Black Holes

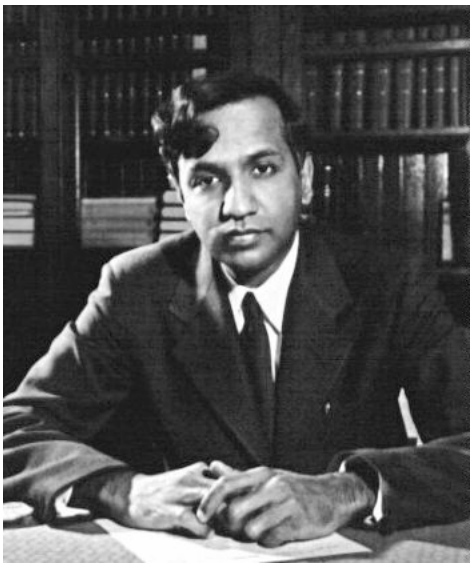
March 27

S.Chandrasekhar (1910-1995)

Calculated the white dwarf mass limit at age 20!

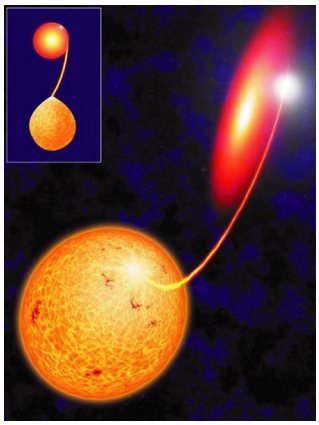
Nobel Prize 1983

Namesake of the Chandra X-ray Observatory



Maximum mass for white dwarf

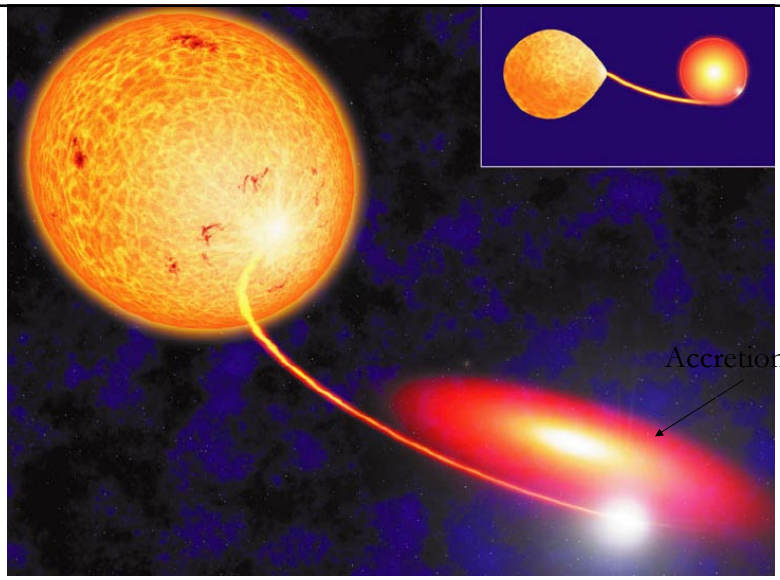
- In white dwarf, degenerate electrons cause pressure.
- In normal gas, pressure depends upon temperature



Maximum mass of a white dwarf

- Chandrasekhar limit = 1.4 solar masses
- Beyond that mass, the degenerate electrons cannot balance gravity and the white dwarf would collapse

What happens to a white dwarf in a close binary system?



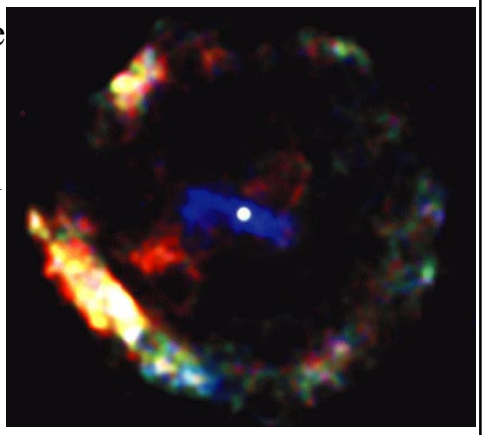
Mass transfer (accretion) can occur from a companion red giant or main sequence star.

If the mass exceeds 1.4 solar masses…

- The white dwarf may explode as a supernova!

