Optically Thick Si IV Resonance Line Emission in Solar Flares:

Preliminary Results from Electron beam driven RHD simulations

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Contributed Talk

4. Eruptions in the solar atmosphere

Optically Thick Si IV Emission During Solar Flares: Non-LTE, Non-equilibrium Simulations

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IRIS has routinely observed the strong Si IV resonance lines during solar flares and other heating events. When analyzing, or simulating, quiescent observations of these lines it has typically been assumed that they are optically thin and resources such as CHIANTI used to produce synthetic spectra from simulations with which to compare to observations. However, this assumption has also been applied to the flaring scenario. We used radiation hydrodynamic simulations of solar flares, computed using the RADYN code, to probe the validity of this assumption. Using flare atmospheres we solved the formal radiation transfer to obtain the non-LTE, non-equilibrium populations, line profiles, and opacities for a 30 level Si atom. Our electron beam-driven flare simulations covered a range of beam parameters: energy flux, $F = [5\times10^8 - 1\times10^{11}]$ erg cm^{-2} s^{-1}, low energy cutoffs, $E_c = [20, 30, 40]$keV, and spectral indices, $\delta = [4, 6]$. All simulations with an injected energy flux $F > 5 \times 10^{10}$ erg cm^{-2} s^{-1} resulted in optically thick Si IV emission. Lower energy flares (down to $F \sim 5 \times 10^9$ erg cm^{-2} s^{-1}) also resulted in optically thick Si IV emission, depending on the other beam parameters. Beams which penetrated deeper were less likely to produce optically thick emission compared to those which strongly heated the upper chromosphere and transition region. Flares that deposit energy at higher altitude than in our simulations might also produce optically thick Si IV emission, even if the energy flux is low. Since we demonstrate that Si IV can become optically thick in flaring conditions we urge caution when analyzing observations, or when computing synthetic emission using the coronal approximation.

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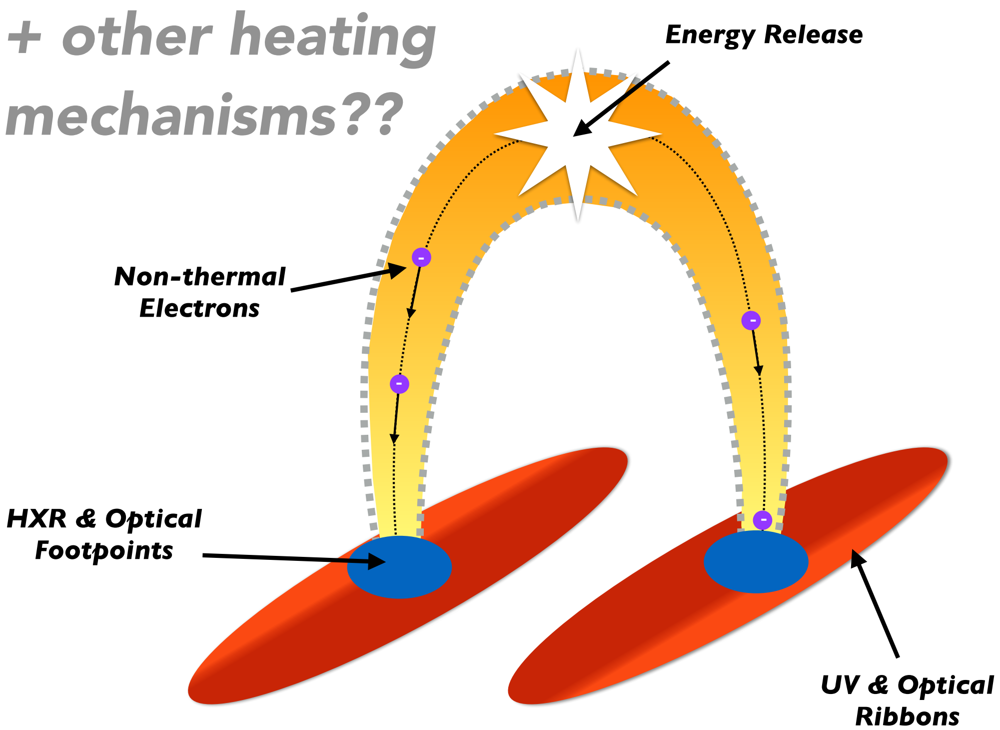
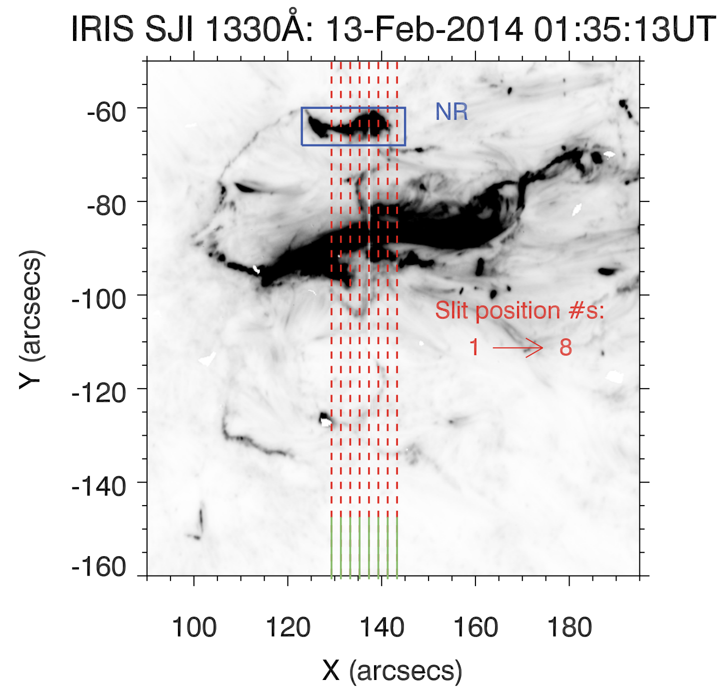
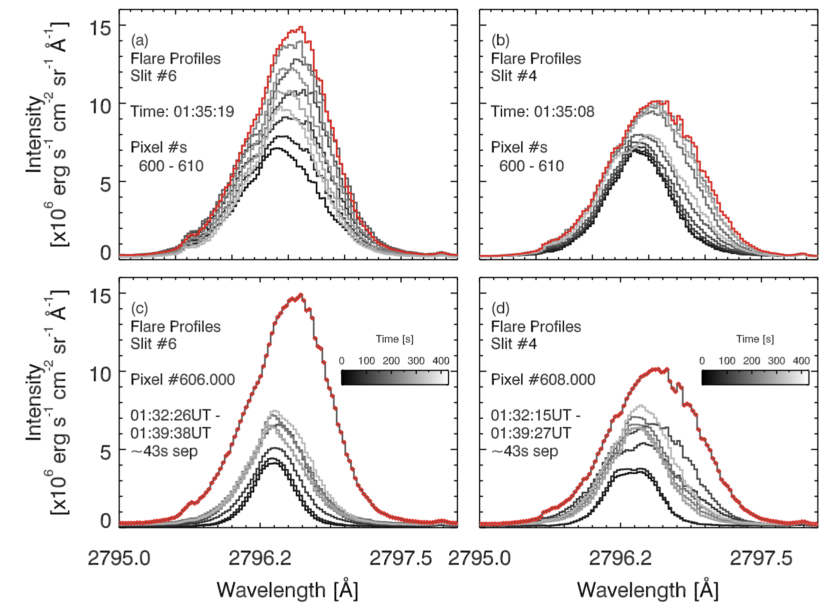
Solar Flares

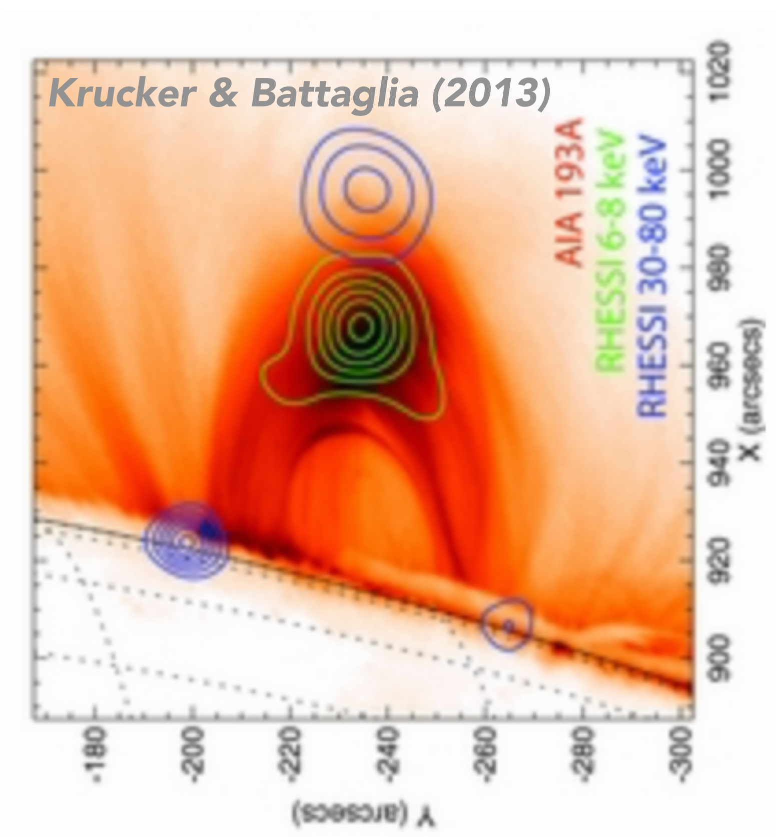
+ other heating mechanisms??

