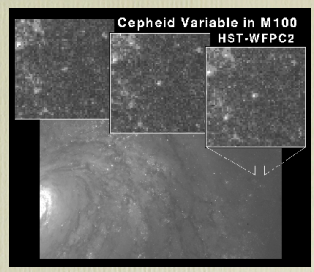
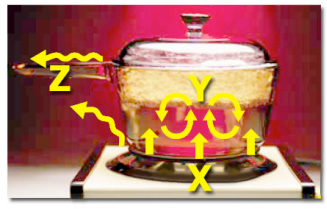
- Vast majority of stars are boring: "main-sequence" (aka middle-class) changing very slowly.
- Some oscillate: e.g Cepheids
- Large bright stars change by factor 3 in brightness



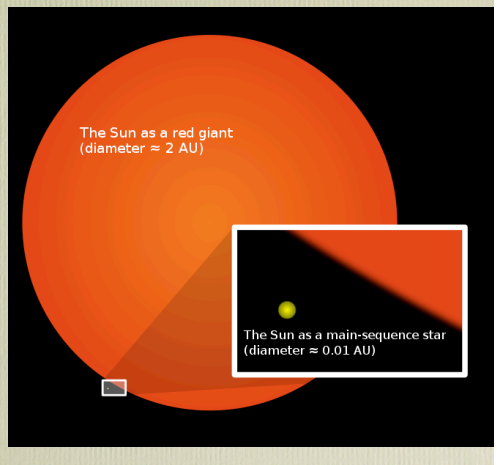
Change colour, size, brightness



- well understood: work by blocking mechanism
- very important since period is proportional to intrinsic brightness:
- i.e. measure the *apparent* brightness, the period tells you the *actual* brightness, so you know how far away it is

Adulthood is dull

- Don't we know it!
- Finally star will run low on fuel and expand
- Becomes red giant

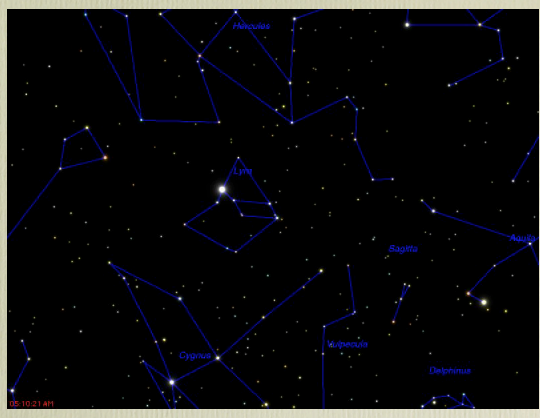


Mostly cannot see inside stars

Then

If stars are small, (like the sun) they puff away their outer layers

This is M57 (Ring Nebula)

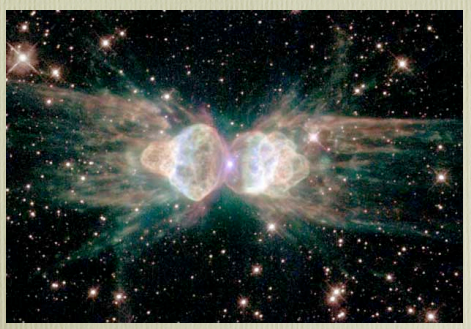


- Planetary nebula
- Central star is a white dwarf (50000°C)
- Hot blue gas at centre
- Coolest red gas along the outer boundary.

- This will happen to the sun, in 5.5 billion years.
- The star blows away its outer layers, so almost all the older ones we knew look like this.