Maximum mass for neutron star

- Neutron star has degenerate neutrons
- maximum mass for neutron star is about $3M_{\odot}$
- If mass is greater, gravity wins. Star collapses; nothing stops collapse.



Supernova in 386AD
X-ray image showing remnant & neutron star.
Fig. 13.6

Which would be bigger in diameter?

- A) a white dwarf with a mass of 0.6 solar masses
- B) a white dwarf with a mass of 1.0 solar masses
- C) a neutron star with a mass of 1.5 solar masses

Escape Velocity

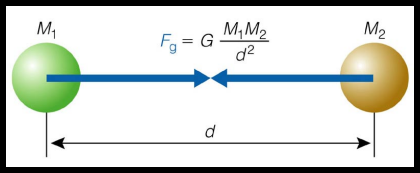
- How fast do you have to go to escape from the surface of an object and never fall back?

Clicker question

What happens to the escape velocity from an object if you shrink it?

A. Increases
B. Decreases
C. Stays the same

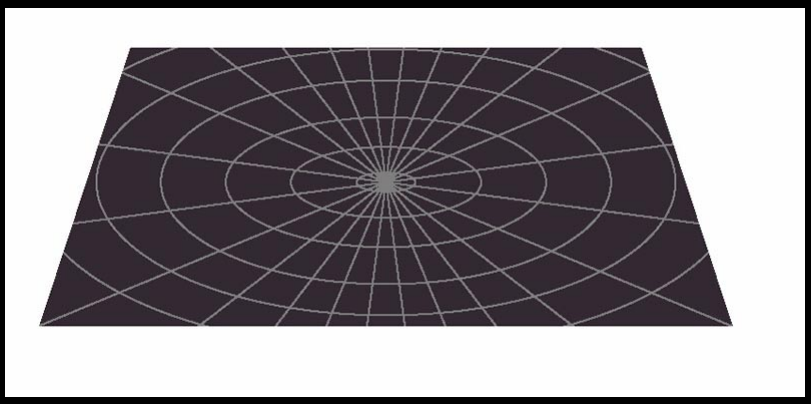
Hint:



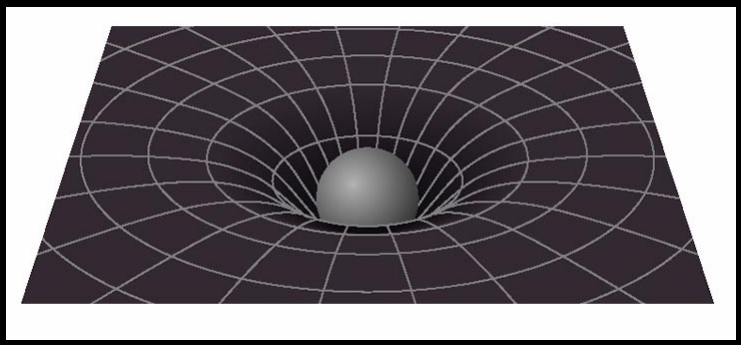
If a mass has a small enough radius

- The escape velocity will be greater than the velocity of light!
- Light is the fastest thing we know of
- This a Black Hole

