Announcements

- Evening Observing this week, through Thu. (Possibly) last Chance, do go!
- HW #8 Due this Sunday at 11:45pm
- Don’t forget your out of class planetarium visit.
Exam 3

- Grades available by tomorrow (snag in processing).

- Buy-back due 10 minutes ago online on M.A.

- Recap now....
Last Time: Lives of Stars

- Stars are born in cold molecular clouds, visible only in infrared and radio light.

- Cloud collapses, proto-star heats up. If hot enough, nuclear fusion of hydrogen will ignite, and a star is born.

- A disk of material coalesces around the star: it’s the solar nebula, from which planets form.

- Jets are sometimes launched from protostars to many thousands of AU.
Stars form in groups, sometimes large groups, which can go on to be star clusters.

Orion is a nearby stellar nursery, in which many stars are currently being born.
**Last Time: Lives of Stars**

* Stars are in a constant struggle of gravity vs. pressure. Gravity wants to collapse the star, pressure wants to expand it.

* Normally, pressure is provided by the heat of the gas inside the star. In certain situations, however, another type of pressure can take over: Degeneracy pressure (electron or neutron musical chairs).
Last Time: Lives of Stars

- Stars spend most of their lives burning hydrogen in the core on the main sequence, a narrow track in the HR diagram.

- More massive main sequence stars are bluer (hotter), larger, and more luminous than the much more common low mass stars.

- A star begins to die when it uses up its hydrogen fuel. How it dies depends on its mass.
**Last Time: Lives of Stars**

- All stars: As H is burned up in core, it leaves behind He “ash”. When H is used up, core begins contracting, and H is burned in a shell around the core.

- Star’s outer layers expand, cooling and getting much brighter, becoming a **Red Giant** star.

- Eventually core contracts enough to become so hot it can fuse Helium to Carbon (\(3 \text{ He} \Rightarrow 1 \text{ C}\)): star is stable again (for a short while).
Low mass stars (< 2.25 $M_{\text{Sun}}$) are supported by degeneracy pressure when their cores collapse at this stage.

The core gets hotter and hotter but the pressure doesn’t increase! Broken thermostat!

A “Helium Flash” occurs, in which a huge amount of helium is burned up in a few seconds.
Once core helium runs out, it begins burning in a shell around the contracting core.

Star becomes a **Red Giant** again. Strong mass loss occurs via stellar winds.

Lower mass stars (< $8 \, M_{\text{Sun}}$) can’t burn carbon: degeneracy pressure stops the collapse, and their life is nearly over.
They swell up and blow off all outer layers, forming a beautiful “planetary nebula”, and leaving behind a small hot remnant of the core called a “white dwarf”. This is the sun’s fate.

White Dwarfs have a maximum mass of $1.4 \, M_{\odot}$. Any larger white dwarf collapses...
Higher mass stars (> 8 M\textsubscript{Sun}) burn hydrogen much faster by using Carbon, Nitrogen, and Oxygen as a “go between”. Consequently, they live much shorter lives.

Higher mass stars don’t have a helium flash, but start burning helium quickly after the core contracts.

When burning H and He in shells, they swell up to Red Supergiants.
Last Time: High Mass Stars

- When they run out of core helium, they can burn Carbon in their cores, and more.

- They add Helium to Carbon to make oxygen, burning in shells and in the core all the way to Iron (Fe).

- After iron, making larger atoms consumes rather than produces energy: bad news.

- Core collapses out of control, electrons are squeezed into protons forming neutrons, causing the star to explode as a supernova.
All naturally occurring elements heavier than iron are produced during the fast supernova explosion.
A supernova can be as bright as a galaxy!

**Artist’s Conception of Supernova**
A supernova can be as bright as a galaxy!
Low Mass Star’s Life in Review (1 $M_{\text{Sun}}$)

1. **Protostar**: A star system forms when a cloud of interstellar gas collapses under gravity.

