ASTR 1120 – April 1

Student needs note taker.

Website
http://casa.colorado.edu/~wcash/APS1120/APS1120.html
Black Holes

• Are there any Black Holes?

YES.

(10 years ago, the answer was “probably”.)
• What Happens when a neutron star exceeds its Chandrasekhar Limit?

• Must Collapse

• No known force powerful enough to halt the collapse

• Result: Black Hole
Things that don’t happen

• Collapse to Singularity

• Winks out of universe

• Explodes by some new force

• Einstein’s prediction wasn’t a “sure thing”
Formation

Neutron Star Collapses

Now it’s inside event horizon and can never be seen again.
A Newtonian Black Hole

Energy Falling To Surface

$$\frac{GMm}{R} = \frac{1}{2}mv^2$$

Kinetic Energy

OR

$$R = \frac{2GM}{c^2}$$

if $v = c$
Schwarzschild Radius

\[ R = \frac{2GM}{c^2} \]  
Two errors cancel.

This is the radius of the “Event Horizon”

The event horizon is a true singularity in space-time.

It is a place where time and space cease to exist.
Geometry of Black Hole

Can you boost the signal?
No, that doesn’t help.

Space Curves
in on itself

There’s no path out!
Curved Space

- "Lines" parallel at one place eventually cross.
- The shortest distance is a curve that is a segment of a great circle.
- The sum of the angles of a triangle is greater than 180°.

\[ C < 2\pi r \]
Rubber Sheet Analogy

- c  circular orbit
- e  elliptical orbit
- u  unbound orbit
Properties - Size

\[ R = \frac{2GM}{c^2} \]

\[ R = \frac{2 \times 6.7 \times 10^{-11} \times 2 \times 10^3}{(3 \times 10^8)^2} = 3000m \]

The radius of a black hole is 3km per solar mass
There is no limit on size or mass.

Note: Volume rises as the cube of the mass. Implies the larger the black hole gets, the lower is its density.

A sphere of water the size of Saturn’s orbit would be a black hole!
Properties – Escape Velocity

No way.

Not even light can escape.

No signal can escape

No particle

Nothing
Properties – Orbital Period

\[ P = \frac{2\pi R_s}{c} = \frac{6.28 \times 3000}{3 \times 10^8} = 60 \mu s \]

Material orbiting a black hole will have milli-second periods
Properties - Basic

1. Mass  (Schwarzschild Black Hole)

2. Electric Charge  (doesn’t happen)

3. Angular Momentum  (Kerr Black Hole)

No “Surface” Features
No Magnetic Fields
No Pulsing

“No Hair”
Jump on In

You won’t make it, but it would be quite a ride!
Properties – Energy Emitted

• Energy Released from accretion

• about 0.1mc$^2$
Time Dilation

Now it gets weird!

Time does not run at the same rate everywhere in the universe.

Twins are not always the same age.

Clocks run a little bit faster in Colorado than in Washington DC.

Folks in DC are actually a little slower than us.
About one part in a trillion.
That’s a millisecond over a lifetime.
Time Dilation

$$\delta t = \frac{\delta t_\infty}{\sqrt{1 - \frac{R_s}{r}}}$$

Some event takes $\delta t_\infty$ out in free space.

Same event takes place at radius $r$ from center of a black hole. Now view it from free space.

Takes $\delta t$ instead. Longer. It looks like things are moving slower.

If you are near the black hole, the rest of the universe appears to be moving faster.
Time Dilation

\[ \delta t = \frac{\delta t_\infty}{\sqrt{1 - \frac{R_s}{r}}} \]

As \( r \) approaches \( R_s \), \( \delta t \) gets longer and longer.

When \( r \) reaches the event horizon, time stops.

We know how to make a time machine with a forward switch only!
Just fly to a black hole and orbit above the surface.

But you can fall in really fast as viewed from outside.
A “frozen star”

If time stops above the surface, it can’t go in.

How does the hole form?

Is the material still stuck in temporal limbo just above the surface?

What’s inside?

If nothing can get out, then how can gravity?
Hawking Radiation

The vacuum makes pairs of electrons and positrons that pop into existence and then annihilate without any net effect.

Above a black hole, one can get sucked in. The other annihilates above the surface to cause radiation.

Since its close to the surface, the light gets redshifted escaping, but it carries energy with it!
Temperature

\[ T = \frac{hc^3}{16\pi^2 kGM} = \frac{10^{-8}}{M} K \]

Hawking derived that the temperature of a black hole is thermal.

Energy for the radiation comes from the mass of the hole.
The black hole shrinks with time.

\[ \tau = M^3 \times 7 \times 10^{67} \text{ years} \]

That’s a really long time unless the black hole is tiny.

A 1kg black hole would last only $10^{-16}$s.
Artist’s impression of Cyg X-1 (NASA)

6M₀ BH orbiting an O9 star.

2000pc away in Cygnus