- But we find all sorts of weird shapes.
- This is the Cats-eye nebula: looks like successive explosions

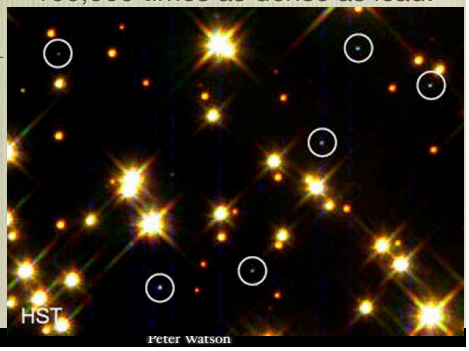
- Mz3: The Ant Nebula.
- Probably magnetic field is creating a "focussed" planetary nebula



White dwarfs

- After the outer shell has disappeared, we are left with a star about the same mass as sun but size of earth (~10000 km)
- Density: ~1 million: ~ 100,000 times as dense as lead.

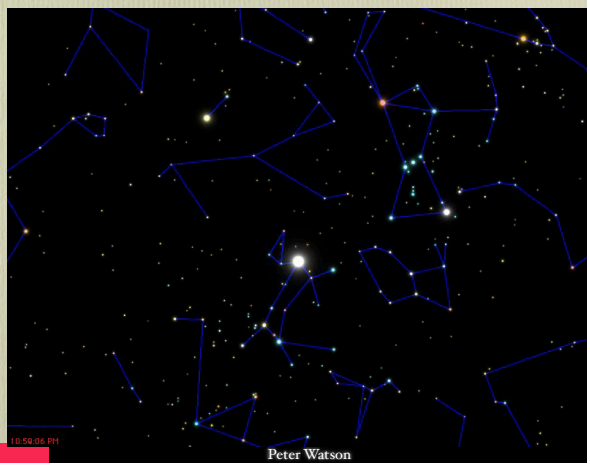
This shows some in M4 (a dense cluster of stars).
Since they are small, they cool very slowly.



Sirius

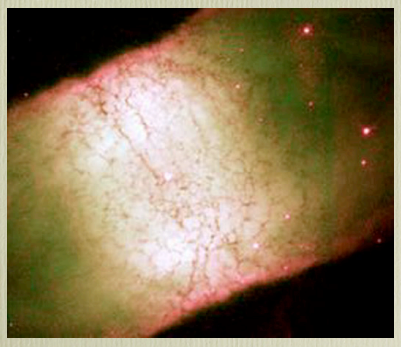
Brightest star in the sky

Has an almost invisible companion white dwarf



- The Eight Burst Nebula
- White dwarf and companion, will probably look like Sirius in 100000 years

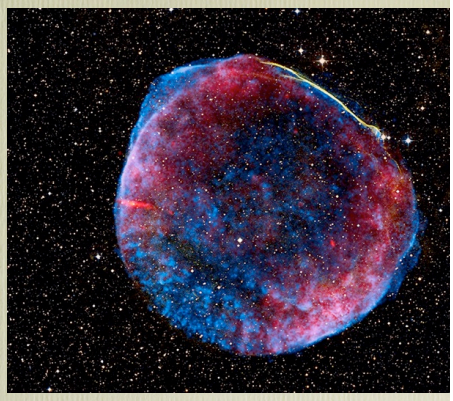
- IC 4406:
- a really weird planetary nebula
- probably a cylinder that we see side on.



Credit: H. Bond (STScI), R. Ciardullo (PSU), WFPC2, HST, NASA

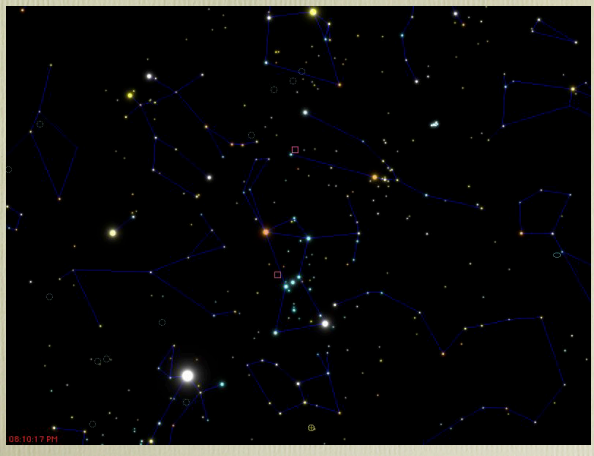
If Stars are large....

