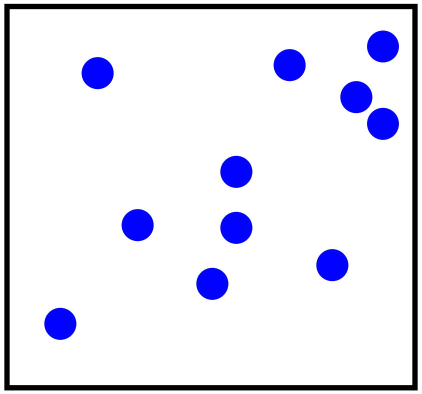
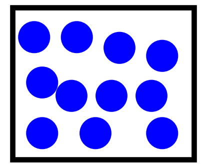
The Life and Death of Stars

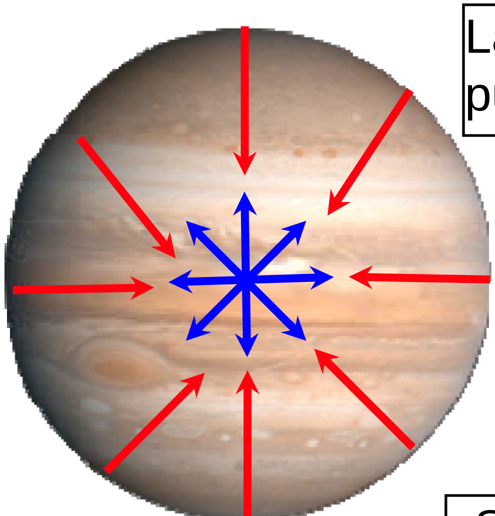
As we compress a box of gas, either the temperature of pressure go up (depends on details of crushing box)





After compression
large pressure on box

Before compression
small pressure on box



Large pressure means large forces on box, pushing to make it expand!

Gravity tries to pull gas of Jupiter in

But pressure pushes out

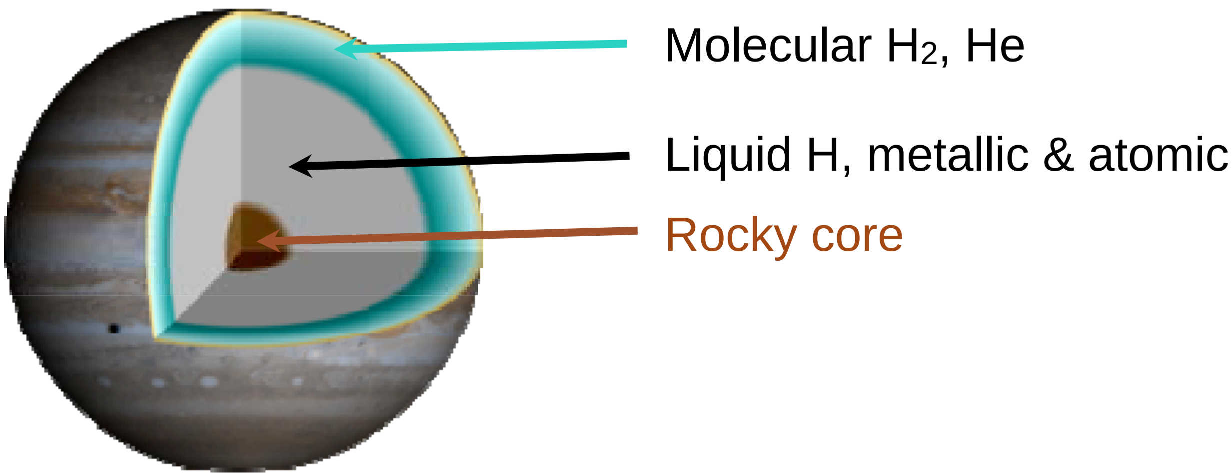
Stable size reached when
force from pressure = force from gravity

Same as you floating on your back in ocean!
(*Archimedes principle*)

Gravity vs pressure

Pressure increases as you approach Jupiter's core.

Pressure gets high enough and atoms are close enough that we have liquid and solids in Jupiter!



