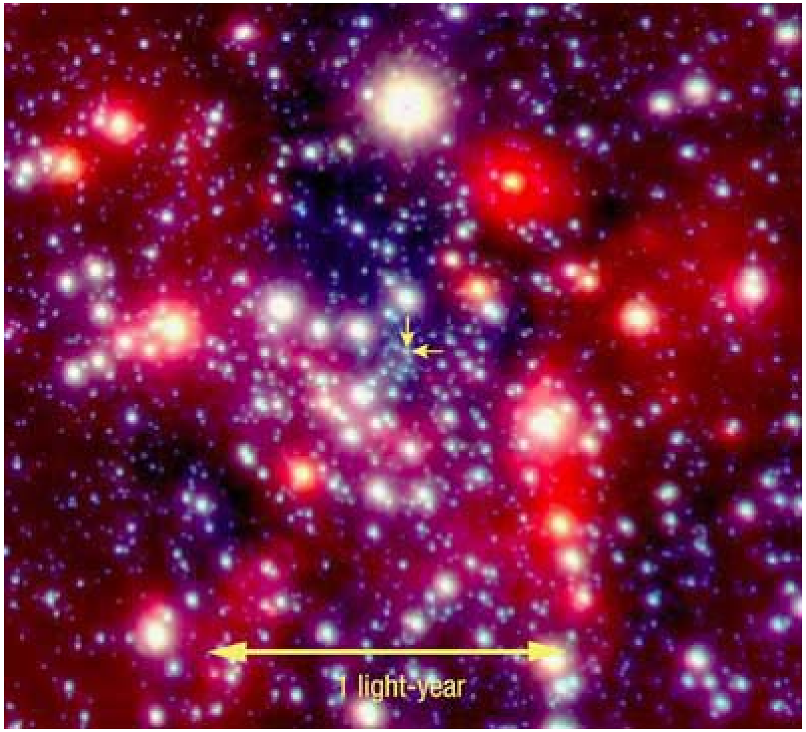
Neutron Stars, Black Holes, Pulsars and More

October 30, 2002

1) Star Clusters
2) Type II Supernova
3) Neutron Stars
4) Black Holes
5) More Gravity

