# Stellar Spectra B: LTE Line Formation

November 9, 2015

**3: Spectral lines from the solar atmosphere: Na $D_1$ in LTE**

In order to compute the spectral profile for Na $D_1$ from the FALC solar model, we need to calculate the extinction $\alpha_\lambda^l$ (eq. 14 in SSB) as function of height:

$$\alpha_\lambda^l = \frac{\sqrt{\pi}e^2}{m_e c}\,\frac{\lambda^2}{c}\,\frac{n_l^{\rm LTE}}{N_{\rm Na}}\,N_{\rm H}A_{\rm Na}\,f_{lu}\,\frac{H(a,v)}{\Delta\lambda_{\rm D}}\left[1-{\rm e}^{-hc/\lambda kT}\right]$$

- Saha-Boltzmann give $n_l^{\rm LTE}$, see Fig. 1.

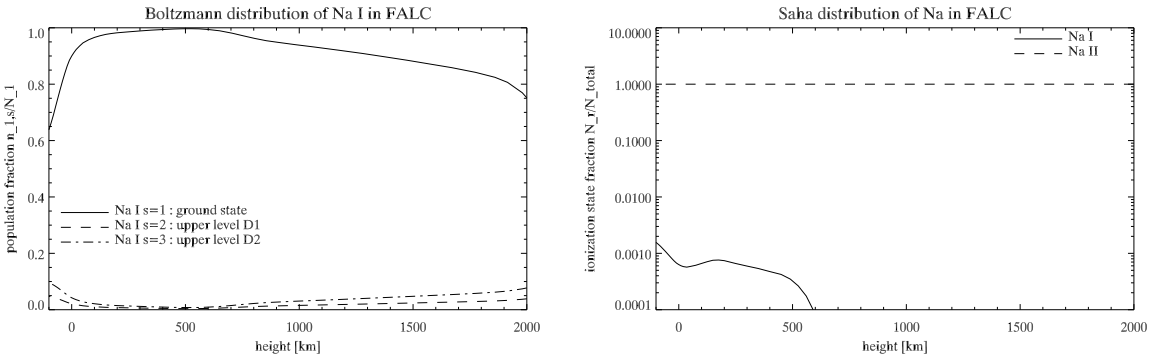


Figure 1: *Left:* Boltzmann distribution for 3 levels in FALC. *Right:* Saha distribution for Na in FALC.

- The Dopplerwidth $\Delta\lambda_{\rm D}$ includes both thermal broadening and micro-turbulence $v_t$: $\Delta\lambda_{\rm D} \equiv \frac{\lambda_0}{c}\sqrt{\frac{2kT}{m_{\rm Na}}+v_t^2}$ (Fig. 2).

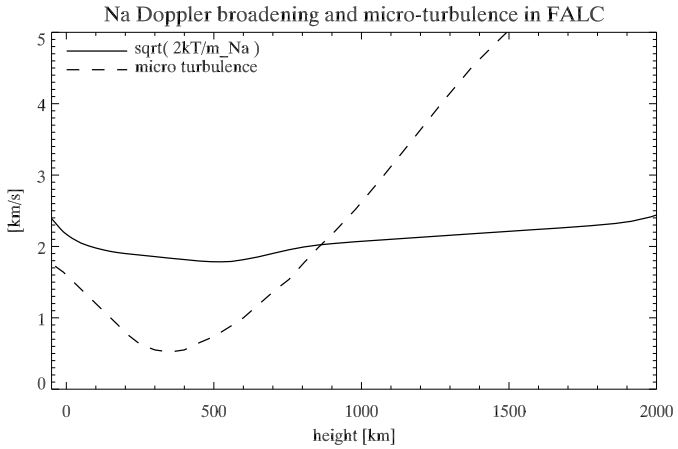


Figure 2: Thermal Doppler broadening and micro-turbulende in FALC.

- We only consider Van der Waals broadening for $\gamma$ that enters the damping parameter $a$ in $H(a,v)$ (see eq. 21). Figure 3 compares van der Waals broadening (using Unsöld's recipe) with natural broadening($\gamma_{\rm rad}$) and quadratic Stark broadening ($\gamma_{\rm Stark}$) from collisions with electrons and ions (data from the Vienna Atomic Line Database). Stark broadening can safely be ignored, natural broadening becomes important in the upper parts of the atmosphere but the impact on the emergent line profile is limited.