Jupiter and Earth's cores compressed to solids. What happens when you get much more massive?

$$M\,(Sun) \approx 1000 \times M(Jupiter) \approx 1000 \times 1000 M\,(Earth)$$

Increasing temperature can also increase pressure. To support the mass of the sun we need lots of energy.....

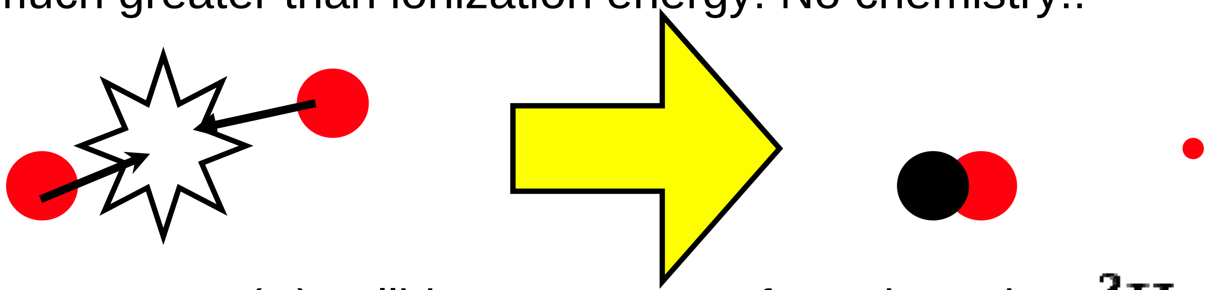
A nuclear reactor in the sky

The Sun is mainly hydrogen. Cannot get energy from chemical reaction

$$H + H \rightarrow H_2$$

Three reasons:

1) Not nearly enough energy
2) $k_B T$ much greater than hydrogen molecule bond -- interactions would break it!
3) $k_B T$ much greater than ionization energy! No chemistry!!



protons (H) collide

form deuterium ${}^2_2\mathrm{H}$
+ positron (“positive electron”)
+ energy

But: Angular momentum seems not conserved!?!

Need an (almost) invisible (almost) massless neutral particle: neutrino! (Pauli)

1. $$p + p \rightarrow d + e^+ + \bar{\nu}_e$$

This reaction does not release much energy and happens slowly.

Weak Interactions

H-fusion: weak interaction : never observed in lab

Basic reaction (we need to create neutrons):

$p \rightarrow n + e^+ + ?$

charge conservation - OK

energy and momentum conservation demands "?"

?=neutrino (anti)
Pauli 1931
("little neutral one")

Diary:
"I did something horrible today"

Pauli assumed that the neutrino has no charge, so it is (nearly) invisible

Since nobody observed it: interacts very weakly – "weak interaction"

How weak? It has to go through matter of thickness of light years (!!!) to have a 50% chance of being observed.

Observed by UC Irvine prof. F. Reines

They set up detector next to a nucular reactor, later in an abandoned mine

"Million-million" neutrinos came out, they saw 3!

May variants of same process. {Energy, Charge, Momentum} has to remain conserved

$n + e^+ \rightarrow p$ + anti-neutrino

$p \rightarrow n + e^+$ + neutrino

In vacuum this could not happen. But inside a nucleus this can happen: "nuclear pot"

1. First step of creating alpha particle/He4

$p + p \rightarrow d + e^+$ + neutrino   d=p+n: "deuterium"

Steps of Solar proton-proton cycle

It takes a thousand million years for an average proton to go through this step!!
Once this step was cleared, fusion process is much faster:

2. $p + d \rightarrow {}^3He$ + neutrino
3. ${}^3He + {}^3He \rightarrow {}^4He + p + p$

This is the "proton-proton" cycle

Faster alternative: Bethe (1939): "carbon cycle": does not need weak interaction
only occurs in stars with higher temperatures

Fred Hoyle (1957): all heavy elements are generated inside stars
"We are all made of stars" (Moby)