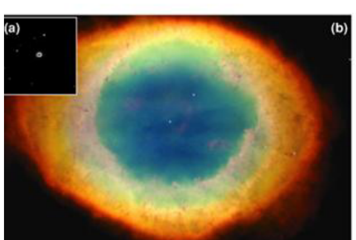


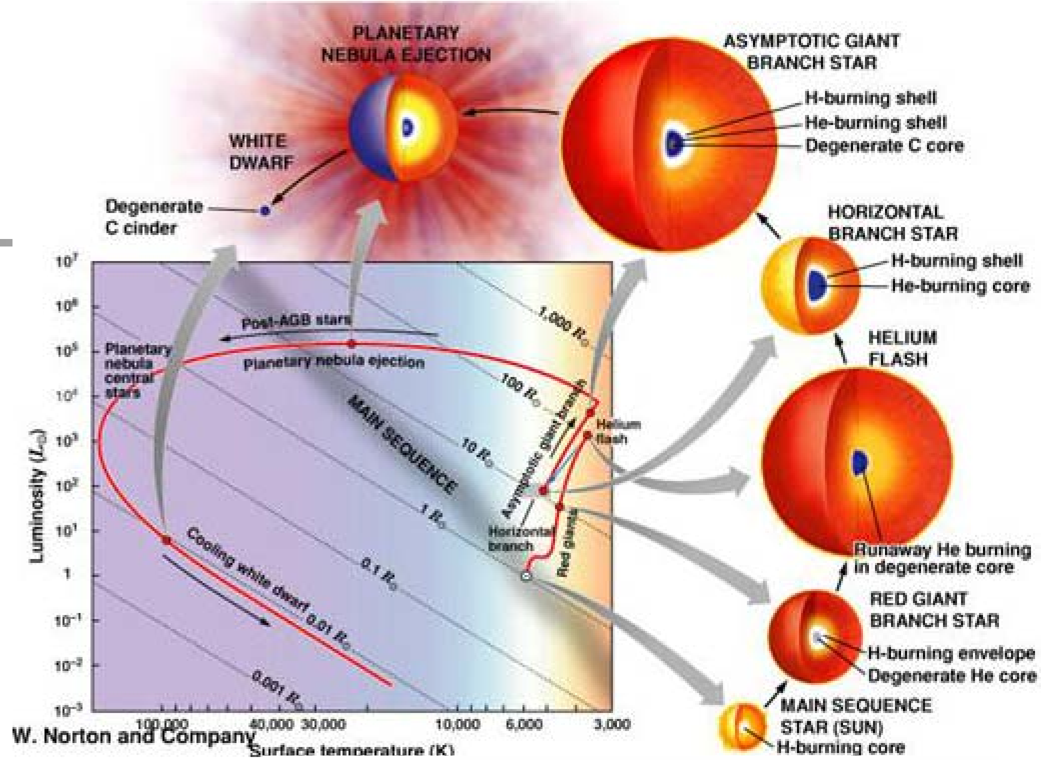
Announcements

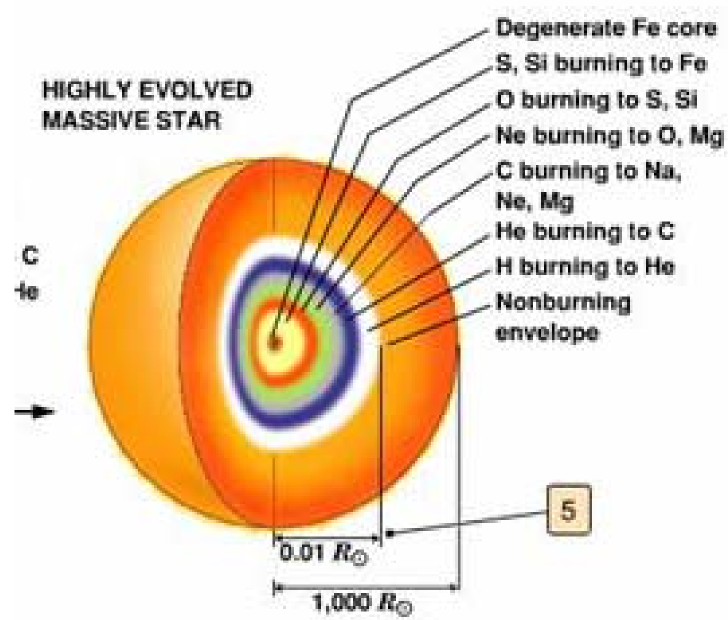
- Extra Credit
  - there is an extra credit assignment available on the course website
  - due Fri. Nov. 1 at 5pm
- Grades
  - scores from the first exam and first 7 quizzes are available through Blackboard
  - do not pay any attention to "Total Score"
- Exam #2 is next week Weds. Nov. 6, 2002

Review

- Stellar lifetime
- Red Giant
- White Dwarf
- Binary Systems
  - Nova
  - Supernova
- More massive stars

