NLTE effects in spectral line formation

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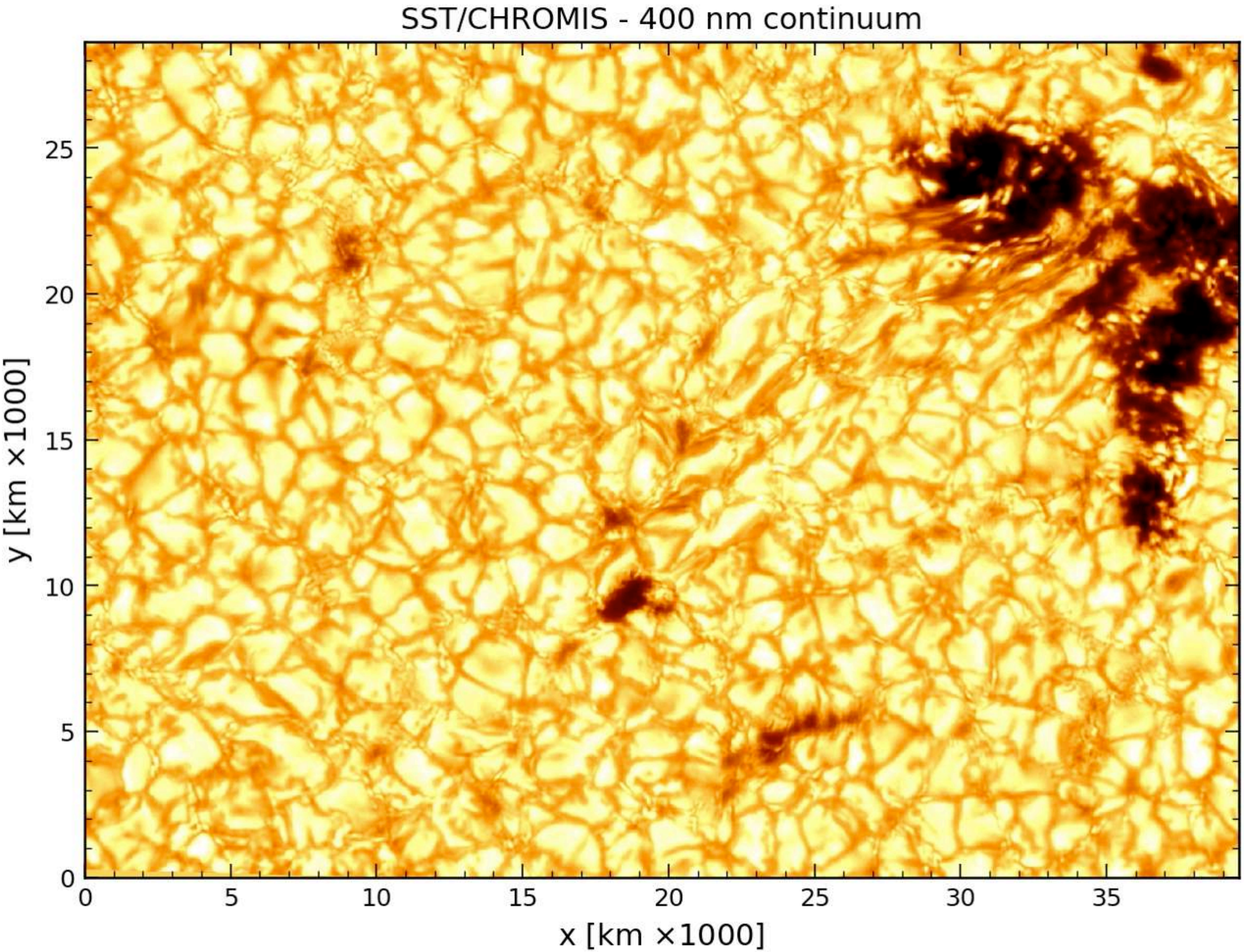
Most chromospheric lines sample a vast range of heights in the solar atmosphere



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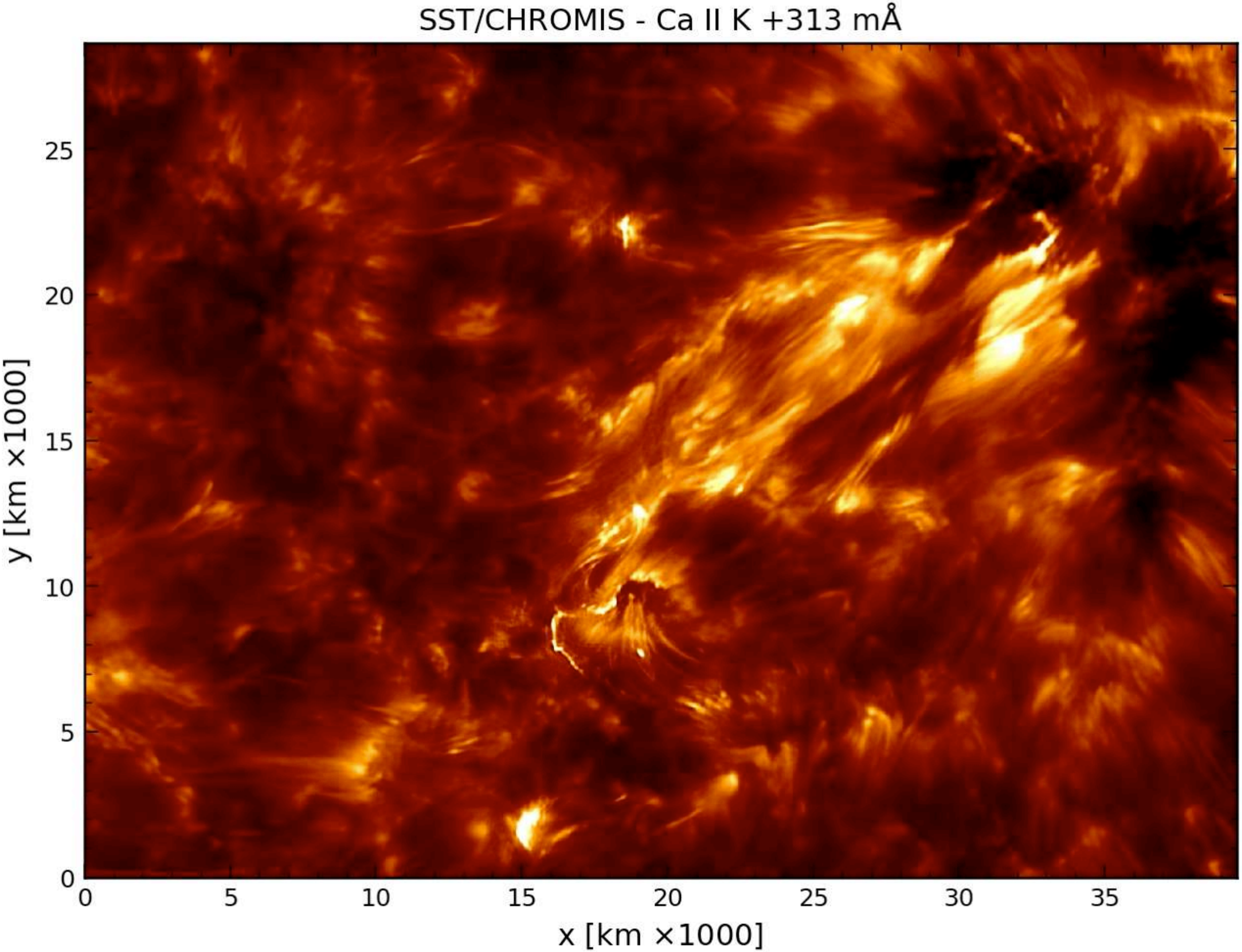

