Homework 4

Should be submitted as a single Jupyter notebook file (.ipynb) to the course Moodle site by midnight on Monday, February 27.

1. Photons created by fusion reactions in the core of the sun do not travel freely through the overlaying layers, but in fact travel only a very short distance before being absorbed by a proton (hydrogen nucleus) and reemitted in a new, random direction[1]. The process by which photons are absorbed and reemitted in the dense sun is described mathematically by a "random walk" process governed by the equation: $d = \sqrt{n} \times \ell$, where d is the total straight line distance traveled, n is the number of interactions, and ℓ is the so-called "mean free path" of a photon, which is the average distance a photon can travel between interactions. The mean-free path in the sun ranges from 0.01cm in the core to 0.3cm in the outer layers, but 0.1cm is a reasonable single-number approximation.
    a. How many times farther does a photon travel in the course of escaping the sun than it would if it could fly straight out (hint: what is the straight line distance it needs to travel to escape the sun?)?
    b. How **long** does it take a photon to escape the sun and how far away could the photon have traveled in that time if it were able to fly straight out of the sun without interacting with anything? Put that number in context relative to something else (e.g. "halfway out of our solar system", "all the way to Alpha Centauri", etc.).
    c. Stars more massive than the sun are both larger and denser. Make an argument for how much longer it should take a photon to escape a star that is twice as large and three times as dense (hint: what property will density affect?).
2. Using the skills that you learned in your labs this week:
    a. Read in and plot the spectra of all seven of the stars provided with this homework (each in a separate file). The files are .csv files with two columns. The first is wavelength in units of nm, and the second is Flux in units of erg/cm^2/s/Hz/sr. Use what you've learned in class to translate this to Joules/m^2/s/nm. Recall that to get rid of the sr (steradians), you just need to multiply by pi. Make one plot showing the spectra of all seven stars with appropriate line colors, labels, legend, etc.
    b. Find the peak of each spectrum and use this to determine the temperature of the star. Label each star in the legend with its temperature.
    c. Overplot thin red vertical lines at the wavelengths corresponding to the Balmer series of Hydrogen, whose wavelengths can be calculated with the formula below, where n=3, 4, 5, 6, 7, 8, 9.

[1] note: this process is very different from what we have been calling "atomic emission" because it takes place in a hot and extremely dense medium. Protons under these conditions can absorb photons with arbitrary energies, not just the

$$\lambda = 3.6450682 \times 10^{-7} m \left(\frac{n^2}{n^2 - 4} \right)$$

d. Write a paragraph describing the strength of Hydrogen absorption lines as a function of temperature in stellar spectra.