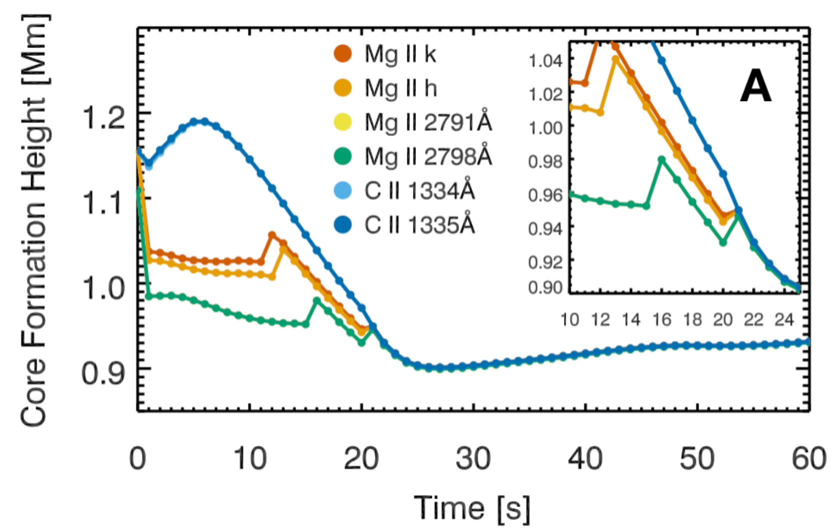


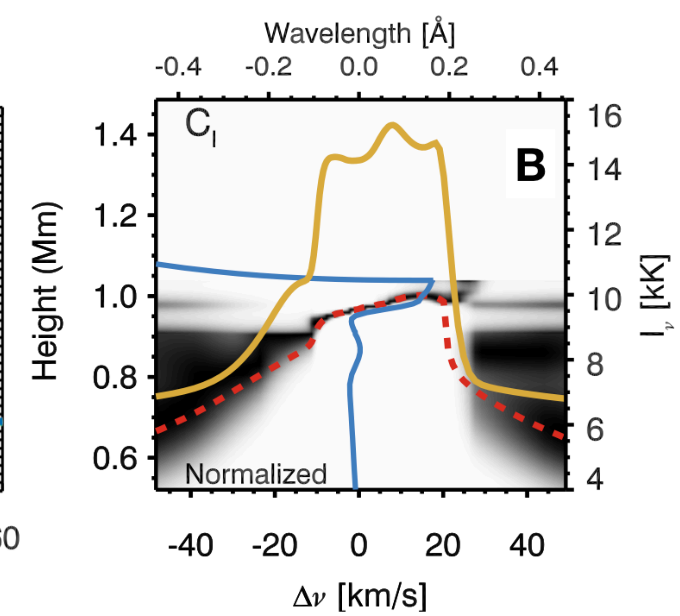




(Observations)







(Models)

Si IV Resonance Lines in Flares — Conclusions upfront

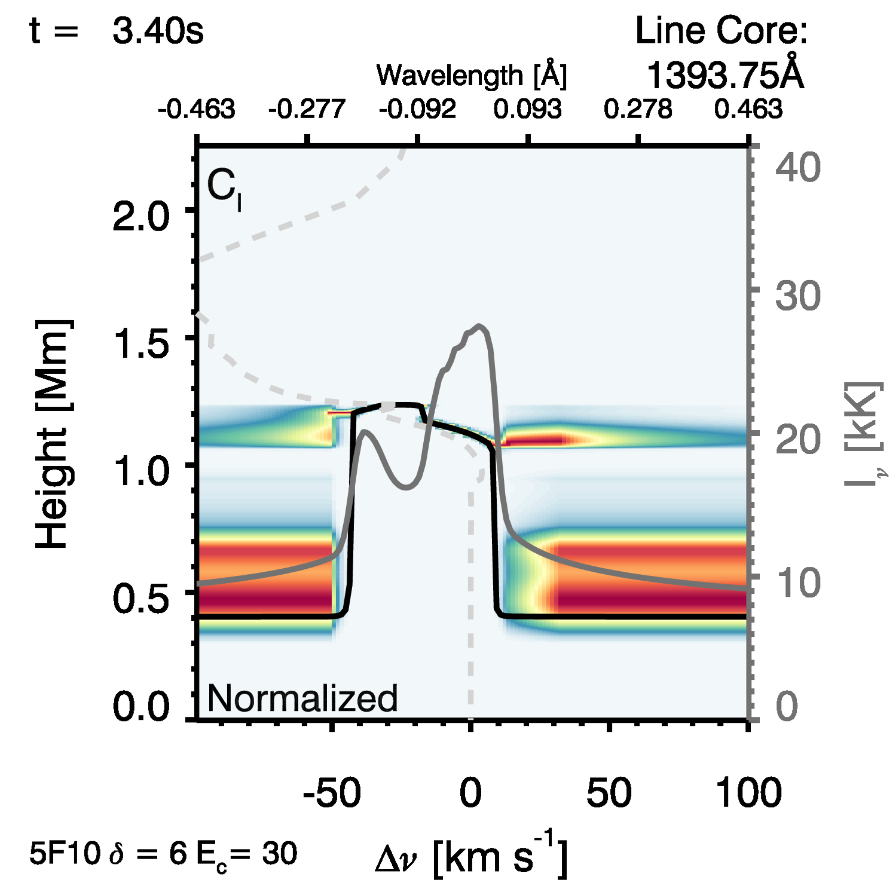
- Investigated Si IV in flares w/NLTE, non-equilibrium RT.

- Large grid of electron beam models :
  δ = [4,6], E_c = [20,30,40] keV,
  F = [5F8, 1F9, 5F9, 1F10, 5F10, F11] erg cm^{-2} s^{-1}.

- RADYN synthesized profiles were different than those from CHIANTI in terms of:
  - — Doppler shifts,
  - — Asymmetries,
  - — Self-absorption features,
  - — Intensities.

- **Si IV profiles became optically thick in many of the higher energy RADYN simulations.** Typically > ~1F10

- Electron column depths between T=30-80kK > ~ 10^{19} cm^{-2} result in opacity effects.



Opacity effects may be important during flares & other heating events.

Possible indication that the upper chromospheric / lower transition region electron density is over-estimated in flare simulations.

Kerr et al (in prep.)

Radiation Hydrodynamics with RADYN — Trace Species

RADYN allows us to investigate the behavior of trace (or 'minority') species, with full NLTE, non-equilibrium radiation transfer (with the usual caveats of RADYN's RT: CRD, no blends):

- Uses the full prior computed RHD solution with a trace species model atom. The atmospheric structure of the original solution is used to solve the atomic level populations and RT for the desired species. This includes non-equilibrium ionisation.

- This method assumes that the radiation produced by the trace species would not affect the atmospheric evolution — there is no feedback, and only RT calculations are performed.

- This is pretty fast — takes a few minutes to several hours for flare atmospheres lasting 50s of solar time, depending on complexity of the atmosphere.

- Can allow us to test the impact of non-equilibrium effects by comparing with RH (in progress for Mg II and Si IV).

Carlsson & Stein (1995, 1997) ; Judge et al (2003)

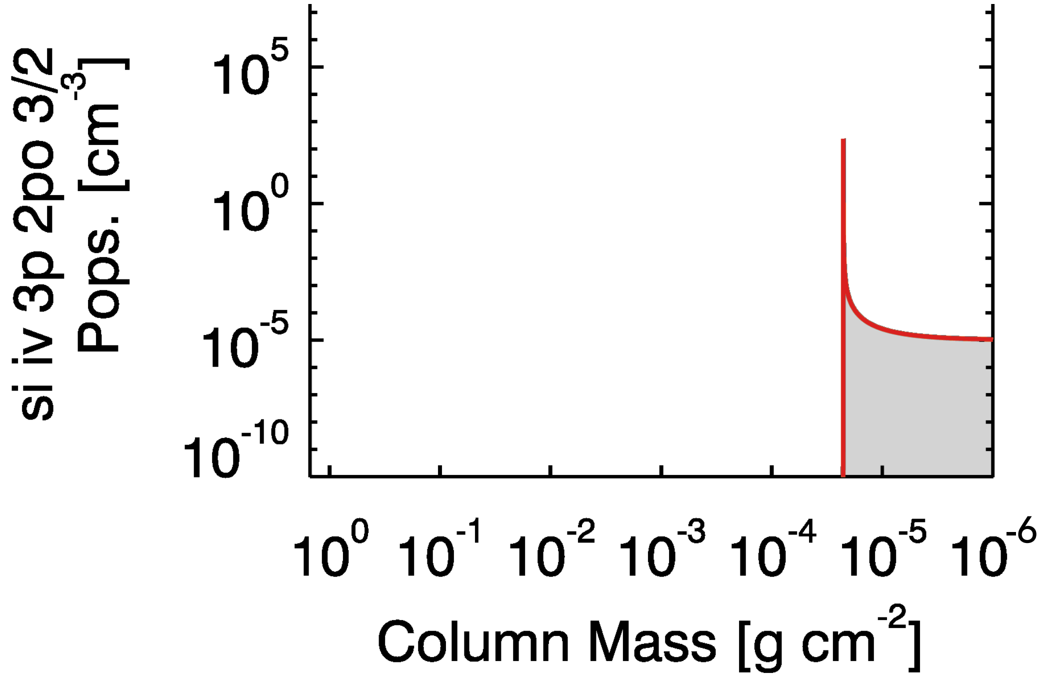
Si IV Model Atom

- 30-level-with-continuum Si atom
  — transitions from Si I, II, III, and IV
  — with the continuum being Si V
  — tested an example that included Si VI, but it had little impact on results.

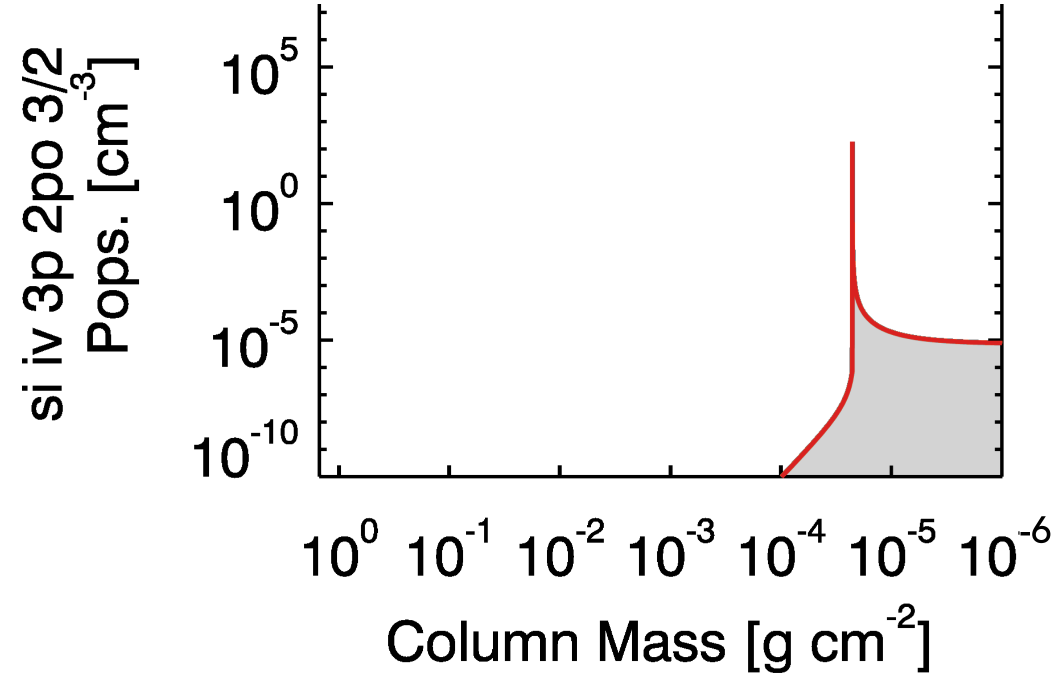
- Originally produced using the HAO-Diper package.

