Wednesday, Oct. 29

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

Reading for this week: chapter 11

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

Our Schedule

Aug 27:	Ch 1+App A	The Scale of the Cosmos
Sep 3:	Ch 2+3	The Sky, Cycles in the Sky
Sep 8:	Ch 4	The Origin of Modern Astronomy
Sep 15:	Ch 5	Telescopes
		Sep 19: Exam #1, Ch 1-5
Sep 22:	Ch 6	Starlight and Atoms
Sep 29:	Ch 7	The Sun
Oct 6:	Ch 8	The Family of Stars
Oct 13:	Ch 9	The Formation and Structure of Stars
Oct 20:	Ch 10	The Lives and Deaths of Stars
		Oct 24: Exam #2, Ch 6-10
Oct 27:	Ch 11	Neutron Stars and Black Holes
Nov 3:	Ch 12	The Milky Way Galaxy
Nov 10:	Ch 15	Cosmology
Nov 17:	Ch 16	The Origin of the Solar System
Nov 24:	Ch 17	The Terrestrial Planets
Dec 1:	Ch 18	The Outer Solar System
		Dec 5: Exam #3, Ch 10-12,15-19

Topics for this week

Compare the two types of supernova: how do they differ in the cause of the explosion and in what is left behind?

Describe neutron stars.

Describe pulsars.

Why do neutron stars rotate so quickly?

Why couldn’t white dwarfs or other stars rotate as quickly?

Define ‘escape speed’.

Describe black holes.

What evidence do we have that there is a very massive black hole at the center of the Milky Way?

The collapse of a massive star

Stars more massive than about 8 M_{sun} can go through a series of fusion reaction leading up to iron.

Fusion of iron absorbs energy instead of releasing it.

That makes the Fe core unstable, and it collapses.

As the core collapses, electrons fuse with protons in the Fe nuclei: $p^+ + e^- \rightarrow n + \nu$

But this reaction absorbs even more energy, decreasing the pressure even more.

The collapse stops when the density reaches that of an atomic nucleus, and the core is made of neutrons.

Neutron degeneracy pressure (and repulsion between neutrons when so tightly packed) stops the collapse.

The dense ball of neutrons is a neutron star.

Type II Supernova

The shells fall onto the core and also fuse to make neutrons.

The envelope falls onto the neutron core and bounces.

It is thrown off at speed as high as 1/10 the speed of light.

The hot exploding gas can emit as much light as 10^{11} stars for a few days.

This happened in the Large Magellanic Cloud (a group of about 10^8 stars about 60,000 pc from here) in 1987.

Testing the theory

What kind of a star was it that exploded in the Large Magellanic Cloud?

We can see the star on photographs taken before the explosion. We know it's the right star, since it's not there in photos taken after the explosion.

It was a luminous blue star, near the top end of the main sequence.

Is this what the theory predicts?

