University of Glasgow

UKRI Science and Technology Facilities Council

Flare Kernels May Be Smaller Than You Think: The Radiative Effects of Flares on the Chromosphere: Results from 2D Modelling

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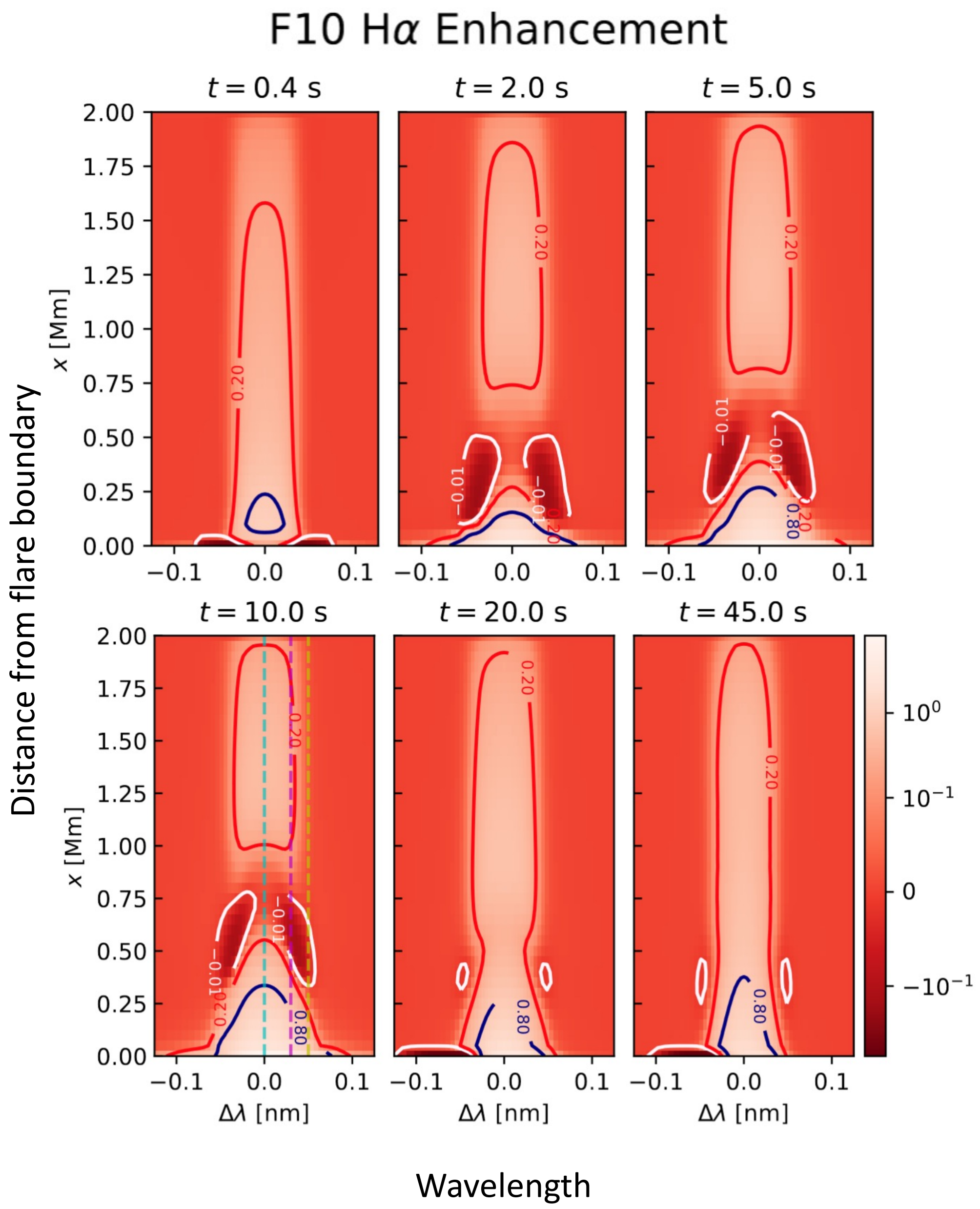
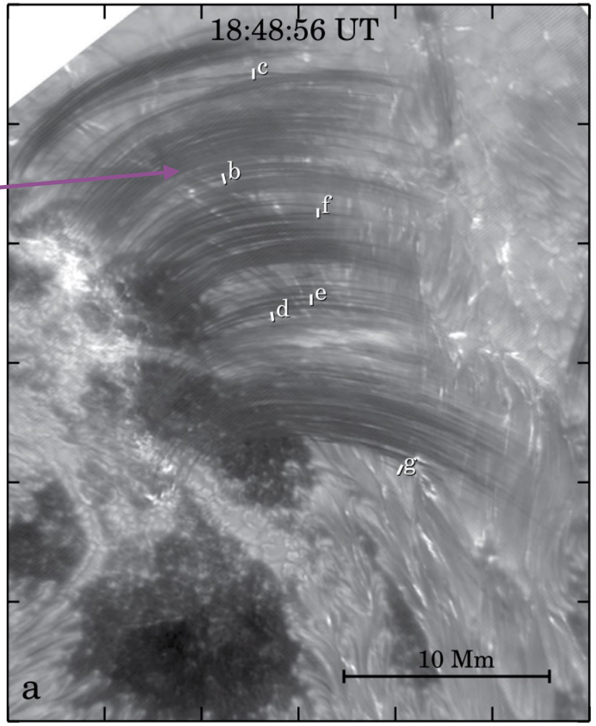
Takeaways

- Radiation from a relatively weak flare can significantly affect atomic level populations and outgoing intensity over 1 Mm (horizontally) away.
- The plane-parallel approximation used in flare-modelling may lead to:
  - Incorrect evaluation of spectral line shapes.
  - Significant errors in radiative losses, and therefore in the plasma evolution.
- Lots more exciting work to be done!

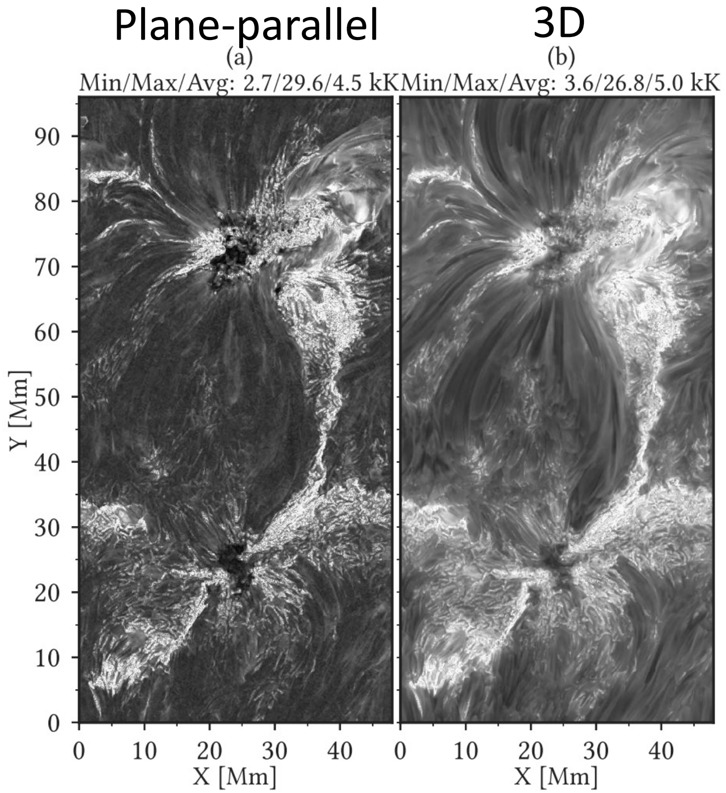


The Importance of Dimensionality

- World is (at-least!) three-dimensional.
    - Current flare models are not (field-aligned 1D).
- Models assume variations stratified along magnetic field lines.
    - Conduction/particle flux suppressed across these.
    - Light is not.
- Individual flare kernels are small:
    - Flux tube bundles 10s-100s km diameter.
- Anisotropies in plasma:
    - Flares produce huge variations in plasma parameters *and* the radiation field.