- Updated the photoionisation cross sections using Topbase, and the oscillator strengths & radiative damping coefficients using CHIANTI.

Photoionisations of Si I included



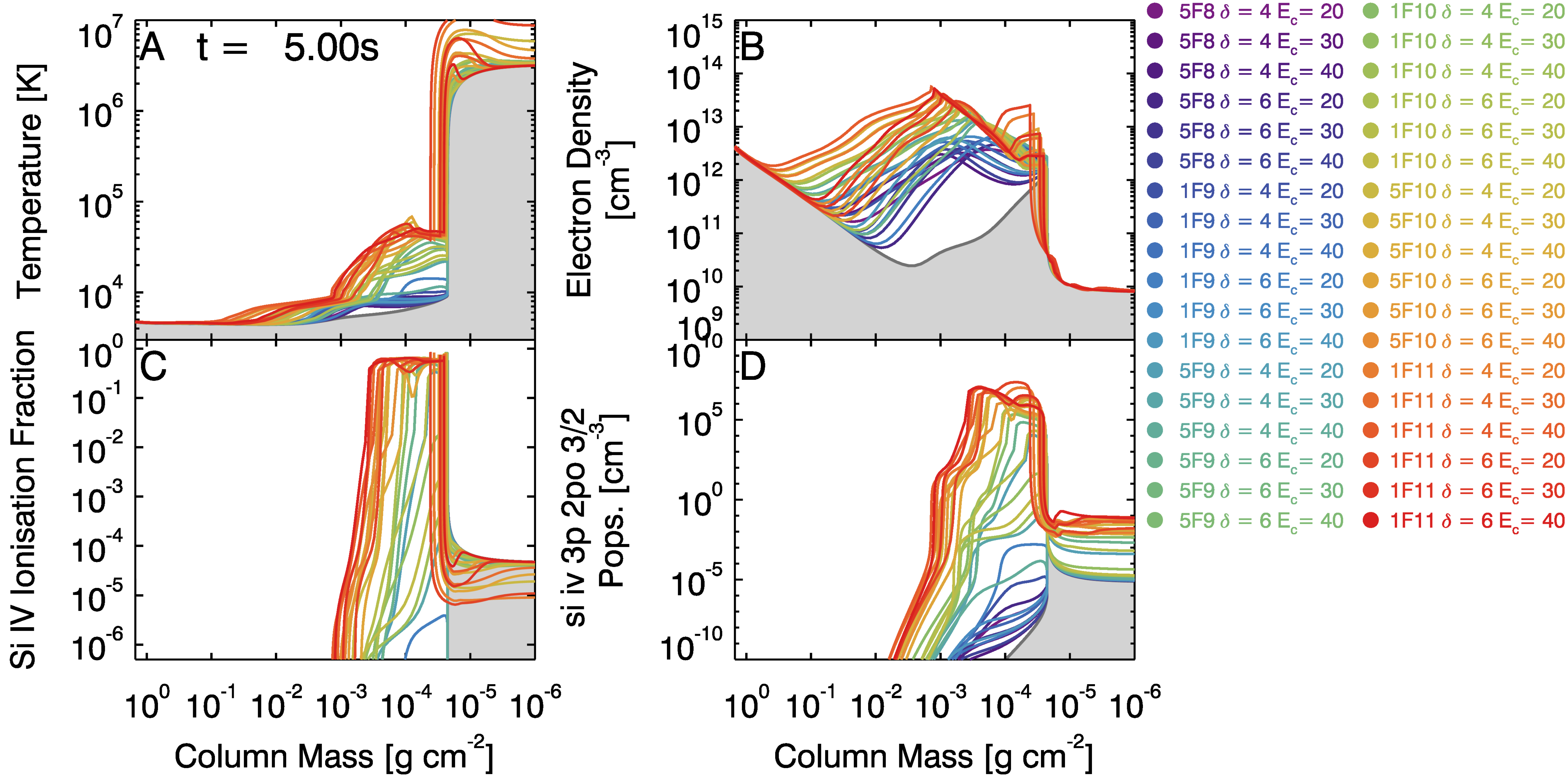
Photoionisations of Si I, II, II and IV included



Judge (1994,2007) ; Arnaud & Rothenflug (1985) ; Shull & Steenberg (1982) ; Cunto et al (1993)

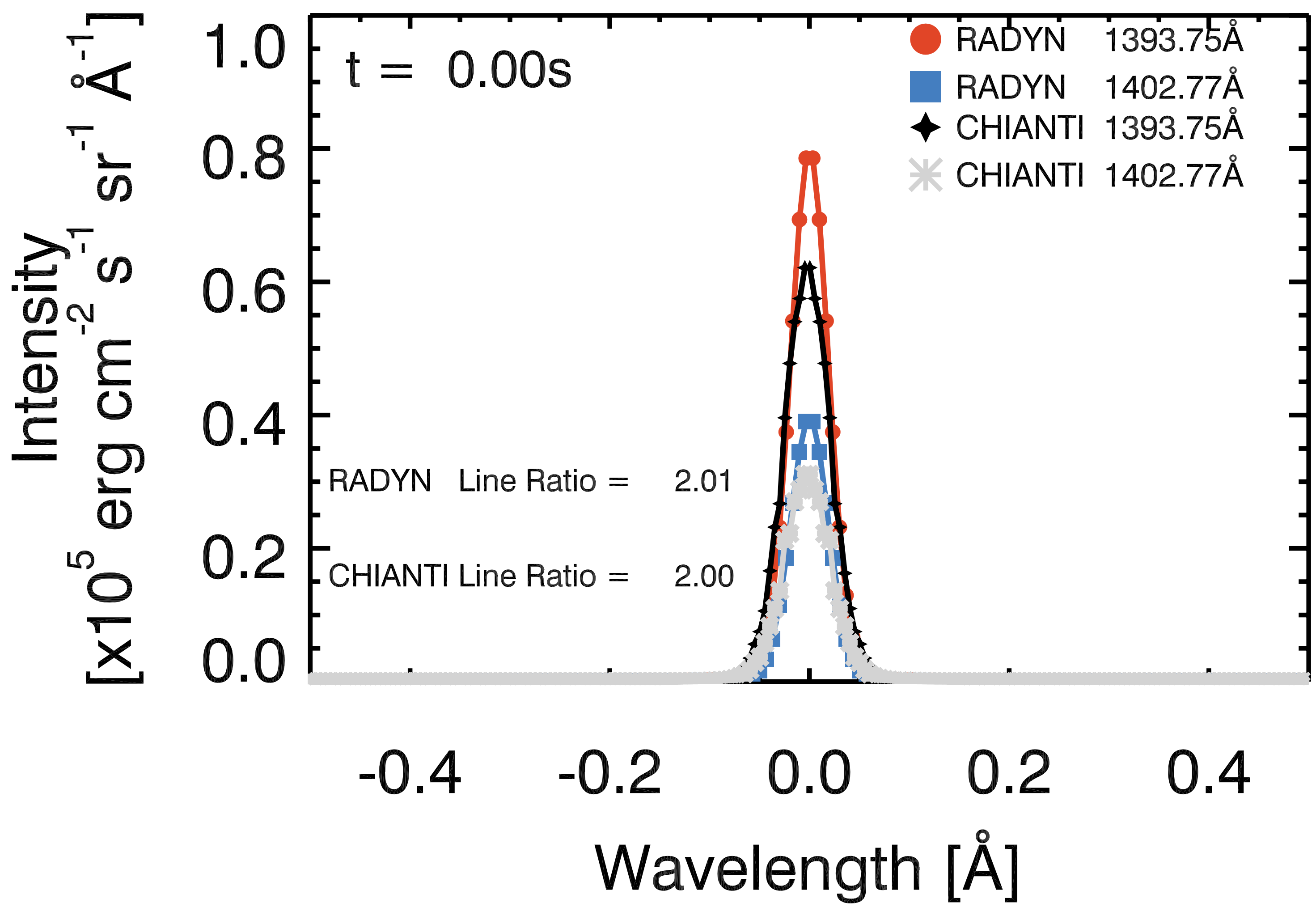
Flare Simulations

- 36 flare simulations covering:
  — δ = [4,6], E_c = [20,30,40] keV, and F = [5F8, 1F9, 5F9, 1F10, 5F10, 1F11] erg cm^{-2} s^{-1},
  — energy injected at a constant rate for 10s.



