Astronomy 150:
Killer Skies

<u>This Class (Lecture 20):</u>
Neutron Stars and Black Holes

<u>Next Class:</u>
Gamma Ray Bursts

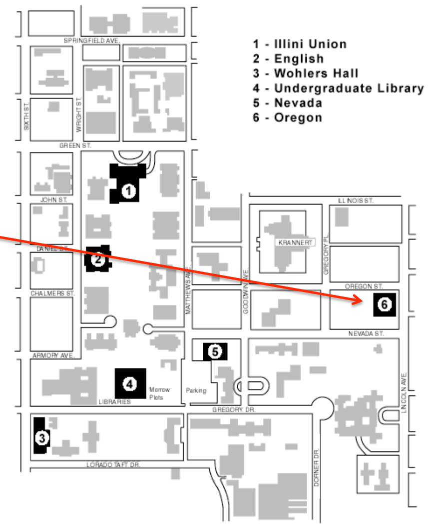
HW7 due on Sunday!

Night Obs/Computer labs due in class on Oct 26th.
HW 2 due on the 26th.
Exam 2 on the 30th!

Music: *Blackhole Sun*– Soundgarden

Computer Lab Help

- We are going to have to computer help sessions at the Oregon Lab.
- Today already happened but tomorrow too: 11:30am-12:45pm.



Don't Forget HW 2

- Orionids are the morning of Oct 21st.
- If you haven't finished HW2, make sure to leave your pan out over that night plus a day or so.
- It doesn't matter if it is cloudy or not.
- HW 2 due on the 26th at 11:59pm.

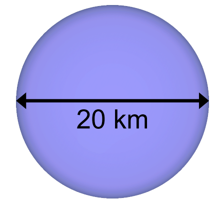
Outline

- What is leftover after a supernova?
  - Neutron star with a pulsar
  - Blackhole
- Cold War discovery

Supernova Leftovers

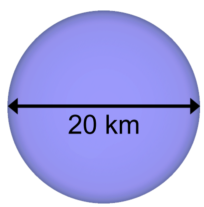
- What's left of the star's core after a massive star supernova?
- A **neutron star**
  - About 1.4 – 3 solar masses
  - Very small diameter – around 20 km!
  - Composed of a sea of neutrons
    - Supported by *neutron degeneracy pressure!*
    - Teaspoon of neutron star material on Earth would weigh almost 1 billion tons!!!!
  - Surface gravity – 200 billion times that on Earth
  - Escape velocity – half the speed of light

Relative Sizes of Stellar Corpses

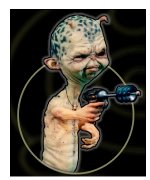


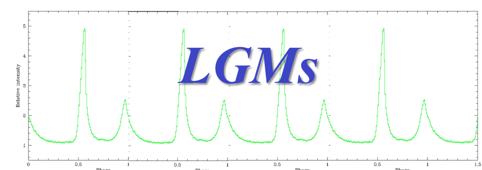
Neutron star

Neutron Stars



How do we know that Neutron stars truly exist?

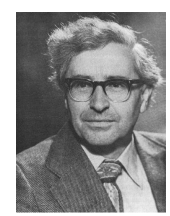




LGMs

- In the late 1960s, Jocelyn Bell discovered radio pulses from the constellation Vulpecula that repeated regularly
  - Every 1.337… seconds
- What could it be?
- Perfect timing, but no real encoding of signal.
- Jokingly called LGMs, then Pulsars.

Jocelyn Bell Burnell

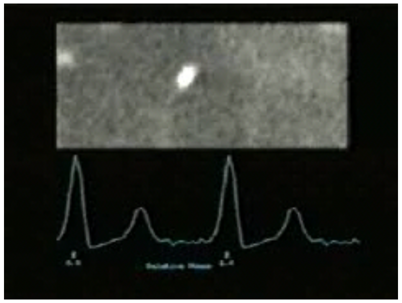


Anthony Hewish

http://www.radiosky.com/rspplsr.html

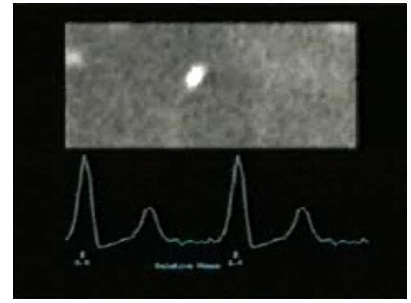
Pulsars

- What could it be?
  - Pulses were too fast to be a variable star
- Very precise, better than atomic clocks.
- Periods from 8.51s to 1.56 ms!