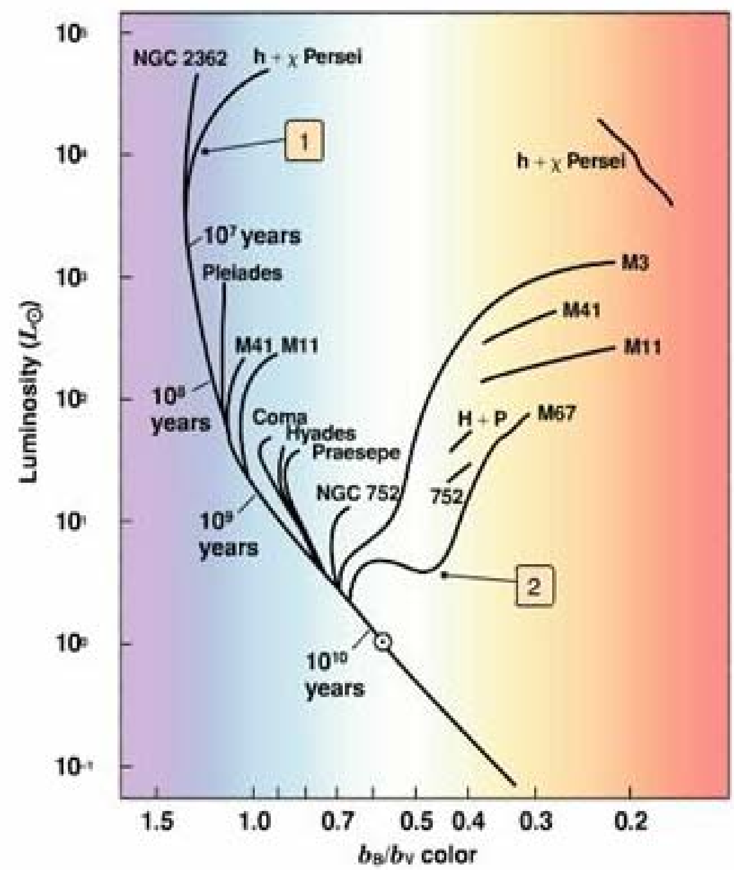






Studying Star Clusters

- Clusters of stars formed at the same time of the same materials
- Studying them tells us about the life of stars
  - plot where stars fall on H-R diagram
- Looking at many clusters tells us how stars leave main sequence



Neutrino Cooling

- Many of the fusion reactions produce neutrinos
  - especially with carbon burning and above
- Neutrinos immediately escape the star
  - carry away energy
  - do not provide additional heat/pressure to star
- Star shrinks in size
  - speeds up nuclear fusion
    - higher density/pressure
  - "snowballs" – star is collapsing

Beginning to Collapse

- Pressure and temperature rise as core collapses
- Photodisintegration
  - light begins to break apart nuclei
    - more energy loss
- Neutrino cooling is occurring
- Electrons and protons combine to make neutrons
  - $p + e \rightarrow n$
- Sources of energy to provide pressure are disappearing
  - core continues to collapse to very dense matter