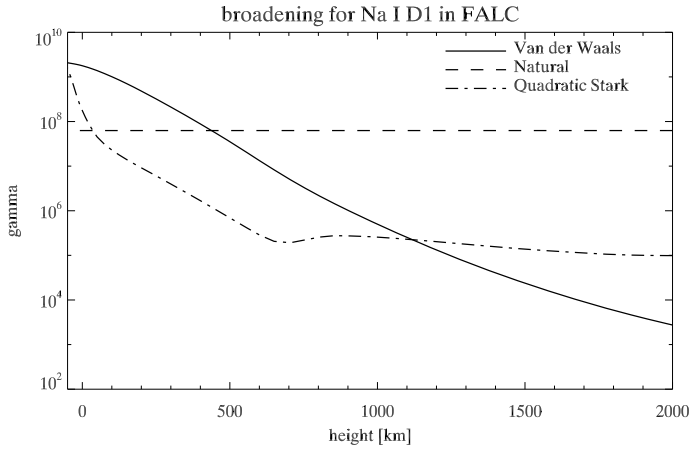


Figure 3: Different broadening agents in FALC.

- Figure 4 shows IDL's `voigt(a_voigt, v_voigt)` in FALC, this is basically what is $H(a, v)$ in eq. 14. The damping wings become weaker for decreasing density with increasing height.

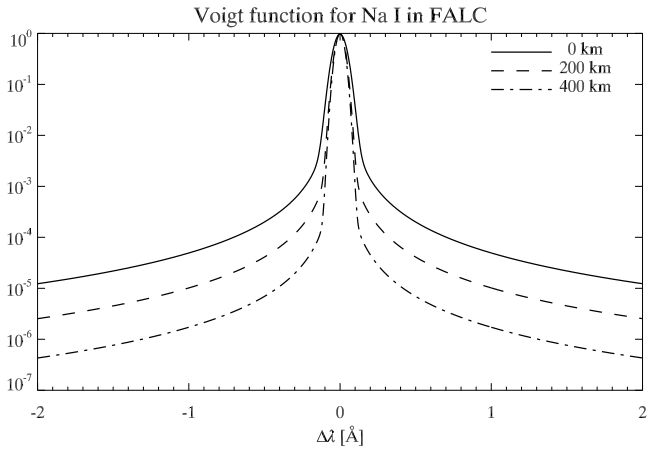


Figure 4: IDL's voigt function in FALC.

- The correction term for stimulated emission $[1 - \mathrm{e}^{-hc/\lambda kT}]$ is nearly constant in FALC (Fig. 5).
- All terms combined and all constants in the right units should give the extinction that is needed to give an absorption profile with a central reversal like in Fig. 8. Figure 6 compares the continuum extinction with the line extinction.

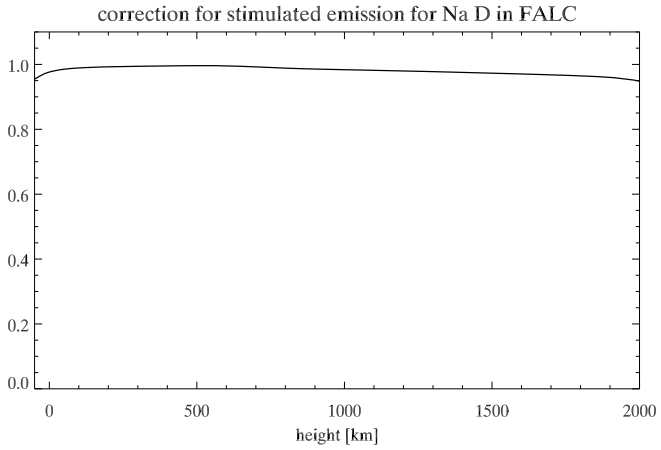


Figure 5: Correction term for stimulated emission $[1 - \mathrm{e}^{-hc/\lambda kT}]$ in FALC.