2. **Yellow main-sequence star**: In the core of a low-mass star, fusion of hydrogen nuclei into a single helium nucleus by the proton-proton chain reactions.
Low Mass star’s life in review (1 $M_{\text{Sun}}$)

**Time**

1. **Helium-burning star**: Helium fusion begins when the core becomes hot enough to fuse helium into carbon. The core then expands, slowing the rate of hydrogen shell burning and allowing the star’s outer layers to shrink.

2. **Double shell-burning red giant**: Helium shell burning begins around the inert carbon core after the core helium is exhausted. The star then enters its second red giant phase, with fusion in both a hydrogen shell and a helium shell.

3. **Planetary nebula**: The dying star expels its outer layers in a planetary nebula, leaving behind the exposed inert core.

4. **White dwarf**: The remaining white dwarf is made primarily of carbon and oxygen because the core of the low-mass star never grows hot enough to produce heavier elements.
High Mass star’s life in review (25 M_sun)

All stars spend most of their time as main-sequence stars and then change dramatically near the ends of their lives. This figure illustrates the life stages of a high-mass star and a low-mass star and shows how long a star spends in each stage of life. Notice that the lifetime of a low-mass star is far longer than that of a high-mass star.

1. **Protostar**: A star system forms when a cloud of interstellar gas collapses under gravity.

2. **Blue main-sequence star**: In the core of a high-mass star, four hydrogen nuclei fuse into a single helium nucleus by the series of reactions known as the CNO cycle.

3. **Red supergiant**: After core hydrogen is exhausted, the core shrinks and heats. Hydrogen shell burning begins around the inert helium core, causing the star to expand into a red supergiant.

4. **Helium burning**: When the core helium is exhausted, the core can no longer contract. The star becomes a red giant, and eventually, it might shed its outer layers.
High Mass star’s life in review (25 $M_{\text{Sun}}$)

6. Supernova: Iron cannot provide fusion energy, so it accumulates in the core until degeneracy pressure can no longer support it. Then the core collapses, leading to the catastrophic explosion of the star.

7. Neutron star or black hole: The core collapse forms a ball of neutrons, which may remain as a neutron star or collapse further to make a black hole.
White Dwarfs, Neutron Stars, and Black Holes

The bizarre Stellar Graveyard
The Stellar Graveyard

All stars burn H to He on the main sequence.

After H runs out, gravity or pressure will dominate, causing the star to change.

After all fuel has been used, stars end their lives as either white dwarfs, neutron stars, or black holes, depending on their mass.
White Dwarfs

- The exposed core of a dead low mass star which has shed its outer layers as a red giant.
- About the size of the earth.
- Very dense: 1 tsp = several tons!
White Dwarfs

White dwarfs are supported by electron degeneracy pressure, which is why they don’t contract and burn their core material.

They have no fusion going on; they cool and fade away.

Usually made of carbon, but sometimes helium (very low mass stars can’t even burn helium!).

Tuesday, November 16, 2010
Later evolution of a White Dwarf: Nova

- We keep saying “super” nova, so what is a nova?
- A binary star system with a white dwarf
- A dying, bloated red giant gives its white dwarf binary companion mass.
What is a Nova?

- When the surface temperature hits $10^7$ K, this hydrogen ignites on the surface.

- Novae are as bright as $10^5$ Suns.

- In contrast, supernovae are as bright as $10^{10}$ Suns!
**White Dwarf Supernova!**

- *If a white dwarf grows larger than $1.4M_{\text{sun}}$, electron degeneracy pressure can no longer hold back the star’s gravity.*

- *It begins to collapse, temperature gets hotter, and it can burn fusion. A “carbon flash” occurs.*

- *The star is destroyed in an instant white dwarf supernova.*
Neutron Stars

The remnant of a massive star’s supernova which ends its life can be a neutron star.

Electrons are driven into protons to form neutrons: essentially a gigantic single nucleus.