Si IV Resonance Lines — CHIANTI & RADYN

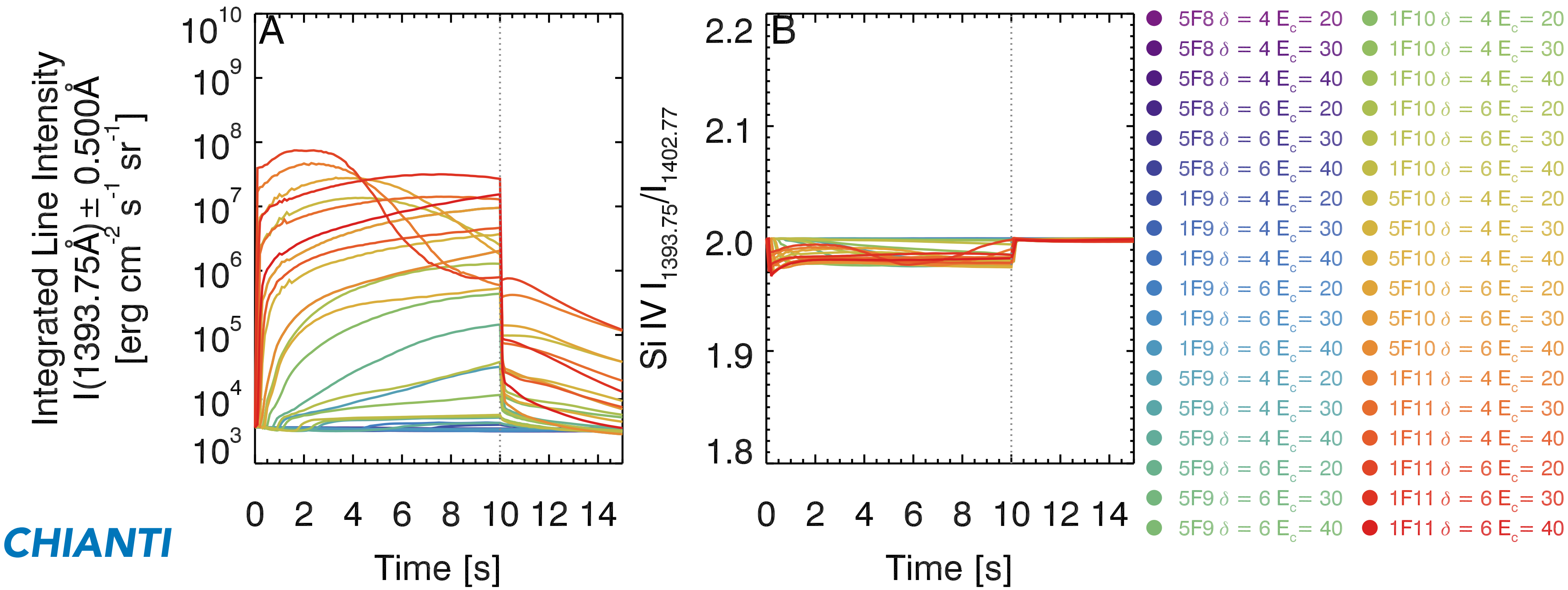
- At t = 0s (the pre-flare atmosphere) the NLTE profiles computed by RADYN are comparable, but slightly (~7%) more intense than using CHIANTI
- NLTE Si IV line forms at T~45kK (c.f. Avrett et al 2013).
- 1393/1402 line intensity ratio = 2.



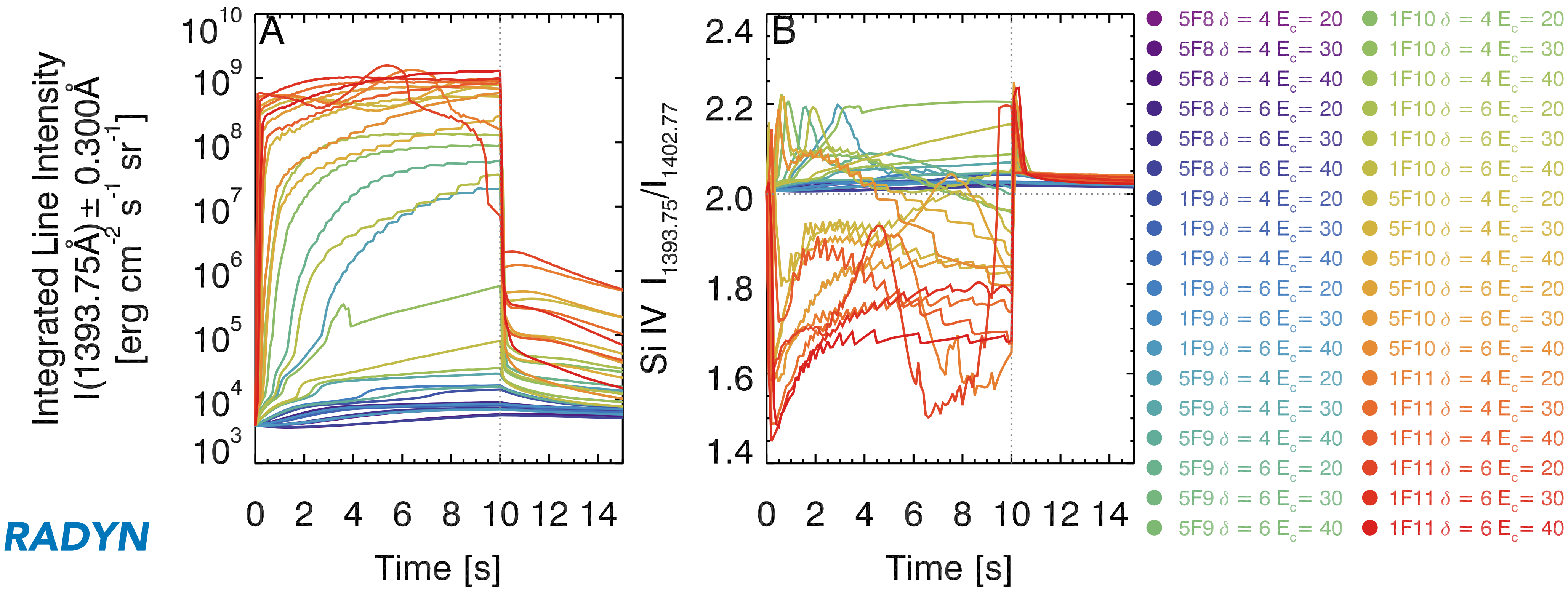
Si IV Resonance Lines — CHIANTI & RADYN

- Line ratio is two if lines are optically thin
- The 1393Å line is formed somewhat higher in the atmosphere
- 1393Å can become more optically thick than the 1402Å line at certain times.