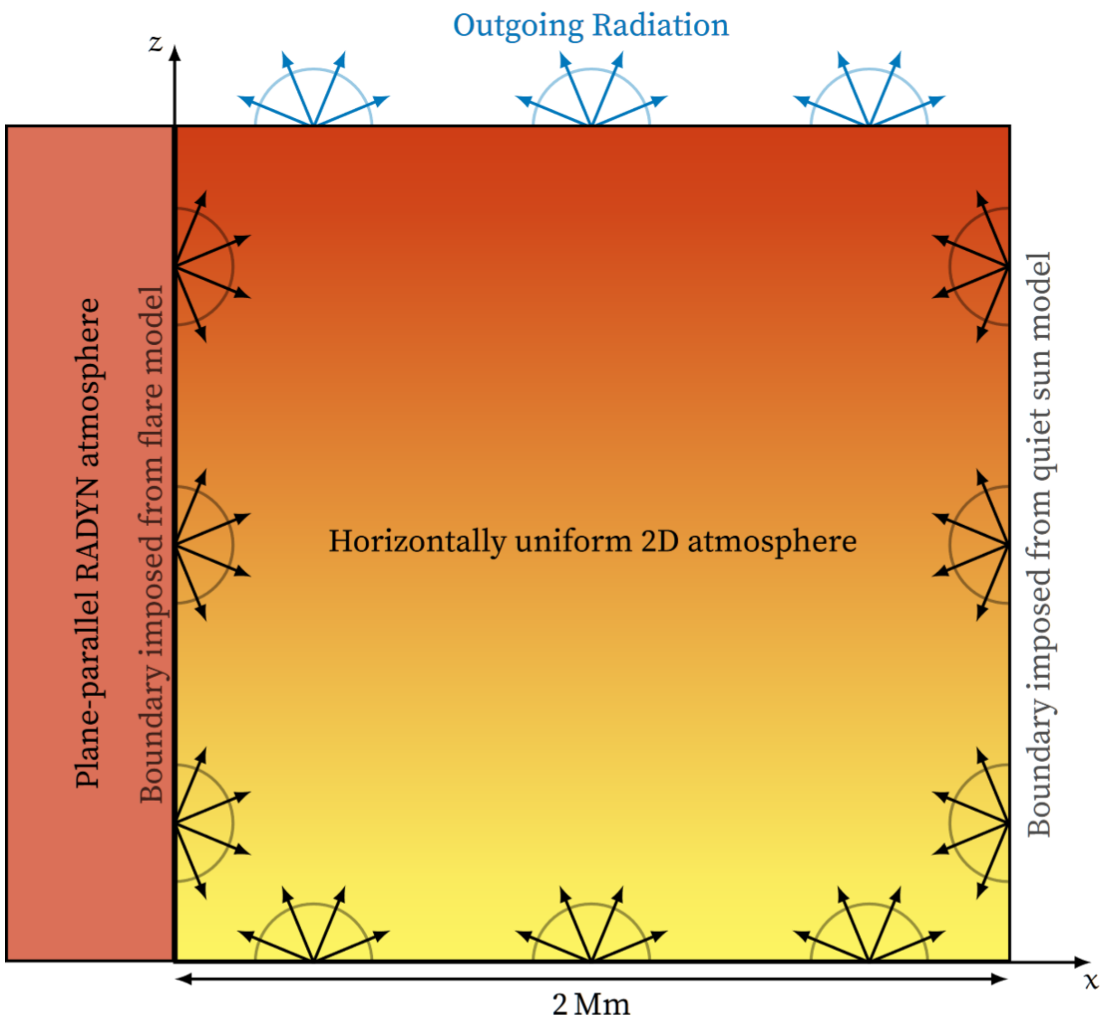
NST/BBSO, Jing et al. (2016)



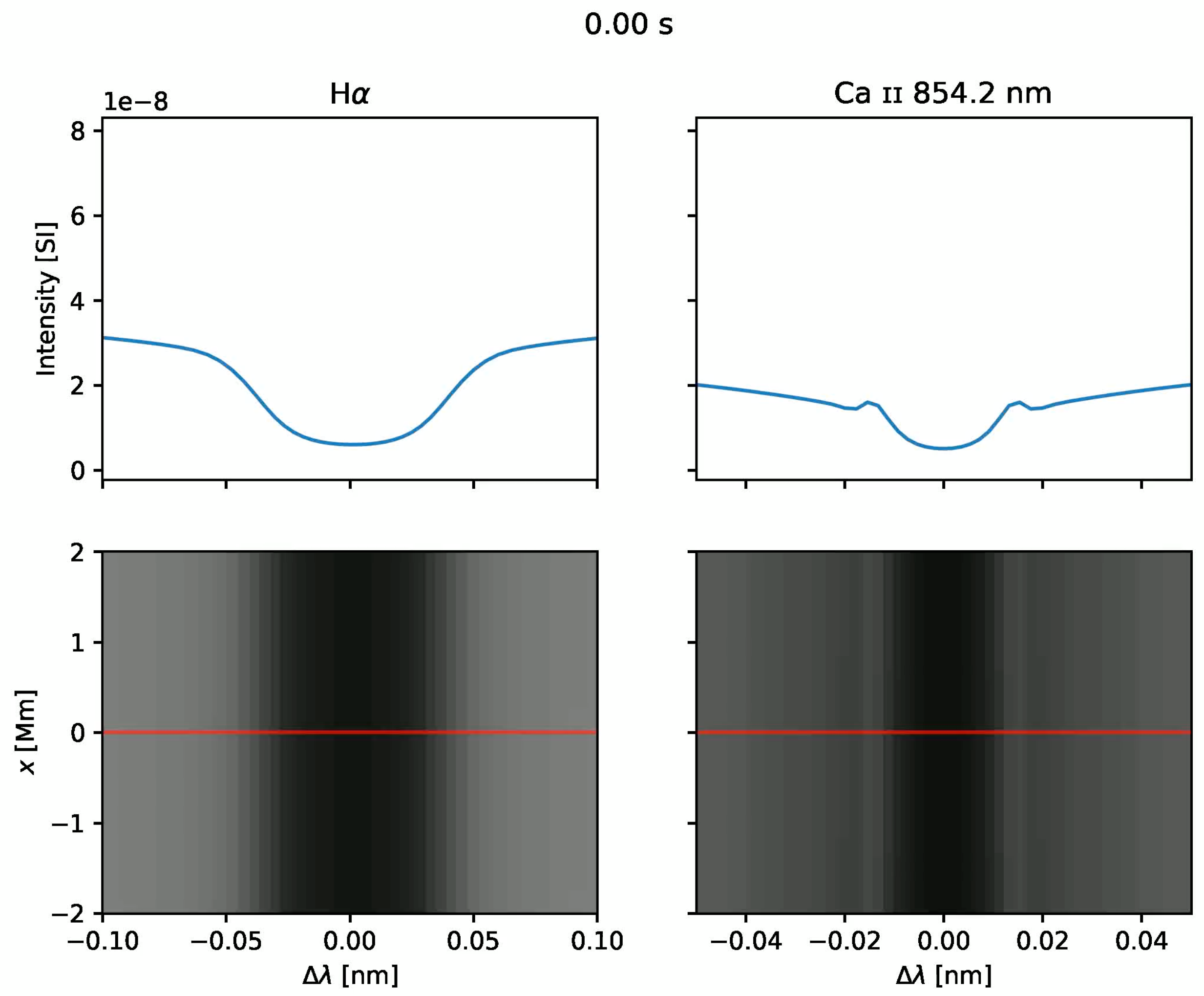
Bjørgen et al. (2019)

Model 1

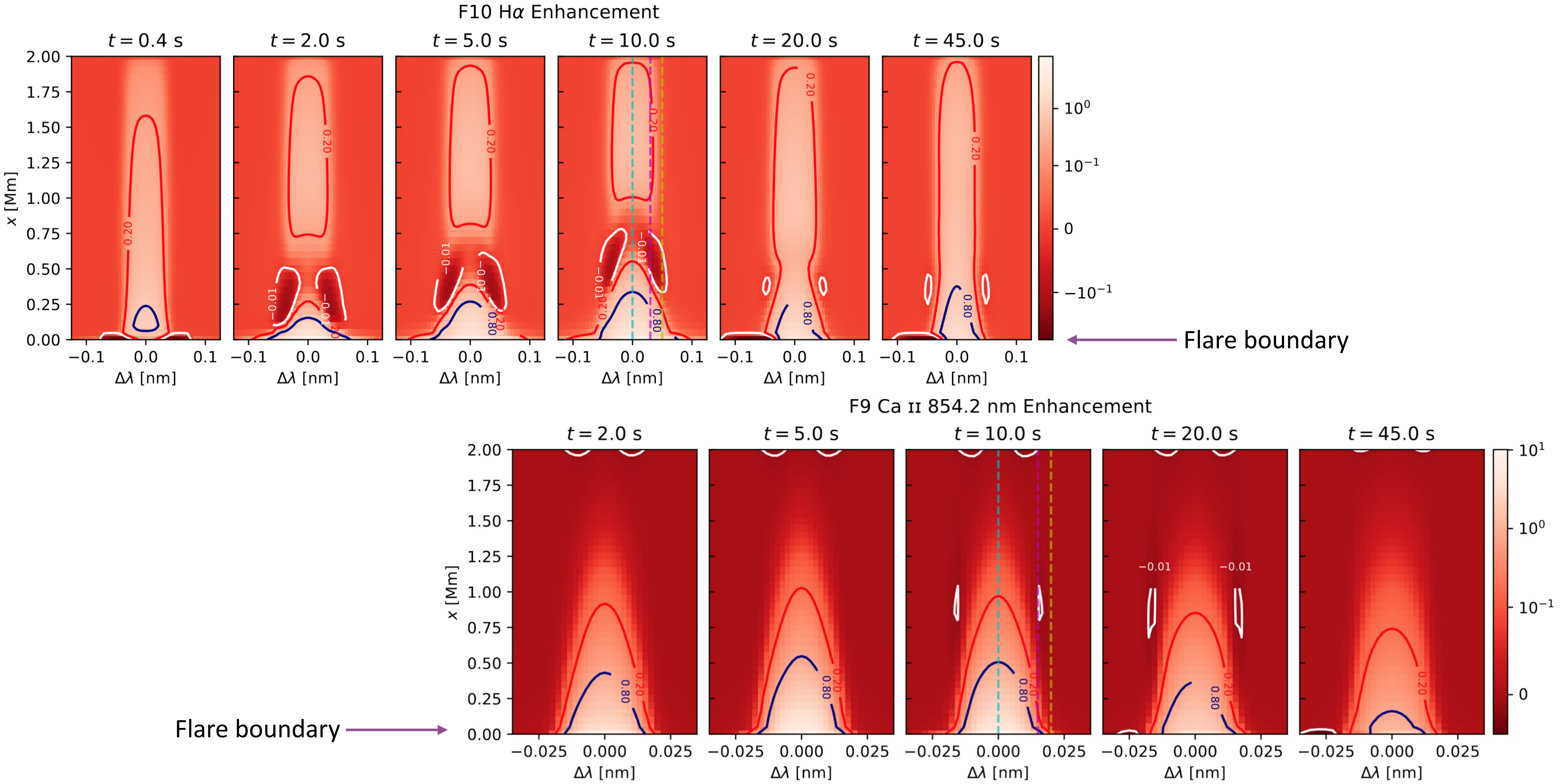
- What effect does a flare's radiation field have on adjacent chromosphere?
  - 2.5D modelling is equivalent to a flare ribbon (into/out of page)
- 2 Irradiating RADYN models (reprocessed with *Lightweaver*).
  - $F = 10^9, 10^{10}$ erg/cm²/s for 10 s
  - $\delta = 5$
  - $E_c = 20$ keV
- Hydrogen ionization is *very* time-dependent (Carlsson & Stein 2002, Leenaarts et al 2007)
  - Reprocess at RADYN's timestep over the full 2D domain.
  - Full CRD NLTE treatment for 6-level H and Ca.
  - Charge-conservation.