Neutron degeneracy pressure supports it against the intense gravity.
Neutron stars are the size of a city (10 km).

- Neutron stars are even denser than white dwarfs because they are smaller!

- A sugar cube of a neutron star would weigh as much as all of humanity, 10 billion tons!
What if you brought some home?

A tiny Ball Bearing made of neutron star matter would instantly plunge through the earth, heading straight to towards the core.

It would surface again on the opposite side of the planet, and fall again.

Again and again it would fall until it settled at the center of the earth.
Or!

- The neutrons, now free, would begin to decay and very quickly release more energy than 1000 Hydrogen Bombs.

- They would expand violently outwards, cooking the atmosphere and surface of the earth.
What if you brought an entire Neutron star home?

The entire Earth and solar system would be crushed onto its surface, forming a thin layer no more than 1 inch thick!
How were neutron stars discovered?

Jocelyn Bell, a 24 year-old graduate student, noticed a regular radio pulse coming from a certain position on the sky in 1967. The period is 1.337301 seconds.

Pulsars are neutron stars that give off regular pulses. Neutron stars spin fast because they are so small (conservation of angular momentum).
The Crab Nebula Pulsar

The Pulsar at the center of the Crab Nebula pulses thirty times a second.

Tuesday, November 16, 2010
Pulsars

Pulsars are rotating neutron stars that act like lighthouses.

Beams of radiation channeled by intense magnetic fields coming from the poles look like pulses as they sweep past Earth.
Cartoon of a Pulsar
Neutron Star oddities

- Some pulsars rotate thousands of times every second: “Millisecond pulsars”

- Incredible magnetic field strengths: 1 “Tesla” is a very strong bar magnet. 100,000,000,000 Tesla in some ultra “magnetar” neutron stars.
The Crab Pulsar in X-rays
How massive can a neutron star be?

- **When a neutron star is larger than about 3 \( M_{\text{sun}} \), it’s gravity is so strong, even neutron degeneracy pressure can’t support it.**

- **Some massive star cores are this large, so after a supernova, the core continues to collapse further, and further.**

- **Nothing can stop it. Not nuclear fusion, not degeneracy pressure. Nothing. It becomes.....**
A Black Hole!
A black hole is an object whose gravity is so strong, not even light can escape it.

To escape the earth, you have to go 25,000 mph. To escape a black hole, you have to travel faster than the speed of light.
Thought Question

What happens to the escape velocity of the Earth if you shrink it?

A) It increases
B) It decreases
C) It stays the same

Hint:
Thought Question

What happens to the escape velocity of the Earth if you shrink it?

A) It increases
B) It decreases
C) It stays the same

Hint:
Black Holes

If you shrunk the Earth to a ball 3 cm in diameter, light could not escape it.

The escape speed from earth is 25,000 mph. The escape speed from a black hole is faster than light. Nothing travels faster than light: NO ESCAPE!

The radius around a black hole where the escape speed reaches the speed of light is called the EVENT HORIZON. It is the point of no return. We can’t observe what happens inside the event horizon.
Consider this 2D rubber mat as a representation of space.

Mass deforms space and what we perceive as gravity is a curvature of space.
**Space Time**

The planets orbit the Sun because the Sun’s mass curves space.
The “well” for a black hole is infinitely deep. Nothing, not even light, can get out.

If something/someone falls beyond the event horizon, it/he/she can never communicate with the outside world again.
What is it like to visit a black hole?

- In order to escape the gravity of the black hole, photons have to give up energy.
- The photons become gravitationally redshifted.
- This is similar to the Doppler shift, but has nothing to do with the motion of the light source.
What is it like to visit a black hole?

Time passes more slowly near the event horizon (as seen by an outside observer).
Death By Black Hole
Reminders

- HW #8 Due Sunday

- Evening Observing This Week: 7:30pm on the roof (Weather permitting)

- Exam scores/Extra Credit/updated participation available tomorrow.