- we get supernovae
- 6 visible in Milky Way over last 1000 years
- SN 1006: Brightest Supernova.
- Can see remnants of the expanding shockwave



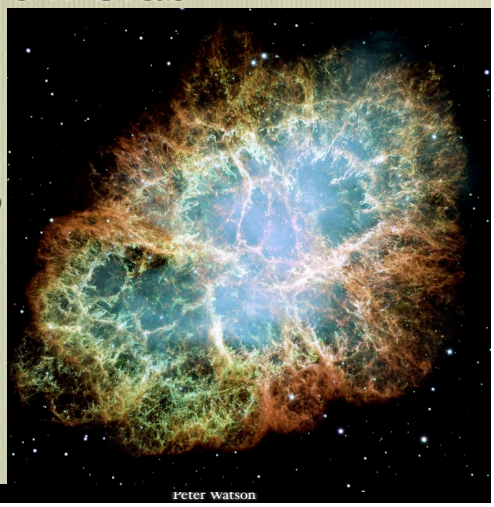
Frank Winkler (Middlebury College) et al., AURA, NOAO, NSF

The Crab (M1)

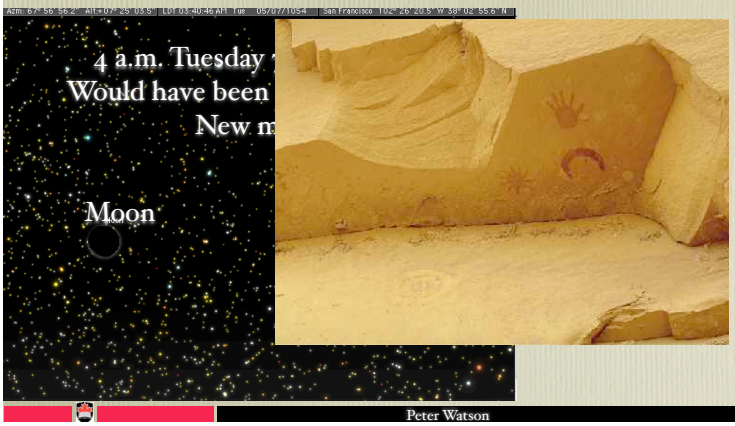


1054: Crab

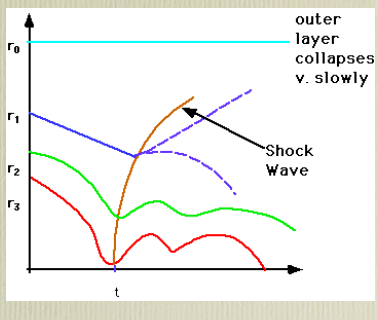
- X-rays (in blue)
- + Optical
- Tangled appearance due to trapped magnetic field



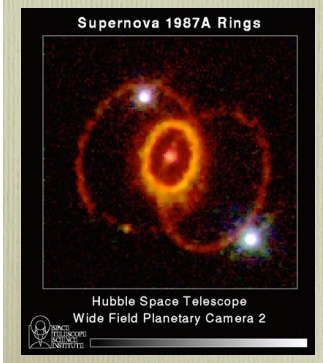
- Recorded by Chinese astronomers as "guest star"
- May have been recorded by Chaco Indians in New Mexico

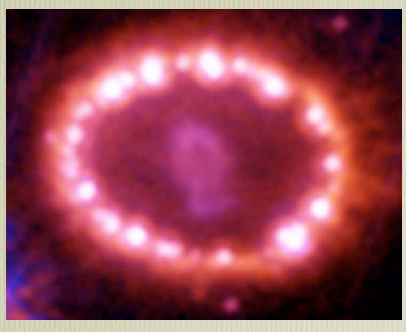


- How do they work?
- Core of star runs out of fueld
- Star collapses, superheats interior
- Shock wave blows off outer layer of star at 1/10 speed of light



- Most recent close one was SN1987a
- Must have blown up earlier, leaving ring of material, now illuminated by new shock wave





Surprisingly…

- Most (98%) of the energy doesn't come out as light…
- It's neutrinos
- As the matter falls in, the nu's stream out!

