Homework 2

Part 1: Using the Saha and Boltzmann Equations

Get started on your program by setting up the initial statements. You will be running the Saha equation and calculating the log10 of the number of *ionized versus neutral hydrogen atoms*. This uses the two provided model atmospheres, needing only the temperature and log10 of the electron pressure for a given layer.

The Saha equation to be solved, which has been rearranged a bit from what is in your book, is:

$$\log_{10}\left(\frac{N_{II}}{N_I}\right) = \log_{10}\left(\frac{Z_{II}}{Z_I}\right) + \log_{10}(2) + \frac{5}{2}\log_{10}(T) - \chi_{ion}\Theta - \log_{10}\left(P_e\right) - 0.4772$$

$\Theta = 5040/T\ [K]$

This is called the “inverse temperature”. It is a classical spectroscopic shorthand (though still used today in the literature), and folds in the Boltzmann constant in units of [eV/K].

$\chi_{ion} = 13.595$ [eV]

This is simply the ionization energy of Hydrogen.

The 2 files you need are: `sun-atmosphere-kamp.txt`, and `vega-atmosphere-kamp.txt`, which Prof. Agol obtained from the NLTE program. Each file represents a model stellar atmosphere, and contains the electron pressure and inverse temperature at different depths or layers within the star. The first row of each file is a list of Θ values, the second row is a corresponding list of $\log_{10} P_e \left[erg\ cm^{-3}\right]$. These are what is needed for the Saha equation above.

(5pts)

You must determine the partition functions for ionized (Z_{II}) and neutral H (Z_I). Review Carroll and Ostlie, Ch 8.1 carefully. State clearly what your partition function ratio is and why.

(20pts)

Your program should:

- Read-in rows of data from both files (together or separately).
- Solve the Saha equation for each layer (i.e. each column of the provided files)
- Create two graphs (or one over-plot, with clear labeling):
    - One showing the $\log_{10}(N_{II}/N_I)$ versus temperature for a Sun-like star.
    - One showing the $\log_{10}(N_{II}/N_I)$ versus temperature for a Vega-like star.

Part 2: Hα Absorption versus Temperature

Recall, stellar spectral type letters were originally determined using the Hα absorption line strength. However, Annie Jump Cannon famously determined the "correct" order with surface temperature that is still in use today (OBAFGKM).

Your goal here is to recreate Figures 8.7, 8.8, and 8.9 in Carroll and Ostlie (2nd ed), which explain why A stars have the strongest Hα absorption based on their T_{eff}. For reference, Appendix G in Carroll and Ostlie gives general properties (including surface temperature) as a function of spectral type for main sequence (class V) stars.

Follow the book's assumption of a fixed electron pressure of P_e = 20 N/m^2. I would suggest reusing the simplified Saha equation from Part 1, assuming the fixed electron pressure (but mind the units). Evaluate each graph using a range of temperatures from at least 5000 to 25000K in 1K increments.

(15pts) Recreate Fig 8.7, showing $N_2/(N_1 + N_2)$ as a function of Temperature.

(15pts) Recreate Fig 8.8, showing N_{II}/N_{total} as a function of Temperature (note the simplifying assumptions that the book makes!)

(15pts) Recreate Fig 8.9, showing N_2/N_{total} as a function of Temperature. Since electrons must be in the first excited state to undergo Balmer absorption, this ratio gives the fraction of atoms that are available to produce Hα absorption (n=2 to n=3) in the atmosphere.

Turn in your write-up, including the labeled plots, as a PDF. Remember to include an attribution for any group work! Also turn in your code or Jupyter Notebook used to solve the assignment. Note: we'd like to be able to run your code to check that it actually works, so be sure (if using Jupyter notebooks) to check that it runs "top down"!

Use the Dropbox upload link. **DUE: Jan 19, 11PM PST**