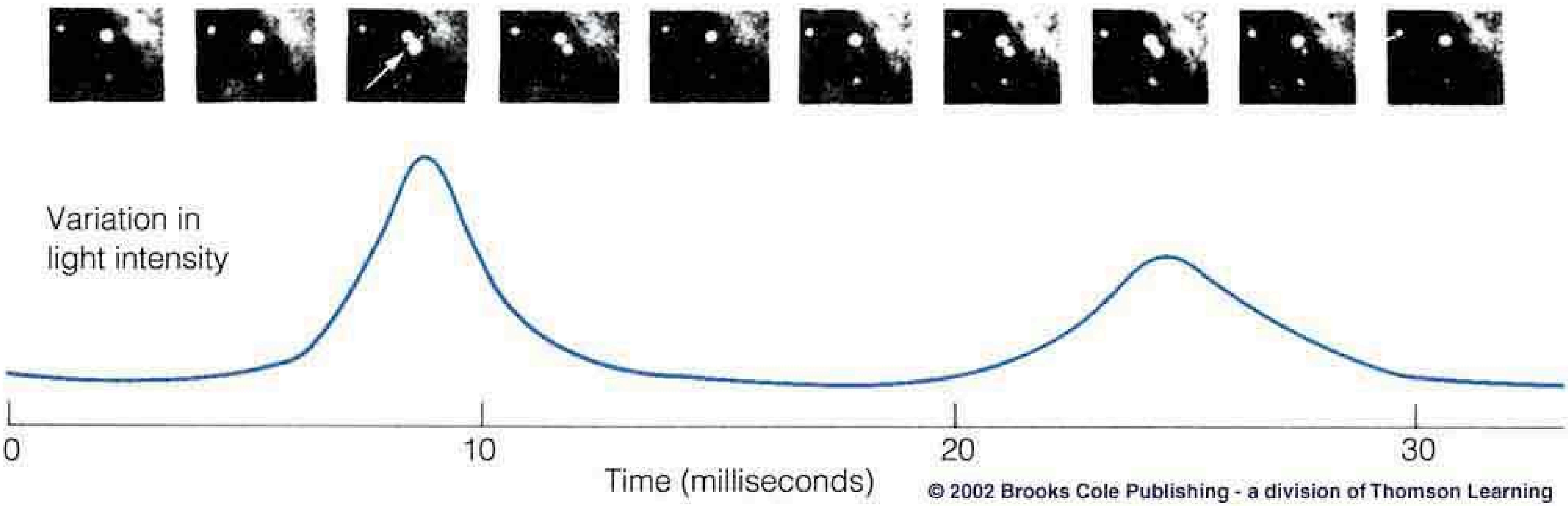
The discovery of pulsars

Jocelyn Bell, a student in England, was observing ‘radio stars’ with a radio telescope in 1967.

She noticed that one of the stars seemed to flicker regularly.

Perhaps jokingly, they at first thought it was a signal from an extraterrestrial civilization, but soon other stars like it were found, and they concluded that it was a natural phenomenon.

(The professor she was working for got the Nobel Prize for the discovery.)


Variation in
light intensity
0
10
20
30
Time (milliseconds)

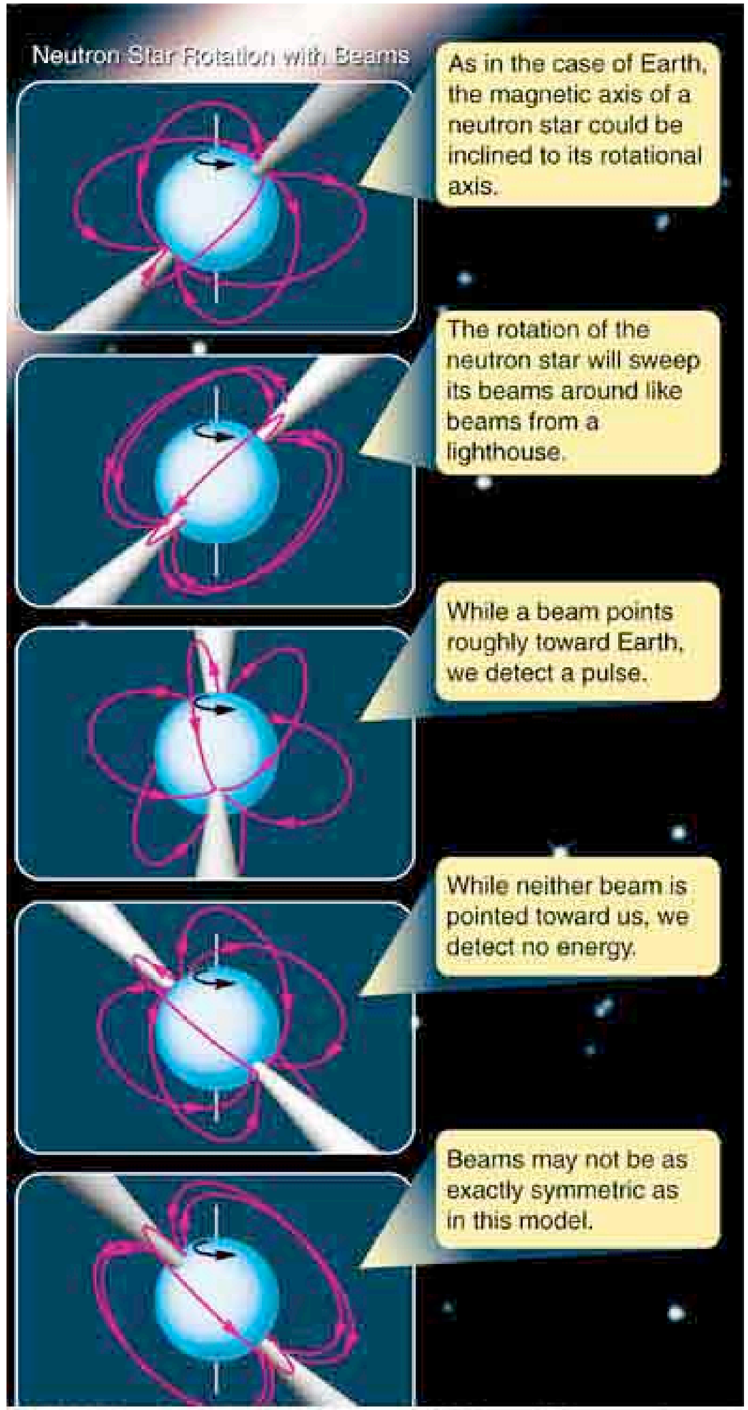
How can a star flash 30 times a second?