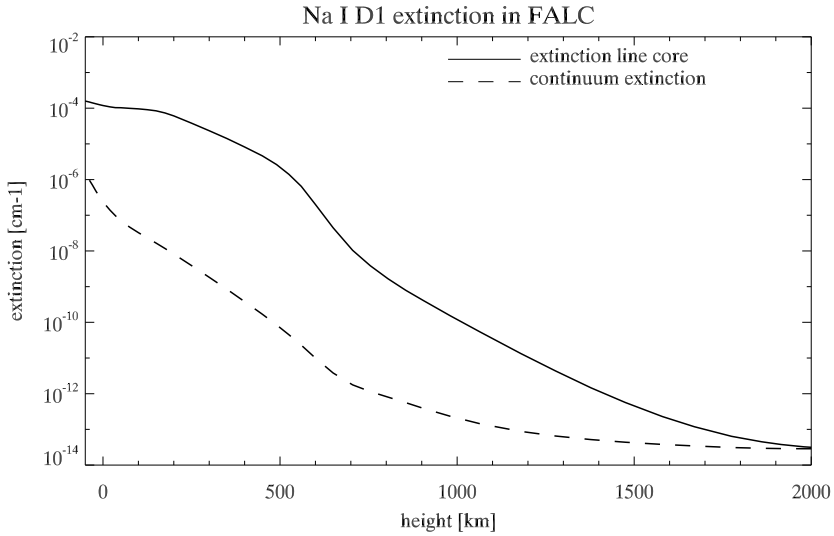


Figure 6: Na $D_1$ line extinction (solid line) and continuum extinction (dashed line) in FALC.

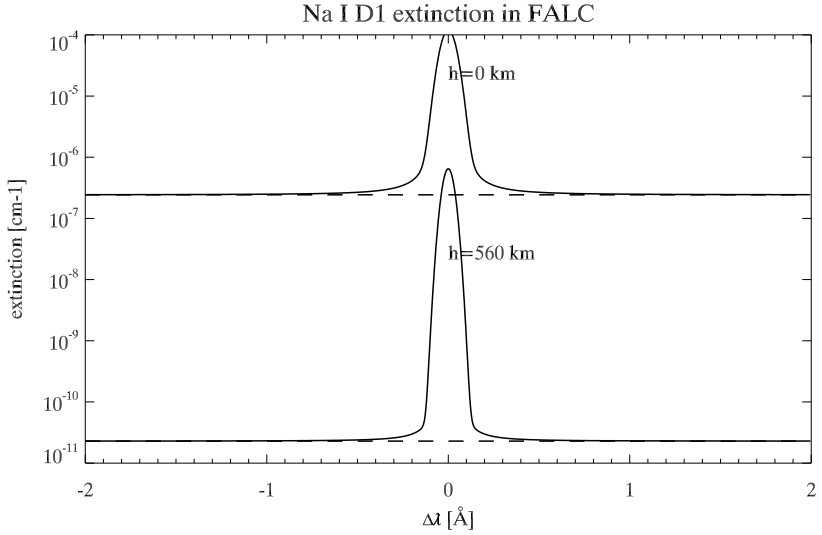


Figure 7: Na $D_1$ line extinction profiles for two different heights in FALC.

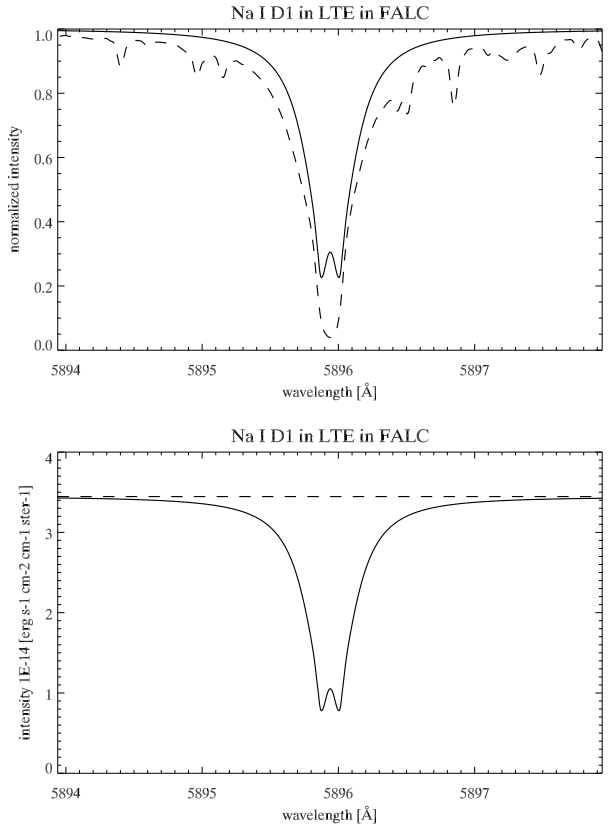


Figure 8: *Top:* The Na D1 LTE line profile in FALC using the Unsöld recipe for Van der Waals broadening (solid line). The dashed line is from the FTS atlas. *Bottom:* The Na D1 LTE profile in FALC in absolute intensity units.