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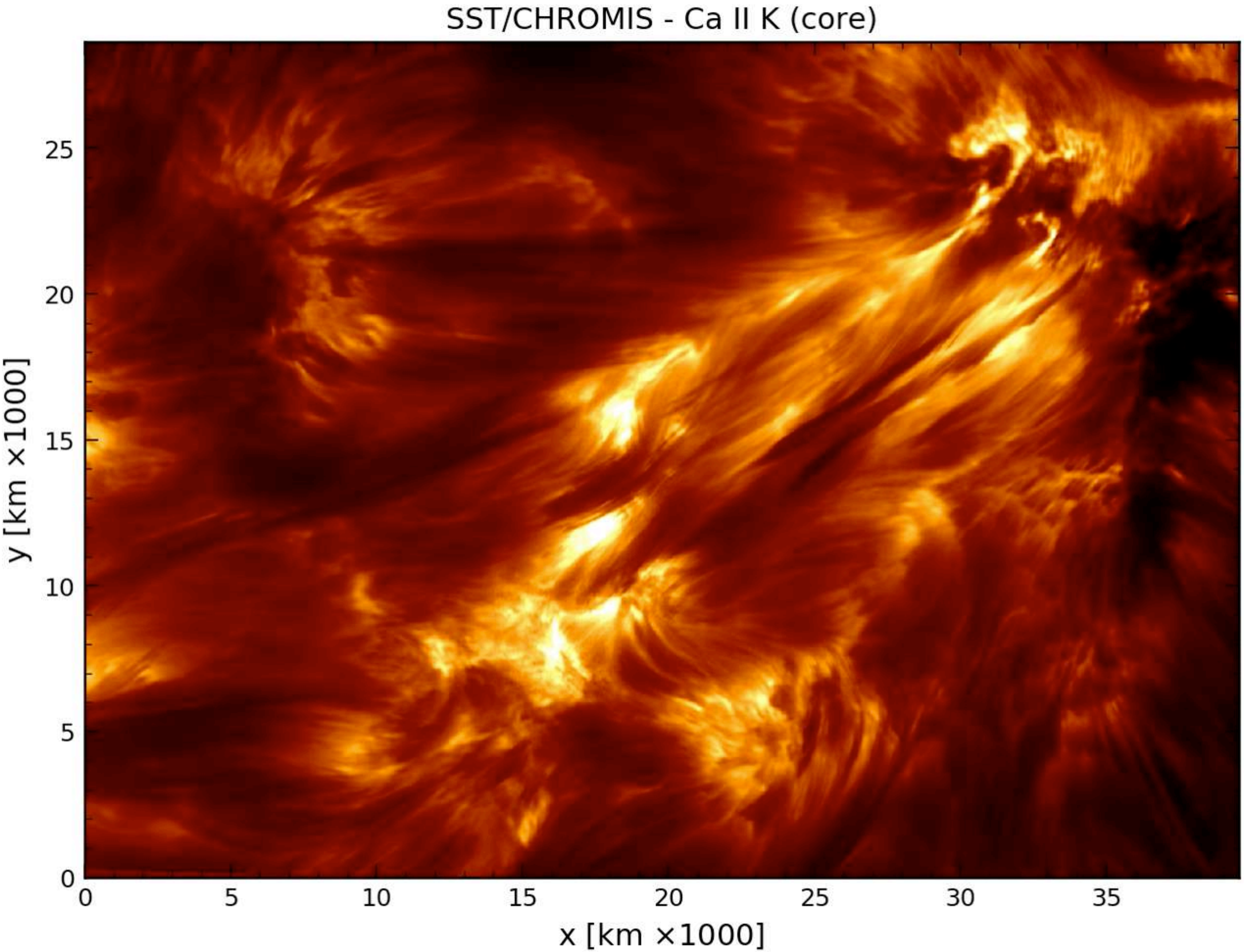
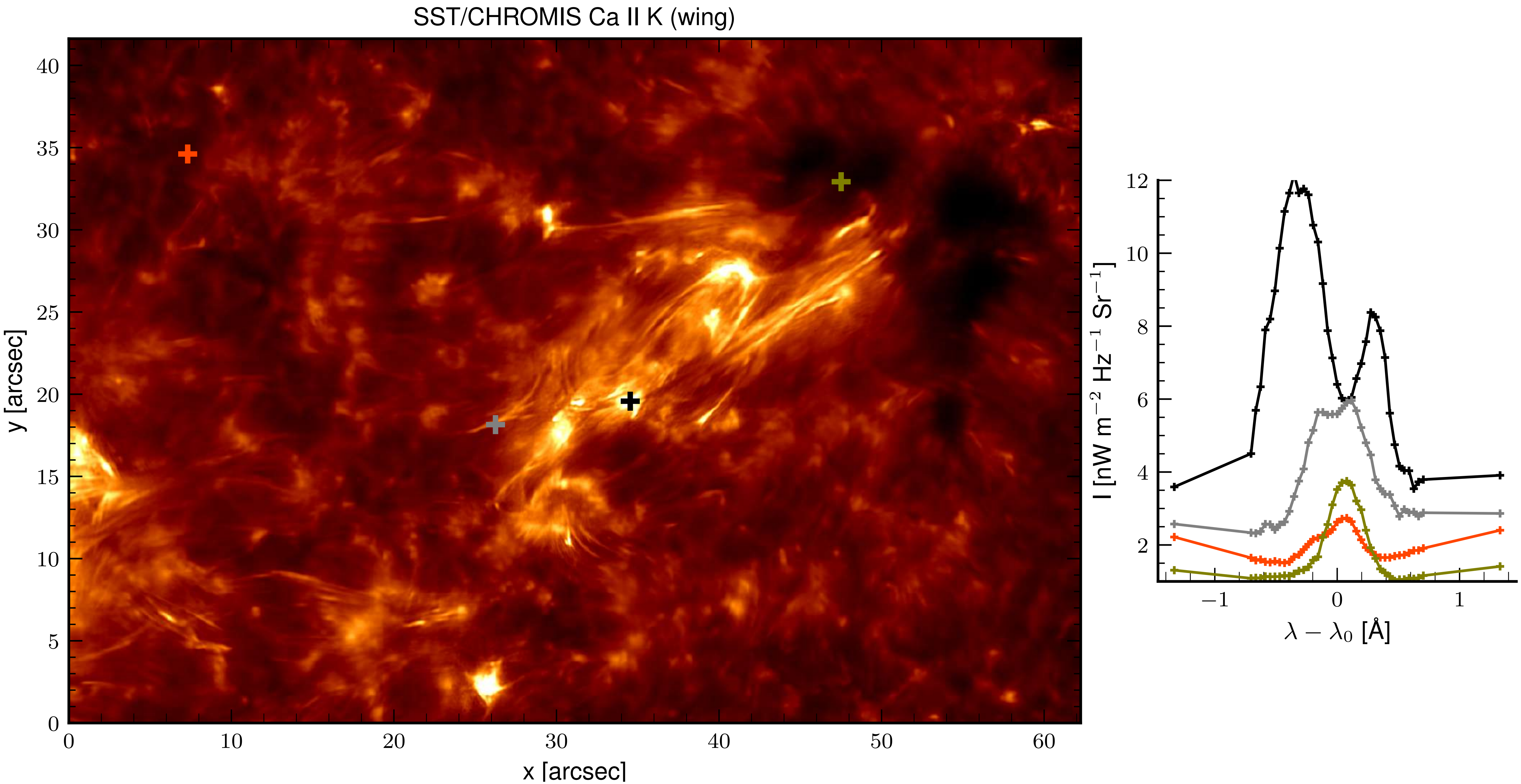