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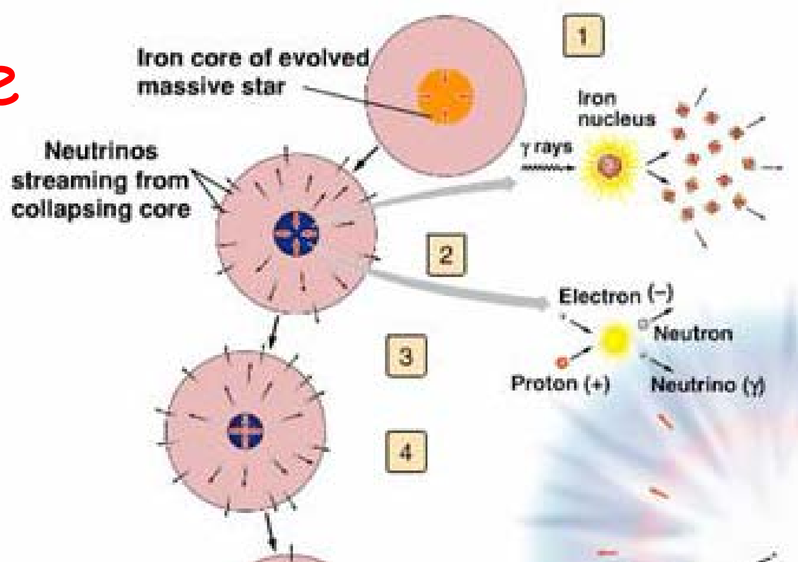
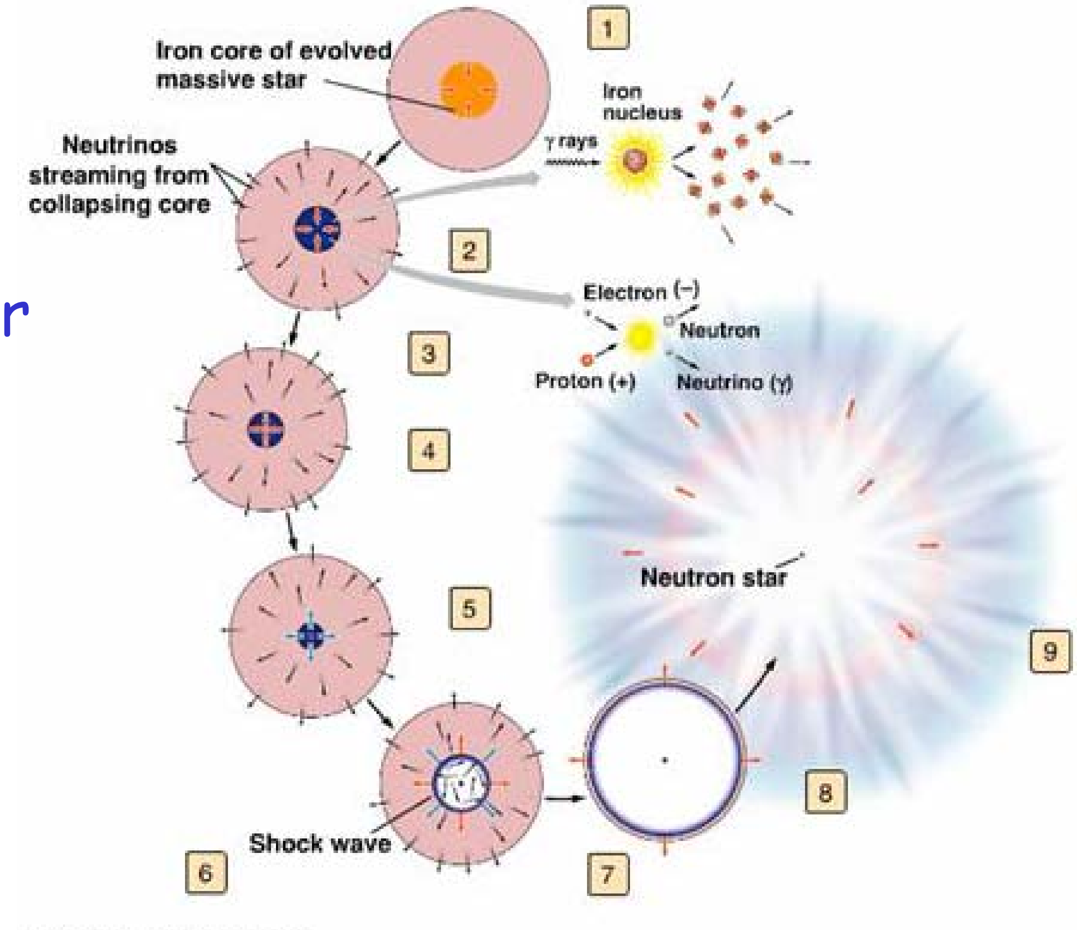


Type II Supernova

- Core collapses
- Density skyrockets
  - nuclei get so close together the nuclear force repels them
- Core bounces
  - particles falling inward sent back outward
  - up to 30,000 km/s
- Type II supernova