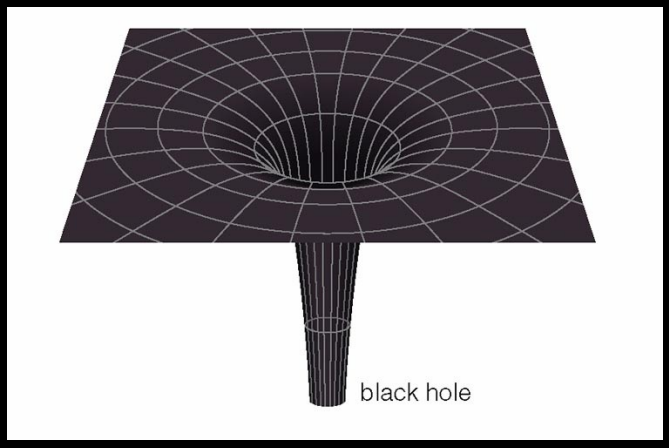
Space-Time



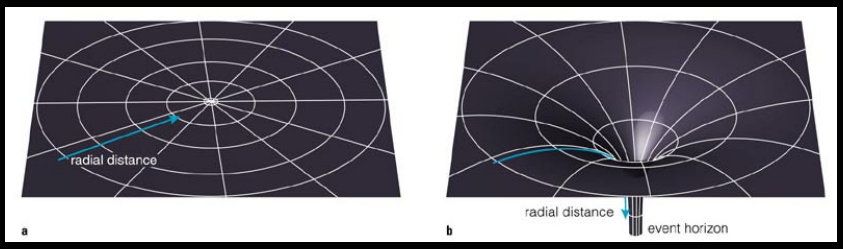
Mass bends space-time



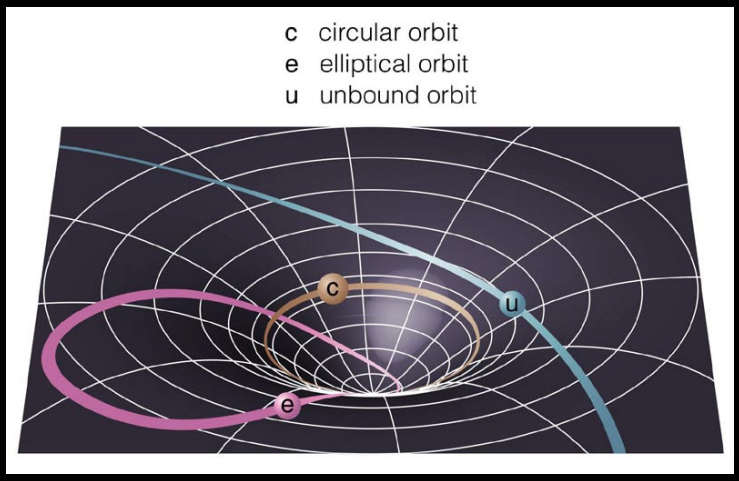
More mass bends it more



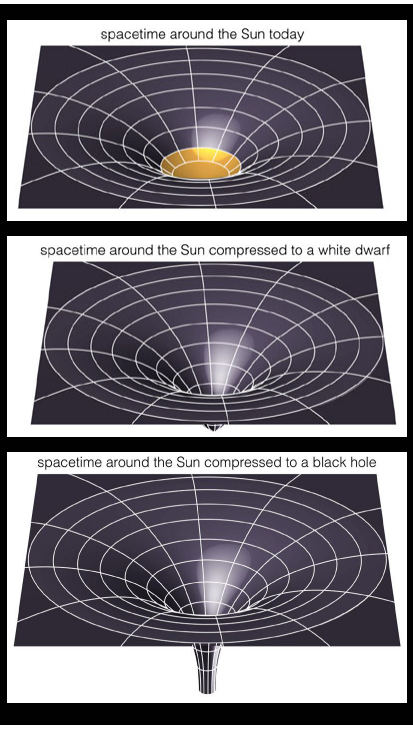
(See Section S3.4)



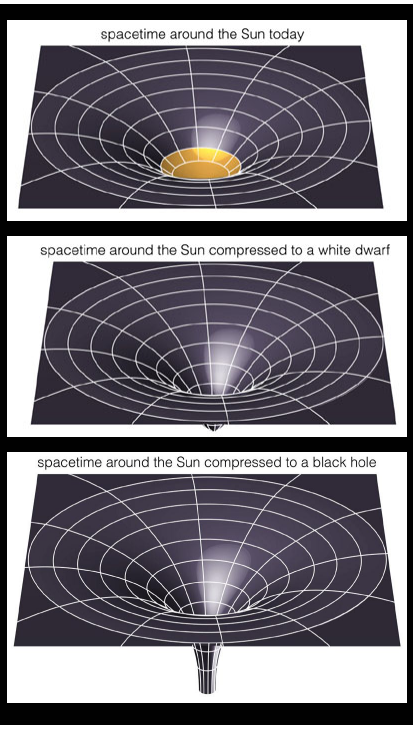
The immense gravity of a black hole strongly warps space and alters time in its vicinity.



Einstein's General Theory of Relativity explains gravity through the warping of space and time



If the Sun shrank into a black hole, its gravity would be different only near the event horizon



If the Sun shrank into a black hole, its gravity would be different only near the event horizon

Black holes don't suck!

No Escape

Nothing can escape from within the event horizon because nothing can go faster than light.