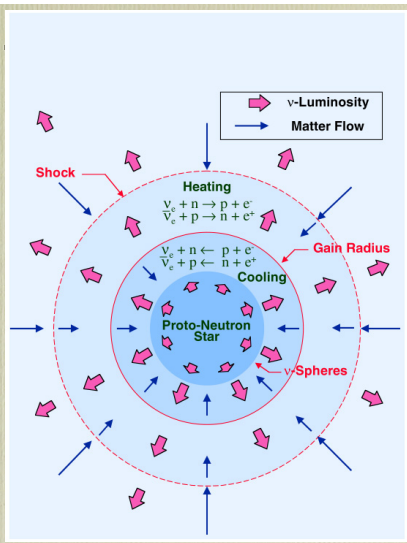
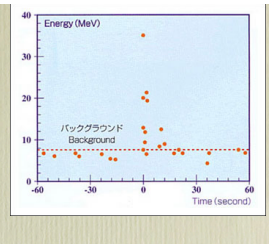
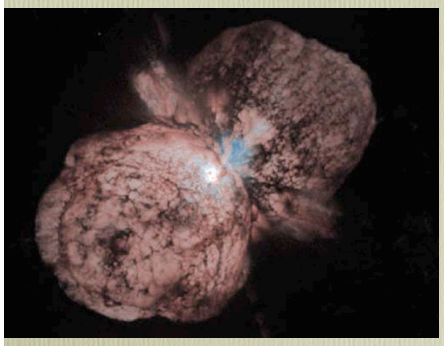


Image credit: TeraScale Supernova Initiative.

Which we can see here…



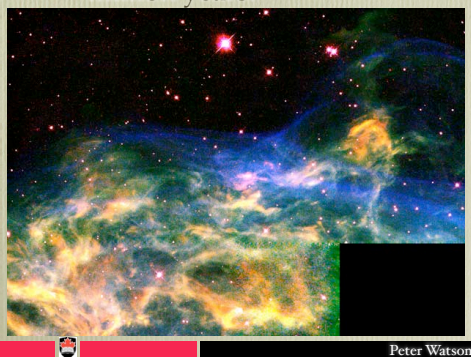
- We would like to catch supernovae before they explode: here are 3 possibilities



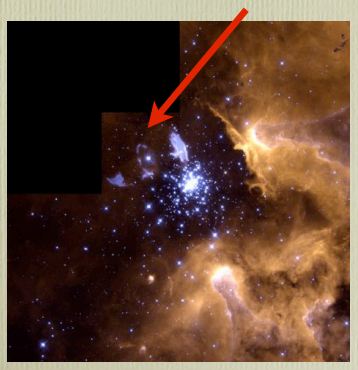
Eta Carinae blew off a lot of material 150 years ago: probably pre-collapse now

Credit: J. Morse (U. Colorado), K. Davidson (U. Minnesota) et al., WFPC2, HST, NASA

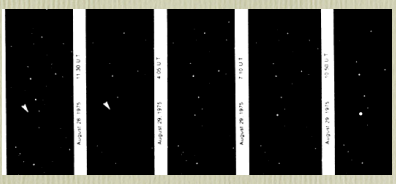
- The Crescent Nebula is a shell of gas surrounding a very hot and unstable central star WR 136
- Should undergo a supernova explosion in next million years.

