Wednesday March 23

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

Reading for this week: Chapter 11

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

The Moon will be full on Friday.
(Easter is the first Sunday after the first full moon after the vernal equinox, which was last Sunday.)

About when will the Moon rise today?

In what direction should you look to see it rise?
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.
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 radius of a neutron star is about $10^5$ times smaller than the radius of the Sun.

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

A. $10^5$ times smaller
B. $3 \times 10^5$ times smaller
C. $10^8$ times smaller
D. $10^{10}$ times smaller
E. $10^{15}$ times smaller
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$E. \ 10^{15} \text{ times smaller} \quad (10^5)^3 = 10^5 \times 10^5 \times 10^5 = 10^{15}$
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?
Density of matter in a neutron star

The density of a neutron star is about $10^{15}$ times the density of the Sun (or about $10^{15}$ times the density of water).

The density of a neutron star is about $10^{15}$ grams / cubic cm, or $10^9$ ton / cm$^3$, or 1 ton / cubic hair.
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:

\[ v_{\text{orbit}} = \sqrt{\frac{GM_{\text{star}}}{a}} \]

For a mass of 2 \( M_{\text{sun}} \) 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.

\[ v_{\text{escape}} = \sqrt{\frac{2GM_{\text{star}}}{R}} \]

For a neutron star with \( M = 2M_{\text{sun}} \), \( v_{\text{escape}} \approx 0.45 \, c \)

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