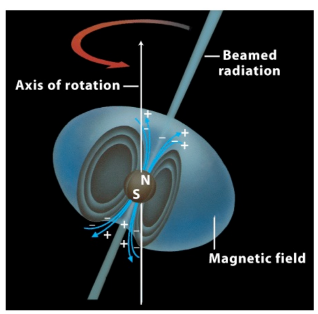
Pulsars

- Could they be something spinning?
  - Would have to be small to be spinning that fast
- They must be spinning neutron stars!



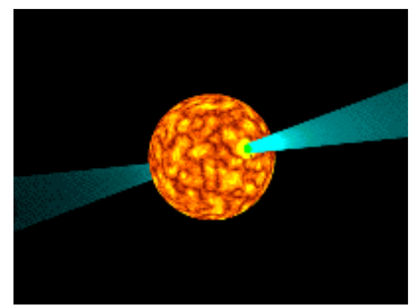
What are Pulsars?

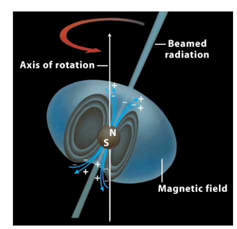
- As neutron core collapses, its spin and magnetic field strength increases
- Typically
  - Surface field strength over 1 trillion times that of the Earth
  - Rotation rate up to 1000 times per second
  - Spin axis and magnetic field axis may not be aligned.

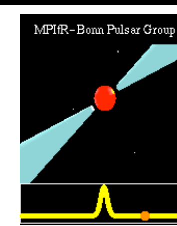


What are Pulsars?

- Intense beams of radiation emanate from regions near the north and south magnetic poles of a neutron star
- Magnetic field beams radiation into space
- If the Earth is in the beam's path, we see the pulsar

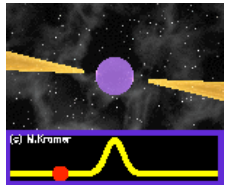






Kinda like a Lighthouse?

- These beams are produced by streams of charged particles moving in the star's intense magnetic field
- As the Pulsar gives energy to its surroundings, it slows down.
- The periods increase (few billionths of a second each day)



http://www.youtube.com/watch?v=jT2wkbPfUYc

http://blogs.families.com/media/lighthouse.jpg

Pulsars

- Pulsars…
  - Now know of hundreds of pulsars.
  - Fastest known have periods of 1.5-3 ms (rotate 300-600 times per second!).
- Very active subject of research…
  - What is the structure of a neutron star?
  - What determines how fast they spin?
  - How do they beam emission?
  - **Magnetars**.

Magnetars

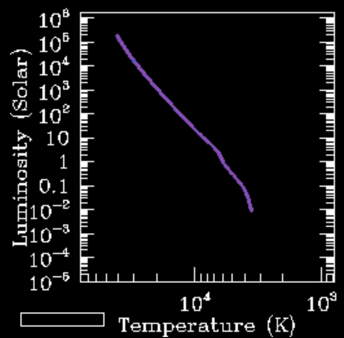
- Spinning neutron stars with incredibly strong magnetic fields.

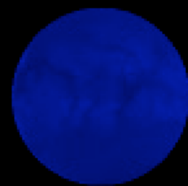
Object	**Strength (Earth = 1)**
Iron bar magnet	10^2
Sustained lab field	10^5
Strongest star	10^6
Strongest lab field	10^7
Typical pulsar	10^{12}
Magnetar	10^{15}

Death throes

- What triggers a supernova?
  - Hydrostatic equilibrium is lost, gravity wins
  - Iron core with $M > M_{Chandra}$
- What happens?
  - Quick core collapse overcoming electron degeneracy pressure.
  - Outer layers rebound off the core, explosion of envelope
- What are end products?
  - Enriched ejecta and compact neutron star (if core mass < 3 solar masses)