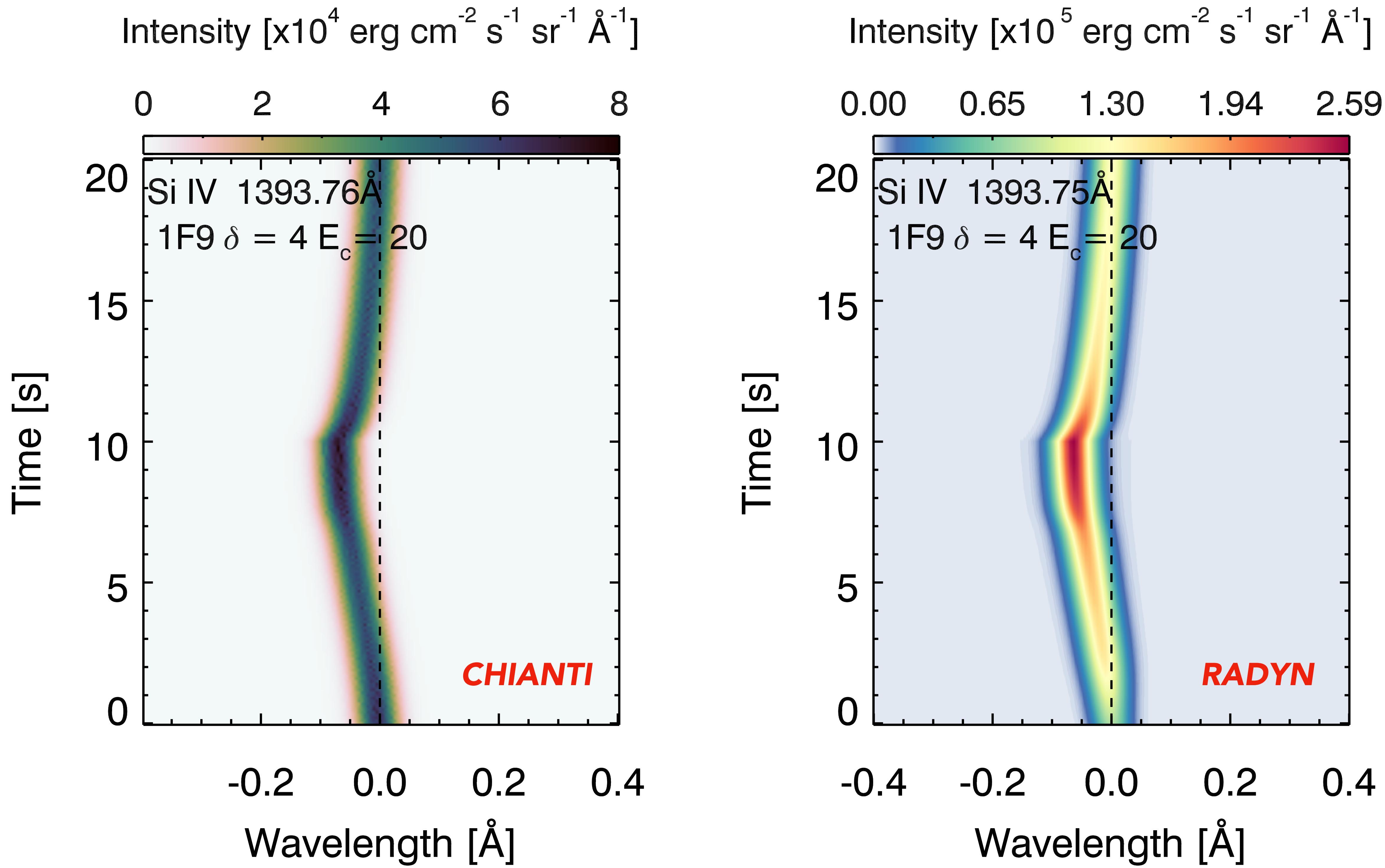
CHIANTI



RADYN



Si IV Resonance Lines Profiles — CHIANTI & RADYN



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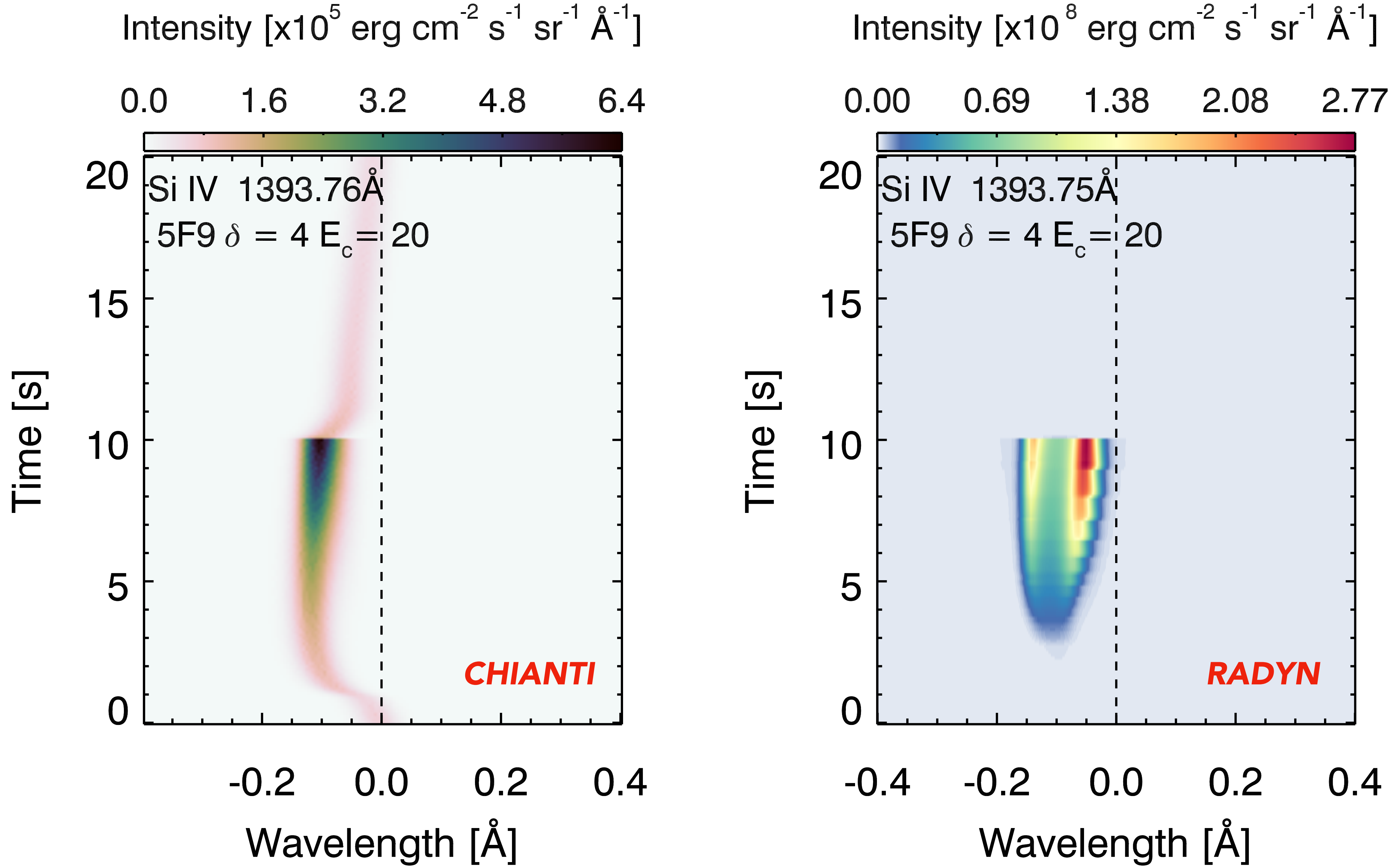

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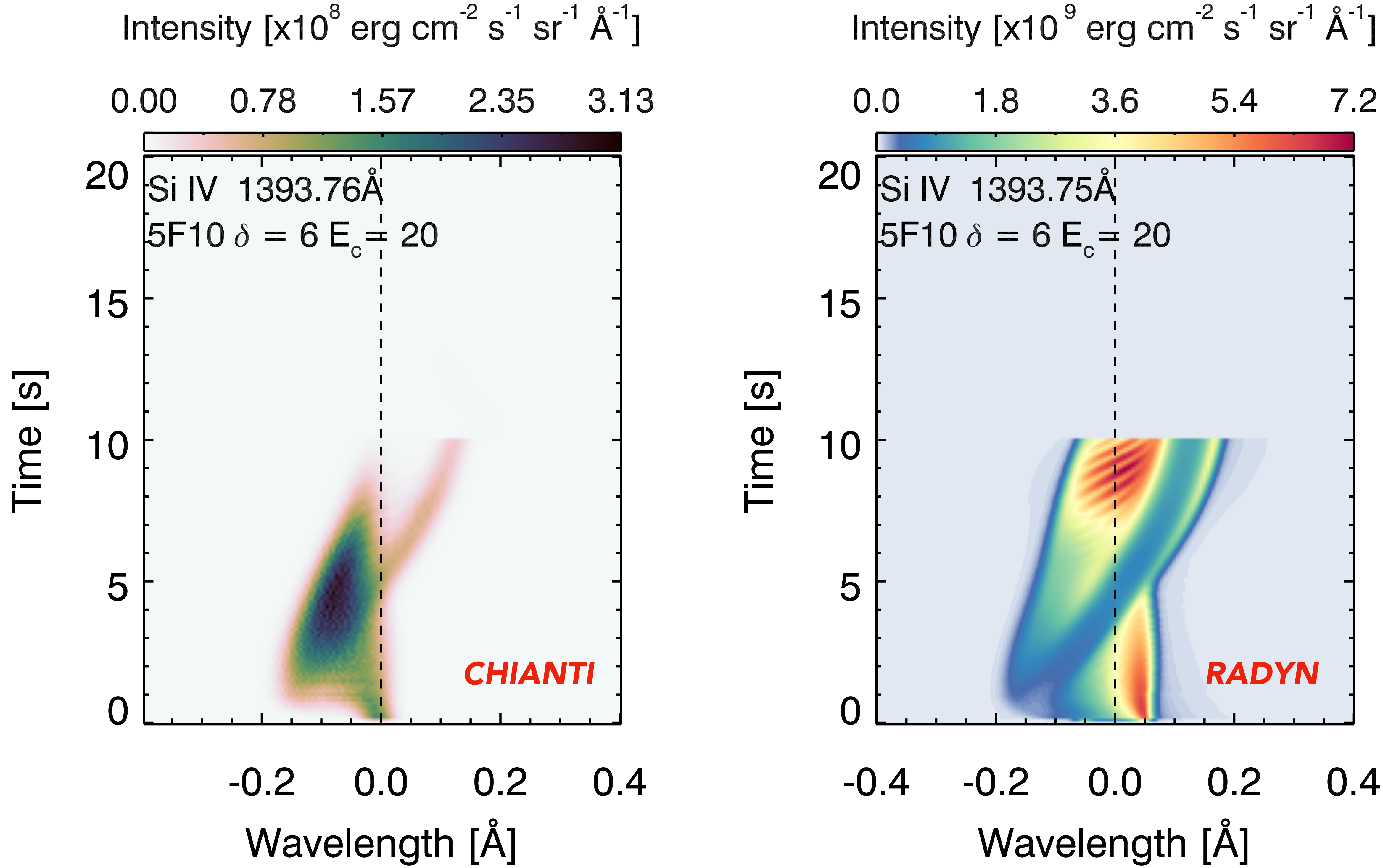
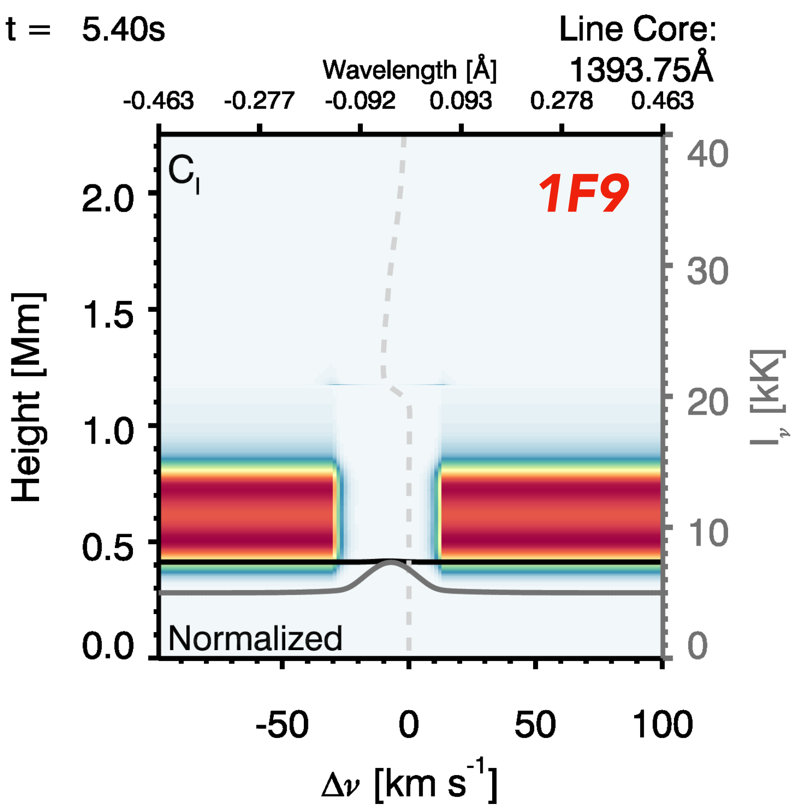
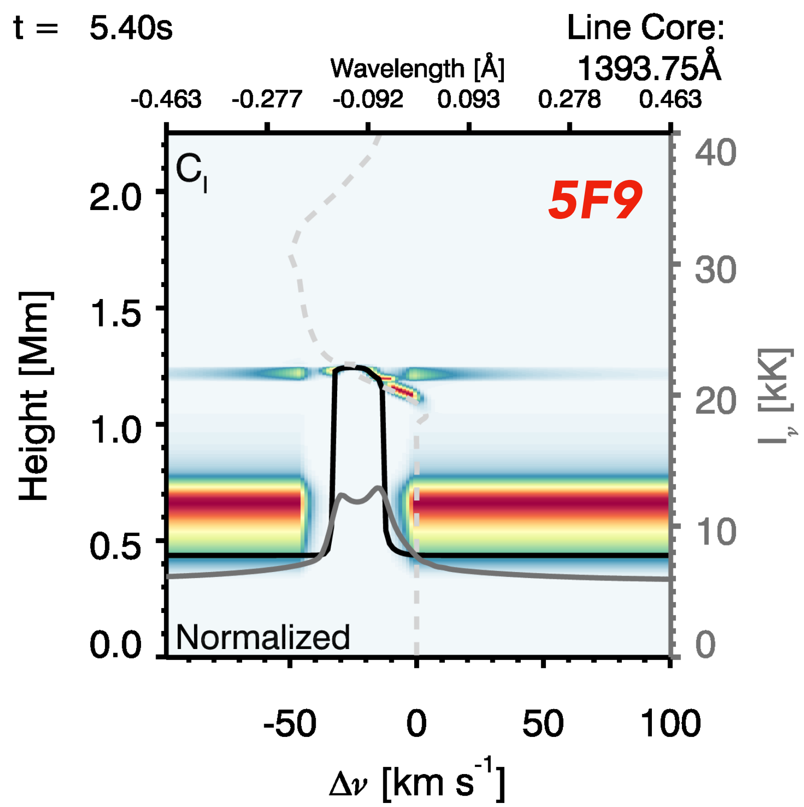
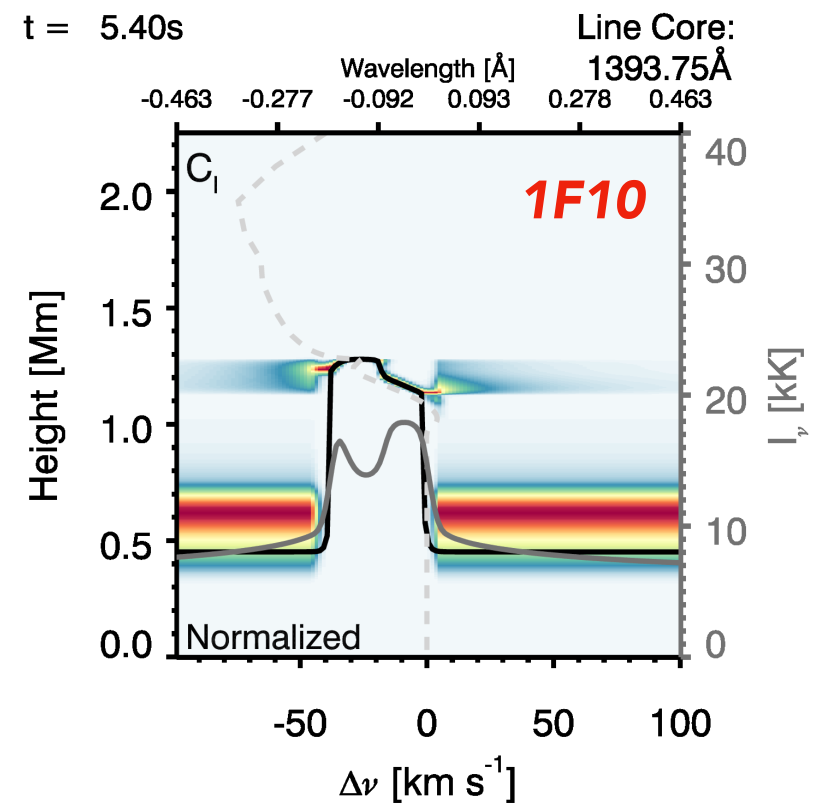
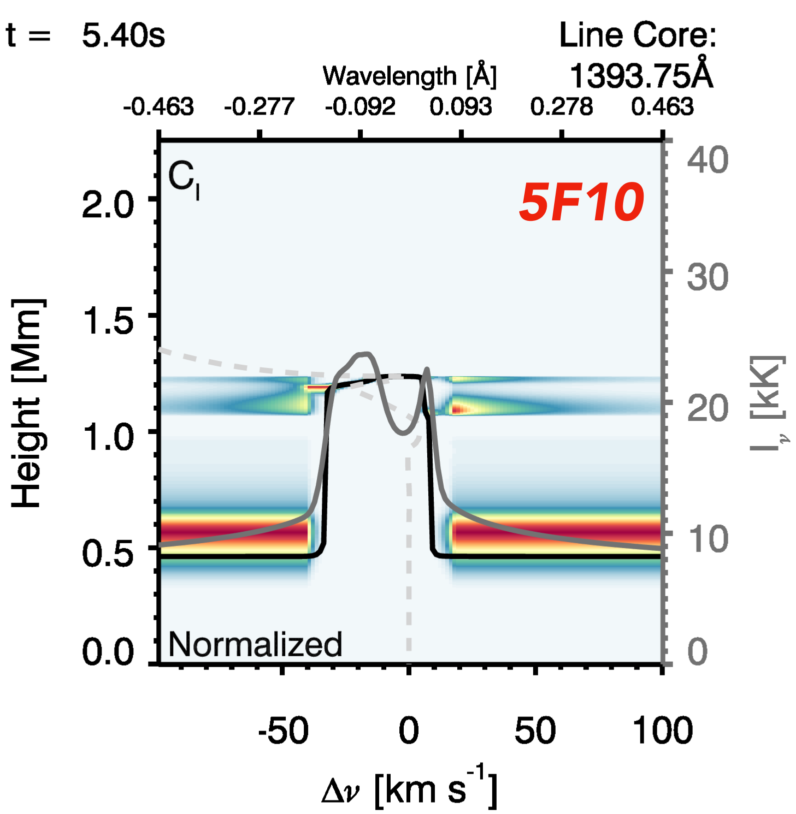