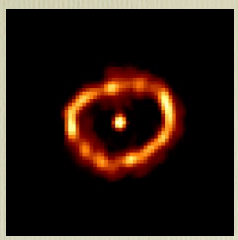


- NGC 3603: can see formation of stars
- contains Sher 25 surrounded by rings: proably pre-collapse

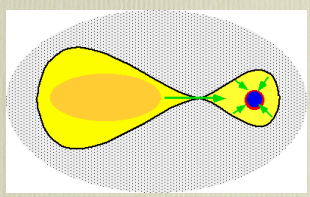


- Nova: stars that repeatedly have minor explosions

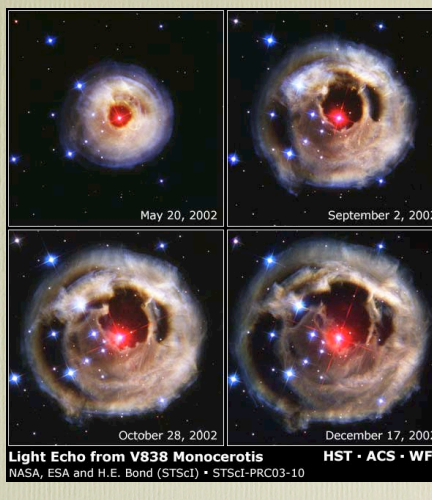




- Always a close binary
- material flows from one star to companion
- triggers explosion

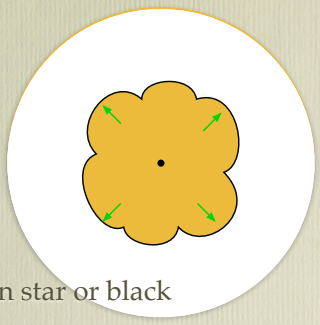


- V838 Monocerotis: Not a nova, since star did not lose material, instead went to M~ -7 (brightest star in galaxy) by expanding and cooling very fast
- lit up dust from previous explosions



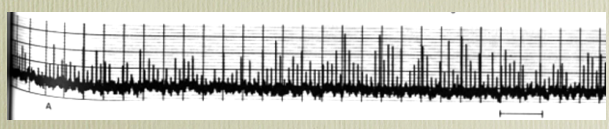
What happens to a star after it goes supernova?

- Large star runs out of fuel
- Collapses and heats up

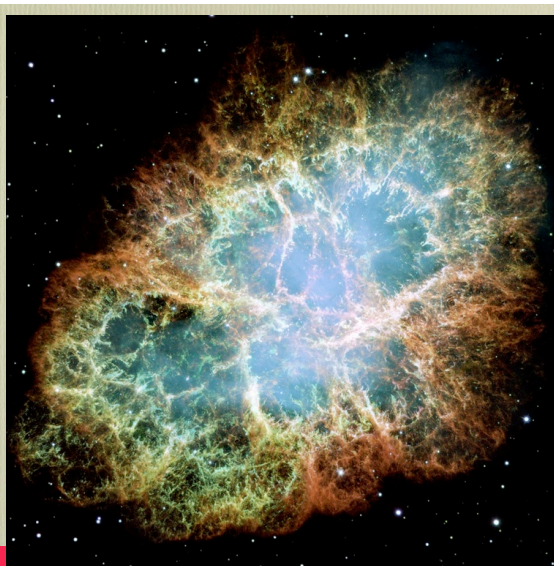


- Outer part explodes out,
- Core gets compressed to neutron star or black hole

- Pulsars
- accidentally observed (1968) by Jocelyn Bell etc.
- Very regular radio pulses
- period of 2 ms up to 4 s
- Note that height of pulse is very irregular



Best known is Crab. Known to be supernova remnant from in 1054 Pulsar at centre has period of ~1/30 s



And you can even listen to them

- This is Vela
- And this is PSR 0329+54

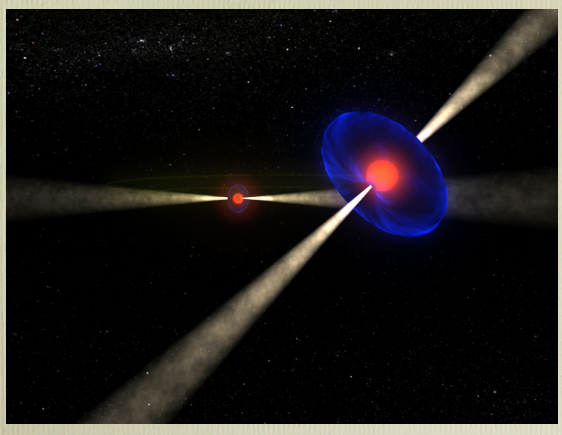
Period of Crab measured to be 0.03308471603 s (i.e. stable to 1 part in billion)

