Items from last time
Fate of massive stars

Remember this Quiz
Which is not thought to be associated with a supernova?
- a. pulsar
- b. neutron star
- c. white dwarf
- d. creation of heavy elements
- e. black hole

Massive Stars
- Massive stars are those that fuse all the light elements up to iron. They become red giants like low mass stars in the process. But they will not form planetary nebulae.
- Instead, as the core gets heavier, atomic protons are pushed into electrons creating neutrons and the entire core collapses!

Supernovae
- In the process of collapsing, the star violently blows the outer layers away, creating a supernova.

SN 1987a
- In 1987 a supernova exploded in a nearby satellite galaxy.
Colors in the intricate filaments trace the light emitted from atoms of hydrogen, oxygen, and sulfur in the debris cloud. The spooky blue interior glow is emitted by high-energy electrons accelerated by the Crab’s central pulsar.

The Crab Pulsar, a city-sized, magnetized neutron star spinning 30 times a second, lies at the center of this composite image of the inner region of the well-known Crab Nebula. The spectacular picture combines optical data (red) from the Hubble Space Telescope and x-ray images (blue) from the Chandra Observatory. The innermost ring is about a light-year across.

Three places stars can end up
- White dwarf
- Neutron star
- Black hole
- Compact cold Brown dwarf
  - If, & only if, it was a brown dwarf to start with.

Supermassive Stars
- Supermassive stars evolve just like the massive ones with one exception. They have so much gravity in the core that we know of no force that can prevent their collapse to a point! We call the resulting entity a black hole.
- To understand this we have to take a peek at General Relativity.

Gravity
- Gravity is best modeled not as an exchange of particles but rather as a curvature in space and time!
- Orbiting planets are then moving straight through space, obeying Newton’s first law of motion. In the vicinity of a massive object, a straight line is a curve because time and space are curved!
Black Holes

- There is no known limit to the curvature; it can be infinite! When the curvature is infinite, it is a black hole.
- Even light, traveling along this infinite curve, cannot find a path out!
- There is a remarkably large amount of evidence supporting the reality of black holes.

Accretion Disk and Jets

- Oddly enough, black holes should manifest themselves by ejecting material from accreting disks surrounding them.
Stars at center of the galaxy move fast

http://www.mpe.mpg.de/ir/GC/index.php

Mass of our central BH + 4.3 M Suns

Reading quiz: The ages of the universe and the solar system are thought to be, respectively,
A. infinite & 14 billion years
B. 14 billion years (both)
C. 10 and 5 billion years
D. 14 and 5 billion years
E. slightly greater than the age of the average BYU professor

The distance ladder
- Radar
- Parallax on earth- triangulation
- Parallax using earth’s orbit
- Standard Candles
- Cosmological redshift

The Basic Idea Behind Finding Distances to Stars:
Every method but triangulation and the expansion of the universe uses this idea.

* We measure the brightness we see.
* We infer the real brightness.
* We calculate the distance from the difference.

Triangulation
- Used to find distances to nearest stars.
- Same techniques used in land surveys
- For astronomy, it builds upon the fact that we know the orbital radius of the earth very precisely.

Triangulation
- Can be used to find distances to the nearest ~10,000 stars.
- All methods of finding greater distances build on this!

1. Real Brightness
2. Farther away
3. Farther away still

The distance ladder

<table>
<thead>
<tr>
<th>Method</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radar</td>
<td>Radar</td>
</tr>
<tr>
<td>Parallax on earth- triangulation</td>
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</tbody>
</table>
We could find the distance to a light bulb if we knew its

A. Wattage and color
B. Wattage and measured brightness
C. Color and measured brightness
D. Area code

The Next Rung on the distance ladder is from the relation between brightness and color.

We measure the color of stars.
Then we infer their real brightness from the H-R diagram.
By comparing their real brightness with how bright they appear to be, we can infer their distance.
This is useful for distances to all the stars in the Milky Way galaxy.

The following Main-sequence stars all appear equally bright. Which is closest?

a) bluish star
b) yellowish star
c) reddish star

A Vast Universe of Galaxies

Anciently mankind thought that the universe was the solar system inside a sphere of stars.
By the 1900s we knew the sun was just one of billions of stars within the Milky Way galaxy.
At this time the Milky Way was thought to be the entire universe.

Where does the solar system reside?

A. at the center of the galaxy
B. in the outer parts of the galaxy
C. in intergalactic space
D. at the center of the universe

REVIEW SESSIONS noon to 2 pm Saturday 377 CB by Amanda (This is room the class is in.)
Tuesday, Dec. 8th
Position of the Sun in the Milky Way
- The sun is 2/3 the way from the galaxy center to the edge.
- Its position was found by measuring distances to the globular star clusters that orbited about the center of the Milky Way.
- Variable stars were used to find the distances.