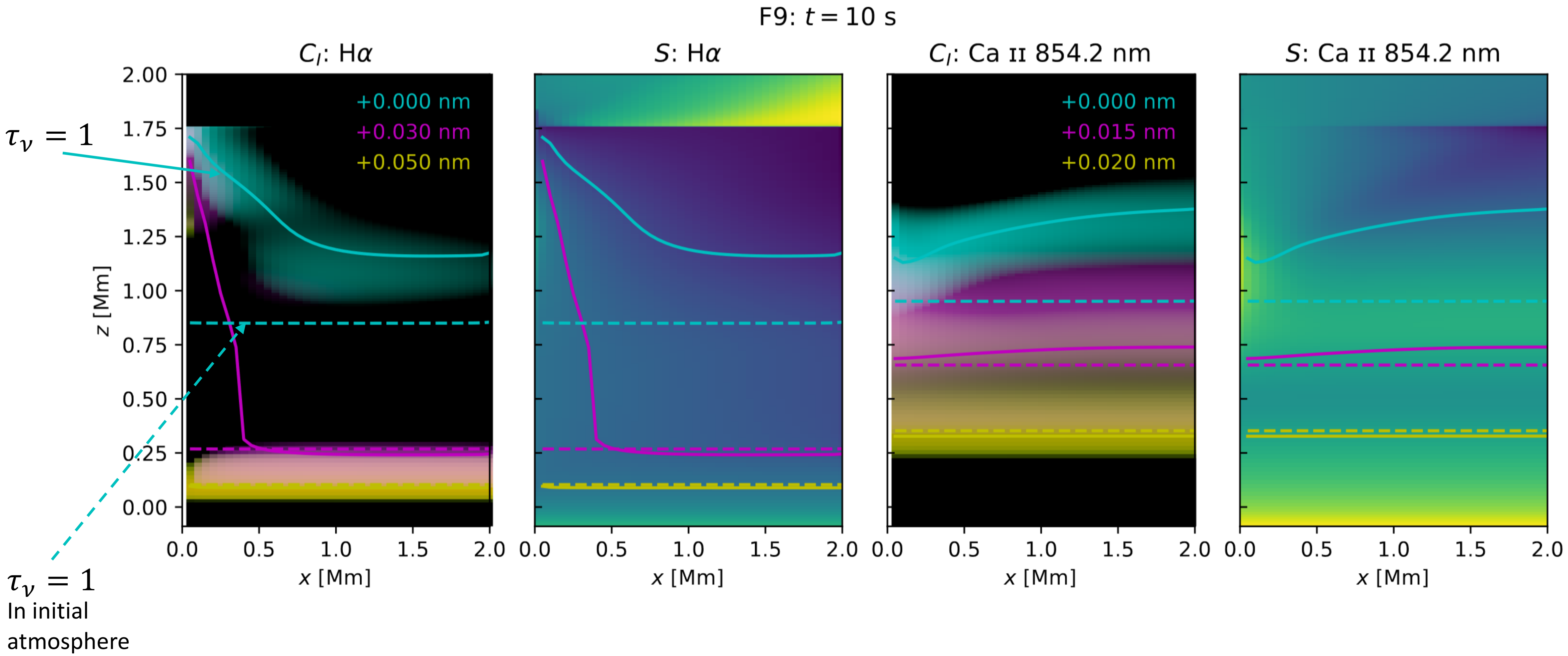
Model 1 F10 Results (Slit Spectrograph)



Line Enhancements



Where is this coming from? (Contribution Functions)



Method similar to COCOPLOT of Druett et al (2021), contribution function integrated over small Gaussian kernels in wavelength.

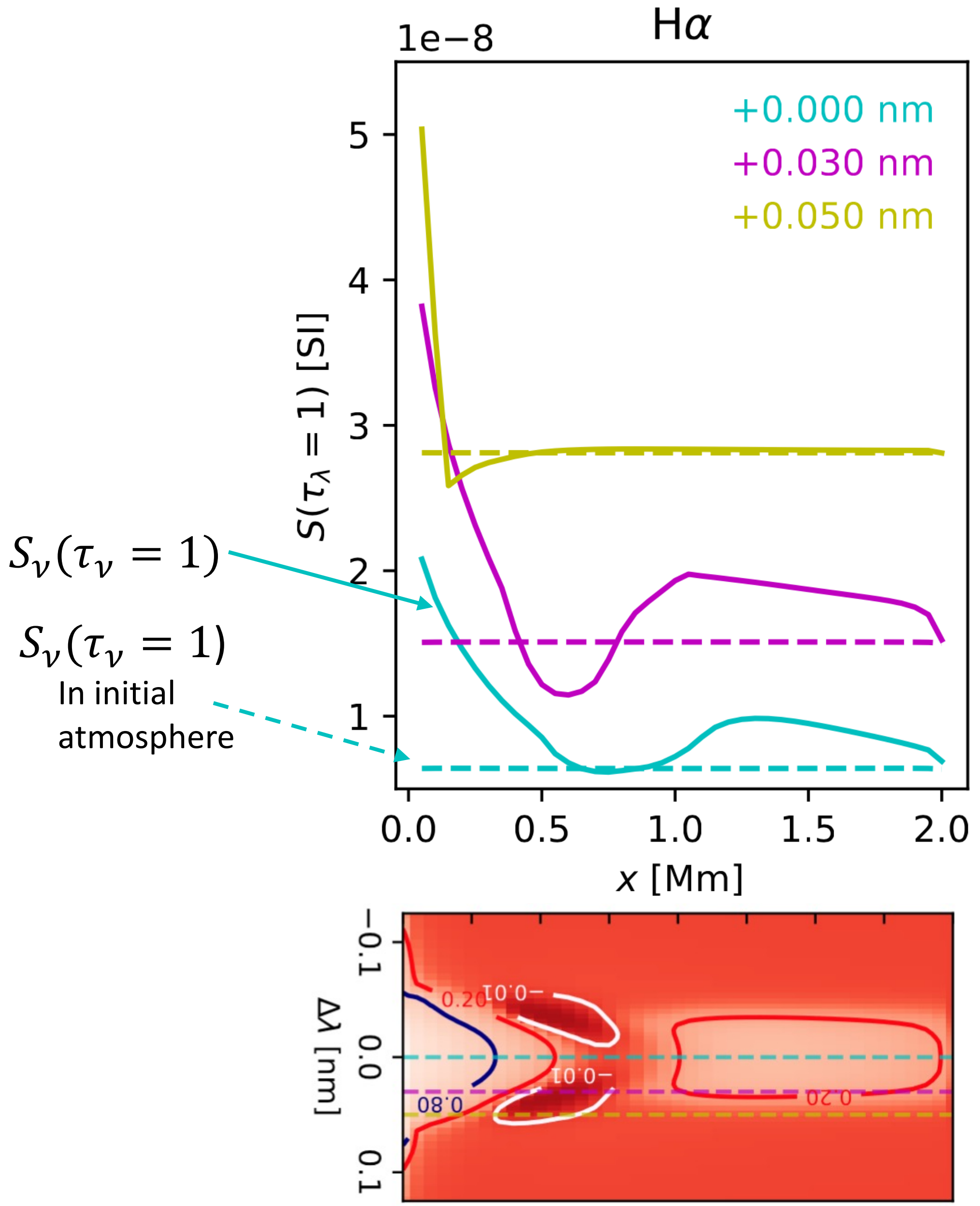
Line formation regions can change by over 1 Mm from purely radiative influence!

Is this helpful?