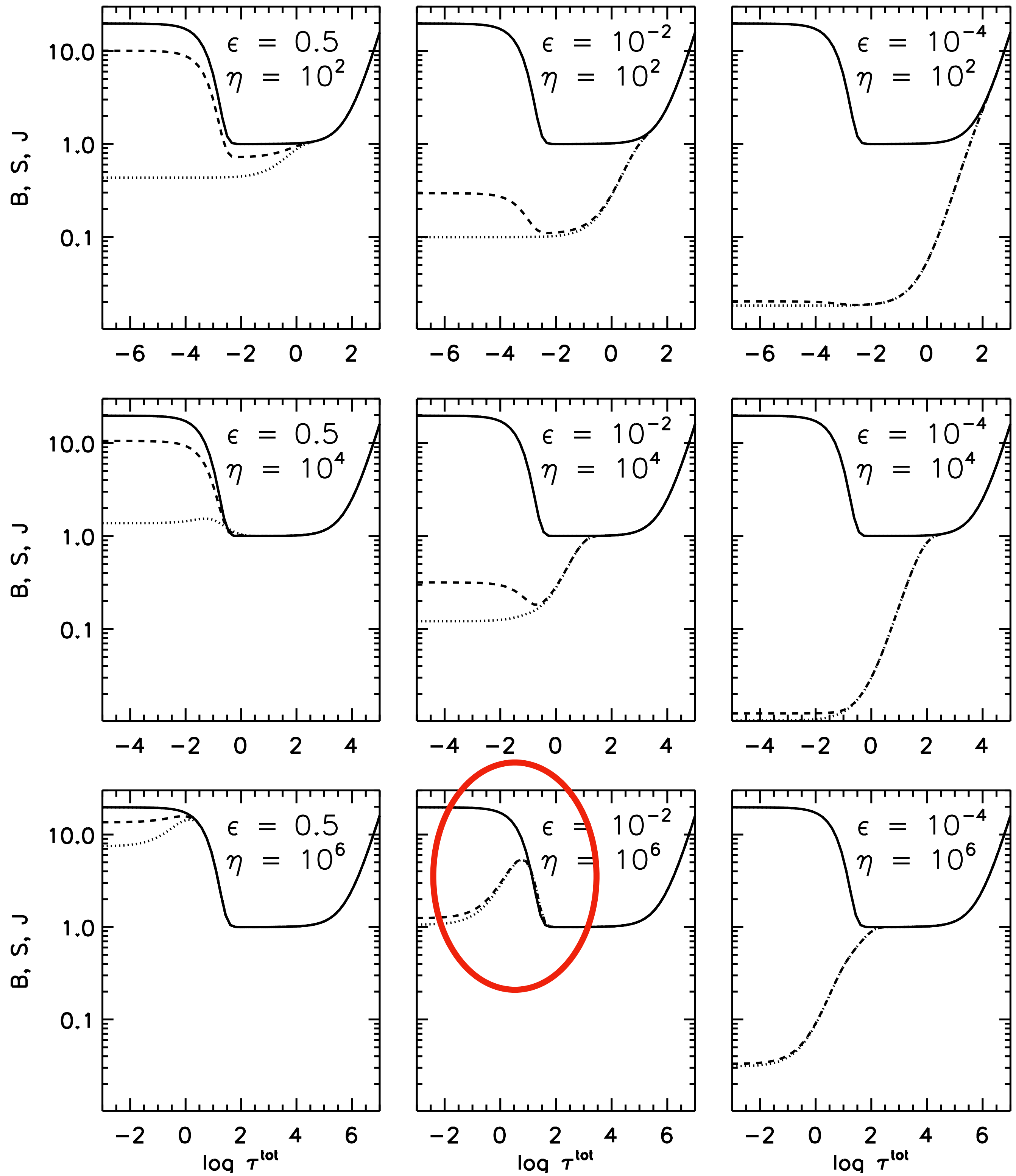
Spectral lines encode information of the plasma conditions



LTE populations in the photosphere / NLTE populations in the chromosphere

LTE vs NLTE line formation

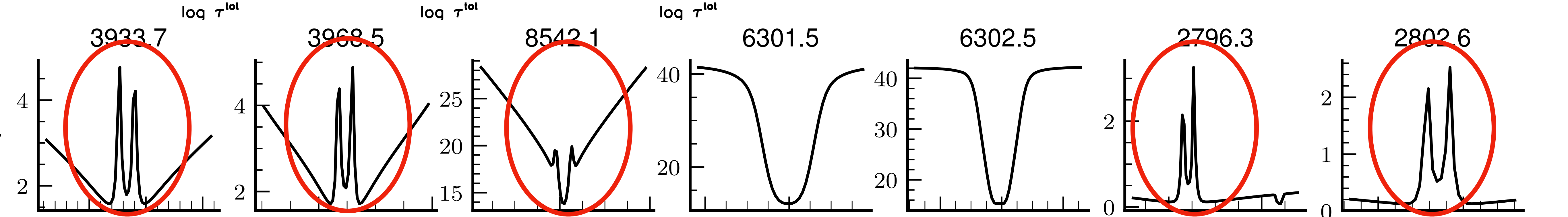
Reproduced from Rutten (2003)