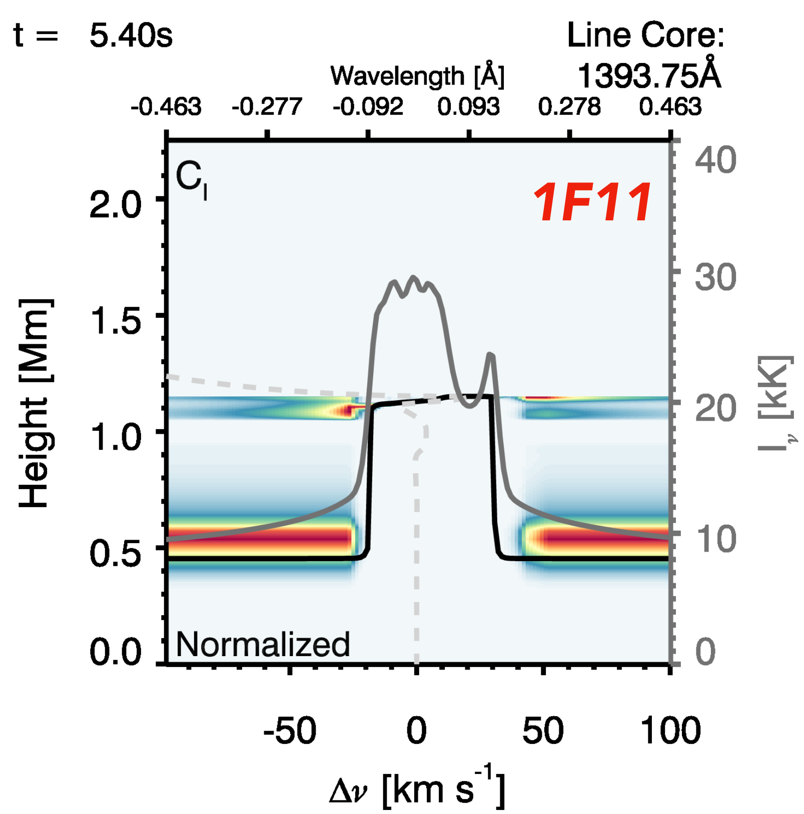
Si IV Resonance Lines — Contribution Fns (RADYN)











- Background image: wavelength normalized contribution function to the emergent intensity.
- Dark grey solid line = Line profile in units of radiation temperature
- Light grey dashed line = Atmospheric velocity (upflows are -ve)
- Black solid line = optical depth unity layer

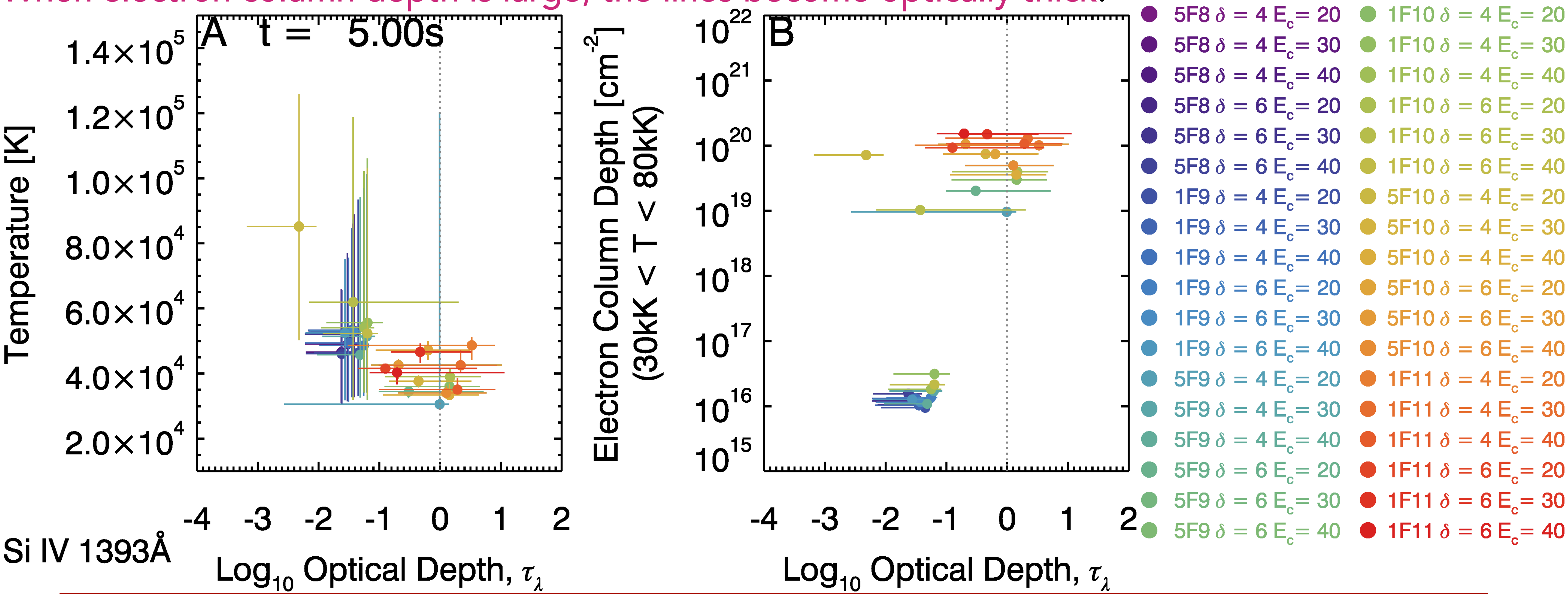
Si IV Resonance Lines — When is opacity important?

- Optically thick when there is a sufficient fraction of Si IV present in the flaring atmosphere. This is a function both temperature and electron density.

- Higher electron density at temperatures at which Si IV can form results in more Si IV.

- Temperature at the peak of the contribution function (A), and the electron column depth between 30-80kK (B) as functions of optical depth

- When electron column depth is large, the lines become optically thick.



