Astronomy 150:

Killer Skies

This Class (Lecture 21):
Neutron Stars and Black Holes

Next Class:
Gamma-Ray Bursts

HW8 due Monday!

Night Obs due in class on Oct 29th.
Exam 2 on Nov 5th!

Music: *3rd Planet*– Modest Mouse

Night Obs is done

Dates:

- Monday, Oct. 4th ✔
- Tuesday, Oct. 5th ✔
- Wednesday, Oct. 6th ✔
- Thursday, Oct. 7th ✔
- Monday, Oct. 11th ✗
- Tuesday, Oct. 12th ✗
- Wednesday, Oct. 13th ✔
- Thursday, Oct. 14th ✔
- Monday, Oct. 18th ✗
- Tuesday, Oct. 19th ✗
- Wednesday, Oct 20th ?

Tonight is last night probably.

Starts at 8pm until 10pm
(expect to spend ~40 mins)

Go to assignment page on class website for more info.

You **MUST** download worksheet before you go.

Can be cloudy, so check webpage before you go.

Question

Did you go to the Observatory yet?

a) Yes, it was okay.
b) Yes, it was cool!
c) Yes, it was the highlight of my life so far!
d) Yes, but it was boring.
e) No, I am waiting until the last possible minute. It is worth 5% of my total grade, so I'll try to get over to the Observatory tonight.

Outline

- Nearby supernova candidates
- Past issues with supernovae
- End products of 10-30 mass stars
  - Neutron stars -> pulsars
- End product of >30 solar mass stars
  - Black holes
- Gamma-Ray Bursts

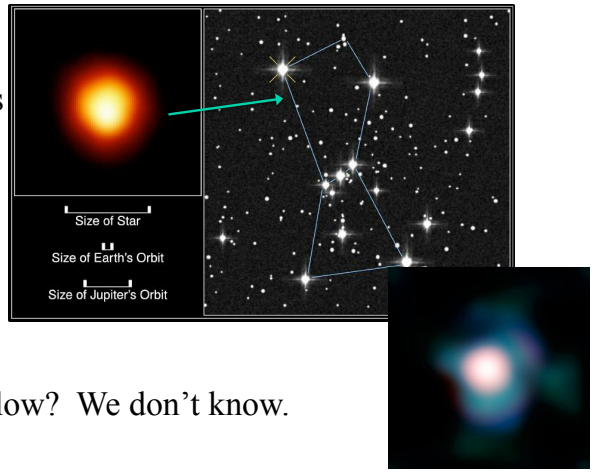
What's Nearby?

- To do real damage to the ozone layer, a core collapse supernova would perhaps need to be within ~30 light years and maybe ~40 light years for a white dwarf.
- What is around us now?
- Massive stars:
  - Spica, ~10 solar mass, MS, 260 lyrs
  - Shaula, ~10 solar mass, MS, 365 lyrs
  - Dschubba, ~12 solar mass, MS, 400 lyrs
  - Al Niyat, ~12 solar mass, MS, 400 lyrs

Millions of years to go. Don't forget we and they are orbiting the Galactic center, so a lot can change.

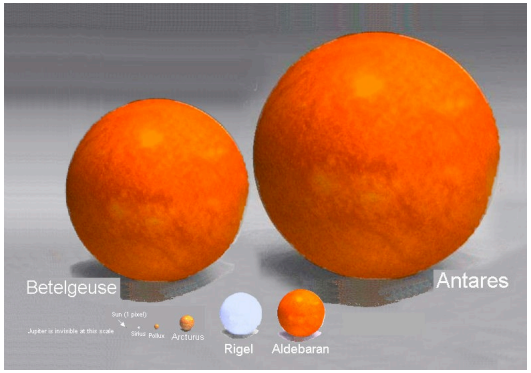
Betelgeuse

- 85,000 times brighter than the Sun, but 640 lyrs away.
- Red Supergiant
- ~15 solar masses
- Clearly an evolved star
- Over the last 15 years it has shrank 15%!
- When might it blow? We don't know.