- Let’s get a trusty tool from the RT toolbox, the Eddington-Barbier relation:

$$I_\nu(\tau_\nu = 0, \mu = 1) \approx S_\nu(\tau_\nu = 1)$$

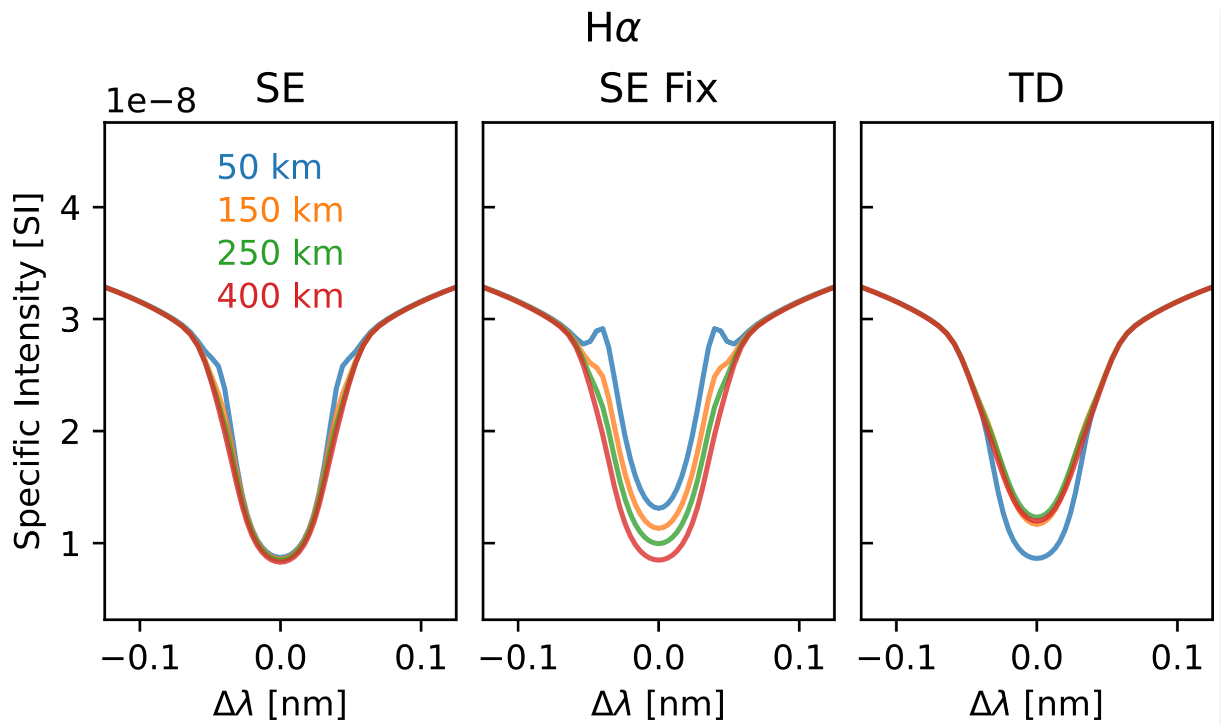
- Looks pretty good for Hα.
- But fails for Ca II 854.2 nm.
- Compare difference between dashed and solid lines with enhancement cuts in lower panel.

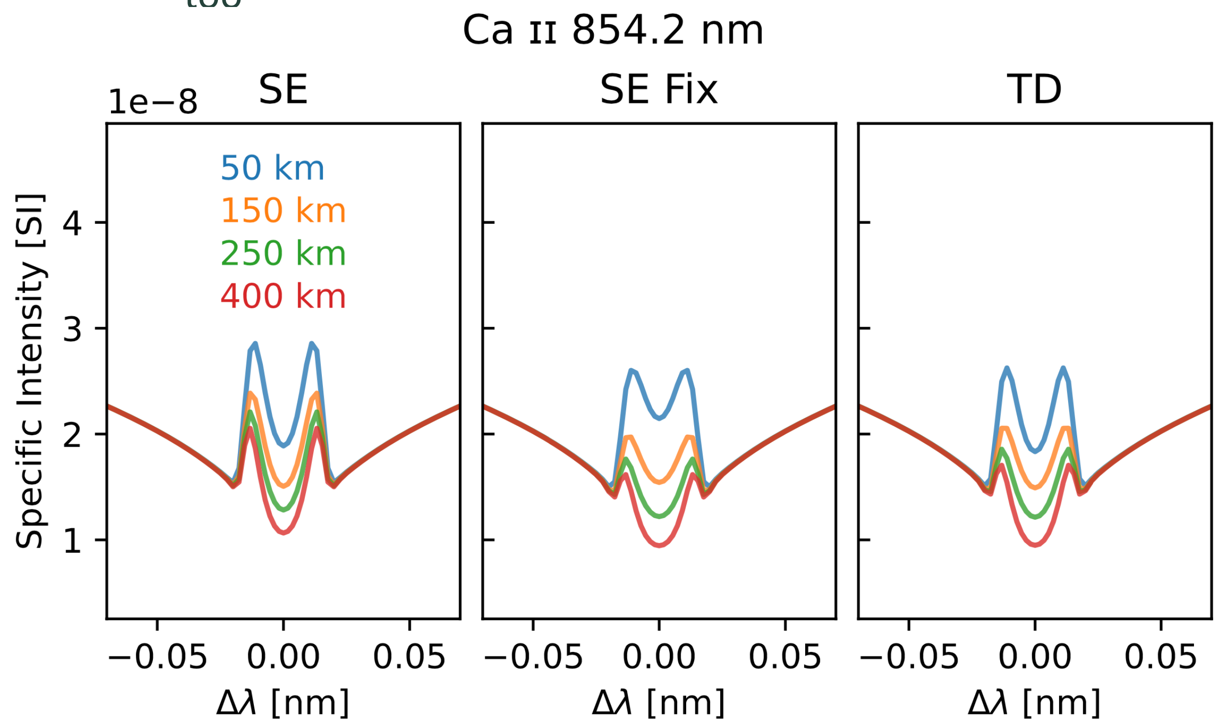


F10 Model
$t = 10$ s

Was time-dependence really necessary?

- Yes. ($t = 15$ s shown here)
- Charge-conservation is necessary, but not sufficient for Hα
- Can we get the electron density for Ca ɪɪ 854.2 nm without it? (Sollum method?)
- Statistical equilibrium likely ~sufficient for Ca ɪɪ too