One heck of an explosion

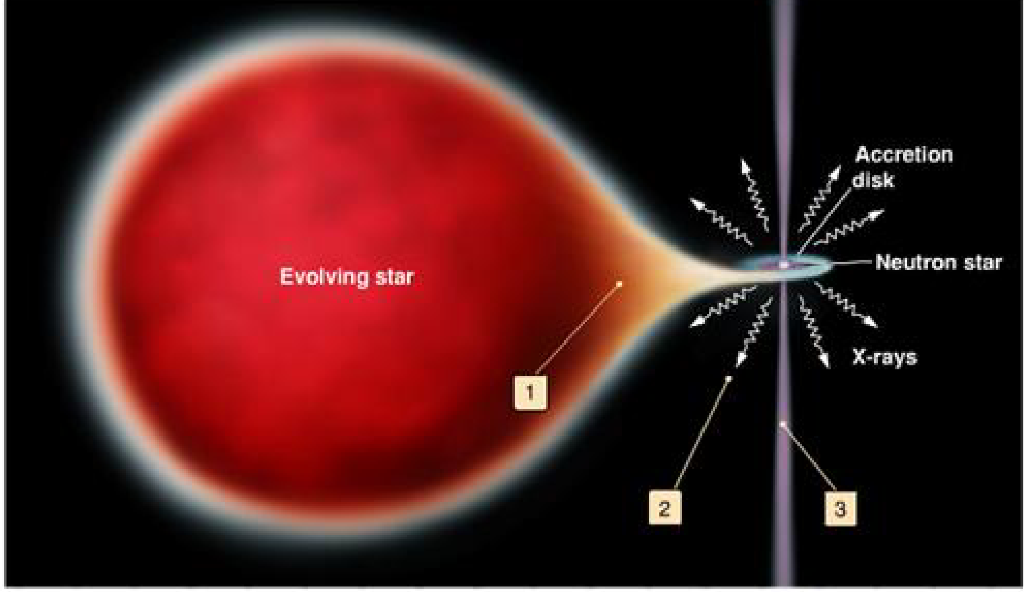
Supernova and Nucleosynthesis

- Normal fusion only makes up to iron
  - but there are many heavier elements
- In dense cores of massive stars, free neutrons are available
  - these neutrons combine with iron and other nuclei to form heavier nuclei
  - very heavy nuclei can be built up
  - more nucleosynthesis
- Heavy nuclei are spread out into the Universe in supernovae explosions

A Neutron Star Is Born

- After the supernova explosion, a very dense core is left behind
- Degenerate
  - now neutron degenerate
- Nuclei are incredibly dense
  - as closely packed as inside of nucleus
  - 1 billion times density of Sun
  - as if the Earth were condensed to the size of Doak Campbell Stadium
- Called a neutron star
  - somewhat similar to white dwarf

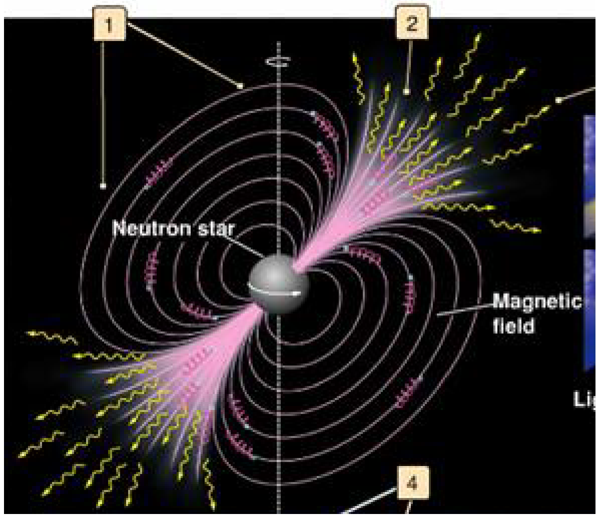
X-ray Binary



- When a neutron star is part of a binary system
- When the other star fills its Roche limit
  - starts feeding matter to neutron star
- The neutron star has an accretion disk
  - heated by matter falling onto it
- The accretion disk heats enough to glow in the x-ray part of the spectrum

