Announcements

- Webwork due on Wednesday
- Test 3 on Friday!
  - Review questions, old test, and all accompanying solutions posted
  - Equation sheet also updated
  - Covers Lectures 21–30
    - Corresponds to Chapter 15-24 (minus Ch 20)
  - Email me if you need to borrow a calculator!
- Polling: `rembold-class.ddns.net`

APOD!

Review Question

What happens as a white dwarf star gains enough mass to equal the Chandrasakhar Limit?

A. Carbon fusion ignites in the star, causing a supernova
B. Hydrogen fusion ignites in a shell around the star, causing a small nova
C. The star collapses into a neutron star, giving off a tremendous amount of energy in the process
D. Rotational forces rip the star apart, scattering its gases

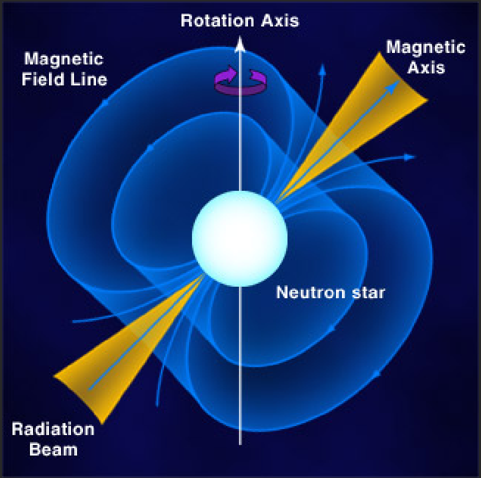
Review Question

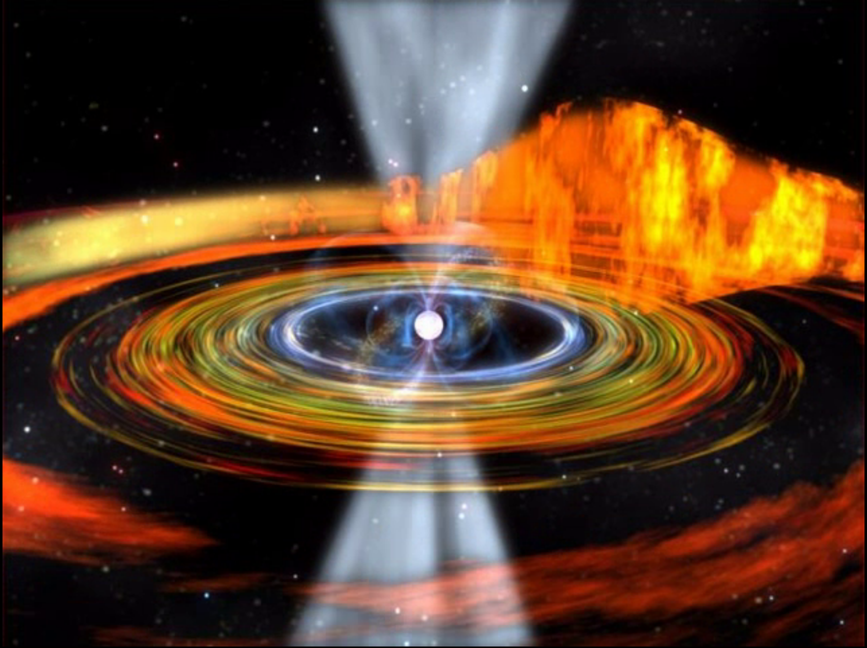
What happens as a white dwarf star gains enough mass to equal the Chandrasakhar Limit?

A. Carbon fusion ignites in the star, causing a supernova
B. Hydrogen fusion ignites in a shell around the star, causing a small nova
C. The star collapses into a neutron star, giving off a tremendous amount of energy in the process
D. Rotational forces rip the star apart, scattering its gases

Structure of a Pulsar

- Strong magnetic fields focus outgoing radiation
- Results in a “lighthouse” effect
- Spins very fast due to conservation of angular momentum
- Rapid spinning causes these beams of radiation to sweep across us