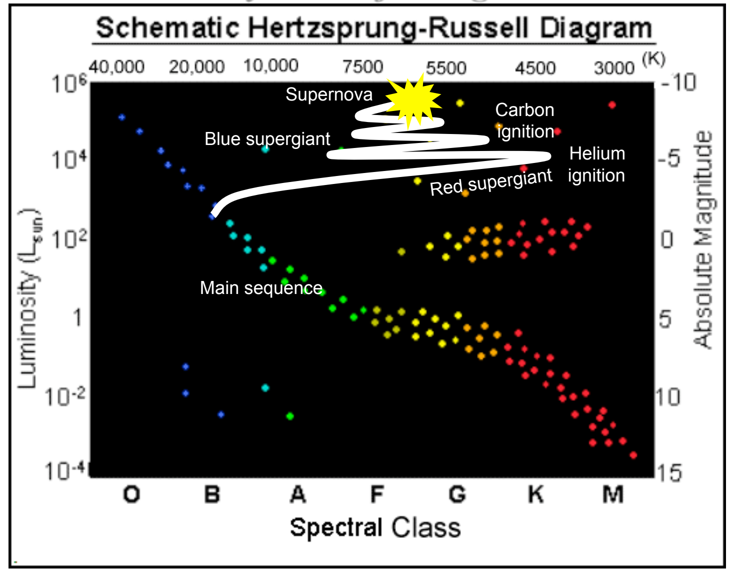
High Mass Stars (15 M_{sun})





http://rainman.astro.uiuc.edu/ddr/stellar/index.html

Evolutionary Path of a High-Mass Star

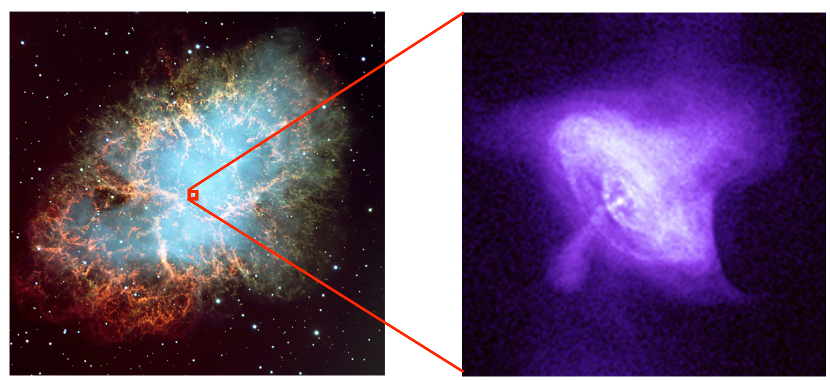


Question

So what supports a neutron star from collapsing?

a) Pressure from fusion
b) Pressure from CNO fusion
c) Electron degeneracy pressure
d) Gravity pressure
e) Neutron degeneracy pressure

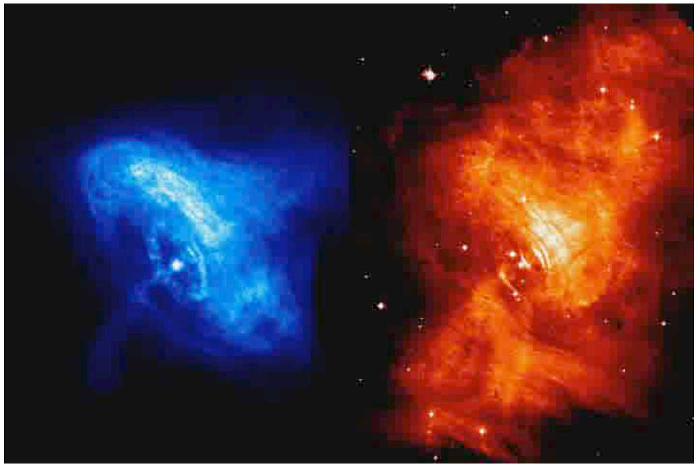
Crab Nebula – Remnant of the Supernova of 1054



