Topics: Background physics, including blackbody radiation and atomic level populations

Reading:

- LeBlanc, Ch. 1 (the first half only, through the middle of p. 17)
- Ostlie and Carroll *An Introduction to Modern Stellar Astrophysics*, pp. 71 - 73 (pdf on the website)

Summary of work to be produced:

- Hand in your solutions to the warm-up questions (QW1, QW3, and QW6) by Thursday at 12:30 pm in the box on the wall outside my office. I'll make some comments on them and ask you to pick them up and look them over well before coming to seminar on Friday.
- 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.
- Bring notes to seminar for the (unnumbered) discussion questions/notes/topics. (I will *not* collect these, but please do make some notes for yourself. I *will* expect you to be able to answer/discuss these.)

Process: We will go beyond simply solving problems in seminar. We will discuss the meaning and implications of your solutions to the problems and we will discuss the most important points in the reading, even if they're not addressed in a numbered problem. To these ends, the numbered problems you have to solve are embedded within commentary – points to note, questions – that will guide our discussion and into which the discussion of your solutions to the numbered problems will fit thematically.

Only bold-faced, numbered questions require written, fully-worked out solutions. And each bold-faced, numbered question includes everything in its formatted paragraph and nothing beyond the end of the paragraph. Warm-up questions, to be handed in on Thursday, are denoted with a **W** in their numbering system. Questions, notes, and topics that are unnumbered are ones you should think about, try to answer, write down a few notes about, and be prepared to discuss (ask as well as answer) in seminar.

I will probably ask you all to write-up and hand in solutions to a small subset of the in-seminar problems by the Monday after seminar (having perhaps better or more complete solutions to the problems after having gone over them in seminar).

Scope: We'll start with a close reading of the introductory material in Ch. 1 of LeBlanc. The questions – both numbered and not – and points I make are designed to get you think deeply about the material at the beginning of the textbook and to generate questions and discussion in our seminar meeting, and these go in order through the material as you'll encounter it in the textbook.

There are one or two things that may require you to consult other resources (like the Astro 16 textbook or perhaps look at later parts of LeBlanc) – e.g. the definitions of the mean free path and optical depth.

Questions etc.: The "basic concepts" in the first chapter focus on light (electromagnetic radiation, or just *radiation*) as measurements of light provide nearly all of the concrete information we have about stars.

But the chapter starts with a basic overview of what a star is and their fundamental physical properties and mechanisms.

The definition of a star: self-gravitating sphere and nuclear energy generation in its core. Note the lower mass limit of stars – what is the *physical* cause?

Note the cgs units. I recommend having places to go for cgs constants, conversion factors, and astronomical values (the textbook is one place) and I *strongly* recommend that you make your own list, by hand, on a single piece of paper. You'll need those values over and over again, and writing your own will make you think about them and even remember some of them and make you more likely to notice when you make a mistake while solving a problem.

"The gravitational collapse will continue until equilibrium is reached..." on p. 2. If the nuclear energy generation rate per unit time at the star's center did *not* equal the power output of the star's surface due to the emission of radiation, what could be going on? In other words, under what circumstances might those two quantities be unequal?

What does *equilibrium* mean in this context? Isn't energy flowing? Things are moving, not static.

Does it necessarily follow that if the surfaces of stars are radiating energy, then their centers must be hotter than their surfaces?

In the middle of p. 2 it's noted that when you look at (or *in to*) a star you see only the exterior – like looking into a fog bank (the underside of heavy clouds is maybe a better analogy). Recall (from Astro 16) that when you look into a light emitting/transmitting medium you see photons that arise from optical depth $\tau \approx 1$. Be prepared to discuss this fog/cloud analogy.

What is *opacity*? What is *optical depth*? What is the *mean free path*? What is its meaning and quantitative definition in terms of density and material properties? How is it related to the optical depth? (You may want to consult Ryden and Peterson.)

Note the definition of *metallicity*, Z (and X and Y) on p. 3. Does the measured value of $Y_\odot = 0.2485$ mean that 24.85 percent of *atoms* in the Sun (really, on the Sun's surface) are helium? Given the values of X, Y, and Z listed for the Sun, what percent of atoms are helium? Assume that all metals are oxygen (with an atomic mass of 16).

Look at equation 1.1. Become very comfortable with it. It will be convenient to express the product hc in eV per Å.

Light has momentum! Compared to classical momentum for a non-relativistic object (mass times velocity), does light have a lot of momentum per energy or a little? Consider the kinetic energy of the non-relativistic object in order to make the comparison.

Make sure you're comfortable with the EM spectrum and its divisions (Table 1.1). UV, visible, and IR are most important for stars. And write that Å to cm (and maybe to meters and nanometers too) conversion factor down on your sheet of constants etc. What is a *micron*?