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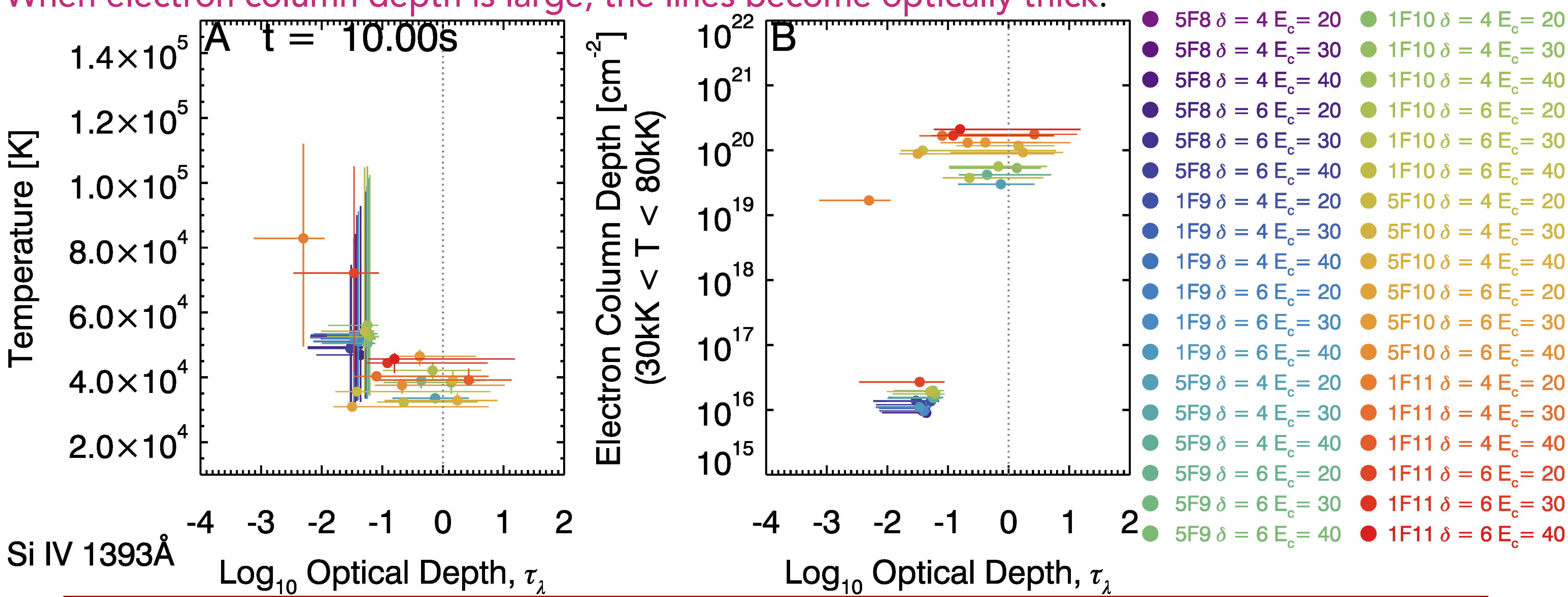

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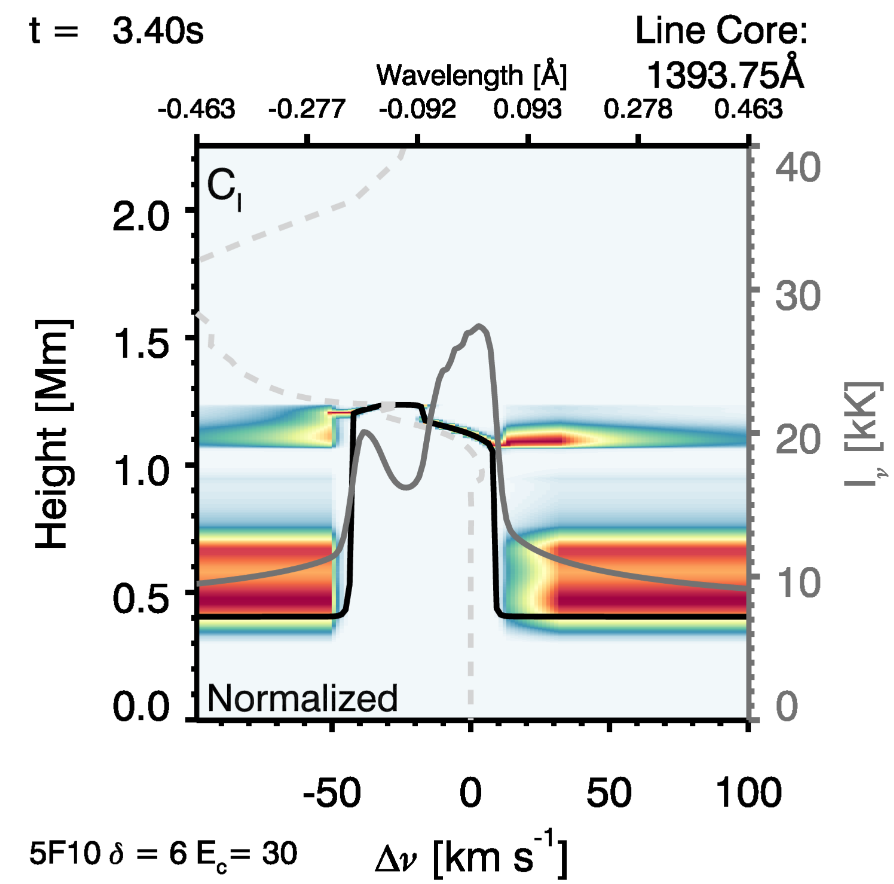

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EXTRA SLIDES

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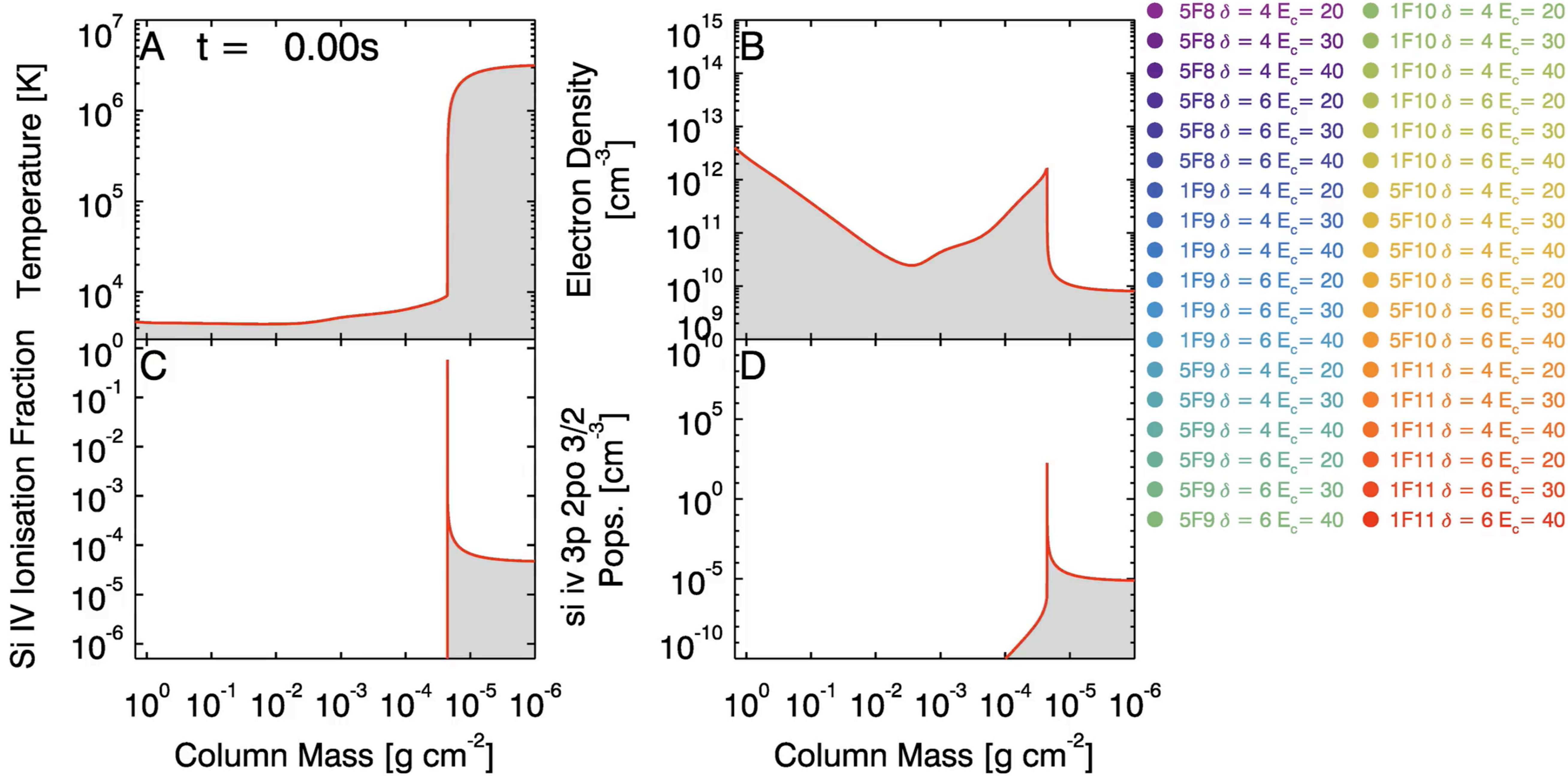
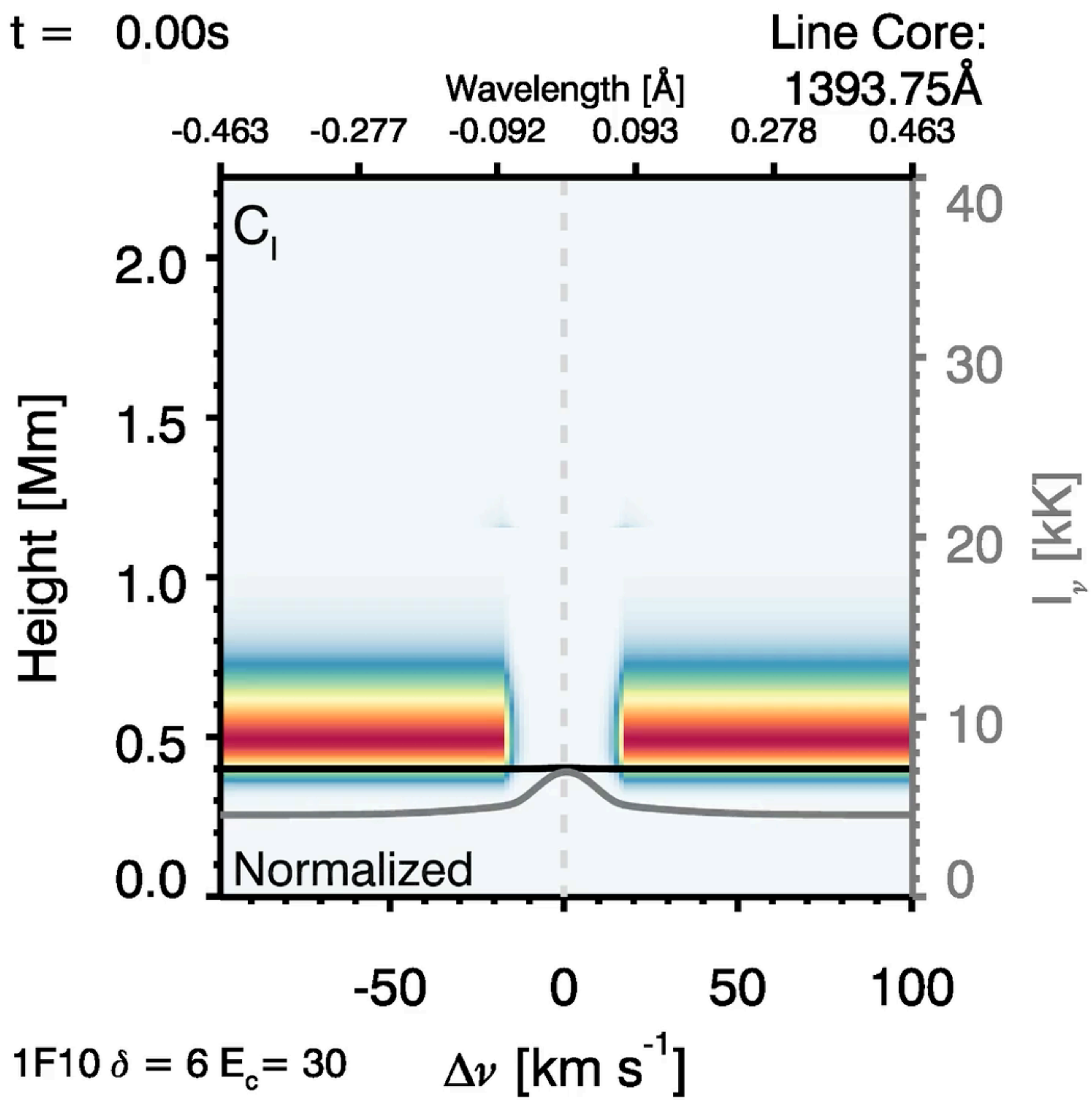