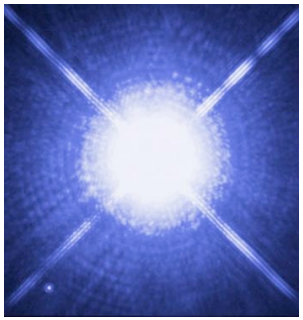
Betelgeuse

- When it does go supernova, even at 640 lyrs, it will be as bright as a Gibbous Moon, leaving shadows on the ground!
- Probably only about 10 million years old



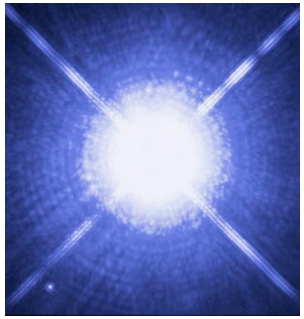
White Dwarf Candidates?

- Nothing really close by.
- White dwarfs are an old population and they tend to disperse in the Galactic disk more, making them more unlikely to affect us.
- That said, one of our very, very close stars is Sirius (9 lyrs!), which is a white dwarf and main sequence A star companion.



Are you Sirius?

- Main sequence star is about 2 solar masses.
- Sirius B, the white dwarf, is about 1 solar mass.
- Someday, Sirius A will become a red giant.
- But most likely, the white dwarf will not become a supernova
- Anyway, it is 10-100 million years away from becoming a red giant.



Core Collapse Supernova Explosions Near Earth

In our Milky Way galaxy:

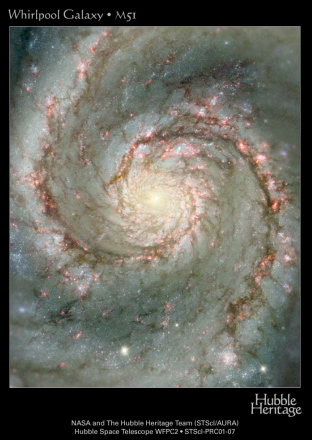
- About 1-2 SN/century
- Most far away: spectacular but harmless

Now: no nearby candidates

Sleep well tonight!

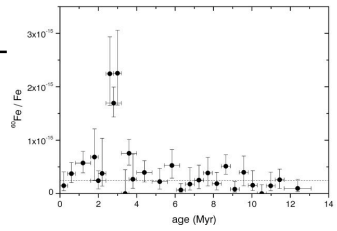
But over the 4.5 billion year history of Earth:

Many nearby events!



Proof of Concept?

- Recent experiments uncovered evidence of a nearby supernova about 3 million years ago.
- Radioactive iron atoms have been found in ancient samples of deep-ocean material-- debris from this explosion.
- Explosion was close, probably a "near-miss," which emitted intense and possibly harmful radiation.
- The resulting environmental damage may have led to some extinctions.



Mitigation

- Not much
- Try not to live too close to a massive star near the end of its life.
- Try not to live too close to a close binary system with a white dwarf.
- With time, our species should one day travel to the stars.
- We could monitor nearby candidates.

Question

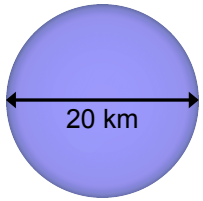
You read a blog that describes how a yet unknown supernova will destroy the Earth in 2012. What is the problem with this prediction?

a) It is very unlikely that a nearby massive star will blow up that exact year.
b) Betelgeuse will not blow for >50 years.
c) Sirius is not going to supernova.
d) There are no supernova-candidates near enough to harm the Earth.
e) There is actually a chance since it has been 400 years since the last visible supernova.

Supernova Leftovers

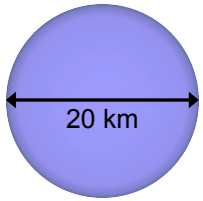
- What's left of the star's core after a massive (10-30 solar masses) star supernova?
- A **neutron star**
  - About 1.4 – 3 solar masses
  - Very small diameter – around 20 km!
  - Composed of a sea of neutrons
    - Supported by *neutron degeneracy pressure!*
    - Teaspoon of neutron star material 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

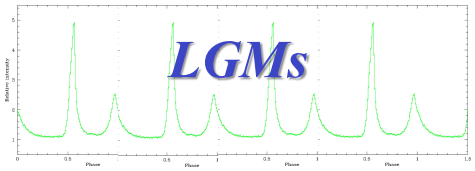


Neutron star

Relative Sizes of Stellar Corpses



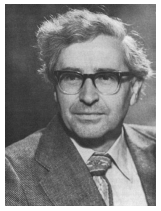
How do we know that Neutron stars truly exist?