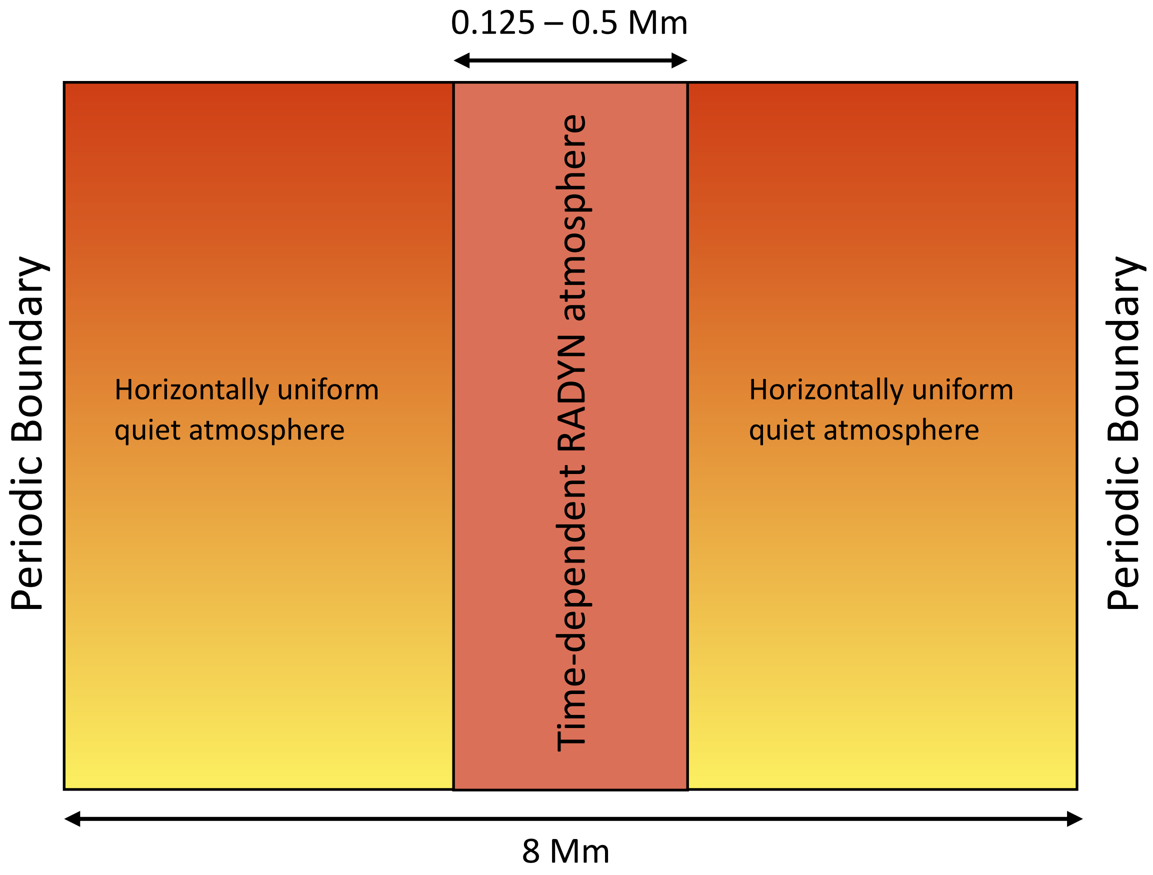




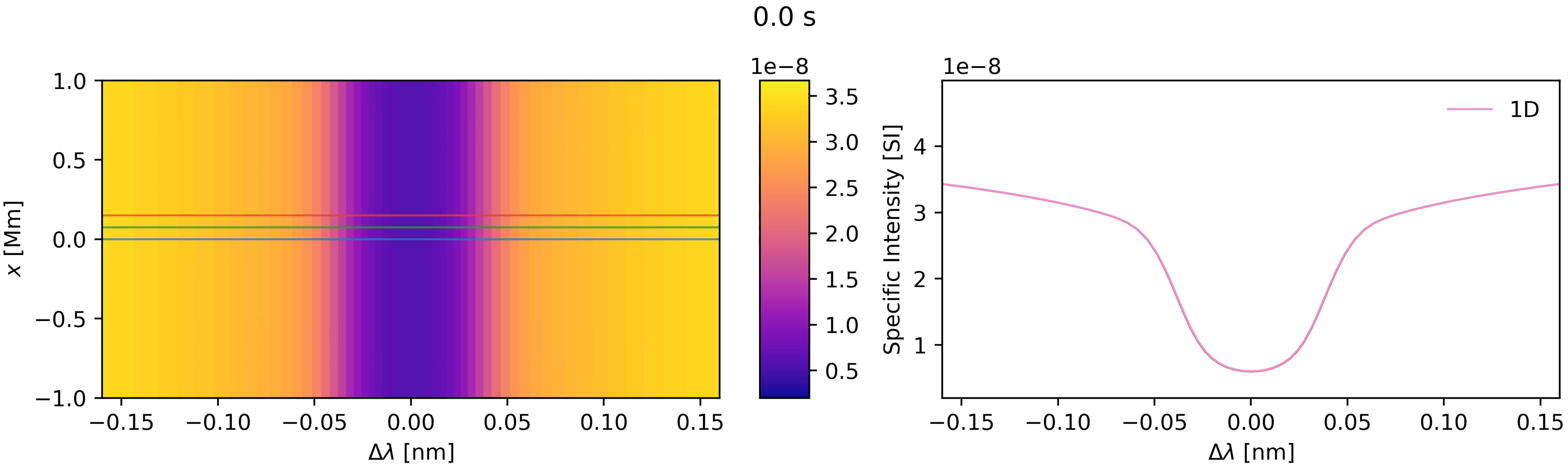
Another model?

Okay, but was the plane-parallel treatment of the flare boundary reasonable?

- I started by saying that flare kernels are small…
- Does this affect the outgoing line-profiles?
  - Idea that plane-parallel slabs have infinite extent is clearly unphysical.
- New Model!
- Put the flare inside the slab, but still hold "quiet" slab properties constant.
  - Different widths: 0.125 – 0.5 Mm
- Periodic boundary conditions in x

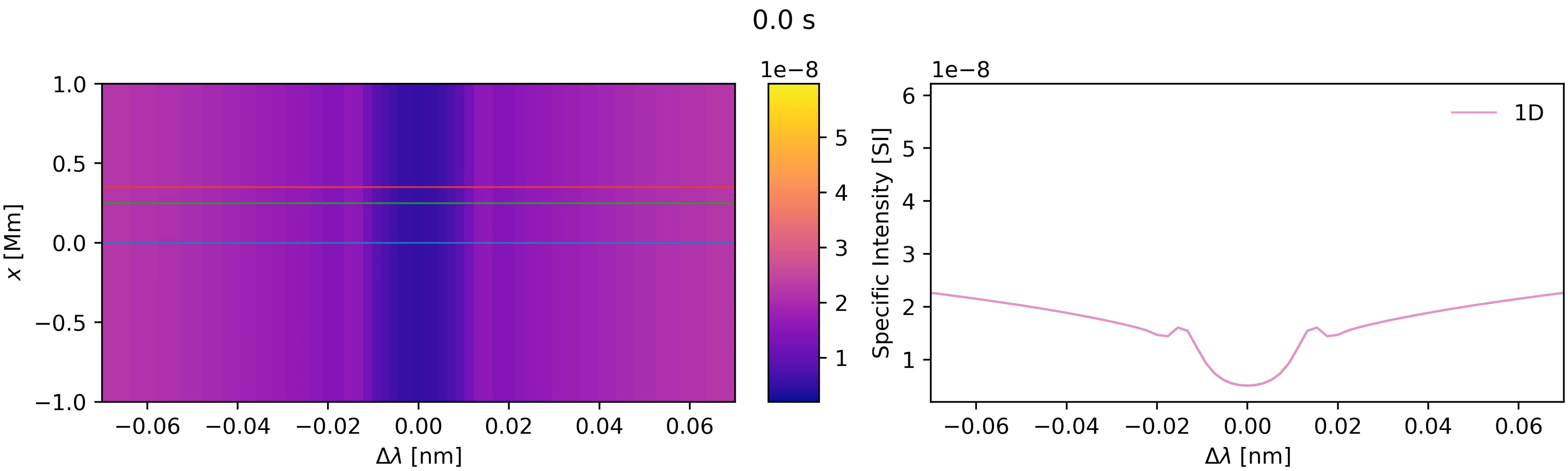


Hα Line Profiles, Kernel: 0.125 Mm



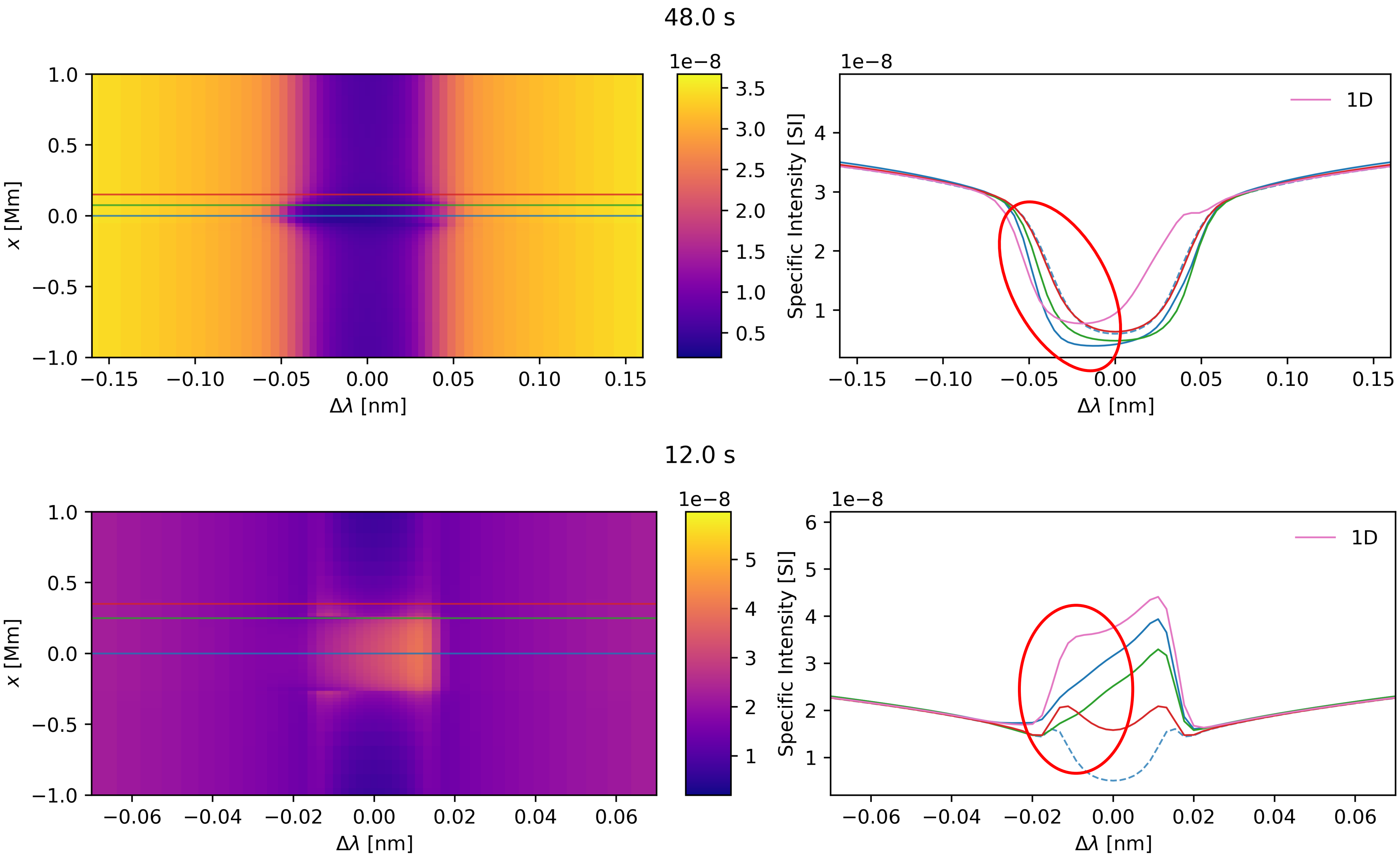
Intensity along three cuts (red, green, blue) and equivalent plane-parallel model.