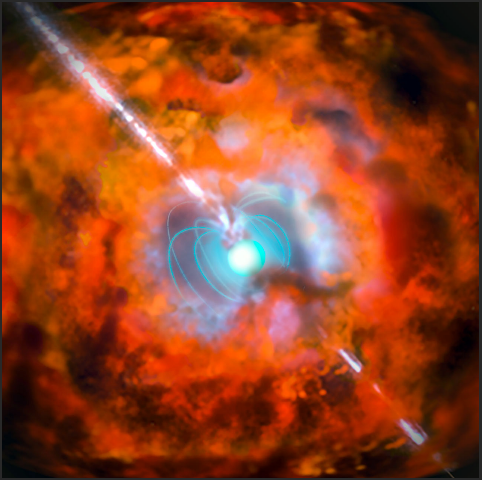


Tick Tock

- Isolated pulsars will eventually slow as they lose angular momentum and energy to the outgoing gases
- Pulsars as part of binary systems may actually speed up
  - A steady diet of more mass lends more angular momentum
  - Can end up pulsing every few thousandths of a second
- There is a rotational speed limit
  - If you spin too fast, gravity can't keep everything contained
  - Is what tells us pulsars must be neutron stars and not white dwarfs

Magnetars

- When spin, temperature, and magnetic field combine in the right combination
- Magnifies magnetic field: creates a dynamo
- Magnetic fields up to 10^{11} teslas
  - Earth magnetic field: 5×10^{-5} T
  - We can't create more than maybe 100-1000 T without ripping apart our machines
- 1 in 10 supernova could create?



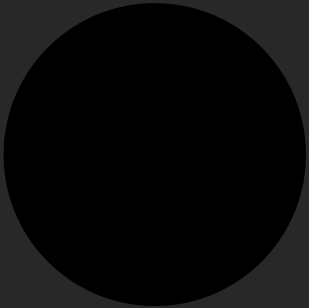
The Power of the (Magnetic) Force

- Magnetic fields create forces on moving charges
  - Say, for instance, the protons and electrons in atoms
- Getting a moon distance away would wipe all your credit cards
- Getting within several thousand kilometers would render all your biochemistry useless
- Getting within 1000 kilometers and your molecular structure just kinda. . . dissolves!

Starquakes

- Crust of magnetar and the magnetic field are locked together
  - Changing one changes the other...
- Crust is under huge pressure from gravity, rotation, and the magnetic field
- A tiny slip, even just a centimeter, releases an insane amount of energy
  - Force the magnetic field to “slip” as well
  - Equivalent to a solar flare, just far, far, far more energetic
- Swift: 2004
  - Designed to look at high energy x-ray sources
  - Wasn’t even looking in the direction of the magnetar flare
  - The amount of radiation swamped and oversaturated all its sensors
  - Compressed the Earth’s magnetic field and ionized upper atmosphere
  - All from 50,000 light-years away...
- Thankfully, these are rare

Grave #3



The Great Escape

- Let's talk the speed required to escape an gravitational mass
- Should depend on the mass of the object and our initial distance away from it
- If we want to barely escape, then we need our final velocity to be 0

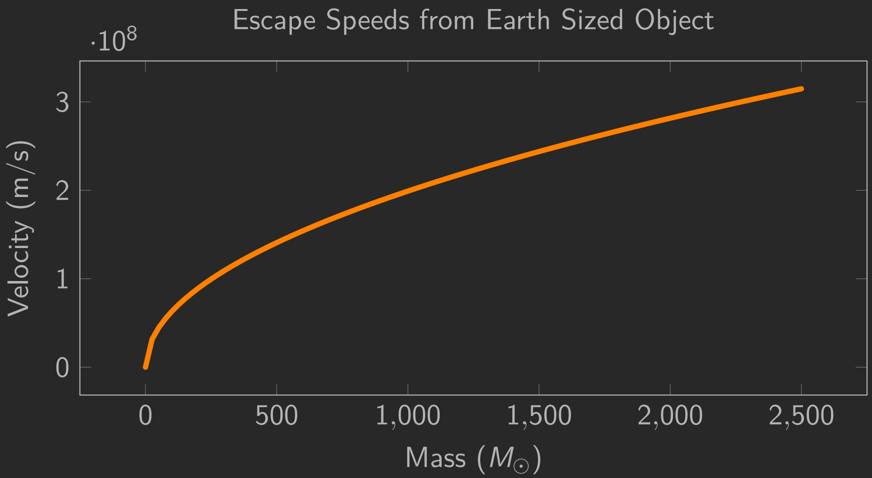
The Great Escape

- Let's talk the speed required to escape an gravitational mass
- Should depend on the mass of the object and our initial distance away from it
- If we want to barely escape, then we need our final velocity to be 0
- This requires that:

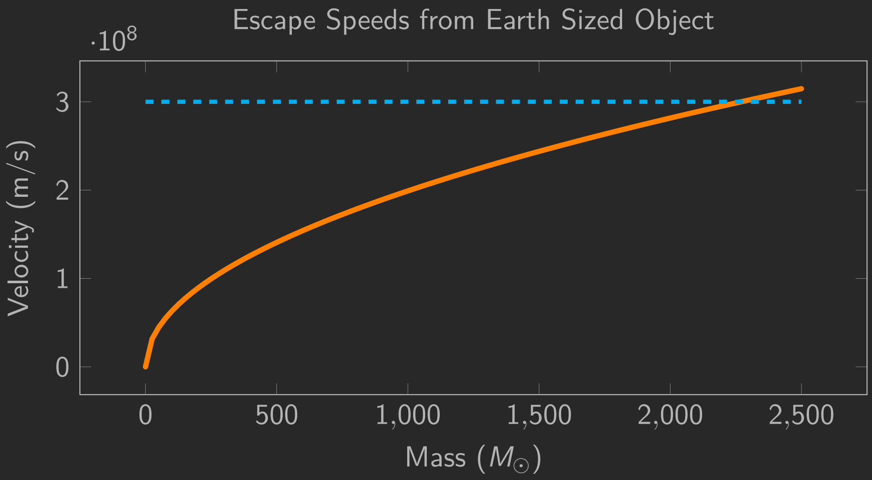
Escape Speed

$$v = \sqrt{\frac{2GM}{R}}$$

Making the Escape



Making the Escape



The Point of No Escape

- Since nothing can go faster than light, for any mass there exists a radius from whence nothing could escape!
- Rewriting our escape velocity:

$$c^2 = \frac{2GM}{R}$$
$$R = \frac{2GM}{c^2}$$

- This radius is called the Schwarzchild radius
- Even light couldn't escape from within this radius
- Makes it "Black"
- And thus we have a theoretical "Black Hole"
- In actuality, created when collapsing stars mass great enough to overcome neutron degeneracy

Some Examples

Example

What is the Schwarzchild radius for our Sun? ($M_\odot = 2 \times 10^{30}\,\text{kg}$)

Example

What is the Schwarzchild radius of YOU? ($M = 70\,\text{kg}$)

Some Examples

Example

What is the Schwarzchild radius for our Sun? ($M_\odot = 2 \times 10^{30}\,\text{kg}$)

$$R = \frac{2(6.67 \times 10^{-11})(2 \times 10^{30})}{(3 \times 10^8)^2} = 2964\,\text{m}$$

Example

What is the Schwarzchild radius of YOU? ($M = 70\,\text{kg}$)

Some Examples

Example

What is the Schwarzchild radius for our Sun? ($M_\odot = 2 \times 10^{30}\,\mathrm{kg}$)

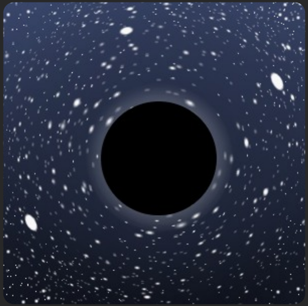
$$R = \frac{2(6.67 \times 10^{-11})(2 \times 10^{30})}{(3 \times 10^{8})^2} = 2964\,\mathrm{m}$$

Example

What is the Schwarzchild radius of YOU? ($M = 70\,\mathrm{kg}$)

$$R = \frac{2(6.67 \times 10^{-11})(70)}{(3 \times 10^{8})^2} = 1 \times 10^{-25}\,\mathrm{m}$$

The Event Horizon



- Since no light can escape, it is impossible for us to see any events that happen within the Schwarzchild radius
- It is as if they were “beyond the horizon”
- Another name for the Schwarzchild radius is the Event Horizon
- Both describe the point at which light can no longer escape
- Commonly imagined as the “edge” of the black hole

Understanding Check

You know that the event horizon of a particular black hole has a radius of 30 km. How massive is the black hole (in solar masses)?
$(G = 6.67 \times 10^{-11}, M_\odot = 2 \times 10^{30}, c = 3 \times 10^8)$