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

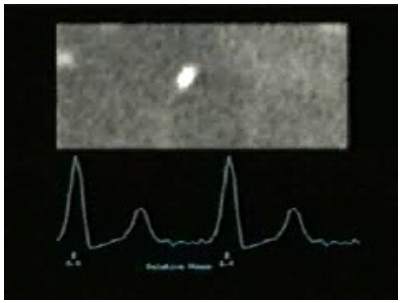


Anthony Hewish

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

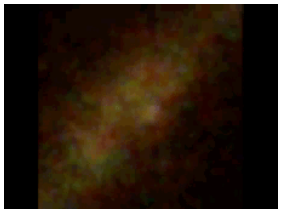
Pulsars

- 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!



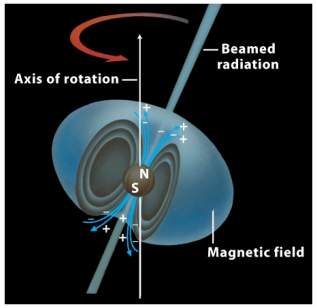
Pulsars

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



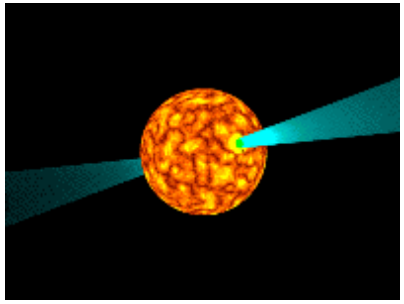
What are Pulsars?

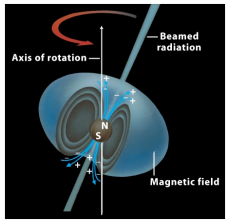
- As neutron core collapses, its spin and magnetic field strength increases
- Typically
  - Surface field strength over 1 trillion times that of the Earth
  - Rotation rate up to 1000 times per second
  - Spin axis and magnetic field axis may not be aligned.

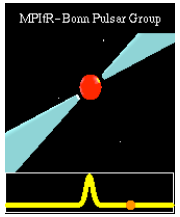


What are Pulsars?

- 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

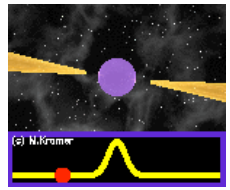






Kinda like a Lighthouse?

- 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

Question

How is a pulsar created?

a) They are only regular pulsing stars, so it is a natural evolution of stars with magnetic fields.

b) Supernova of a massive star, leaving a neutron core mass of 1.4 to 3 solar masses.

c) By evolution from a supergiant to a compact, hot, but pulsing star.

d) Through the evolution of a binary system.

e) They are ET communication encoders, emitting faster than light particles.

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

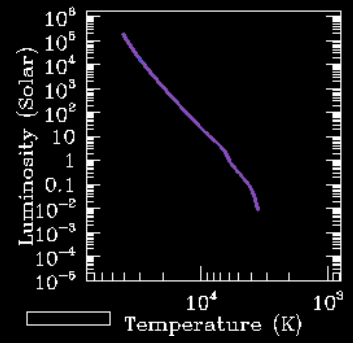
- Spinning neutron stars with incredibly strong magnetic fields.
- Can be dangerous on their own, more latter.

