Wednesday Mar. 2

Syllabus and class notes are at: www.as.utexas.edu

Reading for this week: Chapter 9

If you want help on anything covered in the course, come to discussion session Thursday at 6:00 in RLM 15.216B or come to office hours.

Agnes won’t have office hours today.
Lacy has office hours M-Th 2-3.
Topics for this week

Explain how astronomers measure masses of stars.
Describe how the luminosities of main sequence stars are related to their masses.
Describe the process of formation of a protostar from a molecular cloud.
Describe the concept of hydrostatic equilibrium.
Describe the concept of thermal equilibrium.
Describe how a star changes if it is not in thermal equilibrium, and how this keeps the Sun’s luminosity stable.
Describe how the mass-luminosity relation can be used to calculate the lifetimes of main sequence stars.
Mass-Luminosity Relation

1 solar mass 1 solar luminosity
10 solar masses 1000-10,000 solar luminosities

Increasing the mass by a factor of 10 makes the luminosity increase by a factor of 1000-10,000, or $10^3$-$10^4$. The rule must be $L \propto M^3$ or $L \propto M^4$.

$L \propto M^{3.5}$ is often used.

Why are more massive stars more luminous?
You should find out this week.
Where do stars form?

The space between the stars is not empty.

The mass of the air in this room is about a ton. If it were cooled so it liquified, it would fill a bathtub.

The gas in a typical region in space the size of this room has a mass of about $10^{-15}$ grams. If it were liquified, the drop of liquid air would be too small to see.

But there is a lot of space between the stars. The mass in the space between the Sun and $\alpha$ Centauri is more than the mass of the Earth.

In some regions of space there is enough gas to make more stars.
How do stars form?

Regions of space with relatively high density (1000 atoms per cubic cm instead of just 1) are called molecular clouds. (The gas is in the form of molecules and the regions look like clouds.)

The gravitational attraction of one side of the cloud for the other can pull the gas together to form a protostar.

When a protostar first forms, it is heated by contraction. Later, fusion will provide its energy.
Equilibrium

Equilibrium is when two influences balance.

For example, when a balloon is inflated, the pressure of the air inside of it tries to make the balloon expand. But the rubber tries to make the balloon contract. If these two forces are balanced, the size of the balloon will not change.

To understand this more we need to know something about how pressure in a gas works.
Pressure in a gas

Pressure is the tendency of a gas to expand. More quantitatively, it is the force the gas exerts on the walls of its container divided by the area of the walls.

The pressure of the air in a balloon depends on how much air is in the balloon and how hot it is.

The formula is:

\[
\text{Pressure} \propto \frac{\text{number of atoms}}{\text{volume}} \times \text{Temperature}
\]
Equilibrium in stars

Main-sequence stars are in equilibrium in two ways:

**Hydrostatic equilibrium** means that the pressure of the gas inside of a star (which tries to make it expand) balances the force of gravity (which pulls one side of the star toward the other, and so tries to make it contract).

The result is that the size of the star doesn’t change.

**Thermal equilibrium** means that the loss of energy by radiation of light balances the generation of energy by nuclear fusion.

The result is that the temperature inside the star doesn’t change.
Stable and unstable equilibrium

An equilibrium is stable if a small change in one of the balanced influences will change the situation by only a small amount.

For example, heating a balloon will make the pressure of the air in it increase. As a result, the balloon will begin to expand. But that will cause the pressure to drop, so it will stop expanding.

An equilibrium is unstable if a small change in one influence causes a large change in the situation. A stick of dynamite is unstable.
Are stars stable or unstable?

What would happen if some gas were added to a star so its pressure increased?
It would be out of hydrostatic equilibrium and would expand. But when a gas expands its pressure decreases, so after expanding a little bit it would again be in equilibrium.

What would happen to a star if the rate of nuclear fusion increased so it was generating energy faster than it was radiating it from its surface?
You would expect it to get hotter.
That would make it radiate more, but it would also make nuclear fusion go faster, and fusion would increase more than radiation, so the star would get even hotter.
Quiz

If a spaceship is orbiting the Sun and it is given more energy, what happens?
A. It goes into a smaller orbit in which it goes faster.
B. It goes into a bigger orbit and speeds up.
C. It goes into a bigger orbit and ends up going slower.
Quiz

If a spaceship is orbiting the Sun and it is given more energy, what happens?

C. It goes into a bigger orbit and ends up going slower. It gains energy of position more than it loses energy of motion.

Like a spaceship, the atoms in the Sun are held in by gravity, but don’t fall to the center because they are moving.

If the atoms in the Sun were given more energy, the Sun would expand and the atoms would move more slowly. Adding energy to the Sun would make it bigger and cooler. Removing energy from the Sun would make it contract and heat up.
Thermal Equilibrium in Stars

Protostars are not in thermal equilibrium. They lose energy by radiation from their surfaces, but they aren’t hot enough inside to ignite nuclear fusion to replace the lost energy.

As a result, they contract and heat up. Once they are hot enough inside (about $10^7$ K) fusion can replace the energy they are losing.

They are then in a stable thermal equilibrium; if fusion slowed down, they would contract and heat up causing fusion to speed back up until it balances the energy they are losing.

Because of this stable equilibrium, the Sun will hardly change for $10^{10}$ years, until it uses up all of the hydrogen in its core.