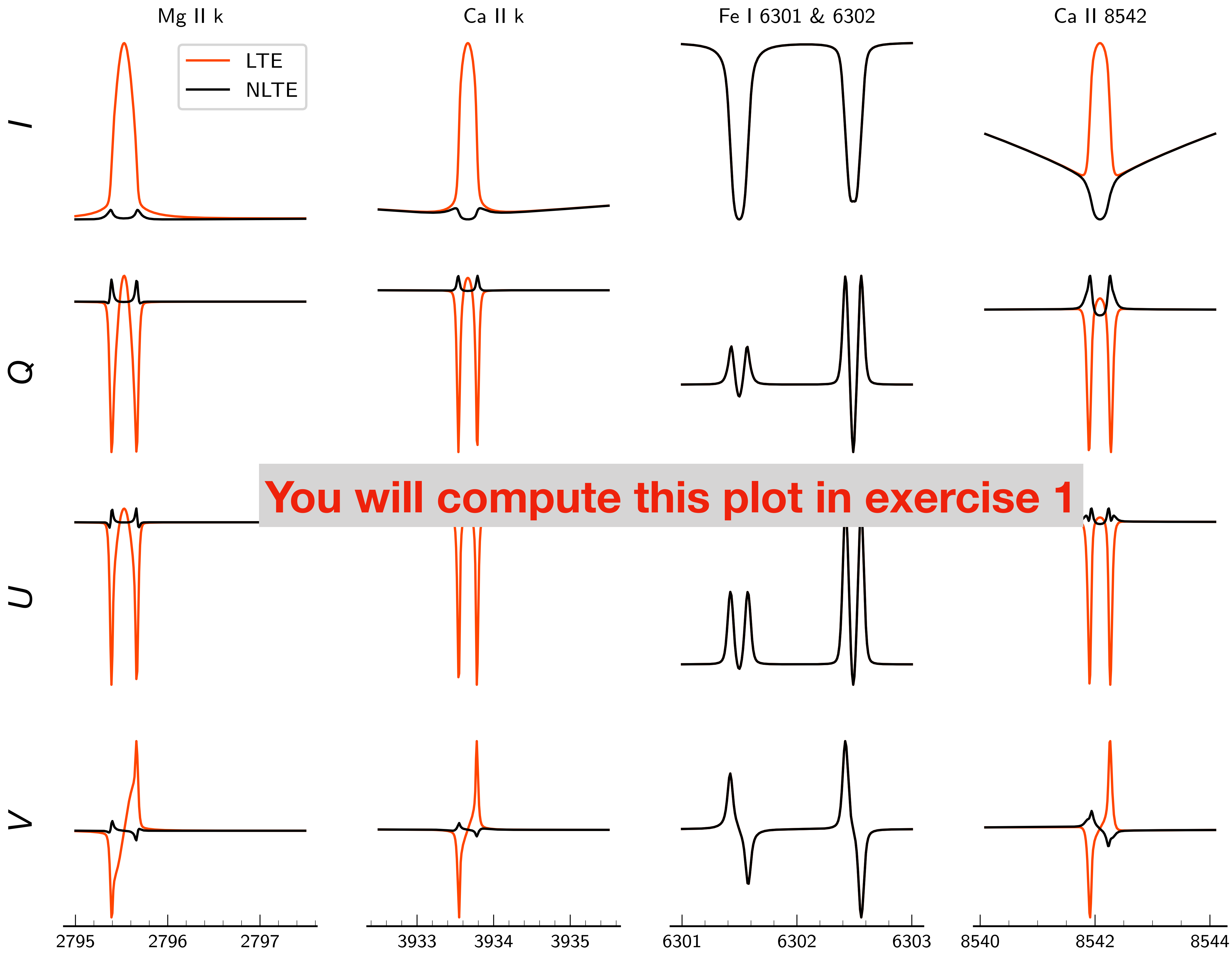
In the photosphere: $S = B = J$

Somewhere in the upper photosphere they decouple: thermalization-depth.

This process is line dependent (η, ϵ)

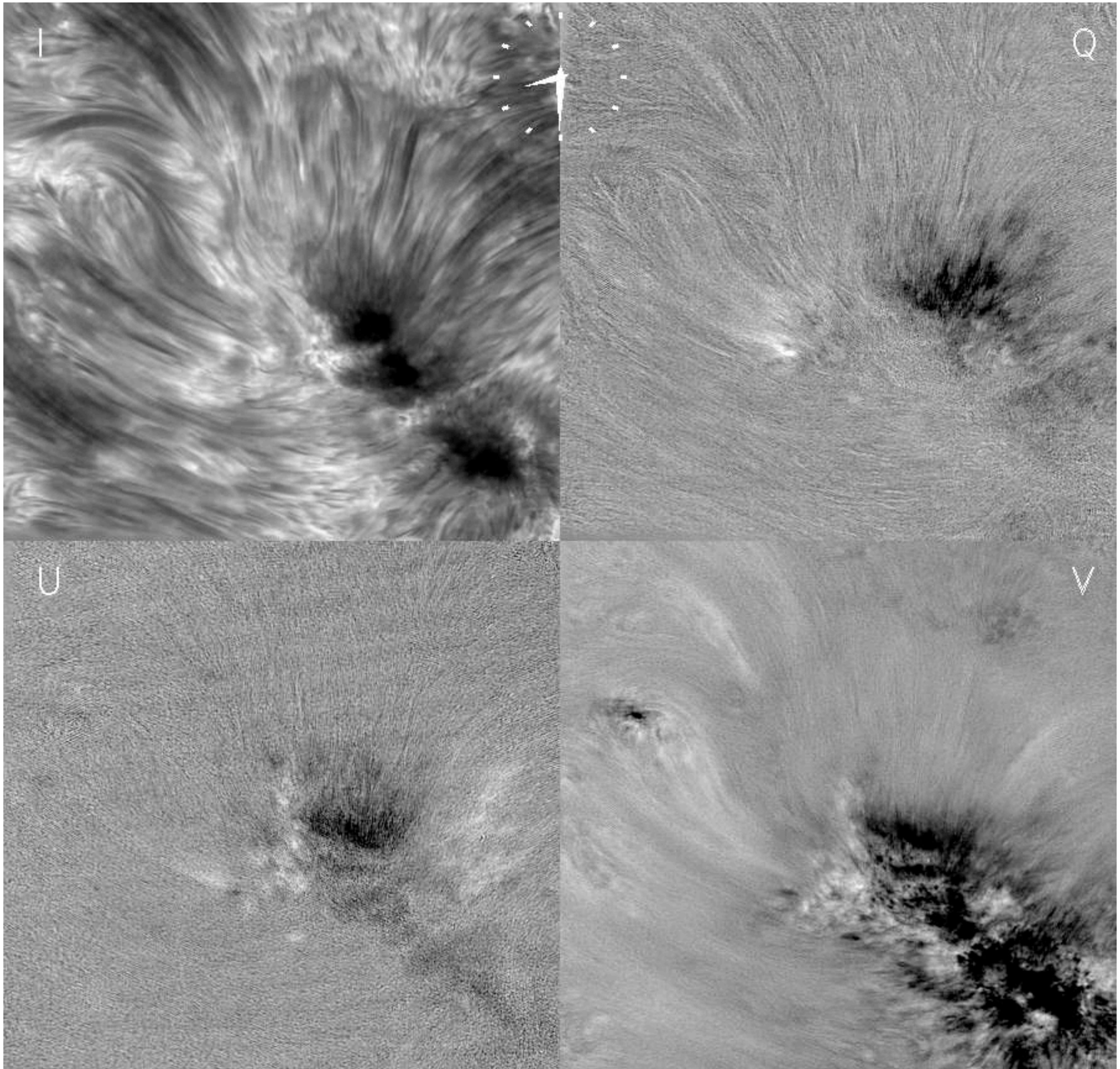


LTE vs NLTE line formation



You will compute this plot in exercise 1

How can we change the polarity of Stokes V?



