# **Astronomy 16 – Modern Astrophysics**

Fall 2014
Week 6

*Questions for the week*:

1. What is the equilibrium temperature of an object heated by Sunlight and re-radiating thermal energy, that's 1 AU from the Sun? (Carried over from last week.)
2. What is the temperature at the *center* of the Sun?

By the end of the week, you will be able to answer these questions.

*Topics:*

**Stellar structure equations and two-point solutions to estimate central properties**
**Radiation transport and energy generation in stars**
**Energy sources for stars**
**Virial theorem**

*Reading:*

The first part of the week, we'll cover the last part of the material originally assigned for last Thursday: The first two sections of Ch. 15 (you can *skim* sub-sections 15.1.2 and 15.1.3).

Then go on and read sec. 15.3 carefully. Nuclear reactions are so important in astrophysics, that it's worthwhile to work to understand the basic physics that's described in this section. Then read sec. 15.4, which summarizes the individual stellar structure equations (and discusses neutrino observations that observationally confirm our understanding of what's going on at the center of the Sun). Read the Appendix too. It's short, and shows you how to calculate the time it takes a photon produced at the Sun's center to make it to the Sun's surface.

Finally, you can review the Virial Theorem from the very end of Ch. 3. It is relevant when we consider the conversion of gravitational energy to heat and light in a contracting star.

*Important concepts and related facts to keep in mind as you re-read, and make sure you can answer while/after you've done the reading. We will discuss all of these in class this week.*

*From last week:*

Do the various dependencies of the scale height on physical properties make (physical) sense? E.g., why should the scale height of an atmosphere be proportional to its temperature?

Study the form of the perfect gas law shown in eq. (15.7) carefully. You might be familiar with a different form (perhaps from chemistry class). Try to figure out how the version you're familiar with relates to this one.

Given the gravitational potential energy formula for the potential energy between two masses, does the formula in eq. (15.48) make sense to you?

And does it make sense that the ratio of an energy supply to the rate at which the energy is used up gives the time the energy supply will last?

*New:*

Why does nuclear fusion require high pressure (or if you prefer, some combination of high density and high temperature)?

Note that the concept of a cross section (sigma) shows up again in this different context as an interaction probability between two particles (here, two nuclei rather than a photon and an atom).

Take a careful look at the nuclear reaction chains (Figs. 15.5, 15.6). Make sure you understand what each symbol means. Is there any net production or destruction of C, N, or O in the CNO cycle?

Why should the CNO cycle operate in higher mass stars (while the p-p chain operates in lower mass stars)?

What's the "triple alpha" process? Why does it require even higher pressure than even the CNO cycle?

When you look at the stellar structure equations (p. 369), where is all this information about nuclear physics hidden?

Looking at the radiation transport equations on p. 369, note that I asked you only to skim the relevant sections. But you should be able to describe in words what convection is (what physical processes are going on in a convecting fluid) and you should think about why convection naturally starts when radiation can't efficiently transport heat. Try to analyze why a boiling pot of water on the stove transports heat from the bottom to the top of the water by convection. Don't forget to think about what sort of wavelength the light has that's generated from the heat at the bottom of the pot. And it might help to know that water is very good at absorbing infrared light. It has a large cross section in the infrared.

When you look at the radiation transport equation, can you draw parallels to Ohm's law? What plays the role of the voltage difference? What plays the role of the current? Of the resistance?

Finally – about the virial theorem – consider a gravitating system in equilibrium ("virialized") that consists only of the Earth and a small satellite in a circular orbit. To raise the satellite to a higher orbit, work must be done against gravity (you want to move it higher up in the gravitational potential well). But, if you look at Kepler's third law, you see that larger orbits have smaller velocities, so the satellite in its new, higher orbit will have less kinetic energy than it originally did. So maybe we can get to the higher orbit "for free" by simply converting KE to PE without having to fire the satellite's rockets and expend additional energy. What does the virial theorem tell us about this? What fraction of the work against PE will the change in KE do for us?