Ca II 854.2 nm Line Profiles, Kernel: 0.5 Mm

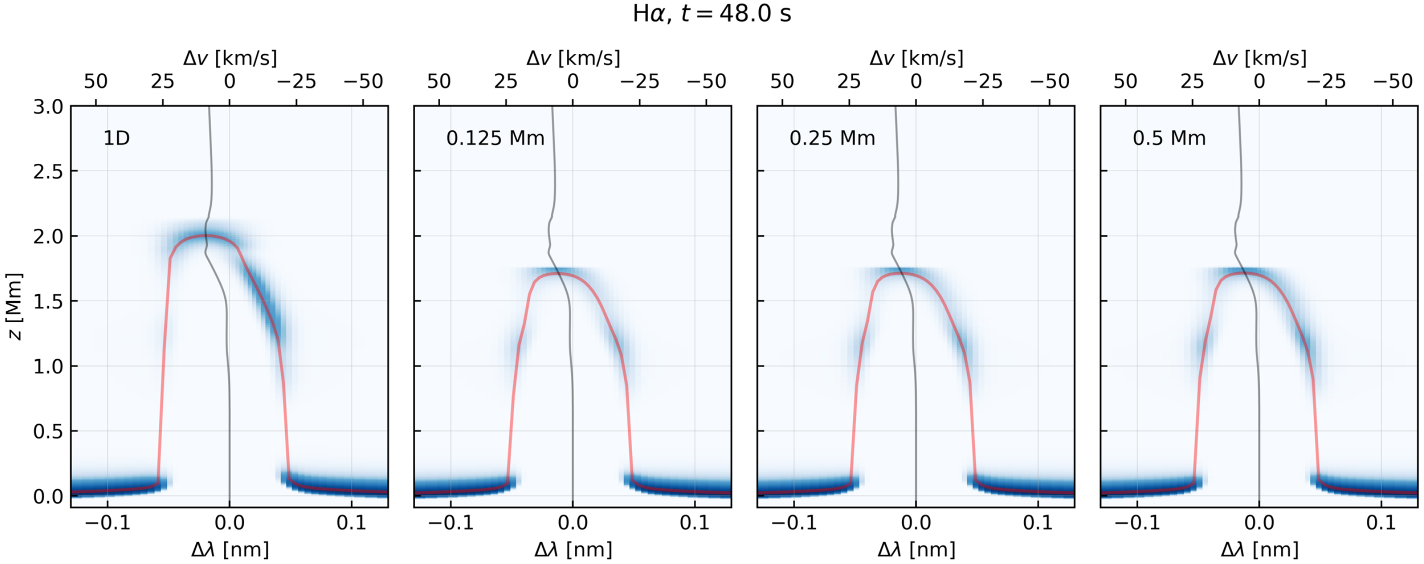


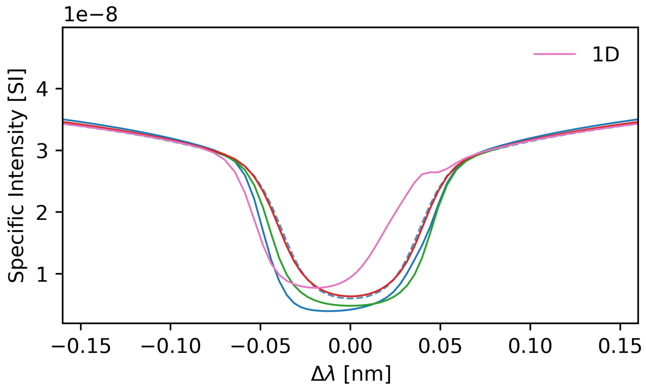
Intensity along three cuts (red, green, blue) and equivalent plane-parallel model.

Closer, but some key differences.

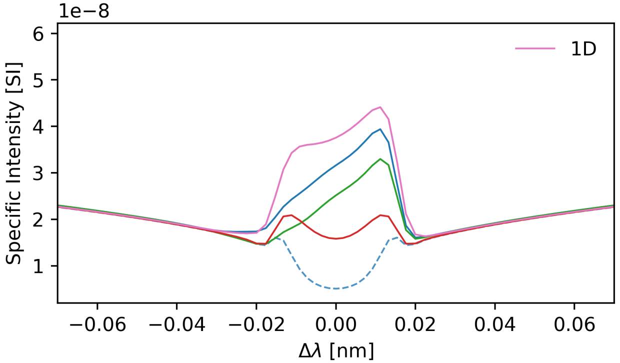


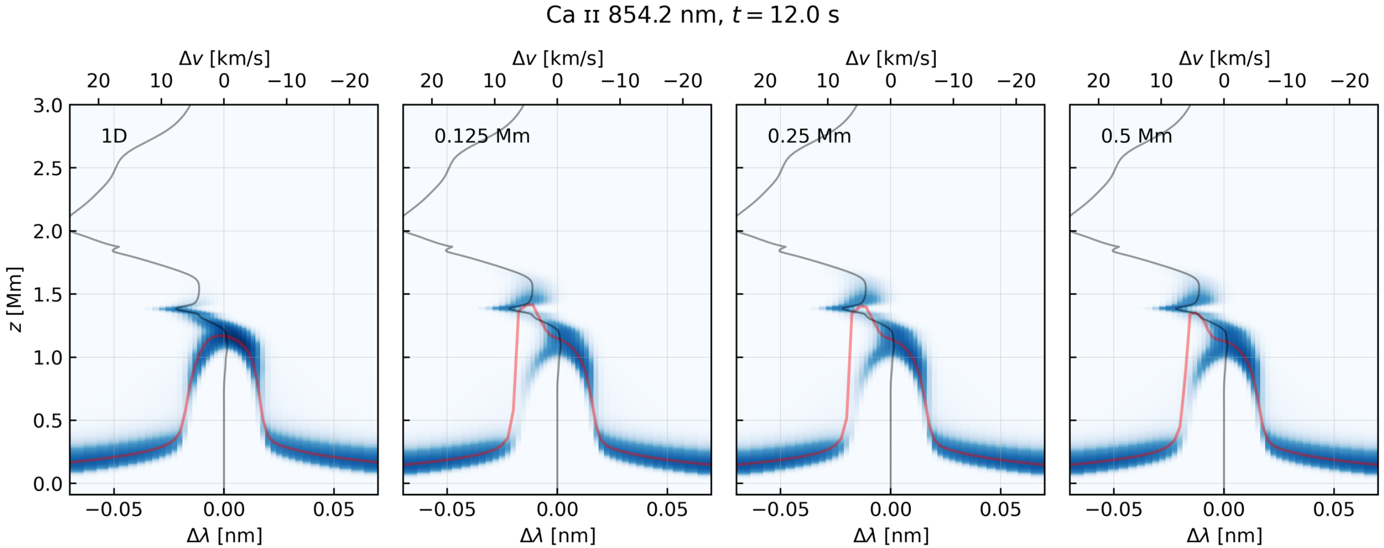
Let’s look at the contribution functions



