ASTR 545
Homework 5

1. Consider the sources of continuum opacity per neutral hydrogen (stimulated emission correction inclusive) in stellar atmospheres:

$$\kappa^{\rm H}_{\rm bf},\ \kappa^{\rm H}_{\rm ff},\ \kappa^{\rm H^-}_{\rm bf},\ \kappa^{\rm H^-}_{\rm ff},\ \text{and}\ \kappa({\rm e})$$

   (a) What is the H^- ion and what is the numerical value of its binding energy and partition function?

   (b) Derive the final n_e and T dependence (scaling) of each of the above opacities. Do not worry about physical constants, etc., simply provide the scaling. As an example, consider the Saha Equation:

$$N_1/N_0 \propto n_e^{-1} T^{3/2} \exp\{-C/T\}\,.$$

   (c) Draw the n_e–T plane (numerical axes are not required) and broadly define regions as designated by the dominant continuum opacity in this plane. For each region, provide a rough estimate of the range of stellar spectral and luminosity classes for stellar atmospheres (this should be intuitive, I am not looking for high accuracy here).

2. The bound–free absorption coefficient per neutral hydrogen is

$$a^{\rm H}_{\rm bf}(\lambda, T) = a_0 \lambda^3 \left[\sum_{n=1}^{\infty} \frac{g_{\rm bf}(n,\lambda)}{n^3} \exp\left\{ -\frac{\chi_{n,0}}{kT} \right\} \right],$$

   where $g_{\rm bf}(n,\lambda)$ is the bound–free Gaunt factor.

   (a) Given that $a^{\rm ion}_{\rm bf}(n,\lambda)$ per ion in excited state n scales as n^{-5}, explain why $a^{\rm H}_{\rm bf}(\lambda,T)$ per neutral hydrogen scales as n^{-3} and with $\exp\{-C/T\}$.

   (b) Compute $a^{\rm H}_{\rm bf}(\lambda,T)$ over the wavelength range 1 Å to 1.6 μm for $1 \leq n \leq 4$ for the temperatures $T = 3000$, 6000, $10{,}000$, and $20{,}000$ K. Plot the four curves and discuss the relative contribution and wavelength behavior to the H bound–free continuum opacity from each n level for each temperature.

   (c) Hand in any codes you wrote and your final plot.

3. Using the routine CPF12 (available on the web page), generate Voigt absorption line profiles for the Fe II λ2600 transition and for the Fe II λ2374 transition over the column density range $11 \leq \log N(\text{Fe II}) \leq 15$ [atoms cm^{-2}] in steps of 0.5 for the temperatures $T = 5000$, $10{,}000$, and $20{,}000$. The atomic constants for Fe II λ2600 are $\lambda_0 = 2600.1729$ Å, $f = 0.2239$, and $\Gamma = 2.70 \times 10^8$ s^{-1}. The atomic constants for Fe II λ2374 are $\lambda_0 = 2374.4612$ Å, $f = 0.02818$, and $\Gamma = 2.99 \times 10^8$ s^{-1}.

   (a) At each N(Fe II) overplot the Fe II λ2600 profiles (flux versus wavelength) for each T. Plot this on a single page placing each N in a separate panel. Make the same plot for the Fe II $\lambda 2374$ profiles. Which transition is the stronger of the two? What atomic constant is primarily responsible for the relative strengths between the two Fe II transitions? Describe how the profile shapes change with T as N increases. What physically governs this behavior?

(b) For the Fe II $\lambda 2600$ transition, measure the equivalent widths, W, [in Å] and overplot the curves of growth, i.e., $\log W$ vs. $\log N(\text{Fe II})$, for each T on a single graph (and label the curves by temperature). From your plot, describe the regimes of the curve of growth and how temperature changes W in these regimes.

(c) Compute the thermal Doppler b parameter, b_{th}, for Fe II for each temperature in km s^{-1}. For each temperature, what is the thermal b parameter for hydrogen? If you were to compute absorption profiles for hydrogen, would you predict they are broader or narrower than the Fe II profiles? Explain.

(d) Hand in any codes you wrote and your final plots.