Friday, Oct. 17

Syllabus, class notes, and homeworks are at:
www.as.utexas.edu → courses → AST 301, Lacy

Reading for next week: chapter 10

The Wednesday help session is in GRG 424 at 5:00 (for the entire semester).

Topics for this week

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 causes protostars to become main sequence stars and keeps the Sun’s luminosity stable.

Describe how the mass-luminosity relation can be used to calculate the lifetimes of main sequence stars.

Gas Properties Simulation

Go to Phet.colorado.edu, run gas properties simulation.

Put some atoms in the box.

Describe what they do. Read the pressure.

Turn up the heat to double the temperature.

  How do the atom motions change?

  How does the pressure change? Why?

Turn the temperature back down and double the number of atoms in the box. Use light atoms this time.

  How do the light atoms' motions differ?

  How does the pressure change?

Turn off collisions. Does anything change?

Hold the temperature constant and turn on gravity.

  How does the distribution of atoms in the box change?

What else can you play with in the simulation?

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?

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.

Lifetime of the Sun

We could figure out how long the Sun will remain a main-sequence star by knowing the rate at which it is generating energy by nuclear fusion (which must equal the rate it is radiating energy from its surface) and calculating the rate at which it is converting hydrogen to helium to generate that energy (using $E = mc^2$). Then if you know the Sun's mass, you know how much hydrogen fuel it has and you can figure out how long it will last.

The answer is that the Sun will use up the hydrogen in its core (where fusion is occurring) when it is about 10^{10} (ten billion) years old. That's about 5 billion years from now.

Given that fact, can we figure out how long a 2 solar mass star will live?

Lifetimes of Stars

A 2 solar mass star has a luminosity of about 10 solar luminosities.

It has twice as much fuel as the Sun (since its mass is its fuel), but it burns 10 times as much fuel each year as the Sun does (since the rate at which it burns its fuel is proportional to its luminosity).

The Sun has a lifetime of about 10 billion years.

What is the lifetime of a 2 solar mass star?

A. 2 billion years

Start with 10 billion years, multiply by 2 for twice as much fuel, then divide by 10 for burning 10 times as much each year: $10 \times 2 / 10 = 2$ billion years.

A good test question

My little car has an 11 gallon gas tank and gets 36 mpg (miles per gallon).

Your pickup truck has a 22 gallon gas tank and gets 18 mpg.

Which of us can go farther on a tank of gas, and how many times farther?

Did you have to multiply 11 x 36 to figure that out?

The general rule for stellar lifetimes

The lifetime of a 1 solar mass star is 10 billion years.

The amount of fuel in a star is proportional to its mass.

The rate at which the fuel is used is proportional to its luminosity.

The luminosity of a star is proportional to mass$^{3.5}$.

Put these facts together:

Lifetime of a star of mass M

$$= \frac{(\text{lifetime of Sun}) \times (\text{amount of fuel / Sun's fuel})}{(\text{rate of burning / Sun's rate of burning})}$$

$$= \frac{(10 \text{ billion years}) \times (M / M_{Sun})}{(M / M_{Sun})^{3.5}}$$

$$= 10 \text{ billion years} \times (M / M_{Sun})^{-2.5}$$