A. $(3.4 \times 10^{-8})M_\odot$
B. $0.01M_\odot$
C. $10M_\odot$
D. $(2 \times 10^{31})M_\odot$

Understanding Check

You know that the event horizon of a particular black hole has a radius of 30 km. How massive is the black hole (in solar masses)?
$(G = 6.67 \times 10^{-11}, M_\odot = 2 \times 10^{30}, c = 3 \times 10^{8})$

A. $(3.4 \times 10^{-8}) M_\odot$
B. $0.01 M_\odot$
C. $10 M_\odot$
D. $(2 \times 10^{31}) M_\odot$

Misconceptions

- Our Sun may one day turn into a black hole
- Black Holes are the universe's vaccuum cleaners, sucking in all their surroundings

Misconceptions

- Our Sun may one day turn into a black hole
  - Utterly, utterly false. Our Sun has nowhere near the mass needed to push past both the electron and neutron degeneracy pressures to form a black hole.
- Black Holes are the universe's vaccuum cleaners, sucking in all their surroundings

Misconceptions

- Our Sun may one day turn into a black hole
  - Utterly, utterly false. Our Sun has nowhere near the mass needed to push past both the electron and neutron degeneracy pressures to form a black hole.
- Black Holes are the universe's vaccuum cleaners, sucking in all their surroundings
  - Nope! Black holes have a lot of mass and gravity, but if you are far away that's all you see. We could happily keep orbiting the Sun even if it were to pop into a black hole this instant!

Big Fish, Small Fish

- Stellar Mass Black Holes
  - Generally several solar masses to a dozen or so
  - Results in fairly small event horizons
- Supermassive Black Holes
  - Many times larger than the Sun
  - Anchor the center of many galaxies
  - The one at the center of the Milky Way is estimated at $4{,}300{,}000 M_{\odot}$!!
  - May actually be crucial to galaxy formation

A Poor Decision

So what happens as you fall into a black hole?

A Poor Decision

So what happens as you fall into a black hole?

YOU DIE!

A Poor Decision

So what happens as you fall into a black hole?

YOU DIE!

But what about in the meanwhile? What would happen?

Tidal Spaghetti

- Recall that the gravity of Jupiter exerts tidal forces on Io
  - Squeeze and stretch the moon
- Black holes have MUCH more gravity
  - And thus MUCH stronger tidal forces!
- Your feet would feel a force thousands of times more than your head!
  - Get stretched!
- Process known as:

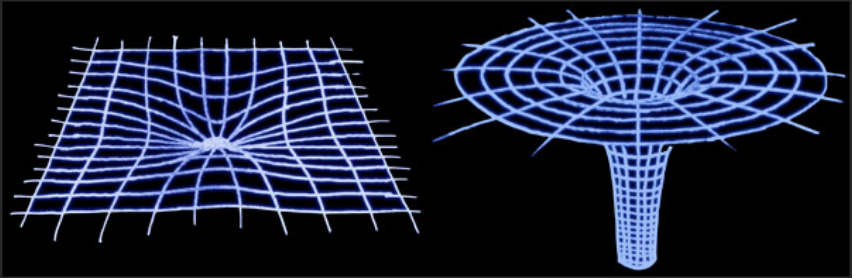
Tidal Spaghetti

- Recall that the gravity of Jupiter exerts tidal forces on Io
  - Squeeze and stretch the moon
- Black holes have MUCH more gravity
  - And thus MUCH stronger tidal forces!
- Your feet would feel a force thousands of times more than your head!
  - Get stretched!
- Process known as:

Spaghettification!

Space-Time

- Einstein showed that space and time are both related
- Can envision as a two dimensional rubber sheet
- Large masses cause indentations in the sheet and bend the trajectories of objects near them
- Since space and time are related, the more space you cross, the slower time ticks



Time Drags

- As you approach a black hole, the curvature of space-time becomes extreme
- As viewed from the outside your time slows down!
  - Can also envision as the light emitted each second takes longer and longer to reach the observer.
  - YOUR time, as far as you are concerned, does not change
- Outsider observer never sees someone cross the event horizon
- The traveler sees the opposite
  - Looking outward, time appears accelerated
  - Would see the entire future of the universe before crossing the event horizon