Topics: Stellar atmospheres, part 1: application of radiation transport, plus spectral line broadening

Reading:

- LeBlanc, Ch. 4 (the first half, from the beginning (p. 109) through the end of the discussion of line broadening mechanisms, on p. 132 – the boxed material on the Zeeman effect) – however, let's *skip* the special topics box on pp. 114-15. *Do* read all the other special topics material in that range of pages, though.
- A few pages (pp. 276-78) from Ostlie and Carroll's textbook: on the diffusion (random walk) of radiation (pdfs available on the website).

Summary of work to be produced:

- Hand in your solutions to the warm-up questions (QW1, QW2, and QW5) by Thursday at 12:30 pm in the box on the wall outside my office.
- Bring solutions to seminar on Friday for all the (non-warm-up) numbered problems. Bring a xeroxed copy to give to me at the beginning of class, and expect to take notes on your original solutions.

Scope: Now that we have some understanding of radiation transport – as well as atomic transitions and level populations, as well as blackbody physics – we can apply that knowledge to modeling stellar atmospheres and interpreting observations of them. Given what we've done the past two weeks, you should be able to take a pre-determined temperature and density vs. depth in a star's (plane-parallel) atmosphere and compute the emergent intensity as a function of viewing angle. From that you could do things like compute the flux you'd observe from the star at a given wavelength.

However, we of course don't know the temperature (and density) structure of the atmosphere of a star ahead of time, and to make matters more complicated, the way that radiation propagates through the atmosphere influences the physical properties of the atmosphere (i.e. the specific intensity as a function of depth, $I(z)$, *affects* the temperature – if opacity is high and radiation gets "trapped" in a given region, that region will get hotter). So, atmosphere modeling is complicated! We will do a little bit of basic work understanding the process, looking at the *grey atmosphere* – one where the opacity has no wavelength dependence – and at limb darkening.

Questions etc.:

Remember: your written answers are required only for numbered, bold-faced questions and the extent of each question is just the paragraph with the bold-face label. There are unnumbered questions between some numbered questions. Come prepared to answer/discuss these, but no need to hand anything in.

Please read the beginning of Ch. 4, through the top of p. 114, very carefully. I would like to go over this material in great detail in class – with student-led discussion. You may/will want to flip back to Ch. 3 as you're reading this new material.

QW1 Problem 4.1. Fundamental expressions for J and K from Ch. 3 would be useful here. In fact, it's a good idea to reread §3.8 and remind yourself that the Eddington approximation is a specific, simple relationship between J and K – this question is *not* referring to the Eddington *two-stream* approximation.

Q2 Problem 4.2.

Are you okay with the concept of *natural broadening* discussed on pp. 120-22? You can read more about it in our Astro 16 textbook, if you'd like. The widths and shapes of spectral lines provide a lot of useful information. Natural broadening is usually minimal but it is always present, so it's discussed first. Also, other important broadening mechanisms (e.g. pressure broadening) have the same Lorentzian profile shape that natural broadening produces.

QW3 Write some Python code (or code in another language) that plots a Lorentzian profile for a user-chosen value of the damping parameter. Consider making $(\nu - \nu_o)/(\Gamma/4\pi)$ the independent variable. What is the peak height of the function? Now also do problem 4.3 in LeBlanc. Please hand in your source code and a plot (if you use a Jupyter Notebook, the plot will be right there in the code) of one profile (make it clear what value you've used for the free parameter).

Q4 Do problem 4.4 (by hand) and also compute the fraction of the *area* under the Lorentzian that's within one full-width at half maximum (FWHM) of the peak (up to a half-width away in either direction). You may want to do this numerically (modifying the code you wrote for QW3).

Comfortable with the Maxwell-Boltzmann distribution (and what it means)? Carefully read how it, combined with the Doppler shift, leads to thermal line broadening with a Gaussian profile (top of p. 124).

QW5 Problem 4.5.

Q6 Write some code to plot a Gaussian line profile and overplot a Gaussian and Lorentzian line profile (i.e. two profiles on one plot) that have the same FWHM.

Q7 If two lines – one from hydrogen and one from iron – have the same Lorentzian damping parameter and are present in the same star (and so arise from plasma of the same temperature), for which line will the Lorentzian component of the combined (Voigt) profile be more apparent? Why?

Q8 What does the quantity $\frac{\pi e^2}{m_e c} f$ represent? What are its units? What is ϕ_ν and what are its units? How do the meanings (and units) of $\frac{\pi e^2}{m_e c} f$ differ from the Thomson cross section, σ_T?

Q9 Read the derivation of the random walk of a photon in Ostlie and Carroll and then answer the following question: According to the standard model of the Sun, the central density is 162 g cm^{-3} and the Rosseland mean opacity at the center is 1.16 $\mathrm{cm}^2\ \mathrm{g}^{-1}$. **(a)** Calculate the mean free path of a photon at the Sun's center. **(b)** If the mean free path remains constant for the photon's journey to the surface of the Sun, calculate the average time it would take for the photon to escape from the Sun. **(c)** Using the plot of the Rosseland mean opacity in Ch. 3 and the knowledge that the density at the Sun's surface is approximately 10^{-8} g cm^{-3}, is your answer to part (b) likely to be an overestimate or an underestimate for the actual Sun? What's your reasoning for this last part? Note that you should be able to demonstrate the derivation at the board. Are you okay with the dot product? And the cancellation of cross-terms in the big sum?