Cepheid Variable Stars
- Henrietta Swan Leavitt (July 4, 1868 – December 12, 1921) was an American astronomer and the deaf[1] daughter of a Congregational minister.[2] A graduate of Radcliffe College, Leavitt went to work in 1893 at the Harvard College Observatory in a menial capacity as a ‘computer,’ assigned to count images on photographic plates. Study of the plates led Leavitt to propound a groundbreaking theory, worked out while she labored as a $10.50-a-week assistant, that was the basis for the pivotal work of astronomer Edwin Hubble and radically changed the theory of modern astronomy, an accomplishment for which Leavitt received almost no credit during her lifetime. NOT REQUIRED READING

Variable Stars as Distance Indicators
- A class of very bright stars called Cepheids, have a tight relation between their real brightnesses and their pulsation periods.
- Pulsation period → real brightness → measured brightness → distance
- The primary mission of the Hubble Space Telescope was to find distances to nearby galaxies using Cepheid variable stars.

External Galaxies
- It wasn’t until 1923 that we fully realized the universe consisted of more than the Milky Way.
- Using Cepheid variable stars, Edwin Hubble determined that the Andromeda galaxy was a separate system of stars.
- Before then we thought it was a solar system forming!

I have checked my quizzes online and they are up-to-date
A. Yes
B. No, but I will
Go on the geology field trip up Rock Canyon today or tomorrow if possible. (RC is behind temple. You will need Your worksheet and the field guide.) And friends! If possible. There are times with TAs:
* Fri Dec 4th 3pm Temp ~ 30°F
* Sat Dec 5th 9:30am Temp ~ 20°F
Go before Sunday if you can! Snow may start on Sunday & certainly will last through rest of week. It is due on Thursday
Galaxies are held together in small to large groups by gravity.

A star cluster with redder stars most likely is _______ than one with bluer stars. pp

A. Older
B. Younger
C. Closer

Planetarium:  
http://planetarium.byu.edu/Scheduling/Calendar.aspx

During your regular lab time (except 22) But why not go early before you take the exam? Remember Clicker. There will be extra sessions this Friday at 11am and 2pm & (3pm?), Monday at 10 am and 4pm (& 5?), and Tuesday at 12, 1, 2, and 3pm for the 5 sections who don’t have an assigned planetarium time and for those students who want to go to the lab before they take the test.
Cosmological Redshift

- A profound discovery of the early 1900s was that all distant galaxies have their absorption and emission spectral lines shifted to the red.
- The amount of the shift is related to the speed of the galaxy.

Doppler Effect

- The amount of shifting is from the **Doppler effect** which causes waves to shift to a higher frequency as they move towards us and down to lower frequency as they move away.
  - Race car engine
  - Train whistle

Hubble Law

- The speed a galaxy moves away from us is proportional to its distance.
  - The farther away the galaxy is, the faster it recedes.
  - This could mean we are at the center of the universe – but not likely.

The variable stars with the following periods all appear equally bright from earth. Which is furthest away?

- A. 10 days
- B. 20 days
- C. 30 days
- D. a fortnight

Note: Fill out the student evaluations for PS 100. You will get two extra credit quiz points if you fill it out and release your name. If you have already done them, you can go back to Route Y and release your name.

Expansion

- If the universe is expanding, the farther away two galaxies are, the faster they move apart.
- Also, all galaxies would appear to be moving away from all other galaxies so our view is not unique.

Distances

- The Hubble Law is used to find distances to the farthest galaxies.
Types of Cosmologies

- Early ideas of the universe held that it was:
  - Infinitely old
  - Infinitely large
  - Unchanging in time
- But this cannot be true because
  - The universe is seen to be expanding and thus it is changing with time.
  - An infinitely large and old universe would never know darkness. This is Olber's paradox.

Olber's Paradox

- All lines of sight end on a star! The sky should be ablaze with star light!
- The solution is that the universe has a beginning
  - Light has not had time to reach us from the greatest distances
  - Glowing stars and galaxies have not always existed.

The Big Bang

- The observed expansion of the universe has led to the only viable cosmological theory: The Big Bang.
  - The universe began as a great infusion of pure energy about 14 billion years ago.
  - Space expanded from that point in time. The energy cooled into matter.

Evidence Supporting the Big Bang

- We see the expansion
- We see a faint glow left from the original fireball.
- Called the Cosmic Microwave Background or 3°K Background Radiation.

Evidence Supporting the Big Bang

- It correctly predicts the chemical abundances of gas clouds.
  - 75% hydrogen, 25% (helium by mass), a tiny amount of lithium. Fusion early after the big bang would produce that ratio of H to He.

The Ultimate Fate of the Universe

- Gravity always pulls, never pushes.
- So the expansion must slow down unless there is another force pushing out.
The Ultimate Fate of the Universe

- Not enough mass → open universe
- Just right → flat universe
- Too much mass → closed universe (bang-bang-bang?)
- Another force → runaway universe.

* This is what we think is happening!

Dark Matter & Dark Energy

The most recent WMAP observations are consistent with a universe made up of 74% dark energy, 22% dark matter, and 4% ordinary matter.

Remember Tests & planetarium

- Test 4 runs Dec. 5-8 free, switches to pay-per-view at 11 am on Wedn. 9th & ends on the 10th. The testing center is always a nightmare during the last week of school so students would do better to take the test in the middle of the day Sat. 5th, Mon. or Tuesday, not on either the 9th or 10th.

When light bulbs are farther away they appear

A. Bluer
B. Redder
C. Brighter
D. Dimmer

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