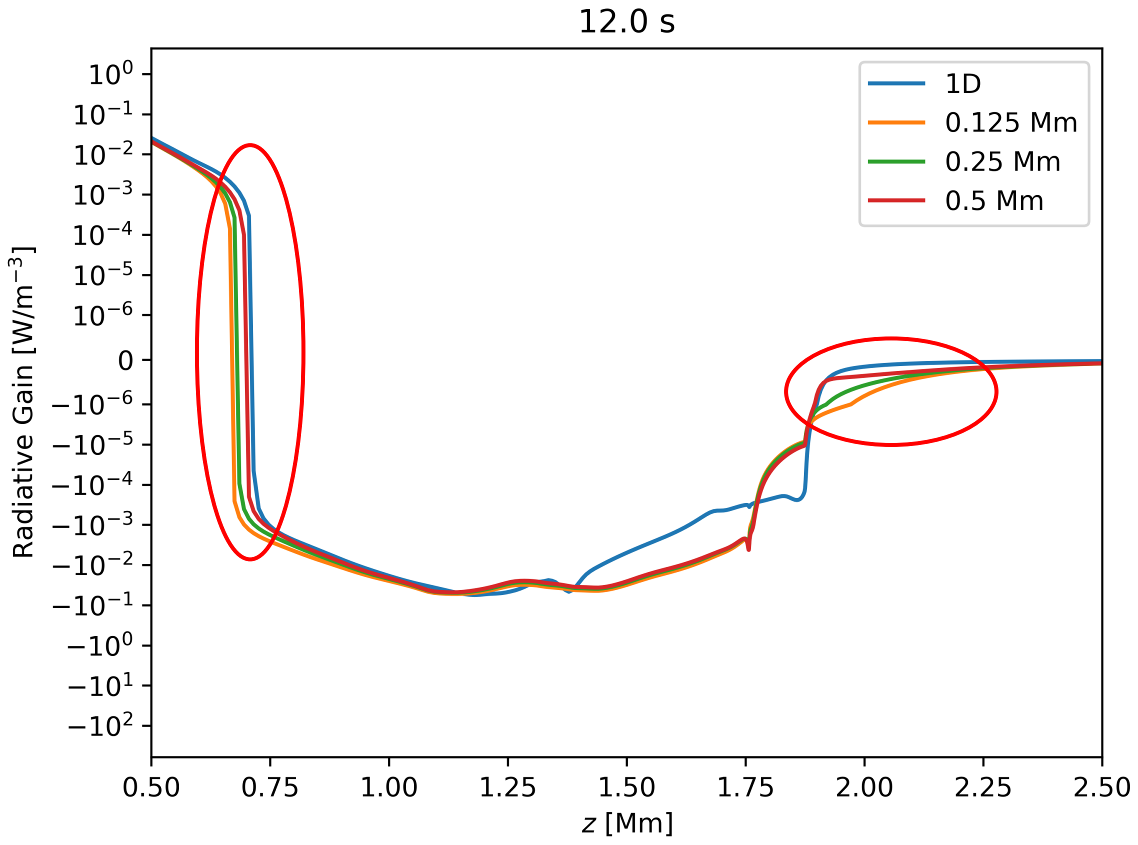


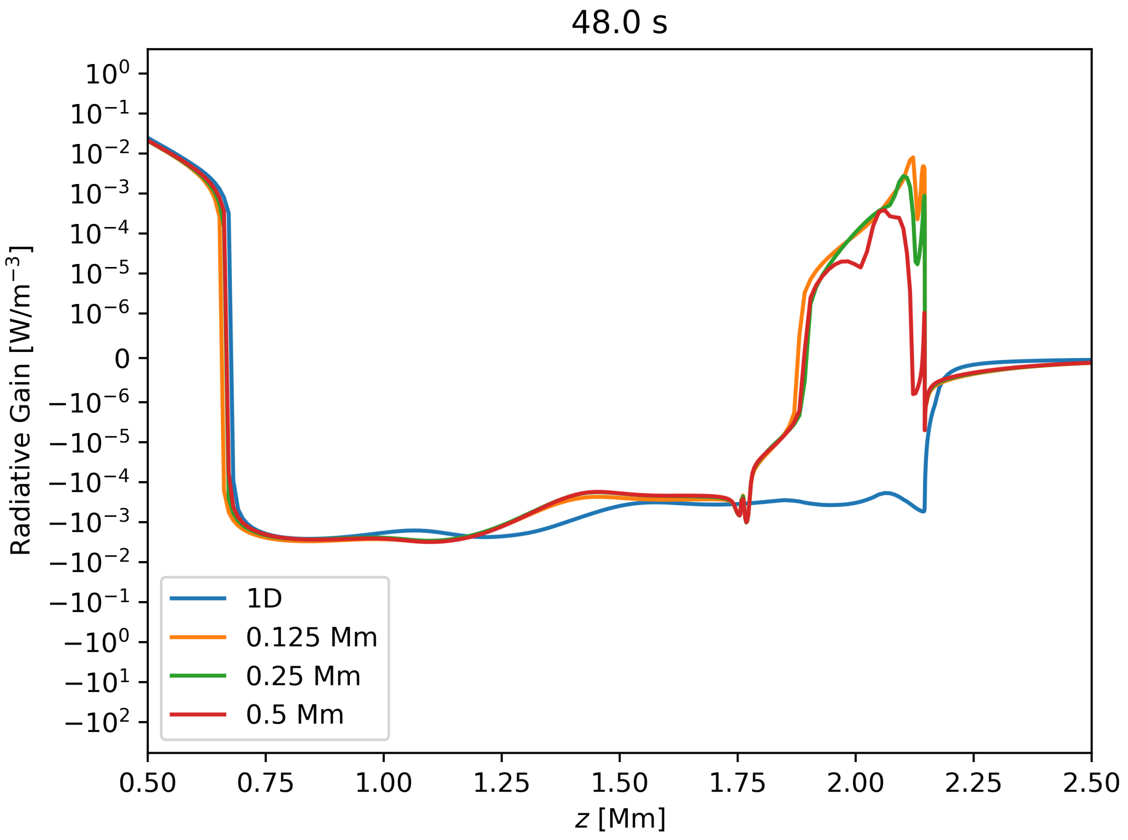
Line formation heights
are clearly different!





Radiative Losses





Conclusions

- Still lots to be done, increasing the dimensionality of radiative transfer for flares.
  - It matters!
- Radiation has far-reaching effects (not constrained by magnetic field)
- Enhancement isn't uniform over wavelength (filling factors…)
- Looking now at IRIS transition region lines; effects are present, but different… watch this space.

- Field-aligned flare models likely overestimate the intensity, line shape is strongly affected.
- Lines form in different regions: losses are affected!
- Is there an *ad hoc* way to account for this?

Thanks for your attention!
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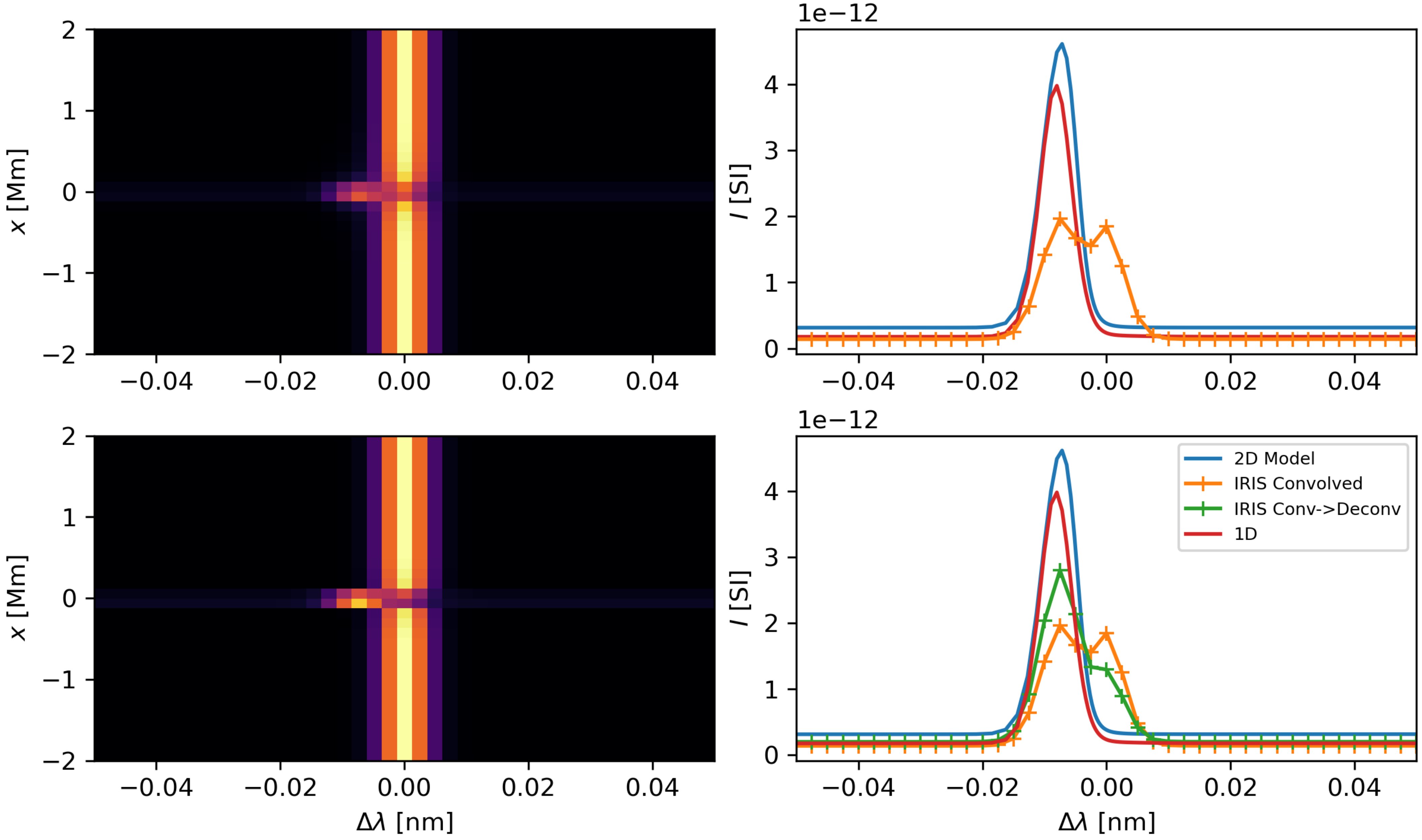
MNRAS preprint: stac2570