Optical - ESO

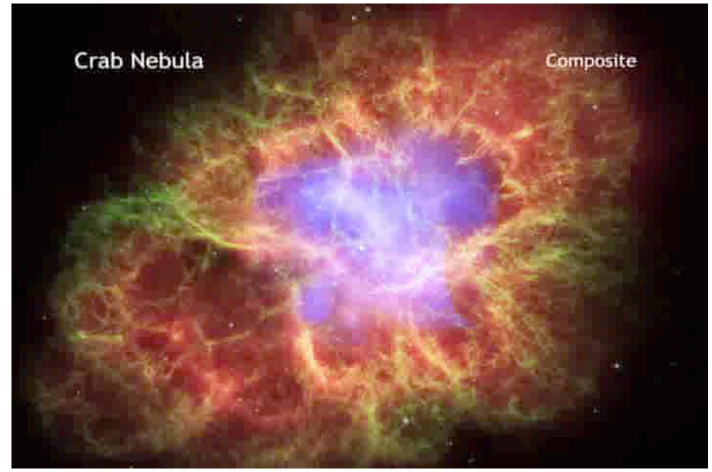
X-ray - Chandra

Crab Nebula – Remnant of the Supernova of 1054

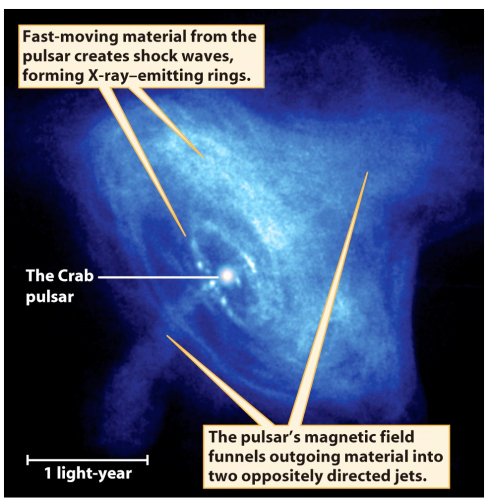


http://chandra.harvard.edu/photo/2002/0052/more.html

Crabby?



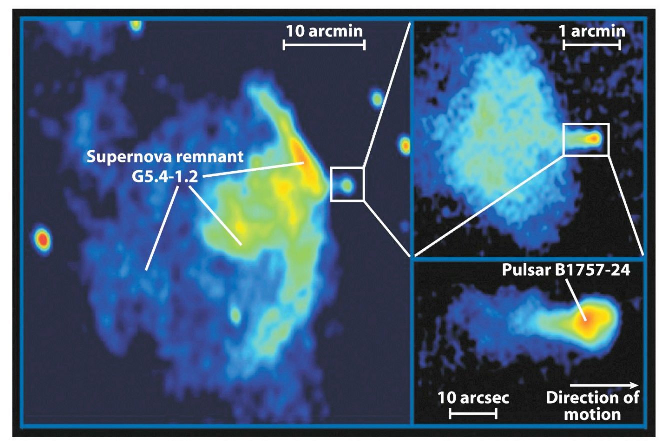
Do You Love the Crab?



http://www.youtube.com/watch?v=b3s11lCxqck

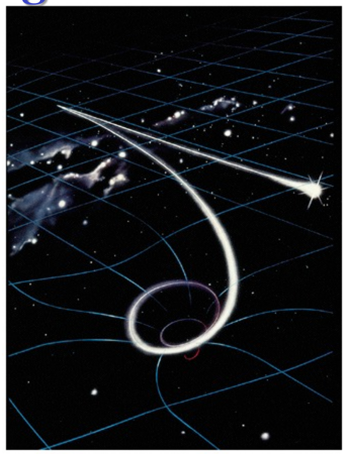
Escaping Pulsars

- Some Pulsars are ejected during the supernovae.
- Can outrun the explosion.
- This one is 600 km/s
- We'll come back to loose compact objects later.



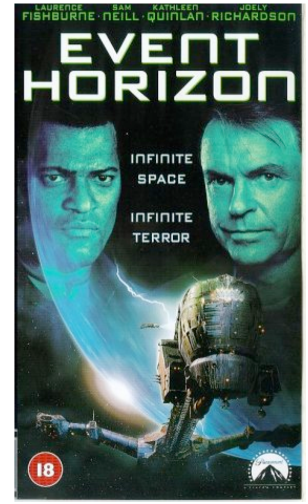
When Neutron Degeneracy Isn't Enough

- Maximum neutron star mass
  - About 3.0 $M_\odot$
  - Original star around 30$M_\odot$
- Beyond this mass, neutron degeneracy cannot stop gravity
- Nothing left to stop, so total collapse– gravity rules!
- A **black hole**
  - $v_{esc} > c$



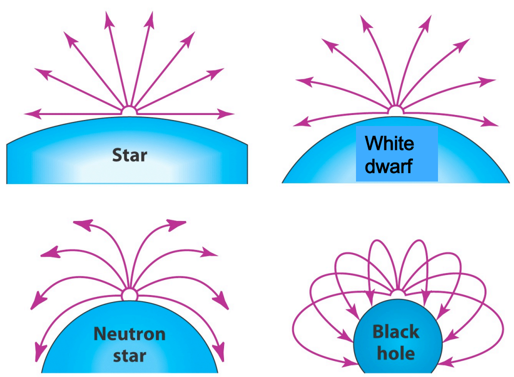
Black Holes

- Black holes inspire fear, awe, uncertainty, and bad science fiction
- Many people think that black holes are dangerous
  - That they suck matter in like "cosmic vacuums"
- Black holes follow the same laws of gravity as everything else



Now, Back to Black Holes

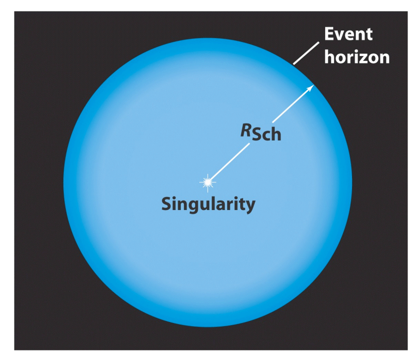
- When matter gets sufficiently dense, it causes spacetime to curve so much, it closes in on itself
- Photons flying outward from such a massive object arc back inward!