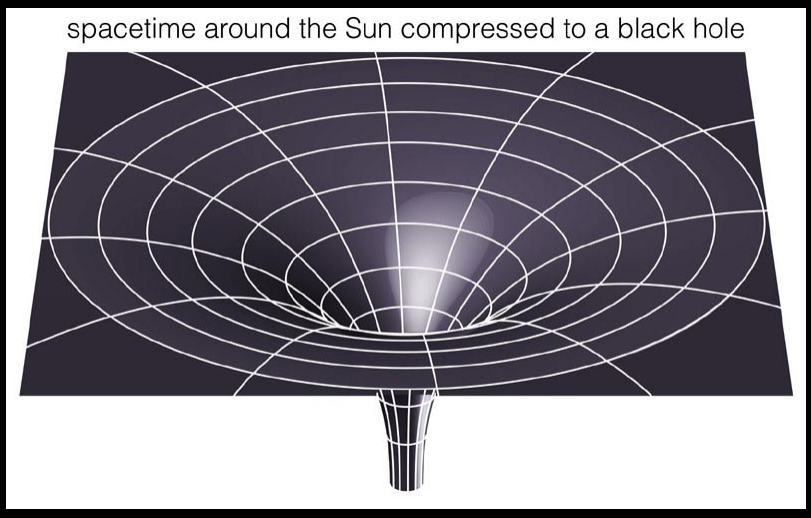
No escape means there is no more contact with something that falls in. It increases the hole mass, changes the spin or charge, but otherwise loses its identity.

No Black Hole Mass Limit

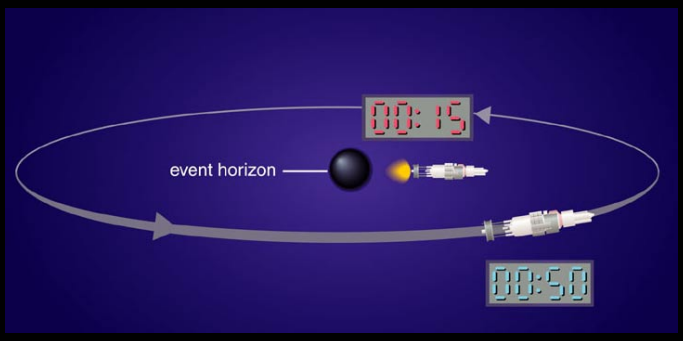
Unlike normal stars, white dwarfs and neutron stars, black holes have no mass limits. Gravity wins.

The smallest ones known ~3 solar masses.

The biggest ~ billion solar masses.