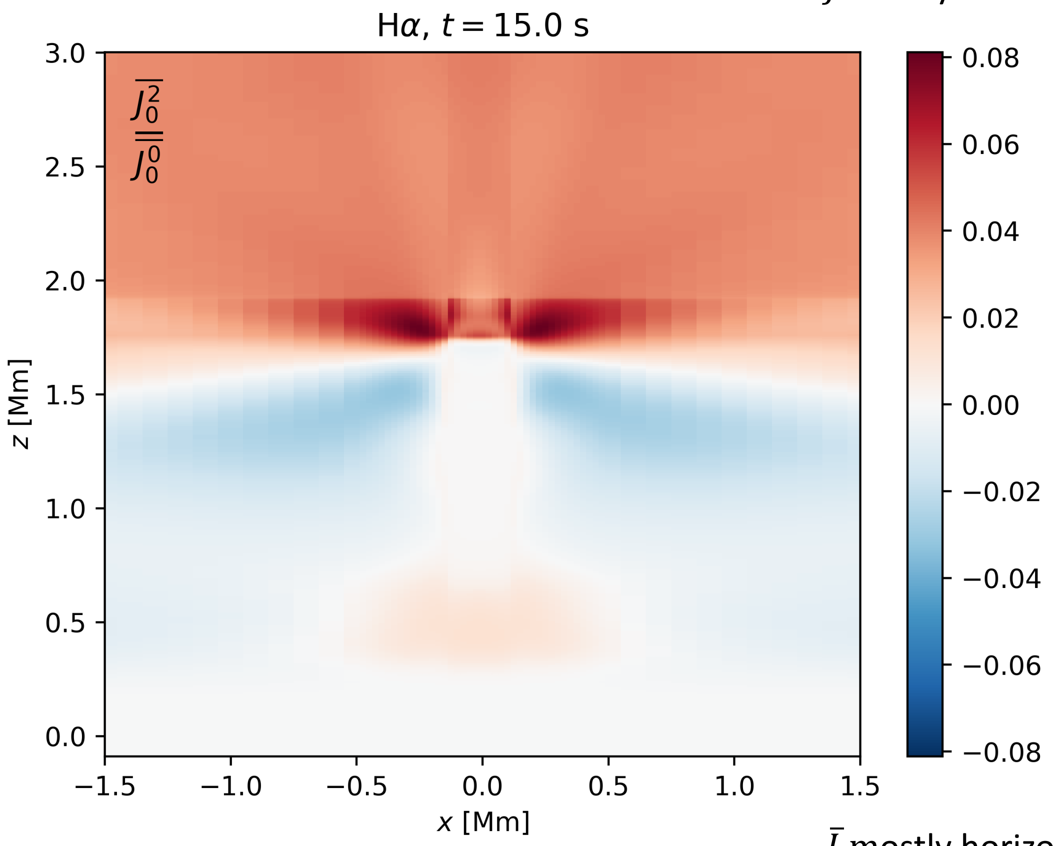
F9, k=0.125 Mm, t=09s



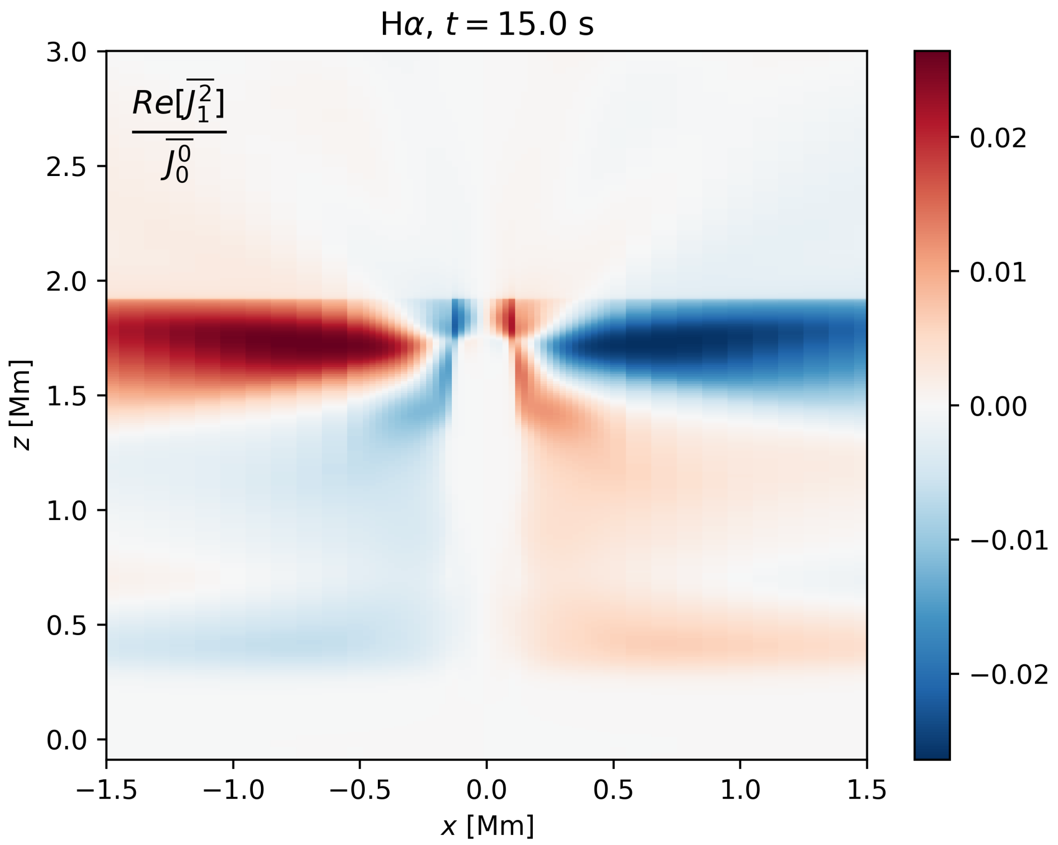
Did someone say tensors?

Significant anisotropy of the radiation field; will further increase with model complexity, leading to scattering polarization effects.

$\bar{J}$ mostly vertical



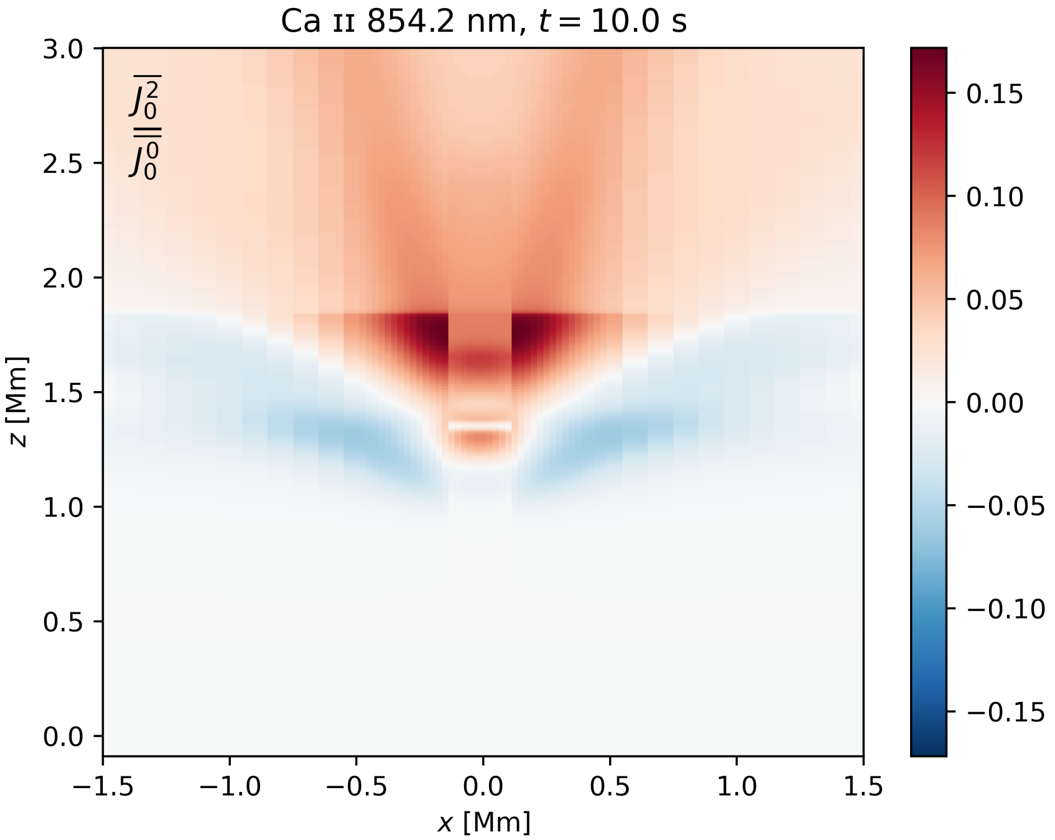
$\bar{J}$ mostly horizontal

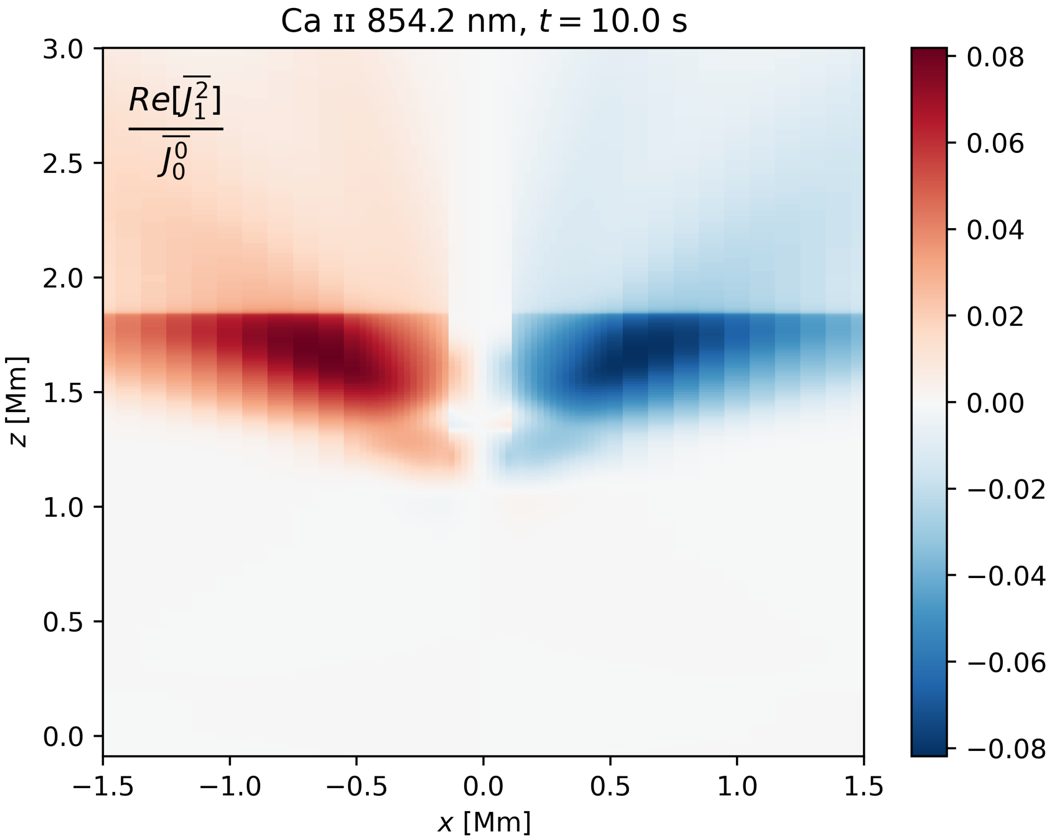


Likely lower bounds, as only Stokes I components included (Trujillo Bueno 2001).

Did someone say tensors?

“Breaking of axial symmetry”.





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