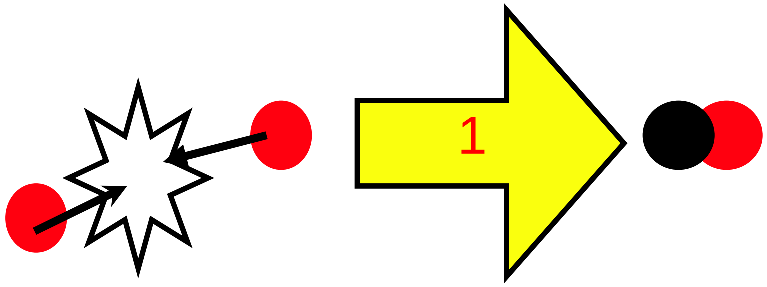
Problem: Solar neutrinos
1968-86 South Dakota: Homestake Gold mine
only on third of neutrinos where observed

Solution (1998):
Something happens on the way from the Sun to the Earth
"Neutrino Oscillations"

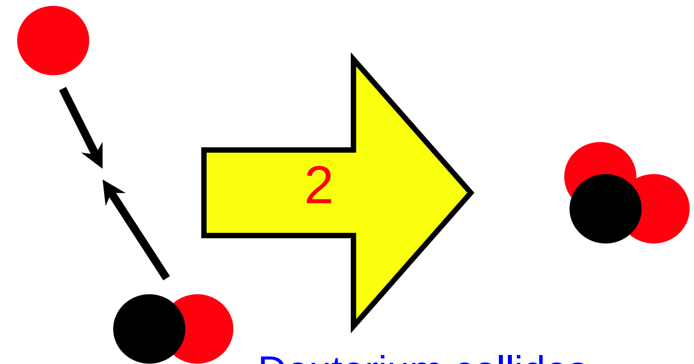
- there are 3 types of neutrinos
- the solar neutrinos turn into the other type of neutrinos
- this is possible, because they have a mass

May explain dark matter ("what concerns me is missing grey mater")