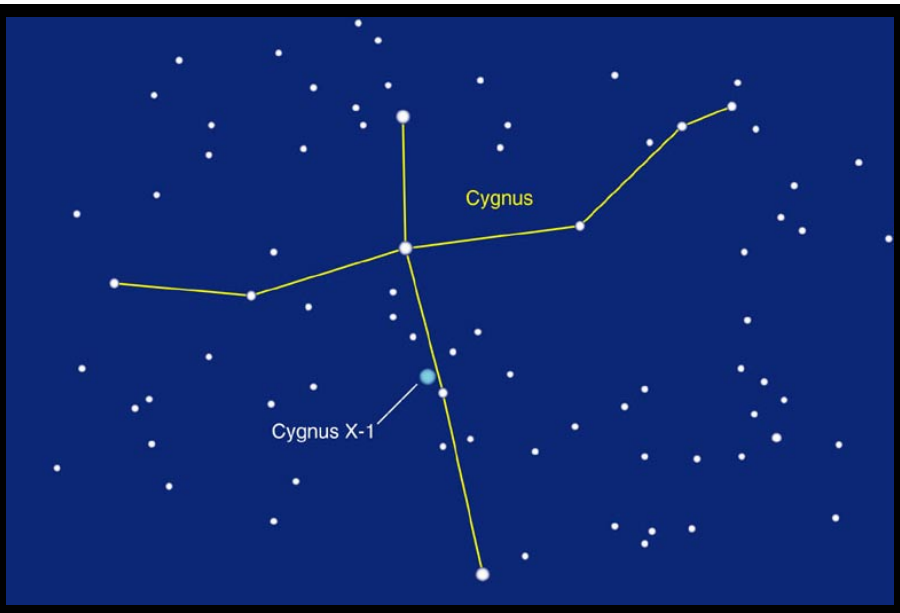


Light pulses take extra time to climb out of a deep hole in spacetime

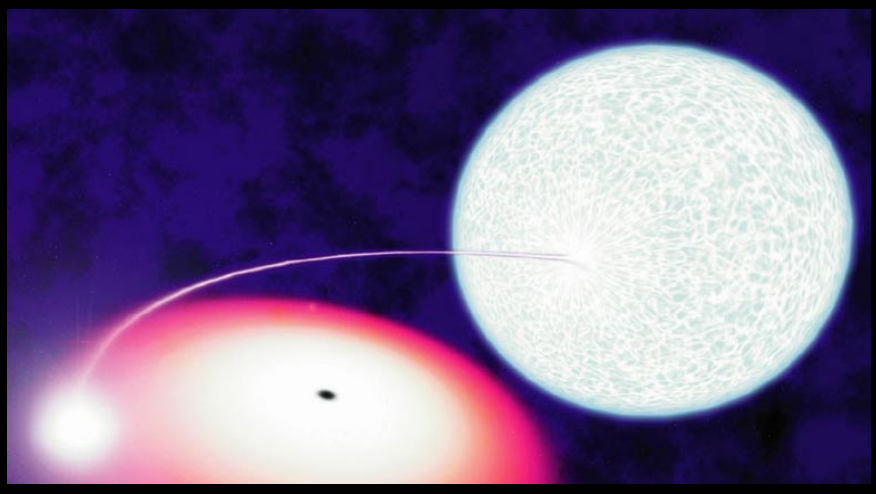


Time passes more slowly near the event horizon

Do black holes really exist?



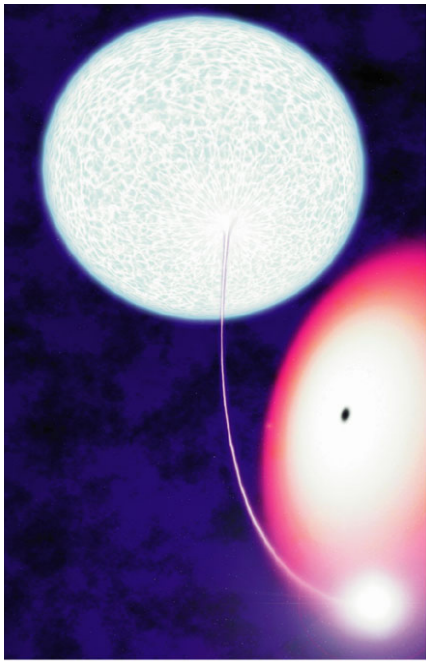
One famous X-ray binary with a likely black hole is in the constellation Cygnus



Some X-ray binaries contain compact objects of mass exceeding 3 M_{Sun} which are likely to be black holes

Cygnus X1

- HD226868, a giant, donates mass to BH
  - Mass falls toward BH, moves fast, gets hot.
  - Hot gas emits X rays
- Mass of companion
  - Mass of companion is $10M_{\odot}$.
- Companion is compact
  - A 10-$M_{\odot}$ star would be seen in visible.



Proving it's a black hole

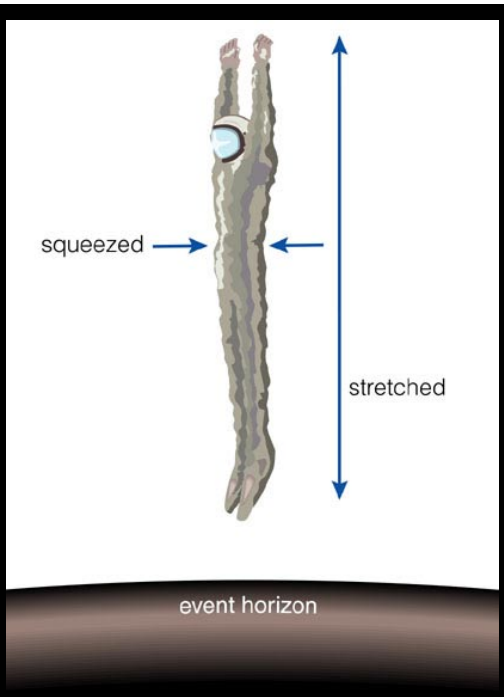
- ✓ Mass > 3 solar masses
- ✓ Too compact (small) to be a star or anything else.

What would it be like to visit a black hole?

What would happen if you fell into a black hole?

When you are far outside the event horizon, your fall does not seem unusual.

But, when you get close to the event horizon…



Tidal forces near the event horizon of a 3 M_{Sun} black hole would be lethal to humans

Tidal forces would be gentler near a supermassive black hole because its radius is much bigger

But we will also encounter black holes

- In the centers of galaxies
- In quasars

And those black holes may have masses of millions or billions of suns