Spinning Neutron Stars

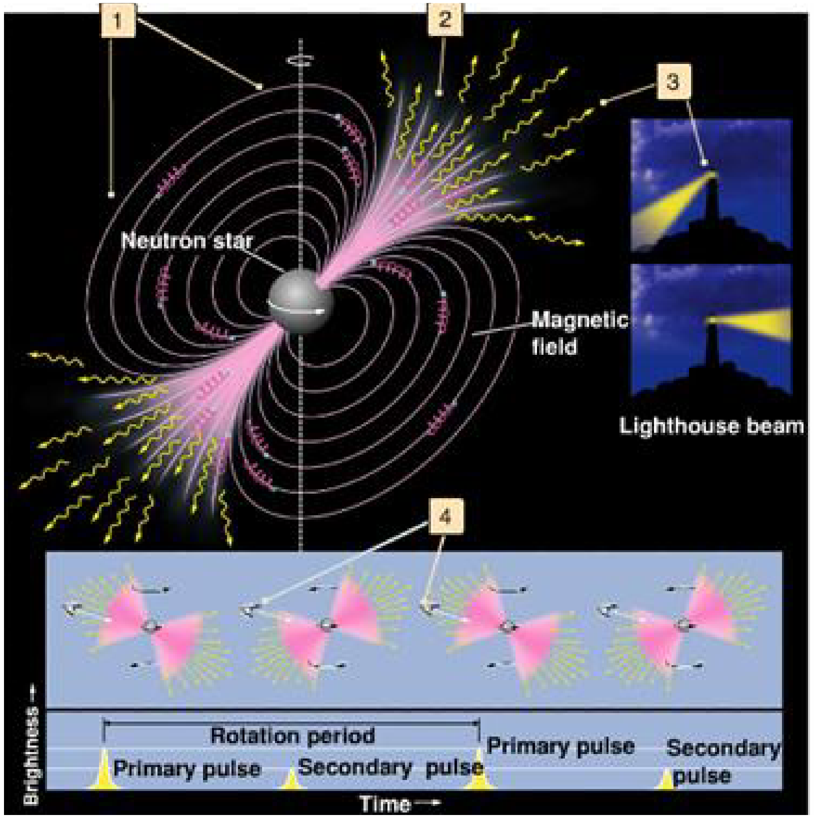
- Neutrons stars spins very quickly
  - get angular momentum from its collapse
  - period is a couple of hours
    - our Sun takes 27 days to rotate
- Very strong magnetic fields
  - very strong magnetosphere surrounds neutron star



- Escaping charged particles follow magnetic field lines
  - creates beams of particles & electromagnetic radiation

Pulsars

- When the rotation and magnetic fields don't line up, beams of particles and light swing around the neutron star
  - we observe "pulses" of EM radiation
- Like a beam of a lighthouse
  - regular pattern
  - May see one or two beams
- Called <u>pulsars</u>



Black Holes

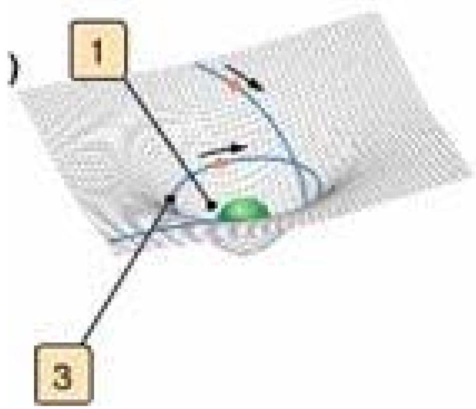
- If the neutron star is more than 3 solar masses, it will become a black hole
  - neutron degeneracy can no longer support the star
- Black holes have very interesting attributes
- We need to learn a bit more gravity…

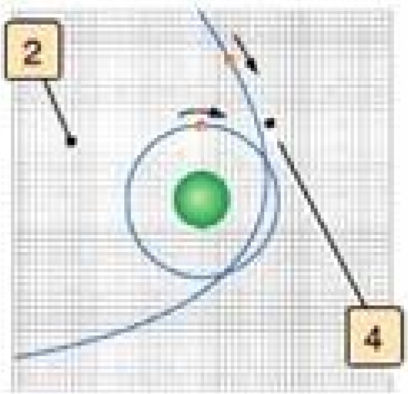
General Theory of Relativity

- Developed by Einstein to handle gravity
  - Special Relativity didn't account for gravity
- Mass is a distortion of space-time
  - we live in 4 dimensional space
    - 3 space dimensions + time
  - mass distorts this space
- Effects
  - bending light
  - time dilation
  - gravity waves
  - more…