A nuclear reactor in the sky



Protons moving fast,
occassionally collide:
slow, not much energy
released

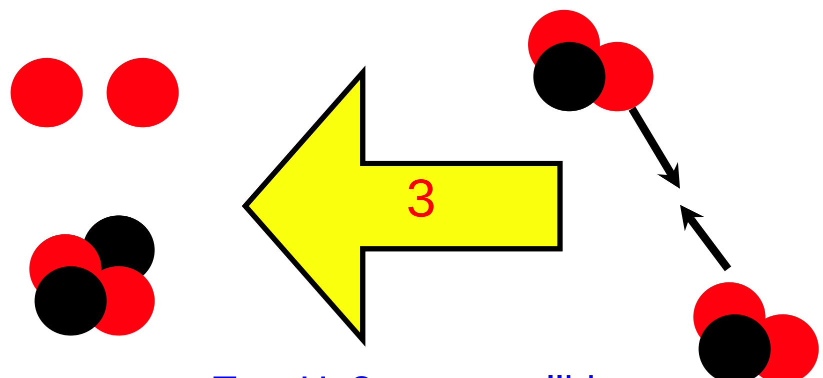


Deuterium collides
with proton:
fast, lots of energy
released

Gravity squeezes nuclei
together,

Nuclear reactions start,
raising temperature,
increasing pressure

Strike a balance with
gravitational collapse



Two He3 atoms collide:
produce He4 and two
extra protons

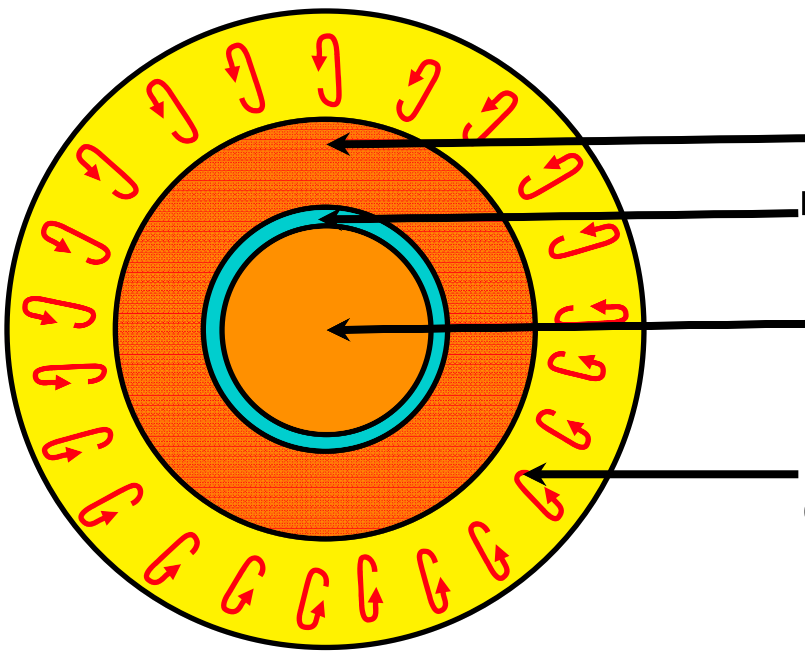
Inside a Red giant

What happens when the sun uses up a lot of hydrogen?
Burning slows down and star starts to collapse

Increased pressure still not enough to make Helium burn
But sufficient to start a different, faster hydrogen burning: Bethe's carbon cycle

Also, H and He separate, He sinks in the core, H burns in shell
1. H burning presses outer layers further out: Star becomes GIANT
2. There is less H burning plus star expands: temperature is less hot
Star evolves from white hot to red hot: RED GIANT

When the sun goes into its red giant phase it will be large enough to swallow Venus!