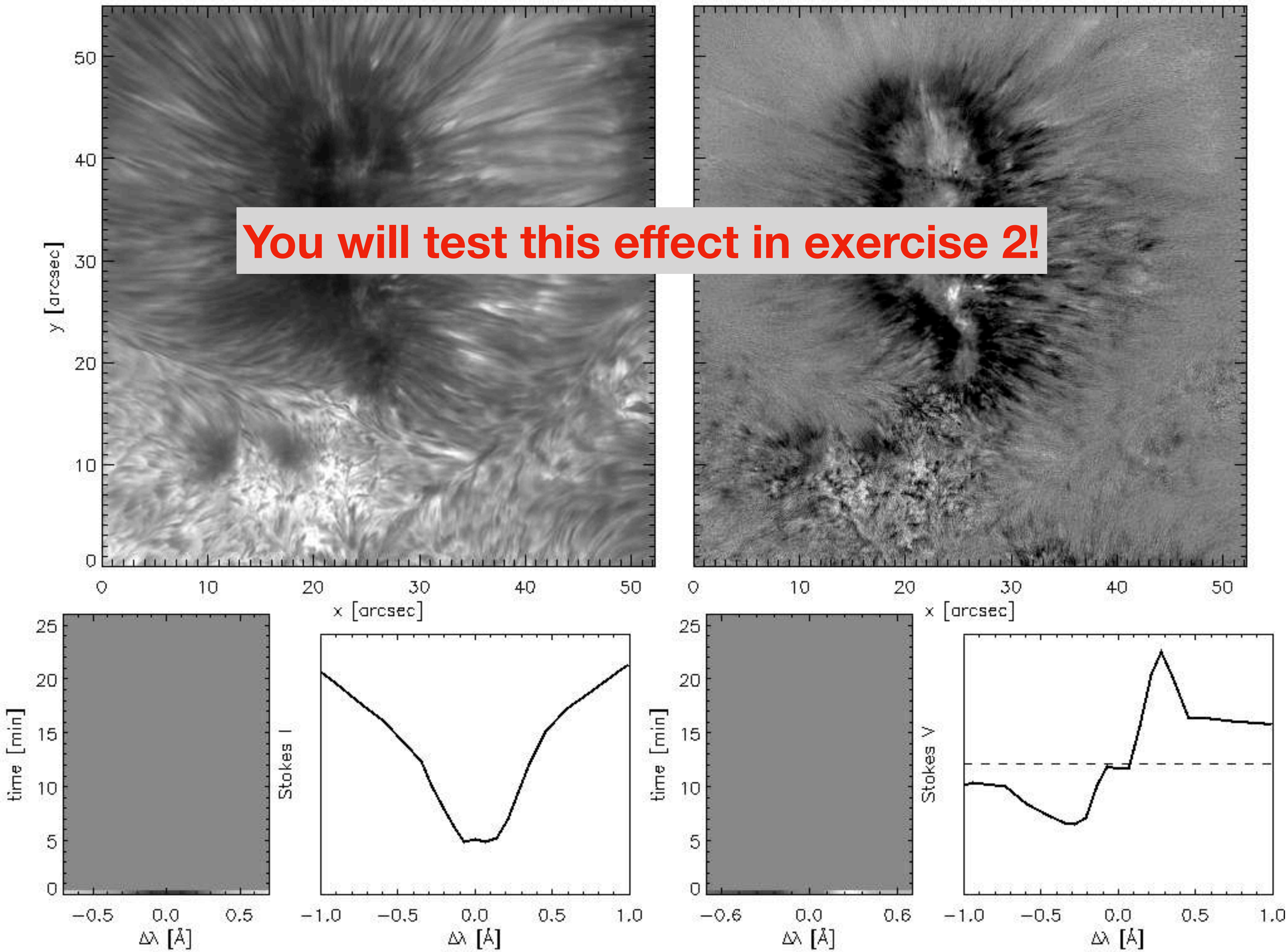
- $\boldsymbol{B}$
- η_0
- $\dfrac{\mathrm{d}S}{\mathrm{d}s}$

$\Delta\nu_D, v_{\mathrm{l.o.s}}, \ldots$

How can we change the polarity of Stokes V?

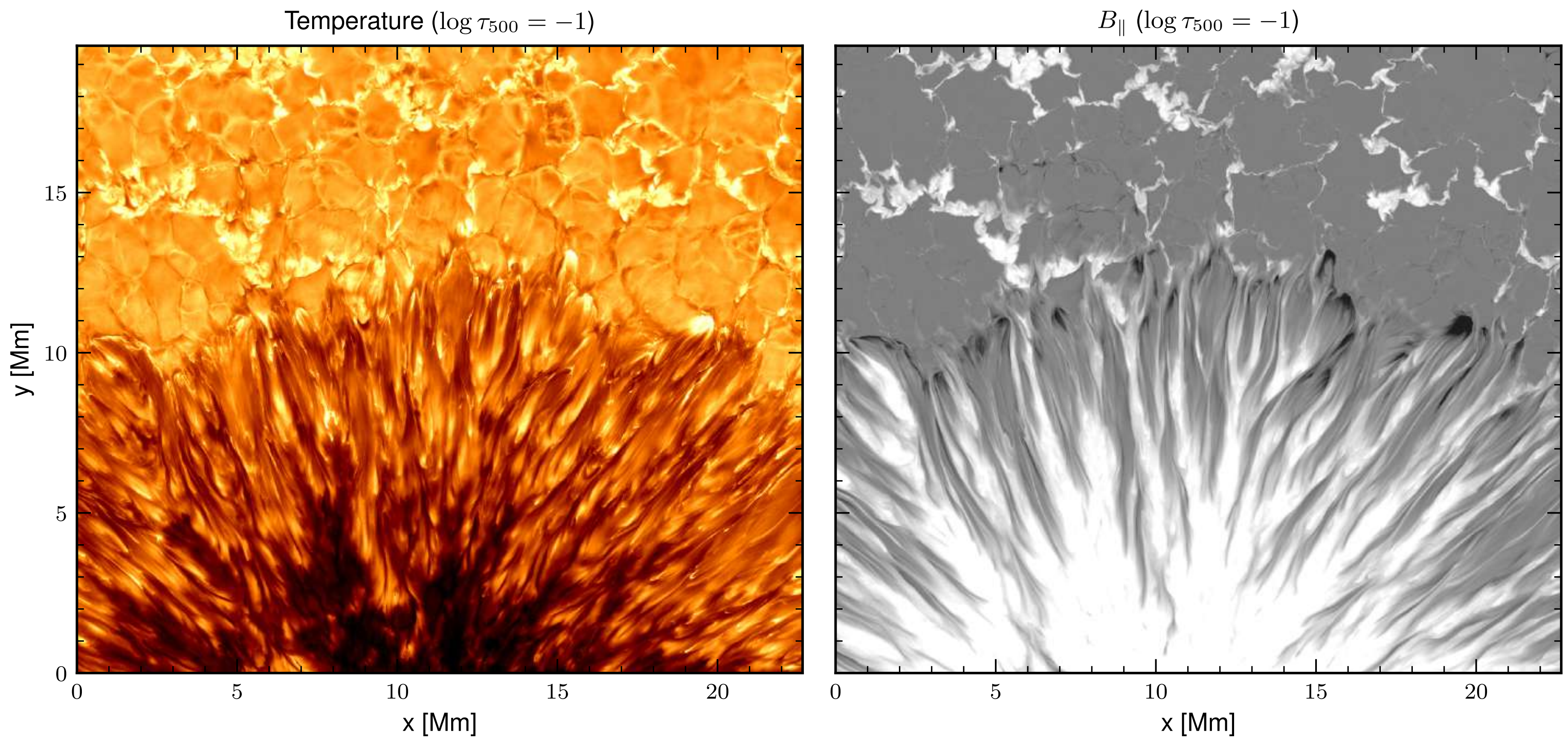
In this case, we can fit the observations with a *constant* $\boldsymbol{B}$ (over time) and a varying source function