A New Way of Thinking

- Imagine a flat rubber sheet (or foam pad)
- Objects moving across sheet move in a straight line (Newton again!)
- Now place a heavy object on the sheet
  - the sheet distorts
- Now objects moving across the sheet will curve due to the distorted space



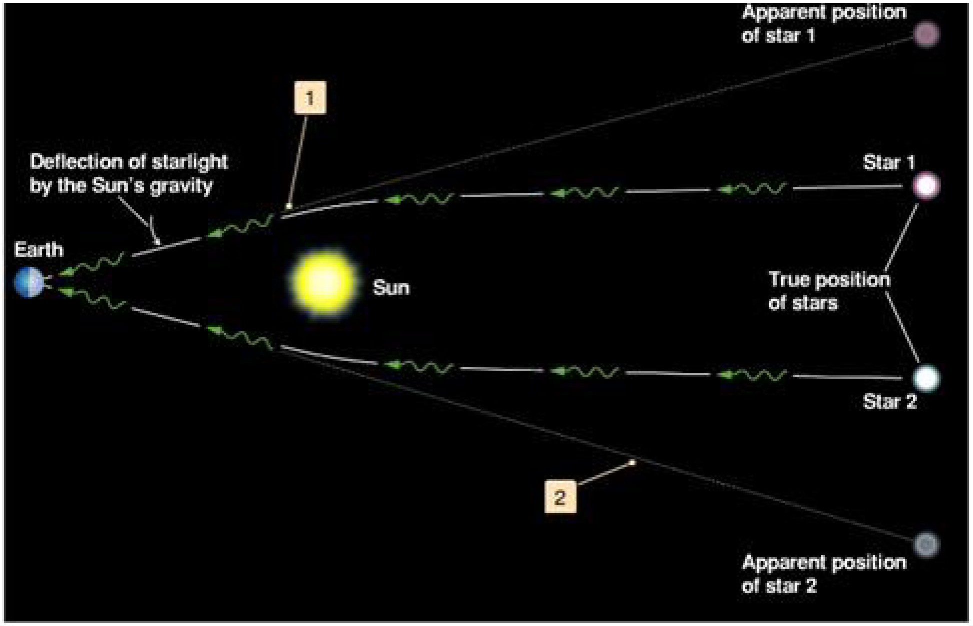


Interesting Effects

- Because space is distorted, even light will bend
  - must follow path across the sheet
- Time is also distorted
  - time appears to run slower closer to mass
- Gravitational red-shift
  - light from a massive object will be red-shifted
    - can't tell difference between Doppler shift and gravitational shift
  - due to time being distorted
    - "light's clock" runs differently than our clock
- Gravity waves
  - collapsing masses send ripples through space time
  - various experiments are searching for gravity waves

Gravitational Lensing

- Bending of light by gravity
  - observed by measuring location of stars during solar eclipse
  - light passing near the Sun was bent, stars appeared farther apart
  - first demonstration of general relativity



Gravity and Black Holes

- Escape velocity – velocity necessary to escape gravitation pull of an object
  - Earth – 11 km/s
  - Sun – 618 km/s
  - as mass goes up or radius goes down, escape velocity increases
- Anything moving at less than escape velocity will eventually be pulled back to object
- What happens when escape velocity is greater than the speed of light?