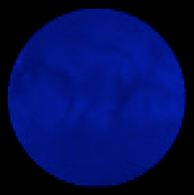
Object	Strength (Earth = 1)
Iron bar magnet	10^2
Sustained lab field	10^5
Strongest star	10^6
Strongest lab field	10^7
Typical pulsar	10^{12}
Magnetar	10^{15}

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)

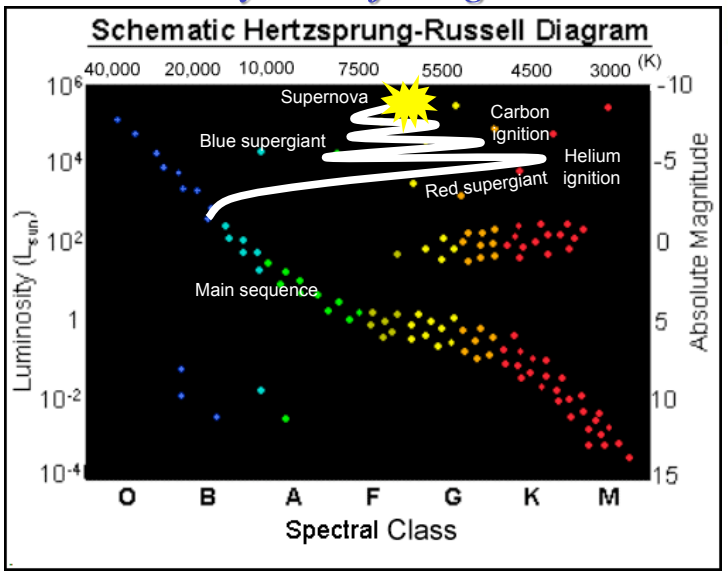
High Mass Stars (15 M_{sun})





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

Evolutionary Path of a High-Mass Star

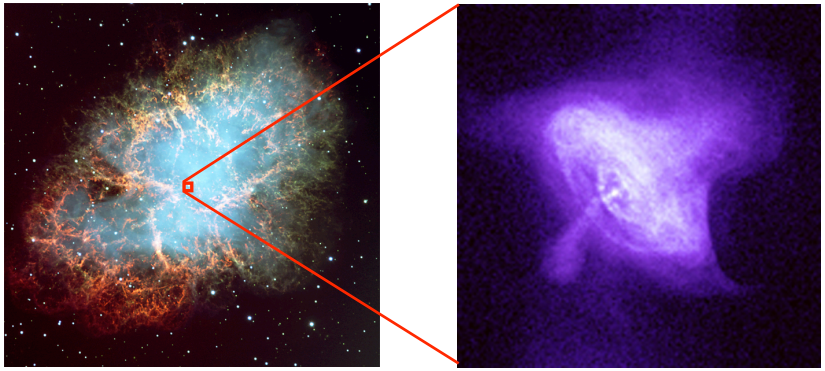


Question

So what supports a neutron star from collapsing?

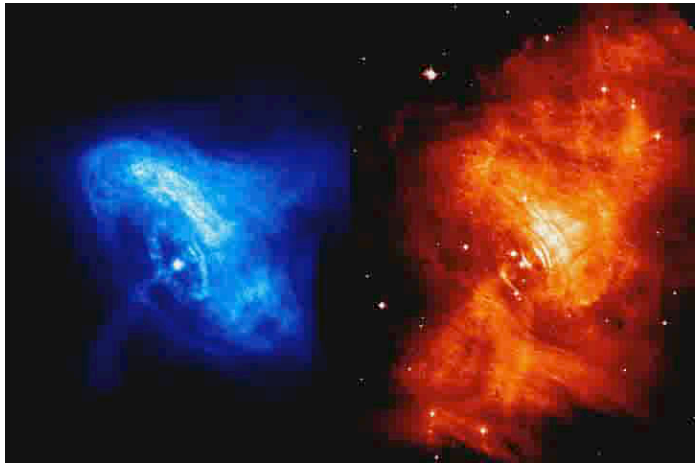
a) Pressure from fusion
b) Pressure from CNO fusion
c) Electron degeneracy pressure
d) Gravity pressure
e) Neutron degeneracy pressure