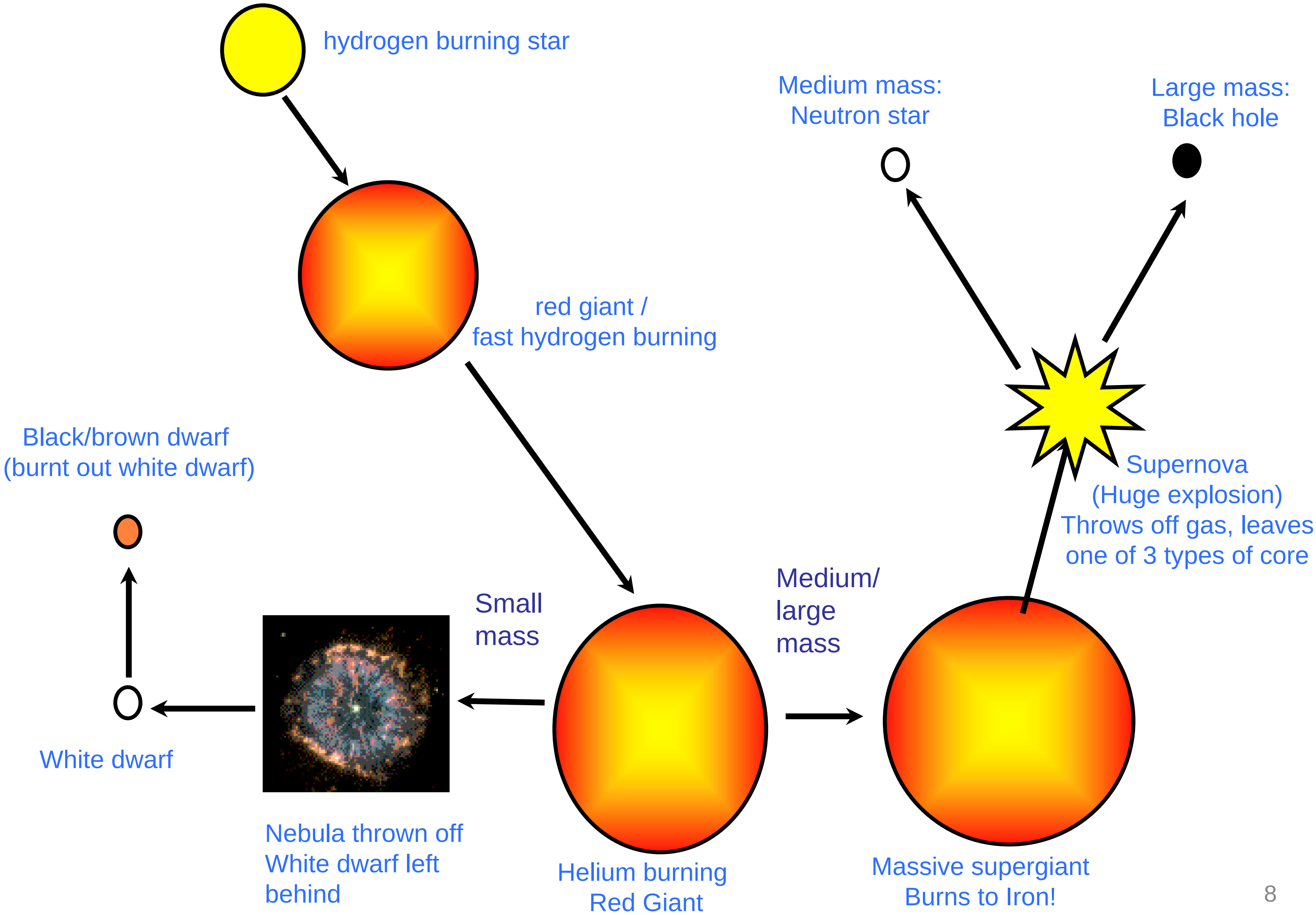


Breaking news!

Earth will also be engulfed in the sun. (Before it was thought the Earth may be pushed out enough as the sun expanded to escape).

http://www.newscientist.com/article/dn13369?feedId=online-news_rss20

Stellar lives

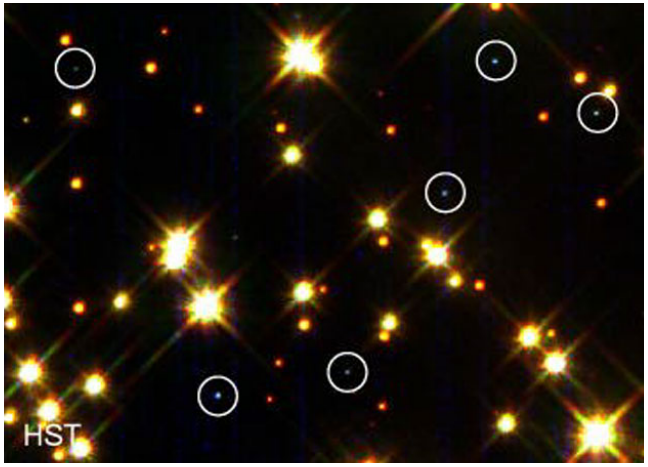


Stars with small mass: White dwarves

1. Red giant throws off out layer: this expanding gas is called a **Nebula**

2. Hydrogen used up, star is propped up
by Helium core supported by the Pauli exclusion
principle of the *electrons*, not temperature:
a **white dwarf** is formed.

Cools off into a brown/black dwarf



Stars with medium/large mass

1. Helium burning starts in massive Red giant

2. Heavier elements are formed through complex nuclear reactions

3. Supernova explosion

The nova of single star can be brighter than entire galaxy!

Chinese observed one in 1054 in our Milky Way
It is today the Crab Nebula

In 1987 we saw one super bright in other galaxy

Bright star of 3 Magii in Bible:
Haley's comet.
Comes every 72 years

Stars with medium mass: Neutron stars

Enough pressure in small core to press protons and electrons to fuse:

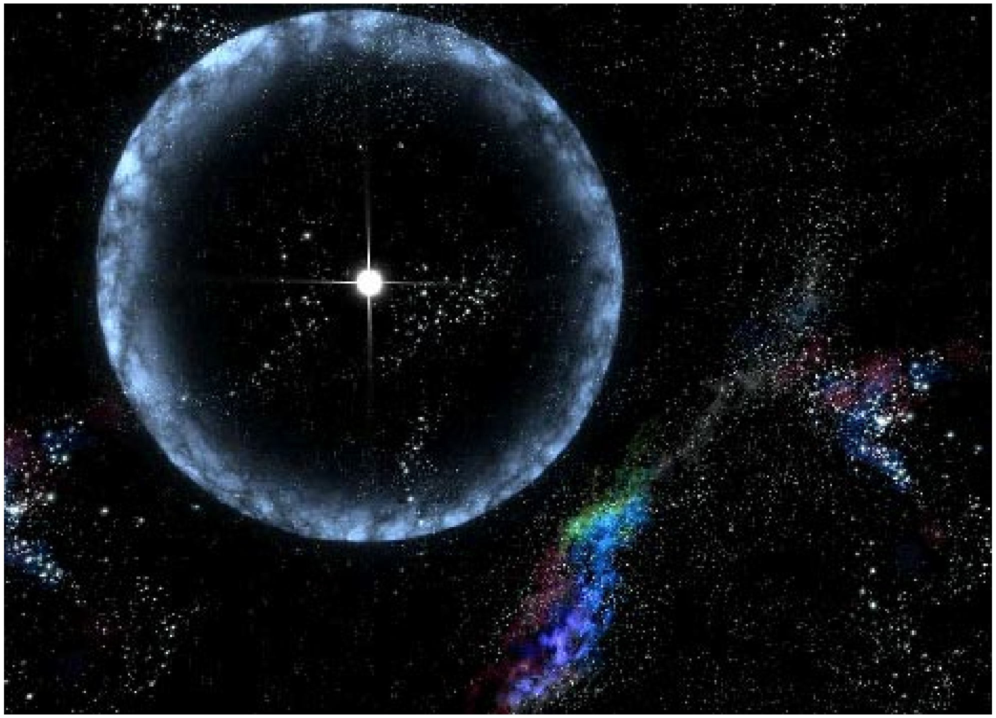
$$p + e \rightarrow n + \nu_e$$

Called “inverse beta-decay” or “electron capture”

The neutron is much smaller than the electron of the atoms: star collapses dramatically.

Collapse stabilized by Pauli exclusion principle *of neutrons*!

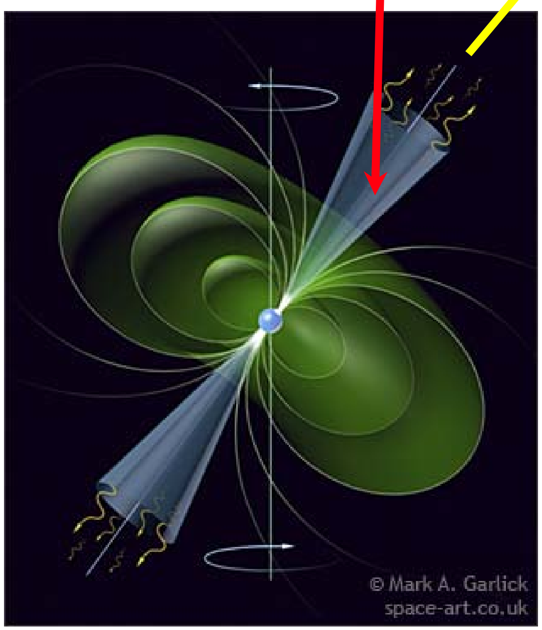
A neutron star with mass = 2 M_{sun} can fit between Davis and Woodland



Stars with medium mass: Neutron stars

Light/particles radiating:

Magnetic field constricts particles, radiation to a narrow cone



Beam sweeps around and hits Earth <u>periodically</u> -- like a cosmic lighthouse!

Discovery: Jocelyn Bell
Nobel to professor only

<u>Period of rotation:</u>
Between 30ms and 8.5 s

<u>Pulsars</u>:

As a neutron star collapses, the angular momentum is conserved. Star starts to spin faster.

Magnetic fields direct charged particles, only a thin beam escapes. If aligned right, the Earth can be hit by this beam once per rotation. Some pulsars (entire stars) are as precise as atomic clocks!

