Topics: wrap up parallax and distances to Solar System objects, start on electromagnetic radiation (light): the spectrum, photons vs. waves and fundamental relationships, the three types of spectra (Kirchoff's laws), Doppler shift, and blackbody radiation

Reading:

- Read the first page of Ch. 5 (including Table 5.1, which is on the next page).
- Very lightly skim sec. 1 of Ch. 5 (see below for highlights of the important ideas).
- Read the beginning of sec. 3 of Ch. 5, but only through the middle of p. 122.
- Review your knowledge of the classical Doppler shift of light. (No need to worry about relativity.) The Wikipedia page is a fine place to do a quick review: https://en.wikipedia.org/wiki/Doppler_effect but please ignore all the mathematical stuff about the Doppler effect of sound – light is actually simpler, since for sound, you have to worry about velocities with respect to the medium, while light has no particular medium. See my commentary below.
- For blackbody radiation, read the paragraph on p. 138 below eqn. 5.76. Skip to the result (eqn. 5.86) and study the plot of that function (Fig. 5.14). And also the related plot (linear axes, x-axis is wavelength not frequency), Fig. 5.15. Study also eqns. 5.96 - 5.98 and eqn. 8.4 on p. 197. (For this blackbody material especially, read my commentary below before reading the textbook.)

Summary of work to submit:

- No work associated with this class assignment to bring to class or turn in, but there is the homework assignment...

Overview:

For this material, we are going to be very targeted in our reading and discussion. We'll focus on the five or so topics listed at the top of this document, and skip around Ch. 5 and in some cases other parts of the textbook and other resources to remind ourselves and/or learn about some of the key, useful characteristics of light. We'll discuss them in class – I will solicit input from you all on Monday evening to find out what topics were confusing and/or warrant extra discussion in class. Below, I have written a paragraph or so about each of the light-related topics. You should use these (rather than all of the material in Ch. 5) as your guide to what's important for Astro 14.

Commentary on the reading, viewing, and other preparation:

Light can be thought of as a massless particle (photon) that can have any energy; the energy manifests itself to us as color. Or light can be thought of as a wave. Its wavelength, in this picture, is what manifests itself as color. There must therefore be a relationship between wavelength and photon energy (and there is! it's eqn. 5.22). One thing to pay special attention to is the division of the electromagnetic spectrum into various regions (Table 5.1). Note what a narrow range of wavelengths is visible to the human eye. Meters are the mks units of length, but we usually are considering wavelengths much shorter than that. Common units for describing the wavelength of light include the micron (μm = 10^{-6} m), the nanometer (nm = 10^{-9} m), and the Angstrom Unit (Å = 10^{-10} m). The visible part of the spectrum goes from 4000 Å (blue) to 7000 Å (red). The energy of a single photon is way, way less than one Joule (usually), so we typically use electron Volts (eV) as the unit of energy when talking about photons. Visible photons have an energy of about 2 eV.

Atoms have energy levels (orbitals) where their bound (attached) electrons can be found. Many quantitative details about the hydrogen energy level structure in §5.1. It's way more detail than we need to know. Focus as you skim that section (read more carefully the end, with the bullet points, and look at the figures and read their captions. I've not asked you to read section 2, but there and in the following section, we learn the very important fact that when an electron in an atom moves from one state to another, energy must be conserved and one way nature does this is by producing a photon (for downward electron transitions) or absorbing a photon (for upward transitions). Because the energy levels in atoms are *quantized* these photons have very specific energies – that's what leads to spectra having absorption or emission lines. Relate this atom-scale picture to the more empirical and macroscopic picture of what causes emission or absorption line spectra given by Kirchoff's laws on p. 122 and summarized in color plate Fig. 3 (in the collection of color figures in the middle of the book).

Regarding the Doppler shift, the key point is that it always exists when the light source is moving with respect to the observer. And it is simply due to the source being closer (or farther) at the time it emits each successive wave. Please look carefully of the image of the swan on the Wikipedia page – do you see how the wavelength of the water-waves it's making is smaller in front of the swan (the direction of motion) and bigger off to the sides (and presumably even bigger behind it, but it's hard to see). The four-frame animation a little further down the page is excellent, too. The second-from-left frame is the basic Doppler effect. And the "Change in frequency" equation right above it is the key (and really, only) Doppler shift equation you need to know/remember. Combine it with $\lambda\nu = c$ to turn it into an equation in terms of wavelength.

The reason we're learning about the Doppler shift now is that it can affect observed spectra in important ways; especially line (as opposed to continuous) spectra. A source that's moving with respect to the observer will have its whole spectrum – including the positions of any spectral emission or absorption lines – shifted. We can measure the rotational velocity of Jupiter, for example, by measuring the relative Doppler shift of light from its left side and its right side. (Physics majors have done this for an advanced lab experiment, in the past, by the way.) In the second half of the semester, the Doppler shift will be vital for measuring the expansion of the universe.

Aside: Even a stationary source can be affected by the Doppler shift, if the individual atoms in it are moving with respect to each other. Specifically, any substance with a temperature greater than absolute zero has random thermal motions (we call that "heat") which will impose a Doppler shift on every photon emitted or absorbed by those moving atoms. Taken together, this leads to each spectral line being broader than it otherwise would be. This is the thermal broadening described on pp. 125-6. (Which I have not – yet – asked you to read.)

For the blackbody spectrum – the context here is that when a hot object is opaque and uniformly hot, it emits a universal spectrum that doesn't at all depend on what it's made of, just on its temperature. Stars, planets, and human bodies, among other things, emit spectra that are, at least approximately, blackbody (given by the Planck function, eqn. 5.86). As you read the very minimal and selective material assigned from Ch. 5, keep in mind the following: Don't worry about the units of specific intensity, I_ν, just think of it as being like (or proportional to) brightness of a light source. But the subscript implies that it's a function of photon frequency. So I_ν is a mathematical function that specifies what a spectrum look like. On p. 138, "conditions for being in LTE" means: uniform in temperature, conditions not varying in time (e.g. fraction of electrons in a particular energy level of a given kind of atom doesn't vary in time), and isolated from its environment (which is a requirement for temperature uniformity). And "optically thick" means opaque. A pottery kiln or windowless oven is a good way to visualize an idealized blackbody source. If we can approximate an objects emission spectrum as a blackbody, then we can take advantage of two super-important properties of blackbodies: (1) their overall emission (summed over all wavelengths) is proportional to the temperature of the emitting object, raised to the fourth power (eqn. 5.96) and (2) the peak of the spectrum (wavelength at which it emits the most light) is inversely proportional to its temperature (eqn. 8.4). This last relationship means, for example, that things (like the surface of the Sun or a lightbulb filament) emit primarily visible light because their temperatures are about 5000 degrees Kelvin, whereas human bodies or the surface of a warm planet emit mostly infrared light because their temperatures are a few 100 degrees Kelvin.