Si IV Resonance Lines — Contribution Fns

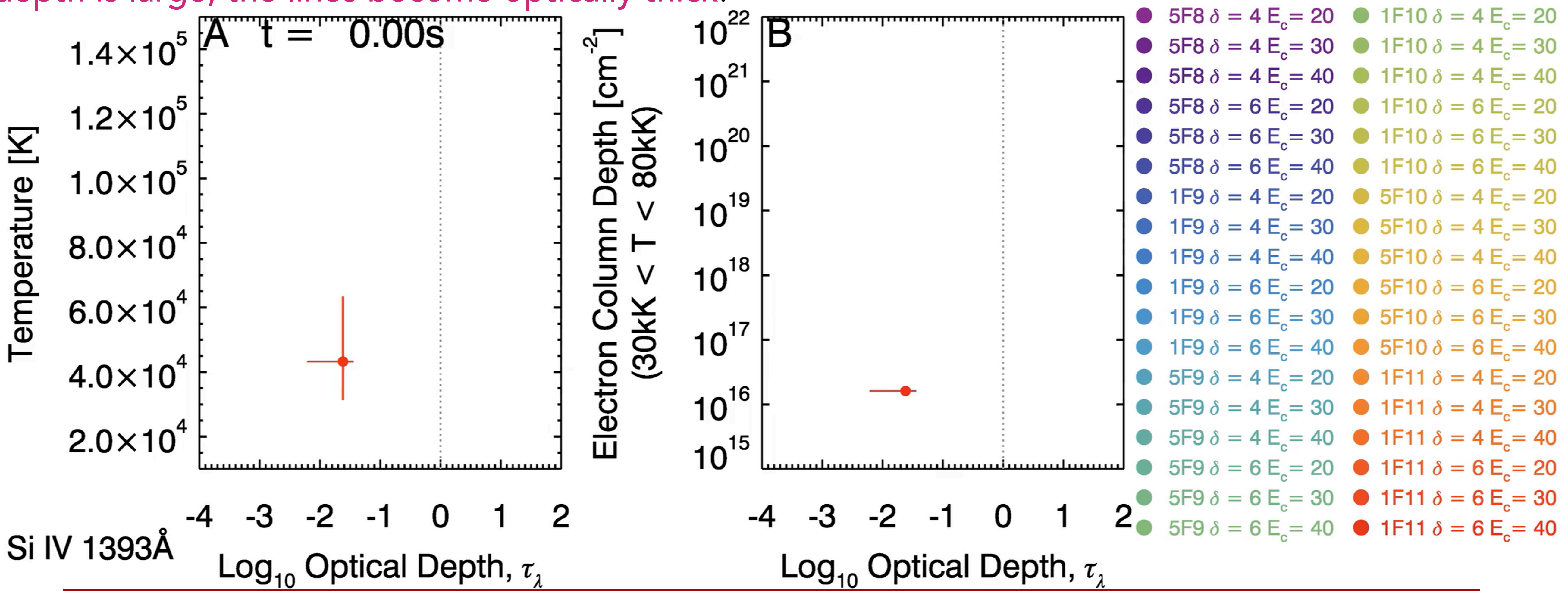


Si IV Resonance Lines — When are they Thick or Thin?

- The lines become optically thick when there is a sufficient fraction of Si IV present in the flaring atmosphere. This is a function both temperature and electron density.

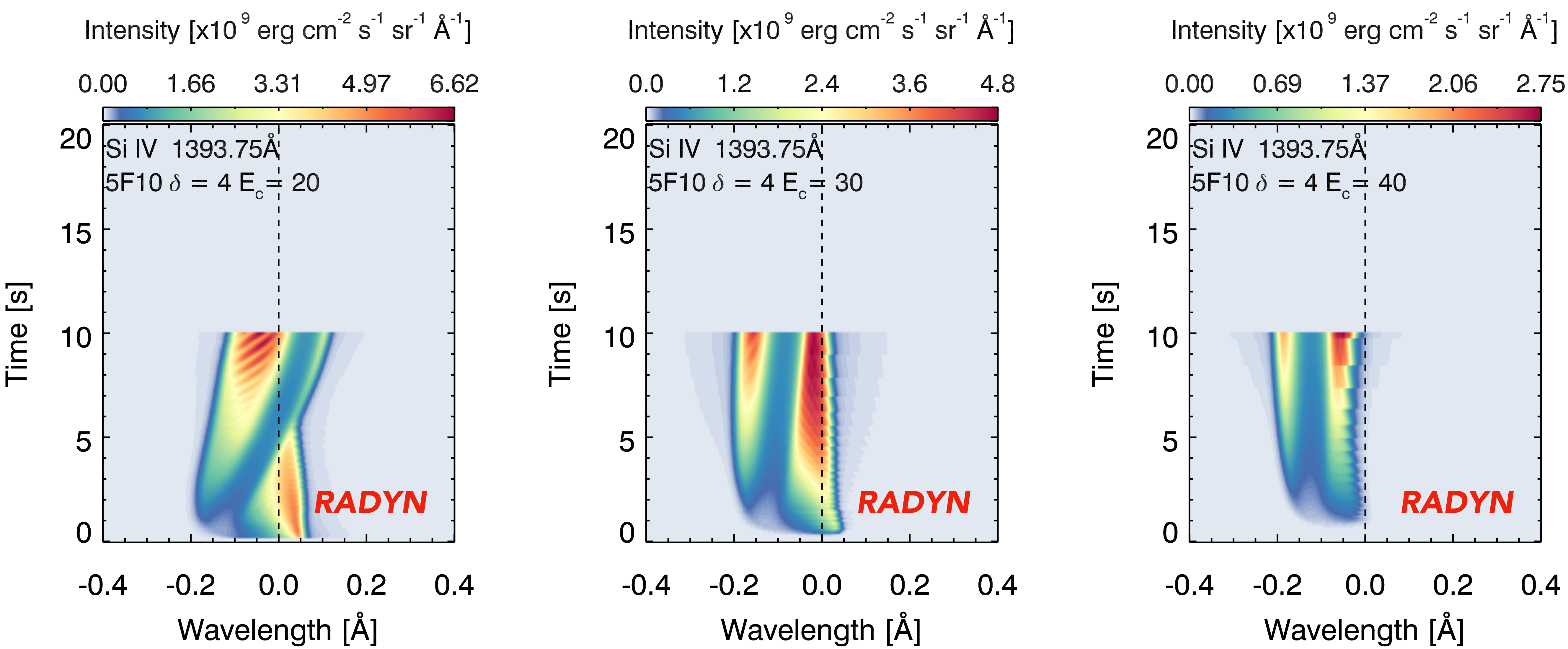
- If there is a higher electron density at temperatures at which Si IV can form then the amount of Si IV increases.

- Below we show the temperature at the peak of the contribution function, and the electron column depth between 30-80kK as functions of optical depth — it is clear that when the electron column depth is large, the lines become optically thick.



Si IV Resonance Lines — RADYN

- The nonthermal electron beam parameters affect the velocity structure of the atmosphere.
- These are all at the same energy flux and spectral slope, but the low energy cutoff differences means that more energy is deposited at progressively deeper heights.
- The Ec = 20keV case results in stronger upper atmospheric heating, driving downflows in the formation region of Si IV, whereas the other two cases are formed in upflowing regions.



Si IV Resonance Lines — RADYN

- The nonthermal electron beam parameters affect the opacity structure of the atmosphere.
- These are all at the same energy flux and spectral slope, but the low energy cutoff differences means that more energy is deposited at progressively deeper heights.
- Only the Ec = 20keV case is optically thick, because heating is stronger in the upper chromosphere, raising the sufficiently electron density at temperatures at which Si IV forms.