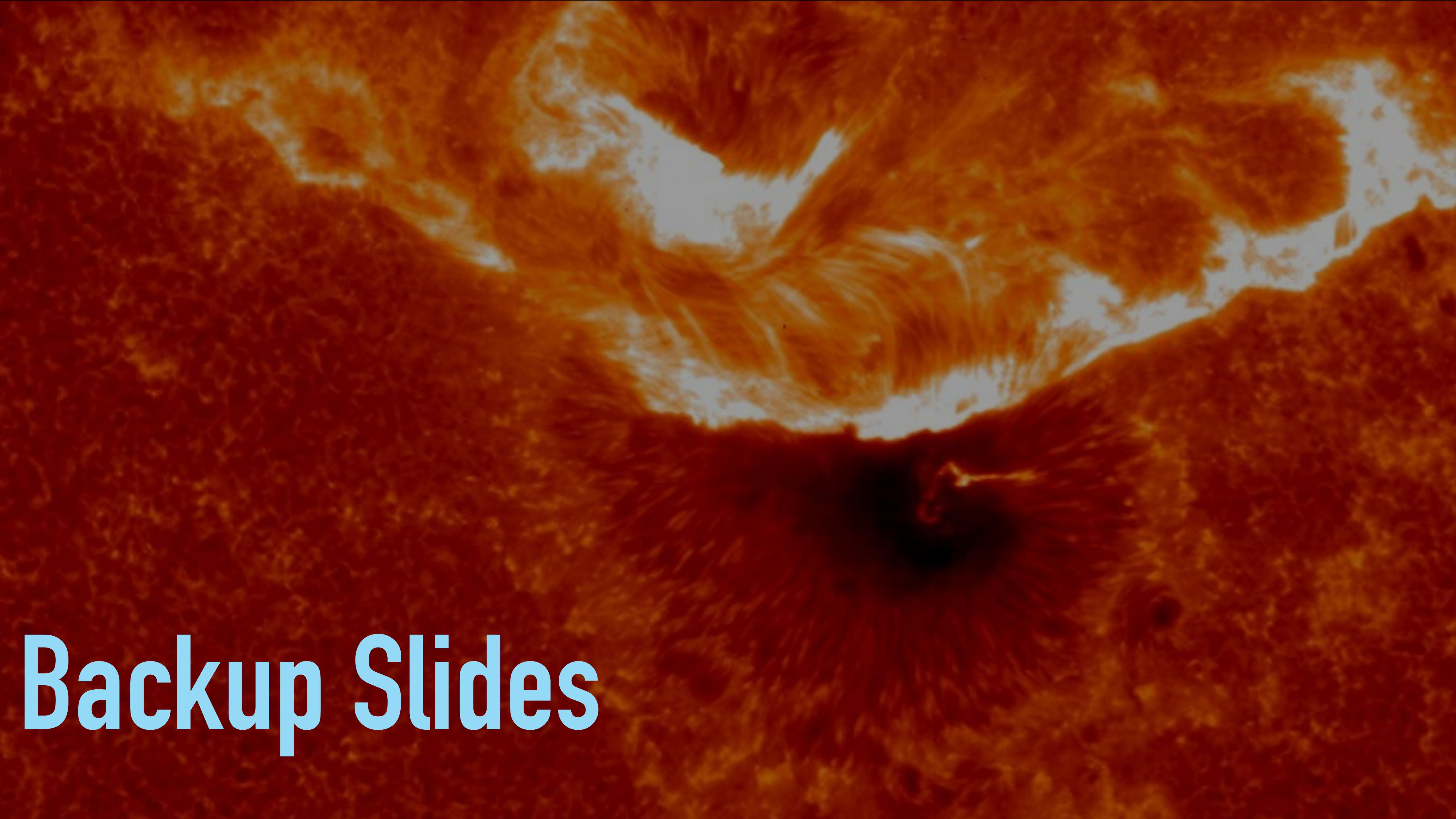
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SUMMARY



- ▶ Characterised upper limits of microturbulence in a chromospheric flare ribbon.
- ▶ O I, Cl I, and Fe II all exhibited red wing components, with nonthermal widths ~ 10 km/s. Stationary components showed only very modest nonthermal widths, and slight blue/red shifts.
- ▶ Lifetimes of the initial brightening/red wing components were 30-90s.
- ▶ Data inspired RHD modelling revealed a reasonably good model-data comparison, **apart from Mg II line widths**.
- ▶ Exploring missing ingredients from our models: nonthermal effects on Mg II formation and likely missing energy deposition at greater depths.



Backup Slides