Even if the Sun could turn on and off in 1/30 second, its radius is about 2 light-seconds, so it wouldn't appear to us to all turn on and off together.

White dwarfs are small enough to avoid this problem, but what could make them flash?

We know of pulsating stars that vary in brightness by varying in size, but they take minutes to years to vary.

They also don't turn off between flashes like pulsars do.


Neutron Star Rotation with Beams
As in the case of Earth, the magnetic axis of a neutron star could be inclined to its rotational axis.
The rotation of the neutron star will sweep its beams around like beams from a lighthouse.
While a beam points roughly toward Earth, we detect a pulse.
While neither beam is pointed toward us, we detect no energy.
Beams may not be as exactly symmetric as in this model.

Can a star rotate 30 times per second?

A star can't rotate faster than the time for a satellite would take to orbit near its surface.

Otherwise the gas near the surface of the star would go into orbit.

So the Earth can't rotate in less than 90 minutes.

The Sun can't rotate in less than 3 hours.

A white dwarf can't rotate in less than about 10 seconds.

But neutron stars are so compact that they can rotate 1000 times a second without flying apart.

They also have strong magnetic fields to direct their beacons.

Density of matter in a neutron star

Density = mass / volume

The density of the Sun is about equal to the density of water, and the mass of a neutron star is somewhat more than the mass of the Sun.

The volume of a neutron star is about 10^{15} times smaller than the volume of the Sun.

How does the density of a neutron star compare to the density of the Sun?

Why do neutron stars rotate so fast?

What happens when an ice skater goes into a spin and then pulls his hands in?

Or what happens to a planet orbiting the Sun if its orbit takes it from far from the Sun in closer to the Sun?

The Sun is rotating, with its surface moving at about 1 km/sec.

If the Sun suddenly collapsed to the size of a neutron star, about 10^5 times smaller than it is now, and gas on the surface of the Sun followed an elliptical path going 10^5 times closer to the center of the Sun, how fast would it go?

How fast could a collapsed star rotate?

If the Sun suddenly collapsed to the size of a neutron star its surface would be moving at 10^5 km/sec.

Neutron stars don't actually rotate this fast because they lost some of their angular momentum when they were red giants.

Orbital speed around a neutron star

We can use Newton's version of Kepler's 3rd law to calculate the speed that an object would have when orbiting a neutron star. The formula is:

$$v_{orbit} = \sqrt{\frac{GM_{star}}{a}}$$

For a mass of 2 M_{sun} and an orbital radius of 10 km, the orbital speed is about 100,000 km/sec.

This is 1/3 the speed of light.

Escape speed

To leave Earth orbit and go to the Moon, the Apollo astronauts had to fire their rockets to increase their speed to about 1.4 times the orbital speed.

$$v_{escape} = \sqrt{\frac{2GM_{star}}{R}}$$

For a neutron star with M = $2M_{sun}$, $v_{escape} \sim 0.45\ c$

If a neutron star had a mass of about 4 M_{sun}, its gravity would make it smaller than 10 km, and its escape speed would be greater than the speed of light.

Neutron stars with masses as big as 4 M_{Sun} can't exist.

Relativity

Einstein showed that Newton’s laws aren’t valid when objects move at speeds near the speed of light.

When an object moving at nearly the speed of light is given energy it doesn’t go much faster. Instead it gets more massive.

He also showed that it is better to look at gravity not as a force, but as a distortion of space around massive objects, making objects that come near massive objects follow curved paths.

That is his explanation for the fact that Galileo’s two balls fell together. They were both following the natural path through curved space.

Type I supernovae

If two stars form together, orbiting each other, the more massive one will burn out faster.

It can turn into a red giant and then a white dwarf.

Later, the less massive star can become a red giant.

If the stars are close enough together, the red giant can pour mass onto the white dwarf.

If the white dwarf gains enough mass to exceed 1.44 M_{sun}, electron degeneracy pressure isn't large enough to support it against its gravity, and it will collapse.

This will cause fusion of carbon and oxygen to make neon and magnesium.

The energy released will blow the star apart.

Nothing will be left behind.