Crab Nebula – Remnant of the Supernova of 1054



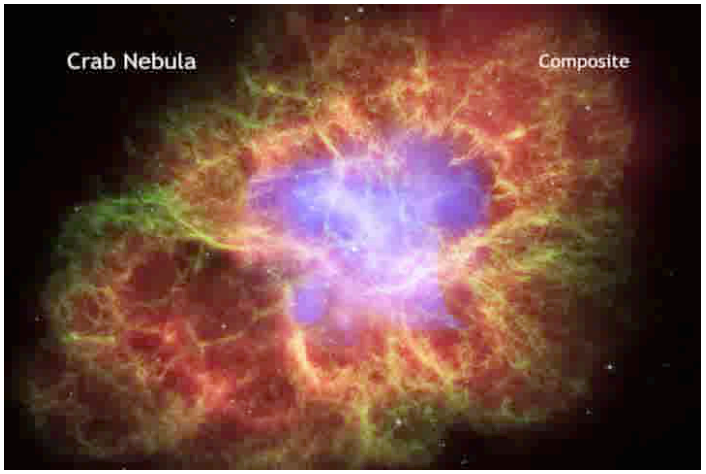
Optical - ESO X-ray - Chandra

Crab Nebula – Remnant of the Supernova of 1054

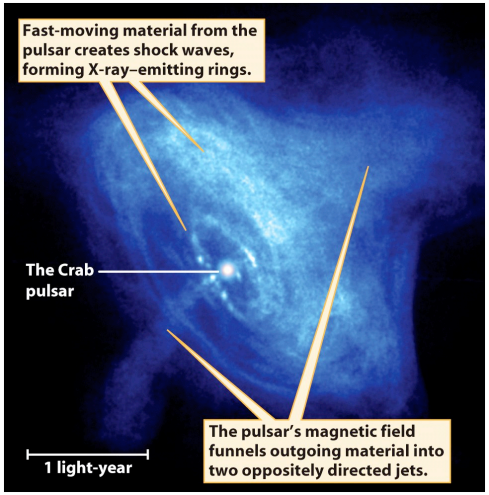


http://chandra.harvard.edu/photo/2002/0052/more.html

Crabby?



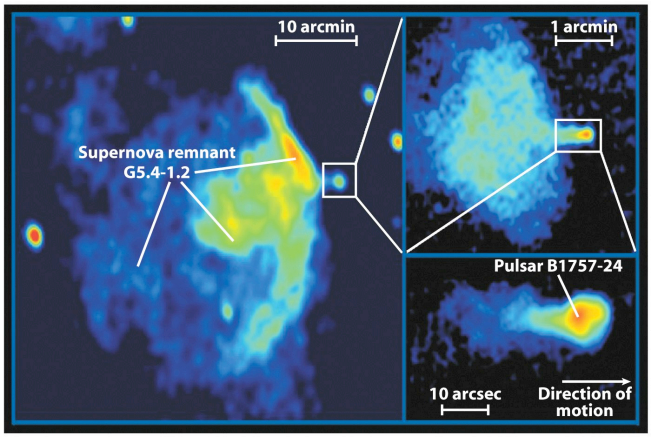
Do You Love the Crab?



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 rogue compact objects later.