Magnetars: Vicki Kaspi McGill

- Magnetic field is ~ 1 billion x strength of MRI magnet

- This shows how the X-ray pulses move through the nebula

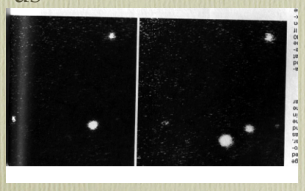
- Double Pulsar

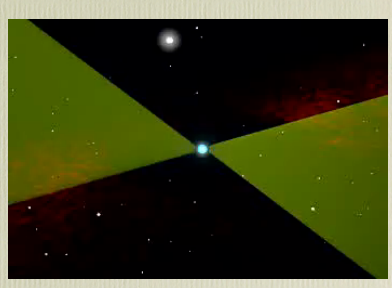


What pulses?

- Now known to be neutron star: predicted by Oppenheimer (yes, that one) in 1935.
- Density ~ atomic nucleus: dime would weigh 2000,000,000 tons!

- Charged particles travel along magnetic field,
- can only escape from poles of neutron star.
- Hence "lighthouse"mechanism: we only "see" pulsar when mag. pole points towards us

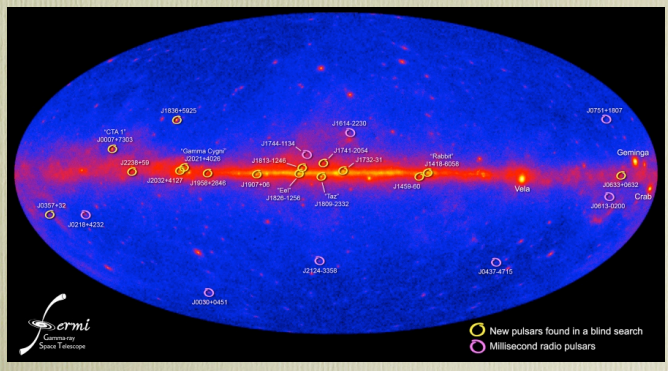




Do we see all the pulsars?

- No, because they would have to be oriented so that they point towards us
- Neutron Star forms from supernova, Period ~1/1000 s
- spins down
- magnetic field will weaken
- Disappear after 100,000 years

This is how the Fermi satellite sees the sky, in gamma-rays



Gamma-rays have huge energies

- Crab?
- OK: old supernova
- Vela?
- OK: old supernova
- Geminga?
- Huh? Second brightest object in γ-rays, almost invisible as a ordinary star
- Turns out to be very old neutron star

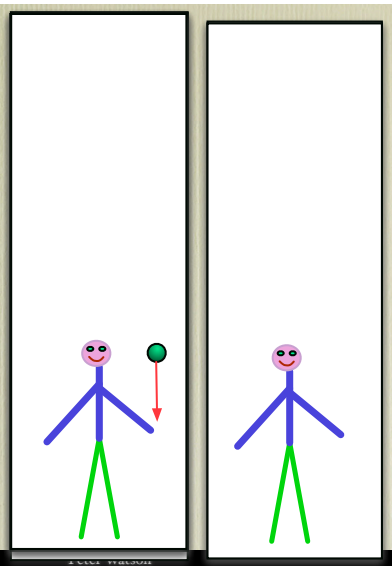
SS433

- And some things are just weird!
- A cosmic lawn sprinkler
- jets come out at 1/5 of speed of light, but are made of cold hydrogen gas!

Black Holes

- Invented by .....?
- Einstein
- Hawking?
- Well, actually, John Michell, rector of Thornhill Church in Yorkshire
- geologist?philosopher? astronomer? Seismologist?
- Polymath.
- presented his ideas to the Royal Society in London in 1783.

