Topics: Hydrostatic equilibrium and stellar atmospheres, including limb darkening and physical properties of the Sun's atmosphere

Reading:

- Read section 1 of Ch. 7 well before coming to class on Tuesday (pp. 172-180, but see below for information about what you should focus on).
- Also read from the last paragraph on p. 213 (beginning of §9.2) to the middle of p. 216.
- And also read section 1 of Ch. 14. You can start reading section 2 if you've got the time...
- Finally, review the exoplanet detection information in section 3 of Ch. 12 (assigned for last Thursday).

Summary of work to submit:

- Nothing to submit for Tuesday's class.

We'll look at an actual *radial velocity curve* for a binary and/or exoplanet system and see how masses are estimated from a sequence of spectral Doppler shift measurements (see Fig. 12.5 on p. 298) and we'll talk about the *inclination angle,* i (see figure on next page), and we'll also discuss the *light curves* of eclipsing binaries and their close cousins, transiting exoplanets. This discussion will last about twenty minutes. It might involve students solving a problem in pairs!

Then we'll move on to new material – application of some of the things we've learned about spectral formation in environments like the Sun's atmosphere: photons we see come from $\tau \approx 1$; the physical layers that correspond to this are different for different wavelengths. And thinking about the optical depth and physical properties in a stellar atmosphere motivates us to think about the density distribution as a function of height or location in an atmosphere like the Sun's. We'll see that a simple assumption – hydrostatic equilibrium (no unbalanced forces, no motion of gas) governs the density distribution (really, the pressure distribution) and that the equation of hydrostatic equilibrium (HSEQ) has a simple solution under certain conditions.

Commentary on the reading:

Read the beginning of Ch. 7 carefully. The physics of limb darkening is interesting and deploys some of the most important, basic concepts we've been learning. Note how one key is the source of opacity – the atomic cross sections, here dominated by an unusual ion, the negative hydrogen ion H^- – one proton with two electrons. Aside, in the near UV – below the Balmer edge near 400 nm that we discussed two classes ago in the context of the solar spectrum – the opacity, or cross section, of (regular) neutral hydrogen is important, but longword of 400 nm, photons don't have enough energy to ionize hydrogen out of the $n = 2$ level (much less out of the ground state) and so H has a negligible cross section in the optical (whereas the second electron in H^- is so loosely bound, that any optical photon can readily interact with it and ionize it, destroying the photon and thus providing a source of strong opacity, or cross section). Now, consider the fact that the photons we see come from a layer at an optical depth of one (or one mean free path below the surface). Look at Fig. 7.2 on p. 174. Where that $\tau = 1$ layer is depends on what part of the Sun we're looking into. Only at the apparent center of the Sun's disk do we look straight in – look in perpendicular to the surface – everywhere else, we're looking into the Sun at an angle and so don't see as deep, and thus the $\tau = 1$ layer is closer to the surface (for views with big angles) where the gas is cooler and the emission is weaker – hence, *limb darkening.*

You can skim the next few pages, but do at least skim them – a lot of interesting phenomenology, including about the *solar wind*, and then a graphic (Fig. 7.6) showing important physical properties as a function of height in the Sun's atmosphere.

Next, read the few pages in Ch. 9 about hydrostatic equilibrium very carefully. Think: why does the Earth's atmosphere not collapse down into a thin, uniform, arbitrarily dense layer? After all, there's a lot of weight in the atmosphere. Fifteen pounds above every square inch of the Earth, at sea level. Do you see how equation 9.8 is derived? What units are on each side? Can you translate the equation into an English sentence or two?

Study carefully the form of the perfect gas law in equation 9.9. We'll be using it a lot; get comfortable with it. Remind yourself what μ is.

Finally, pay close attention to the definition and concept of *scale height* (equation 9.15). By how much does the pressure in an atmosphere change as the location under consideration changes by one scale height?

Now transition to Ch. 14 – there's our new friend HSEQ again! And the perfect gas law. What is the scale height of the Sun's atmosphere? What physical factors make it different that the Earth's scale height? Is the Sun's scale height small or large? Compare it to the Sun's radius... Why does the Sun appear to have a sharp edge? If you had to compute the optical depth one location in the Sun, for a given atomic cross section, σ, what equation would you solve?

Finally, step back and look at the big picture – HSEQ must hold everywhere in the Sun. So to compute the physical properties – the pressure, the local gravity – we have to know how the density and temperature and composition (encoded into μ) vary throughout the Sun. But if we knew (even just some of) these things, we could compute the pressure profile $p(r)$ for the Sun.

Section 2 of Ch. 14 shifts gears – given a stellar atmosphere in HSEQ, what does its spectrum look like and what trends are there? Think about how answering this question involves solving the Saha and Boltzmann equations (like we did for hydrogen Balmer absorption in Ch. 5 – Fig. 5.13). Finally, take a look at (click on) the leftmost image at the top of the class webpage, as you start to think about spectral subtypes.