- Neither light or matter can escape its gravity, it is a **black hole!**

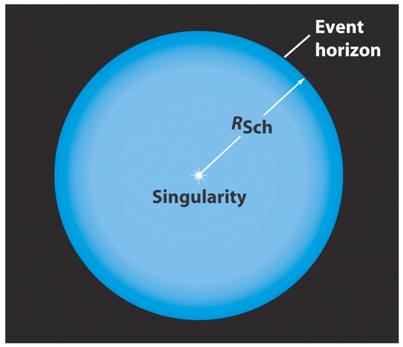
Black Hole

- The matter in a black hole collapses to a point – called a **singularity**
- A black hole is separated from the rest of the Universe by a boundary, the **event horizon**
- Nothing can escape from within its radius
- This radius is called the Schwarzschild radius.



Black Hole

- The Schwarzschild radius is $R_{Sch} = \frac{2GM}{c^2}$
- More massive black hole = larger the event horizon
  - $R_{Sch} = 3\ (M/M_{\odot})$ km
  - If mass of an object is in space < R_{Sch} then objects is a BH
  - For Earth $R_{Sch} = 1$cm
- The radius of no return
- Cosmic roach hotel

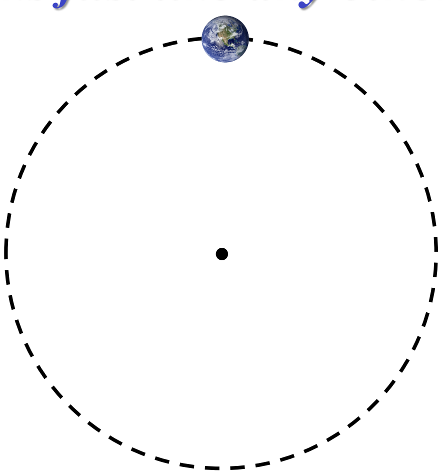


Thought Question

What do you think would happen to the Earth if the Sun collapsed into a black hole?

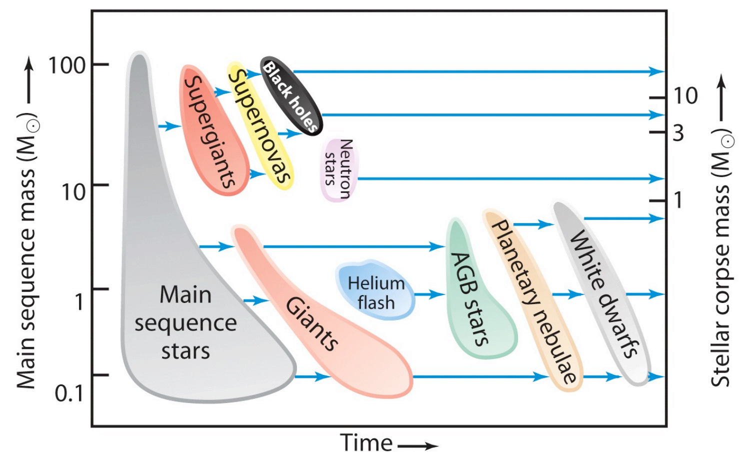
1. Fall in directly
2. Slowly spiral in
3. Stay in its orbit
4. Slowly spiral away
5. Fly away in a straight line

Well outside of a black hole – It looks just like any other mass



Don't worry, we'll come back to black holes later.

Stellar Evolution Recap



http://www.youtube.com/watch?v=jT2wkbPfUYc 3:15+

Imagine

- Astronomers are the first to know.
- A clear detection of neutrinos surprised everyone
- Gamma and x-ray telescopes are quickly blinded by the bright light from the object
- Then in the night sky a star gets brighter and brighter, easily seen with the naked eye and still getting brighter.
- The first supernova in 400 years!

Imagine

- The power grid collapses
- The sky around the star is blue!
- Gamma Rays have already destroyed the ozone layer, we just don't know it yet.
- Severe sunburn, but UV radiation will kill off phytoplankton, the base of the food chain
- A new mass extinction is happening!

AP