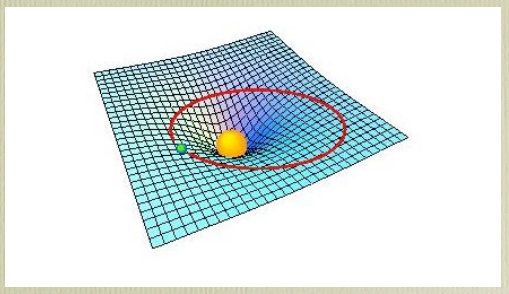
- A particle will escape from the earth if it has positive energy
- At the earth's surface, "escape velocity" is 11 km/s



- However w… radius wou… velocity?
- In particula… light c, noth…
- If the earth … Black hole
- This is the S… hole radius…

So what is a black hole like?

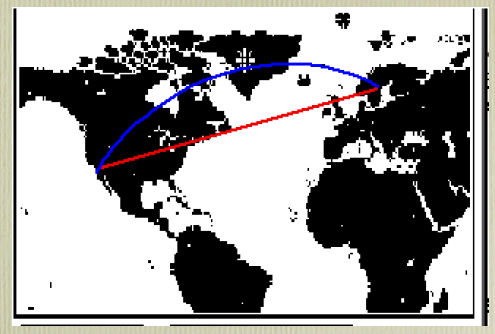
- It warps space (and time) round it



So planets are actually moving in "straight" lines in a curved space…

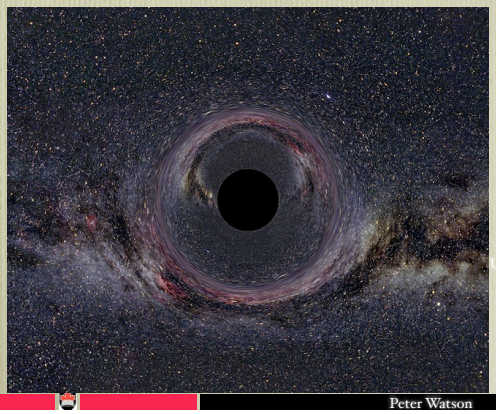
- "Lenses extend unwish through curving wherewhon till unwish returns on its unself" e.e.cummings

- What is a straight line?



Did you think a laser beam was straight?

- One way to see a black hole: it's black!
- If we are really lucky....(or unlucky) as a gap in the sky



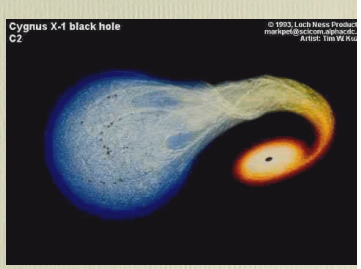
- Stuff falling in will become very hot and produce X-rays
- So want binary star, one invisible but heavy, producing lots of X-rays

Best candidate is Cygnus X-1

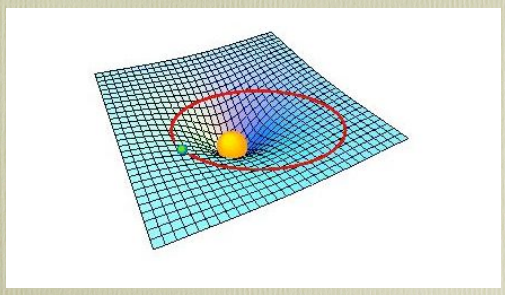
Mass of primary star ~20M_o

Mass of invisible object M~9M_o

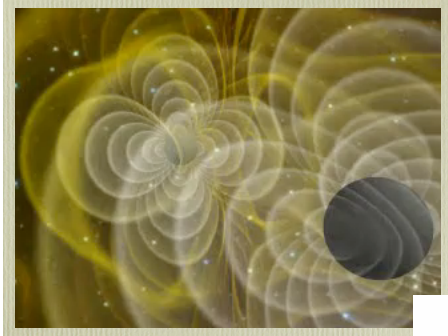
Power output in X-rays is 10,000 x total power output by sun!