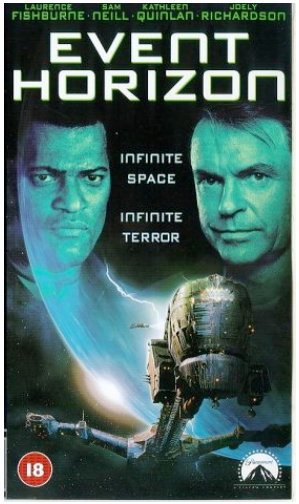


When Neutron Degeneracy Isn't Enough

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

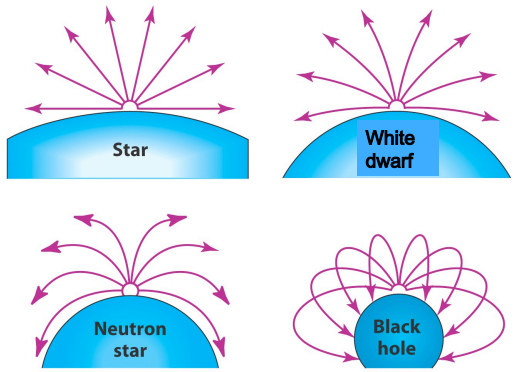
Black Holes

- 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

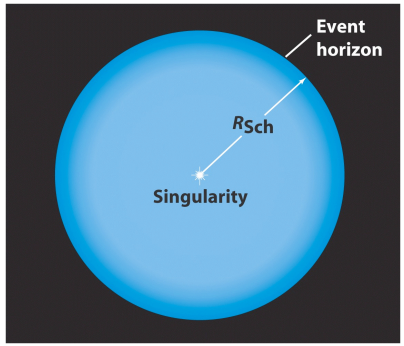
- When matter gets sufficiently dense, it causes spacetime to curve so much, it closes in on itself
- Photons flying outward from such a massive object arc back inward!



- 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.

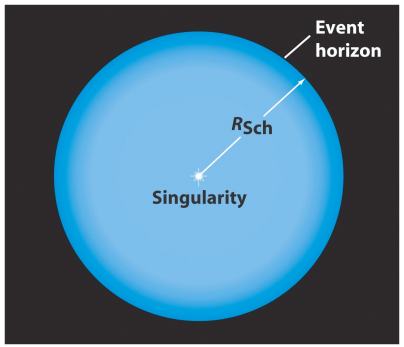


Black Hole

- 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} = 1cm
- The radius of no return
- Cosmic roach hotel

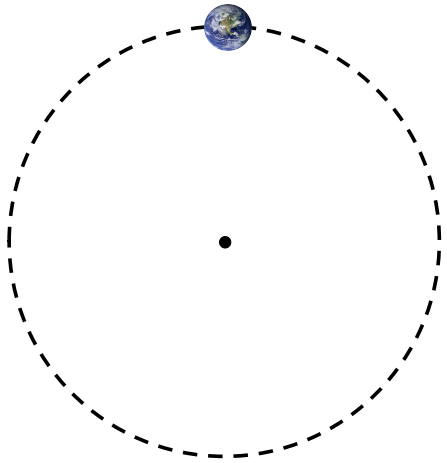


Thought Question

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

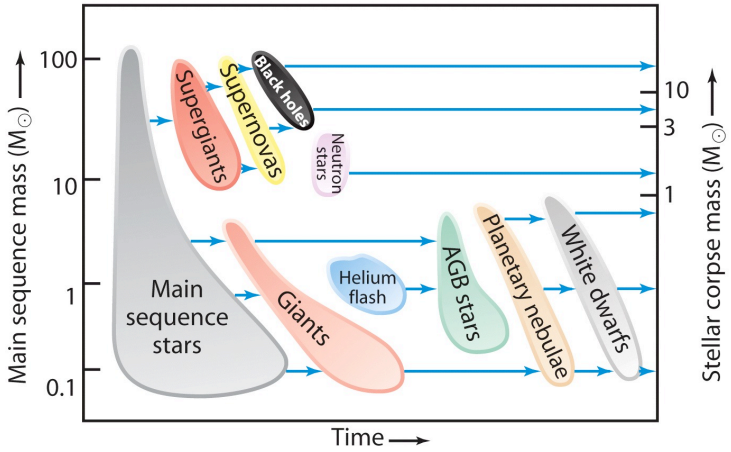
a) Fall in directly
b) Slowly spiral in
c) Stay in its orbit
d) Slowly spiral away
e) Fly away in a straight line

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!

Supernova on Steroids?

Is there any nova bigger than a super?

Imagine

- The beam comes without warning.
- You're walking downtown, hanging out, suddenly, an incredibly bright light in the sky!
- It hurts to look at it at first, then it begins to dim.
- Hours later, silent subatomic particles slam into the Earth's atmosphere.
- No matter if people are inside or not, a large fraction of the Earth is exposed to lethal radiation.
- 60% of the population of the world starts dying from the high dose.

Imagine

- The ozone layer has been dramatically damaged, and solar UV radiation will kill off the food chain.
- A thick layer of smog forms and the sky turns a dark reddish-brown. Plants begin to die, then the acid rain starts.
- A new ice age begins.
- Survivors realize that the supermassive star Eta Carinae exploded.
- As you die, you wonder how a star trillions of miles away killed you, and why didn't Leslie talk about it in class?