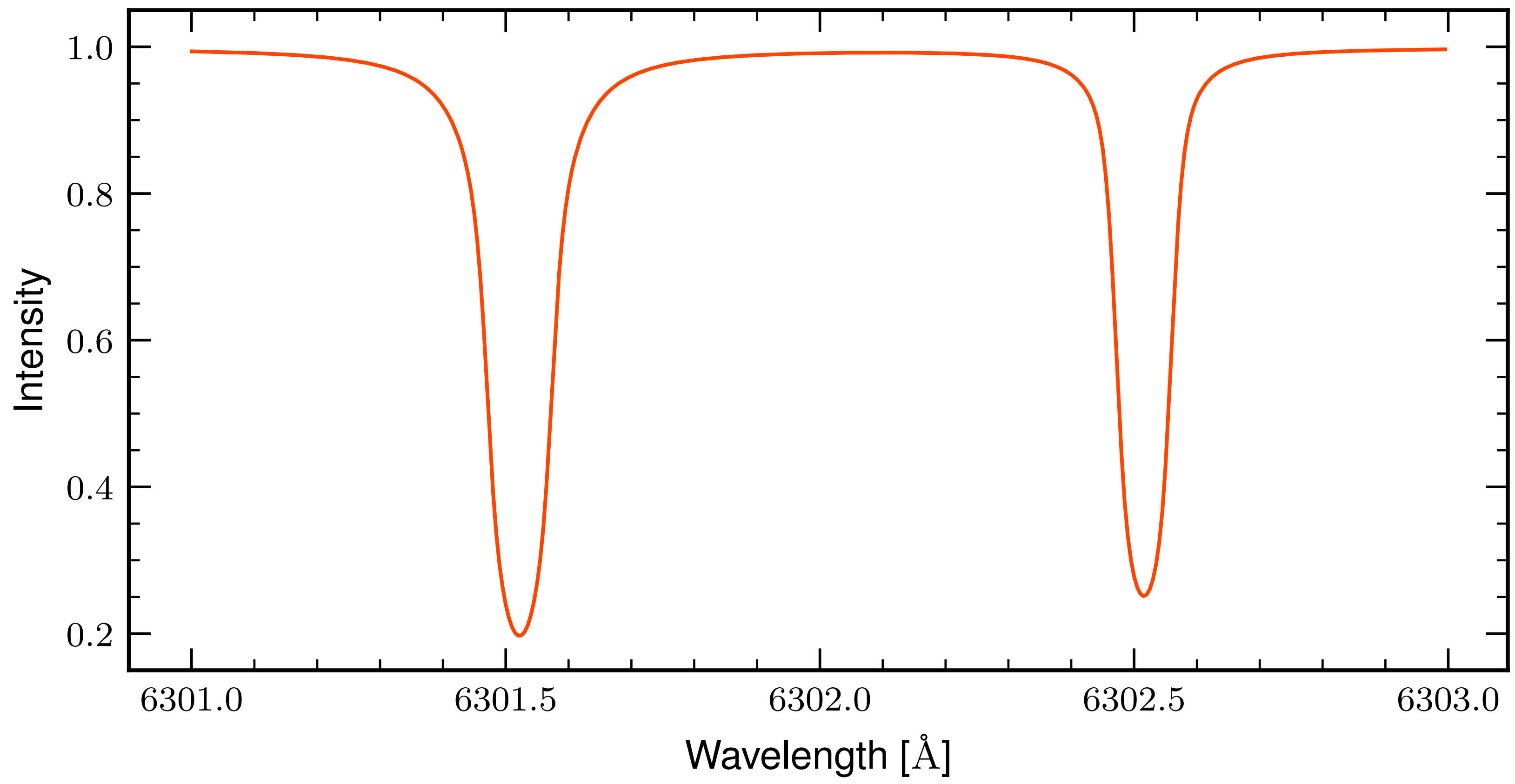
You will test this effect in exercise 2!



How can we change the polarity of Stokes V?

Why don't we see that effect (in an obvious manner) in the photosphere?