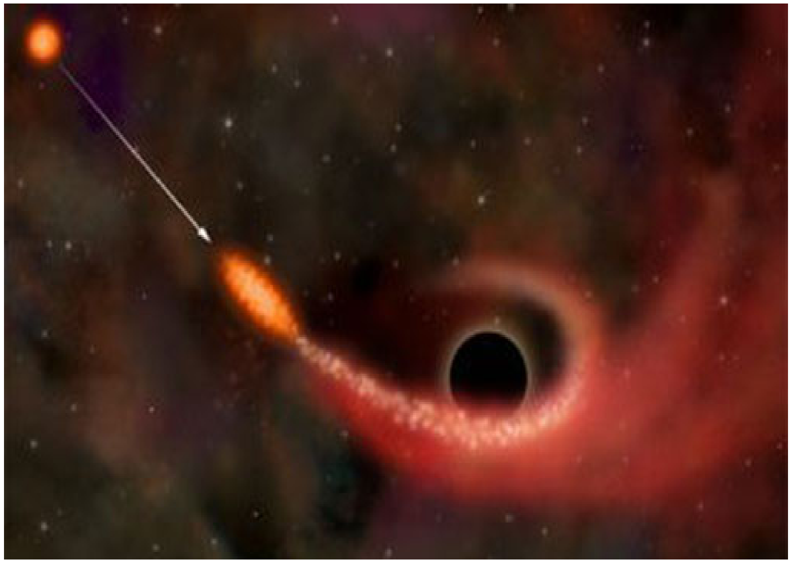
First pulsar discovered called **LGM** (little green men) because it looked like aliens trying to contact us with periodic flashes!

Stars with large mass: Black holes

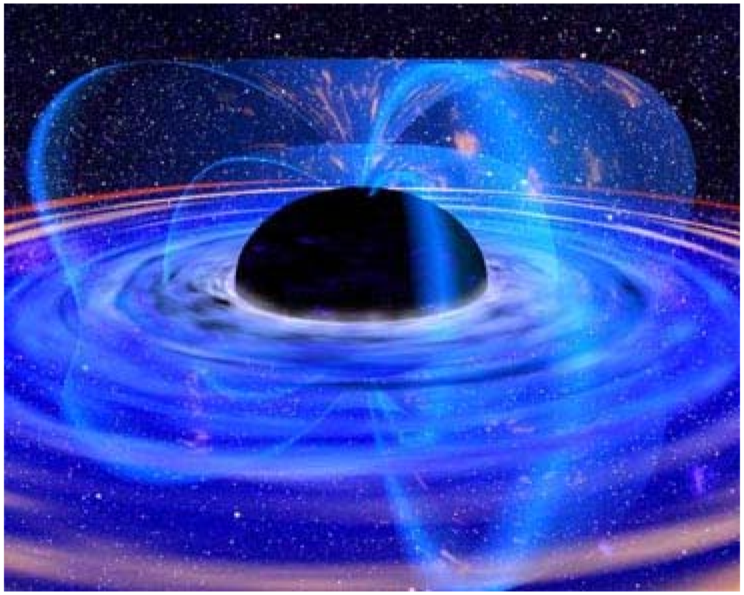
Gravity too strong to be supported by neutron pressure

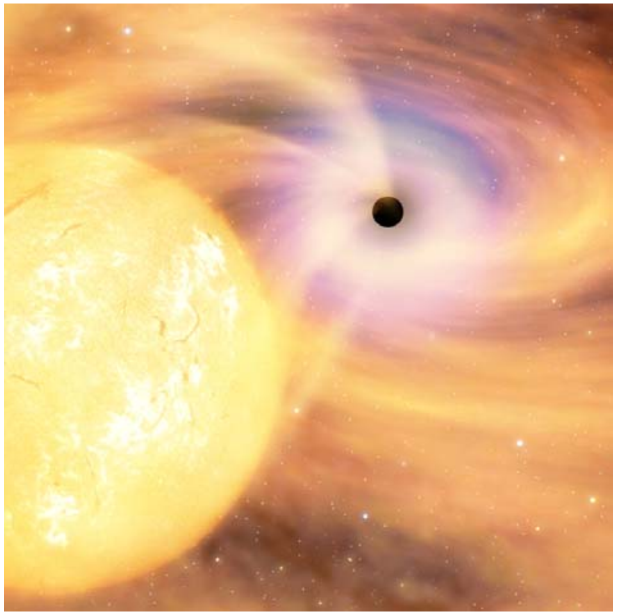
Eventually *no* amount of pressure can stop collapse!