Event Horizon

- If mass is large/dense enough, there is some radius at which escape velocity is larger than speed of light
  - not even light can escape the object
  - event horizon
  - Schwartschild radius
    - maximum radius a black hole can be
    - for 1 M_{Sun}, it's about 3 km
    - for 2 M_{Sun}, it's about 6 km
- Anything within the event horizon is lost forever
- But remember, gravity outside the event horizon is the same as for a star of that mass

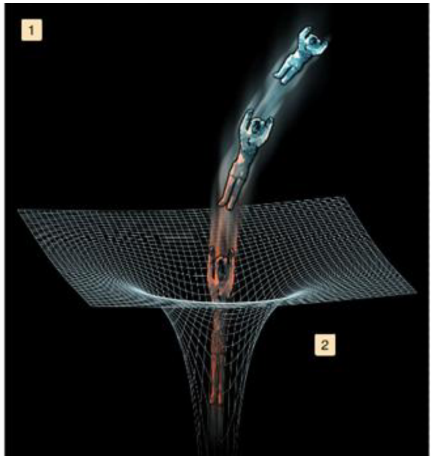
Black Holes

- From the viewpoint of general relativity, a black hole is an infinitely deep hole in space-time
  - called a singularity
- Properties of black holes
  - mass – all the material which is inside the event horizon
  - angular momentum – from material which fell in
  - charge

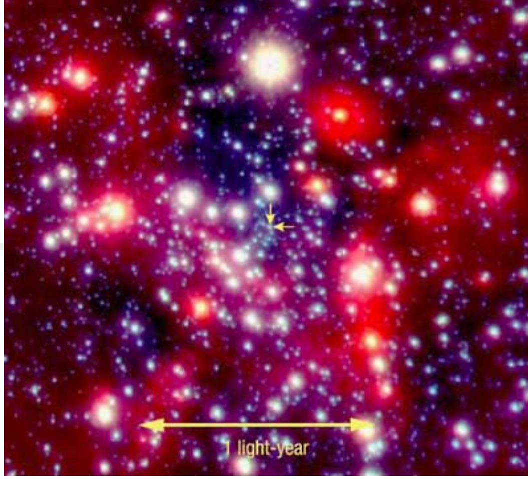
ALL OTHER INFORMATION IS LOST!

Falling Into A Black Hole

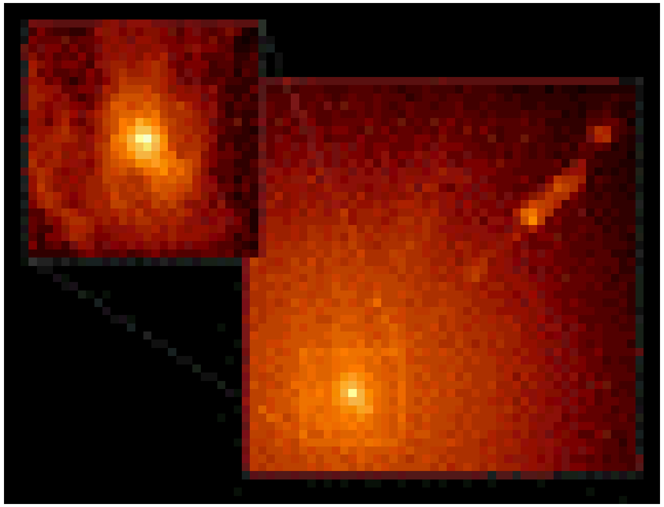
- Imagine a clock falling into black hole
- Appears to run slower – longer between ticks
- Appears to slow down its fall
- Gets "redder"
  - longer wavelength
  - Gets harder to see
- Tidal forces tear it apart
- At event horizon
  - length between ticks is infinite, wavelength is infinite, appears to stop (but we can't see it anyway
- To the clock it just keeps ticking away normally until torn apart or enters the singularity



Observing Black Holes



- Impossible to "see" directly
- Gravitational lensing is small
- Easiest to see if lots of material around
  - binary system
- Cygnus X-1
  - large visible star (B class)
  - invisible partner
  - strong x-ray emitter
  - mass of partner must be at least 8 solar masses and very small



- Colliding black holes?
- Black hole at center of galaxy?

Cepheid Variables

- Large stars which vary size/temperature
  - changes luminosity
- Have a very specific period
- Period is related to luminosity
  - Once you know the period, you know the luminosity, and you know the distance
  - a yardstick of the Universe