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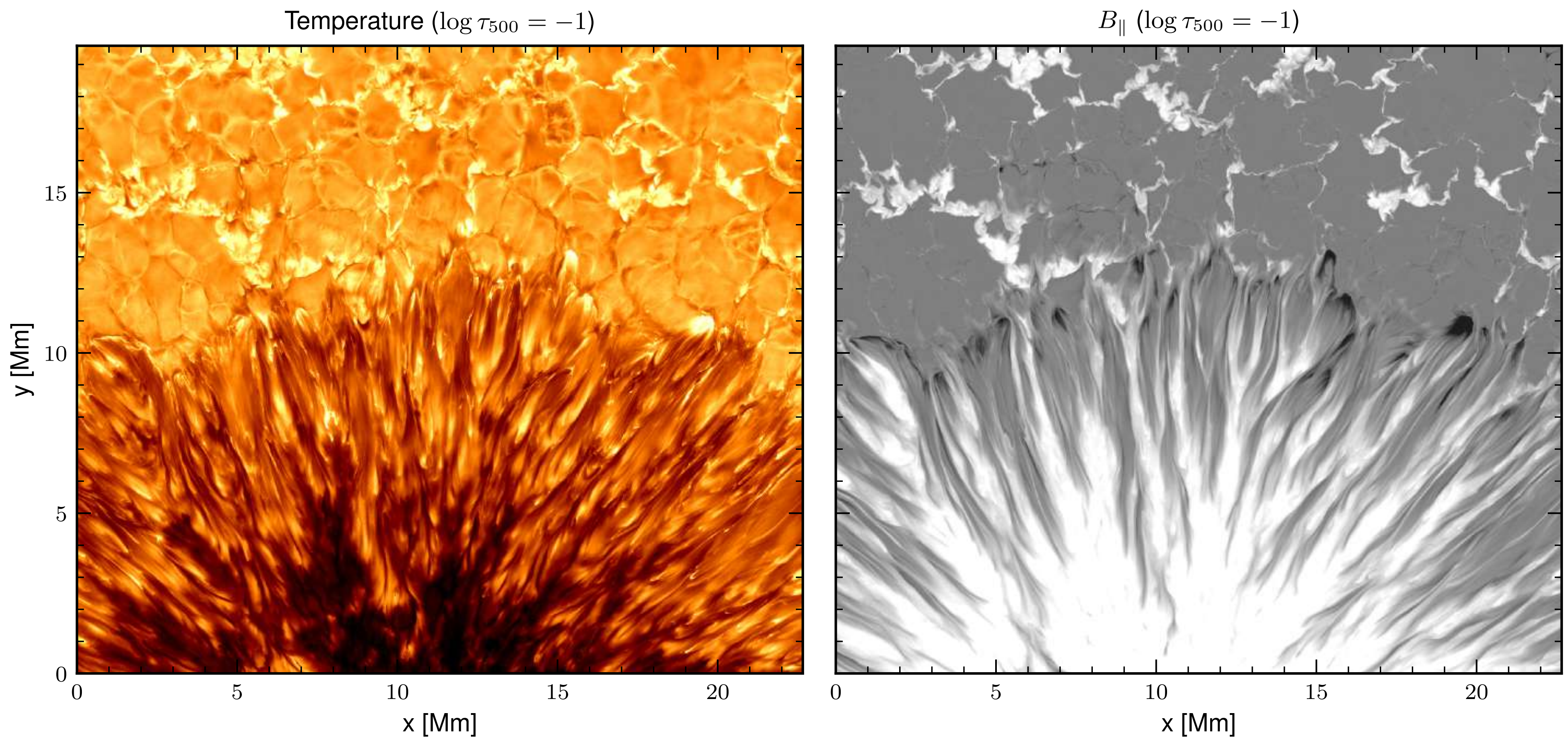
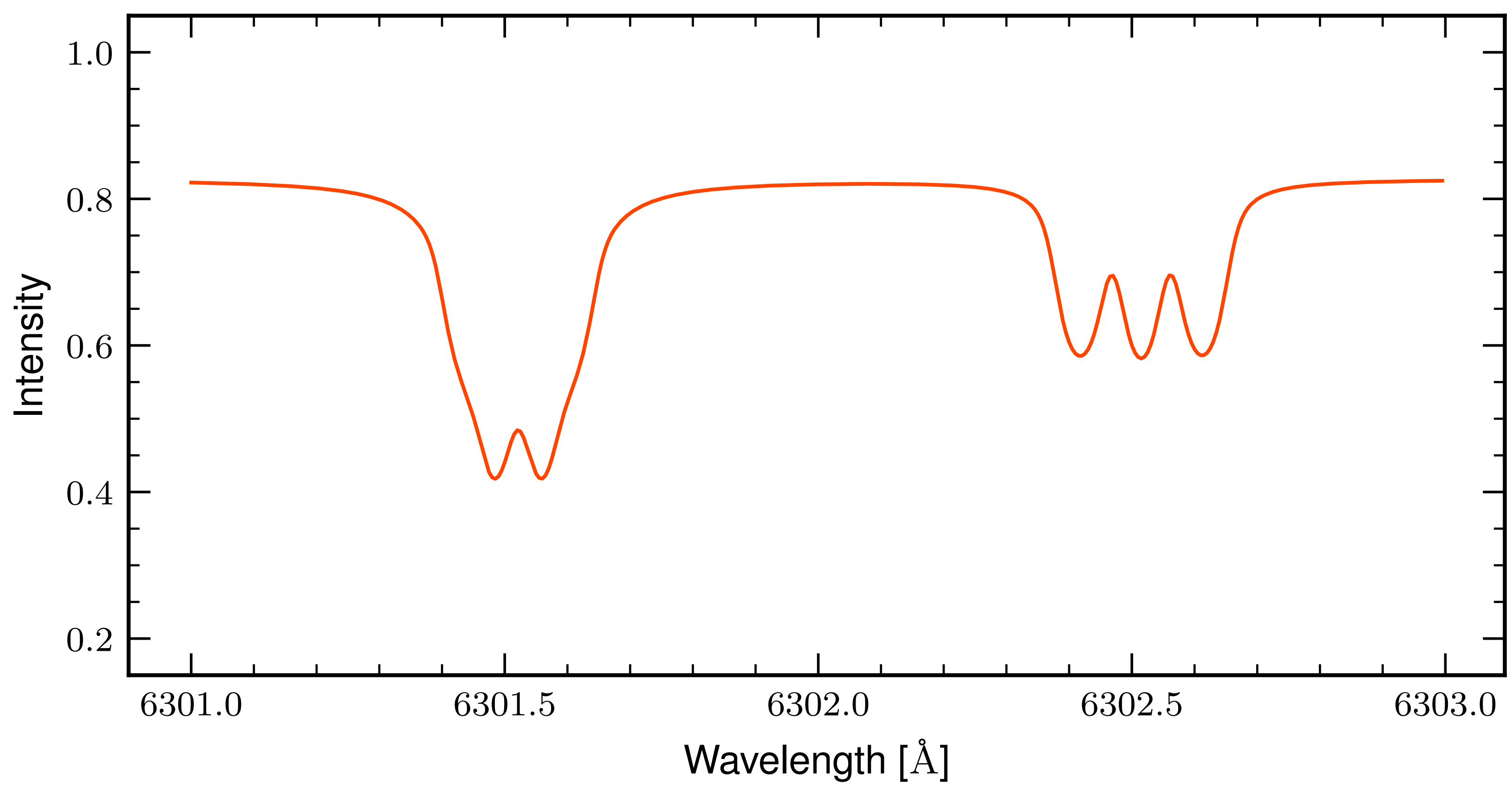




NLTE electron densities in the chromosphere

Electrons are the main source of collisions: they move fast (low mass) and there are many!

Each element contributes to the electron density depending on the ionization degree

In the photosphere collisional rates are large: we can assume LTE in most situations

Saha: $$\frac{n_z^{r+1}}{n_z^r} = \frac{1}{n_e} \frac{2U^{r+1}}{U^r} \left(\frac{2\pi m_e kT}{h^2} \right)^{3/2} \mathrm{e}^{-\chi_r/kT}$$