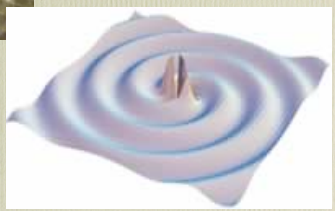


- Could be hypernova: death of very large stars
- Or black holes merging
- If a BH can distort space

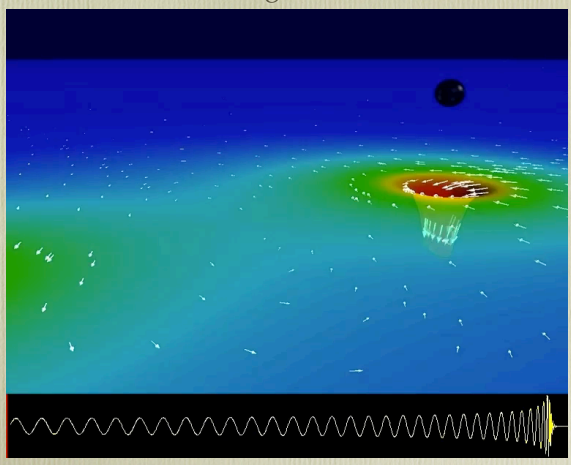


- Then moving BH's will produce a wave in space





- Black Hole merger: The Caltech/Cornell SXS Collaboration

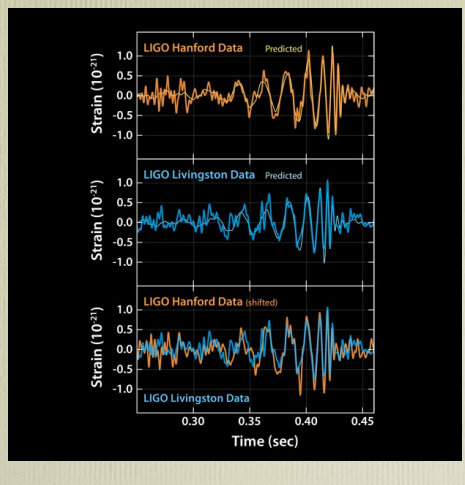


- and these will radiate gravitational waves

- And this is maybe where it is happening now:
- Two galaxies have collided and the black holes seem to be coalescing

3C75 X-rays from Chandra

- Which we might be able to pick up on earth as gravitational waves
- This is LIGO: twin detectors in Louisiana and Washington

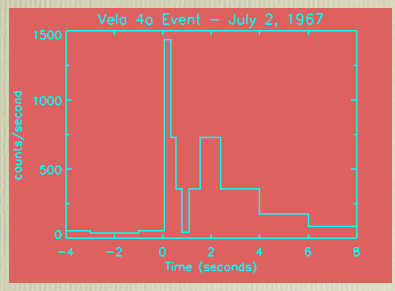


and they found a second one!

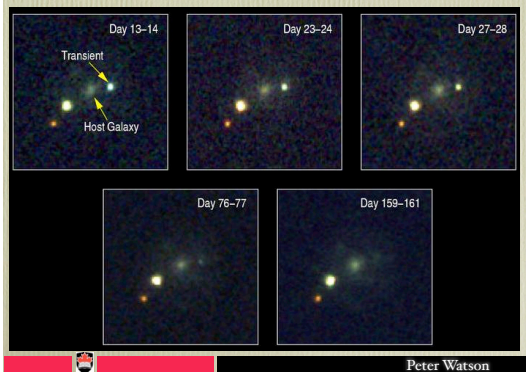
- Which you can listen to!

Gamma-ray bursters

Found accidentally by Vela satellite (designed to look for γ's from nuclear explosions).



- Vary short (often less than 1/100 s!) intense bursts of γ-rays.
- Don't repeat, don't come from any known object



Seem to be massive explosions in very distant galaxies

- Could be hypernova: death of very large stars
- Or black holes merging
- If a BH can distort space