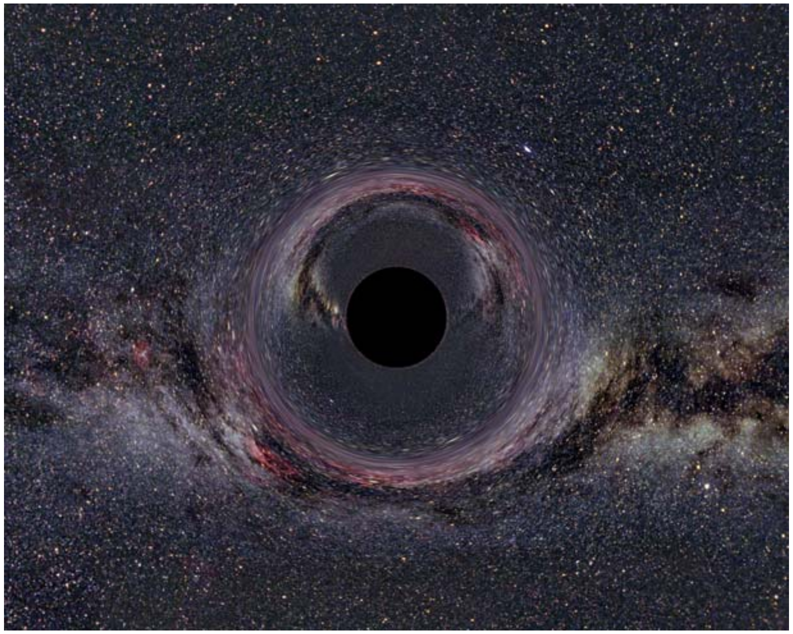
Black hole forms! All matter forced into the central "singularity". Our equations break down, gravity so strong not even light can escape (hence the "black" in "black hole")



Black holes



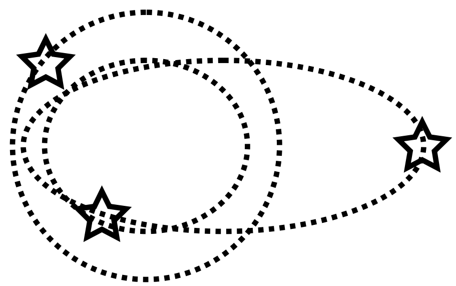




“Seeing” black holes against a black sky

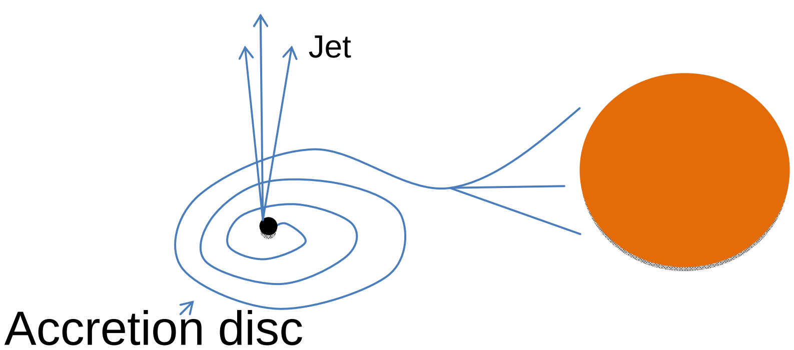
Indirect:

For ***very*** massive black holes, we can see other stars orbiting around it (e.g. black hole in center of galaxy)



(Stars pulled in by unseen object)

Direct: If matter “accretes” onto blackhole then while it is in a “death spiral” around the hole matter heats up, lets off jets of radiation.



A common source of mass is if there is another star nearby. Blackhole acts like “cosmic vampire” and its always night in space.

Sucks gas off neighbour, gas releases energy and falls into black hole.

Summary

- **The balance of two forces sets the size of stars:**
  - inward: gravity
  - outward: pressure (sources: Pauli principle, temperature)

- **Stars start by burning hydrogen, then burn Helium.**
  The rest of the cycle depends on mass

- **The final stage of a star's life:**
  - small mass: white dwarf
  - medium mass: neutron star
  - large mass: black hole

- **Neutron stars have strong magnetic fields, which direct the emitted light/particles in narrow rays, act as "cosmic lighthouses"**

- **Black holes suck material in and grow ("cosmic vampires"). Seen by gravitational effect (if HUGE) or by energy released as matter falls in.**

- **All elements EXCEPT for H and He came from nuclear reactions inside stars, scattered by huge explosions of previous stars: (super)nova.**