OK, now we turn our attention to blackbody radiation and the Planck function (§1.3). I will provide fewer questions and comments, but you should still be prepared to discuss, for example, the units of the Planck function and their relation to the units of *flux*, and the reasons equations 1.3 and 1.5 look different from each other and what the justification is for equation 1.4.

This would be a good point to re-read the Ostlie and Carroll background on blackbody radiation. Start at the top of page 71 and read through the middle of page 73. Note how the Rayleigh expression for blackbody radiation uses a classical approach but the full (correct) version – the Planck function – assumes that light is quantized. Starting with equation 1.5, show that in the limit $h\nu << kT$ the Planck function approximates

Rayleigh's expression. Note that in this approximation, the quantum mechanical constant (h) goes away and you're left with the classical expression. What is the *ultraviolet catastrophe*?

Here are some questions/problems related to (§1.3) that you should answer/solve in writing:

QW1 Do problem 1 at the end of the chapter. Make the substitution $x = \frac{h\nu}{kT}$. And note that the integral: $\int_0^\infty \frac{x^3}{e^x-1}dx$ is equal to $\frac{\pi^4}{15}$.

What is the definition of *flux, F* and what are its units? The Planck function is generally given as the specific intensity, which is essentially flux per solid angle. What is *solid angle*? What are its units?

Q2 Do problem 2 at the end of the chapter. Make the same variable substitution suggested for the previous problem. Here you'll end up with an equation that cannot be solved analytically. Please solve it either graphically or numerically by hand using guess-and-check. Ask me questions if you're unsure how to do either of these, but give it some thought first.

Section 1.4 is about the characterization of measured broad-band[1] radiation properties and how to relate those measurements to physically meaningful quantities (like the luminosity of a star, but also less directly, its temperature and radius).

Note that the inverse square law is embedded in equation 1.11. Make sure you're very comfortable with the definitions and units of luminosity and flux. (Note further that luminosity and flux can be defined at a single wavelength, over a range of wavelengths, or over all wavelengths (this last case is called the *bolometric* flux or luminosity). Often we (and the textbook) will ignore the wavelength dependence or simply implicitly recognize that without a wavelength or wavelength range specified, these quantities can refer to any of the definitions. Further, magnitudes are either defined for a specific filter – in which case the filter is indicated with a subscript – or as bolometric magnitudes.)

What is the definition of a *parsec* (and what is geometric parallax in general and for a star as observed from the Earth at multiple positions in its orbit)? How many light years, AU, and cm in a parsec?

QW3 Do problem 5 at the end of the chapter.

Q4 Do problem 3 at the end of the chapter.

Q5 Do problem 4 at the end of the chapter.

QW6 Do problem 3.9 from Ostlie and Carroll (see pdf linked from the website and Moodle). For part (a), express your answer in both cgs units and solar luminosities. For part (d), please also complete the following sentence, "A difference of five magnitudes corresponds to a factor of [blank] in brightness and a factor of [blank] in distance for objects with the same luminosity." Be prepared to show these two relationships mathematically. For part (f) please do the problem two ways – once using the luminosity from (a) and the distance, and once using the result from (e). Also, pleasue use the SIMBAD website/database to find some information about this star. (See the SIMBAD link on the right side of the class website.) Specifically, what is its *spectral type*? What's the *most recent paper published* that mentions this star? What are its *B and V magnitudes*? What is its *parallax*? What units is parallax given in by SIMBAD? How does the parallax you find there, converted to parsecs, compare with the distance given in the problem by Ostlie and Carroll?

Section 1.5 is about level populations (Boltzmann) and ionization distributions (Saha) of atoms and about the quantized nature of the energy levels themselves. This is especially relevant for understanding spectra

[1] By *broad-band* we mean radiation properties measured over a large range of wavelengths and *not* with high spectral resolution but perhaps with some distinction made between fluxes or magnitudes in one filter bandpass and another – see Figure 1.3 and the brief discussion of *colors* defined as magnitude differences or flux ratios between two different filter bandpasses.

of stars and specifically, for example, for going from the measurement of the strength of a spectral line to an estimate of the abundance of the element that produces that line.

Q7 The strength of an Hα absorption line tells us how many electrons are in the $n = what?$ level? And which level's population of electrons is proportional to the strength of an Hα emission line?

What do the g values for a given energy level represent? What is the meaning of the partition function?

Q8 Do problem 7 at the end of the chapter.

Q9 Do problem 8 at the end of the chapter.

So! I really do expect you to be able to answer – at least to some extent, and if not fully answer, then ask a useful question about – all the *unnumbered* questions in this section of the document. I expect you to be able and willing to go to the board and present an answer or explain a concept, related to any of these questions.

Note finally that I expect you to be able to explain any of the example problems and their solutions in the shaded boxes embedded in the text.