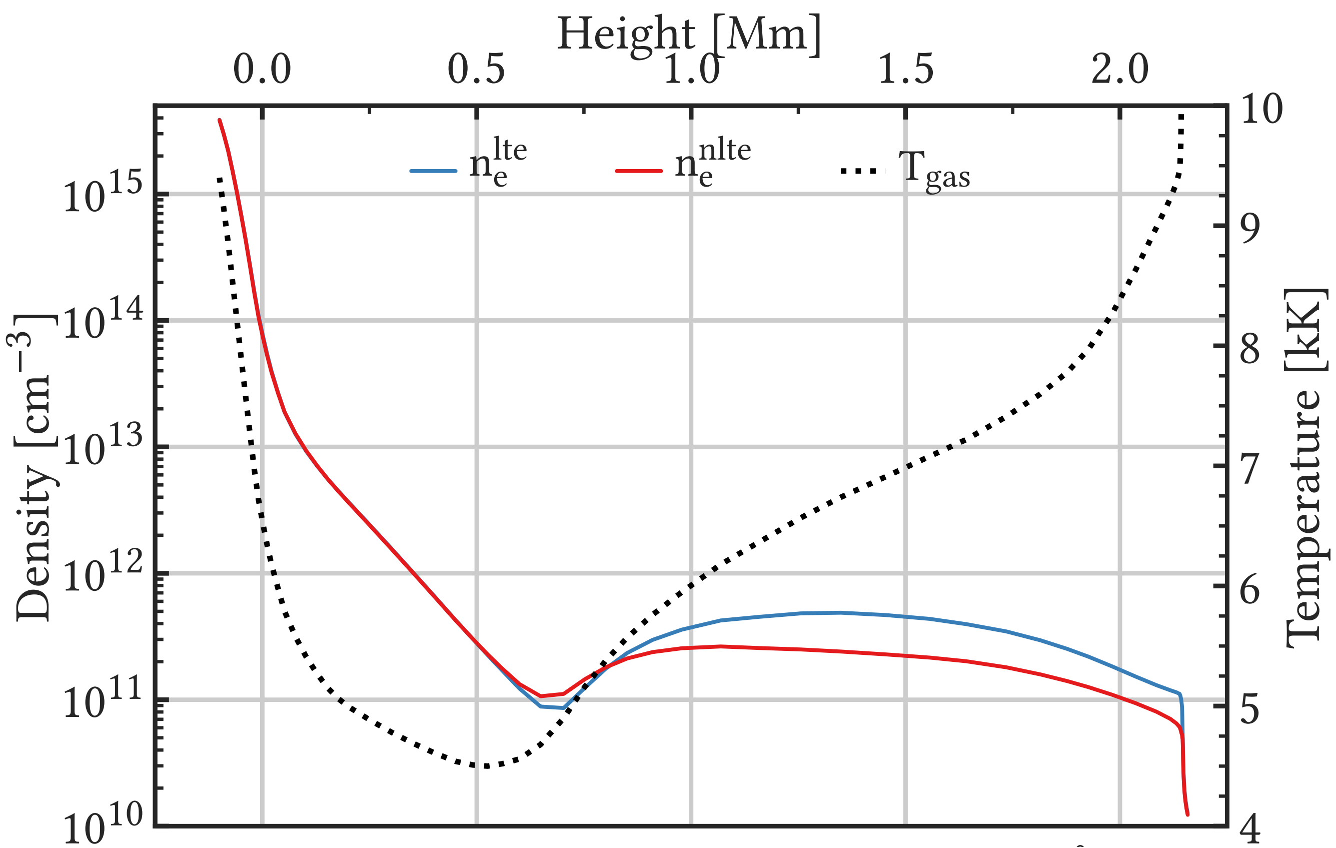
$$n_e = \sum_z \sum_{r>1} n_z^r$$

We can compute how many electrons come from each element and iterate n_e.

NLTE electron densities in the chromosphere

In the chromosphere the main electron donor is hydrogen, which cannot be modelled in LTE.

Bjørgen 2019, PhD thesis



By assuming n_e^{LTE}, we overestimate/ underestimate collisional rates and also the coupling to the local conditions

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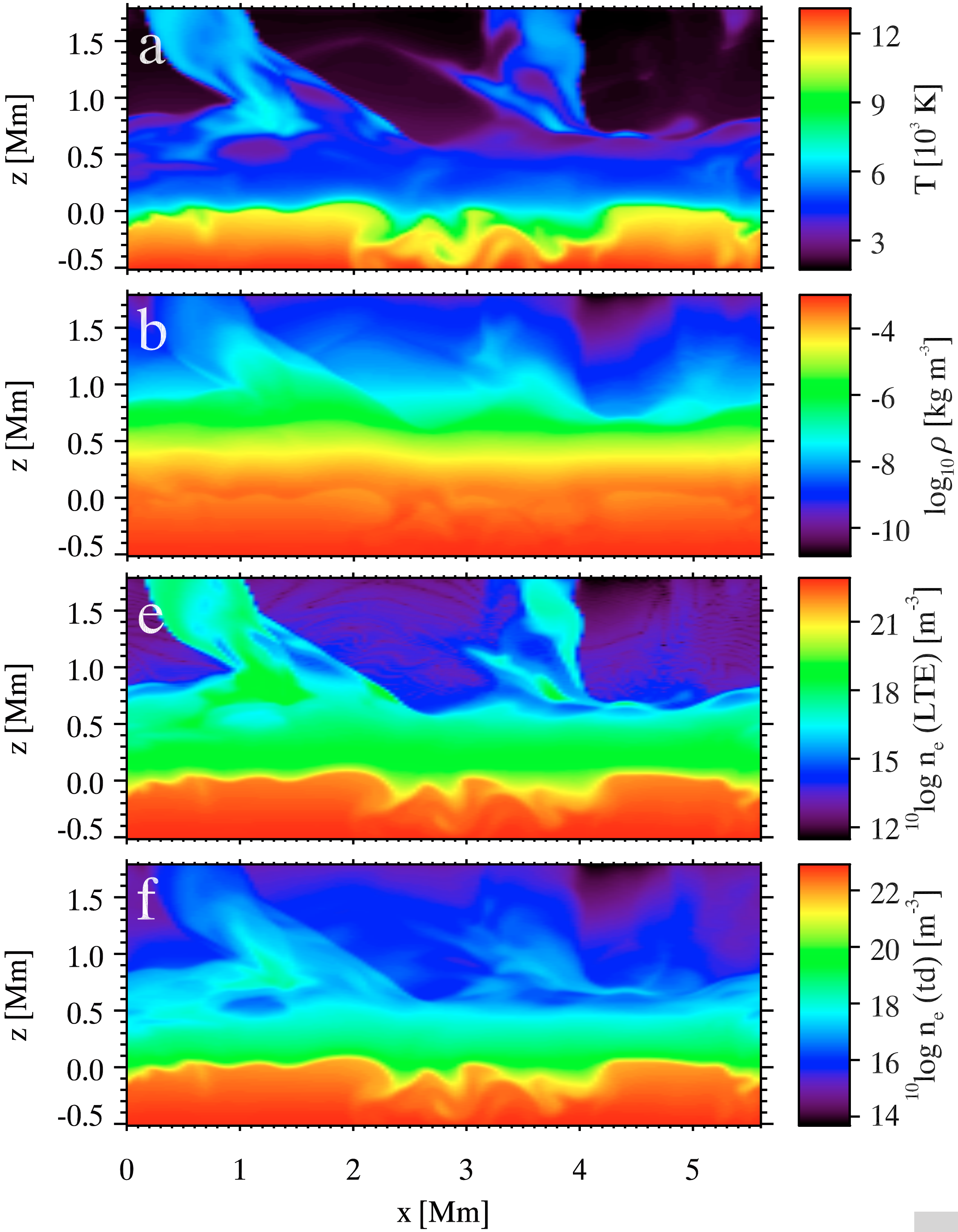

Leenaarts & Wedemeyer-Böhm (2006)

In fact, statistical equilibrium is not sufficiently good in the chromosphere to explain H ionization: time evolution must be accounted for!

Remember the rate equations:

$$\frac{\mathrm{d}n_i}{\mathrm{d}t} = \text{rates into level } i - \text{rates out of level } i$$

$$\sum_{j,j\neq i} n_j P_{ji} - n_i \sum_{j,j\neq i} P_{ij} \neq 0$$

However if we don't have time information we can only assume statistical equilibrium

We can include H as an active NLTE atom and recompute its contribution to the electron density after each NLTE iteration.

You will test this effect in exercise 3

To take home

- In the chromosphere the dramatic time variability observed in Stokes V can be explained with a *relatively* constant magnetic field vector over time.

- NLTE electron densities have a large impact in the chromosphere as they affect collisional rates of the atom under consideration.