Stars, Galaxies & the Universe Announcements

- Reading Quiz #9 – Wednesday (10/27)
- HW#8 in ICON – due Friday (10/29) by 5 pm
  - available Wednesday

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Stars, Galaxies & the Universe Lecture Outline

1. Black Holes – recap & myths and truths!
2. Binary Systems - Regular stars (21.1-21.3)
3. Binary Systems – Compact objects (21.4)

But use the lecture notes for this material as the book goes into too much detail!

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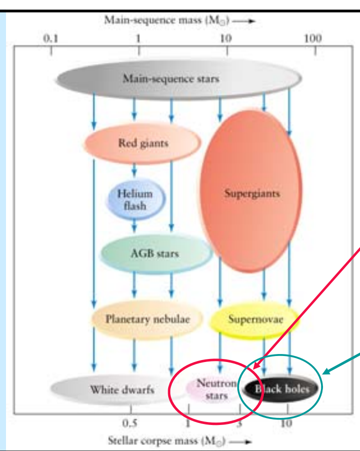
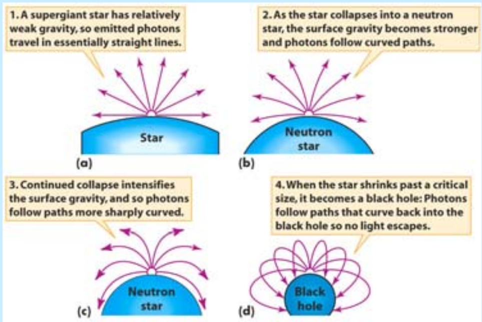


Are all pulsars neutron stars?

Are all neutron stars pulsars?

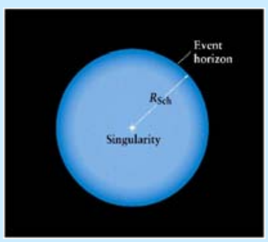
Black Holes!!

Black Holes are a natural consequence of Einstein's theory of gravity

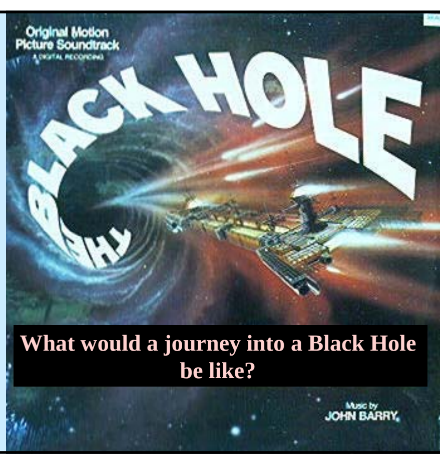


A black hole has only a "center" and a "surface"

- The black hole is surrounded by an *event horizon* which is the sphere for which light cannot escape "surface"
- The distance between the black hole and its event horizon is the *Schwarzschild radius* ($R_{Sch} = 2GM/c^2$)
- The center of the black hole is a point of infinite density and zero volume, called a *singularity or "center"*



A black hole is TRULY black!



What would a journey into a Black Hole be like?

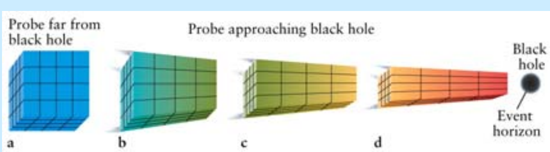
Schwarzchild radius (R_{sh}):

- the radius at which an object MUST be a black hole
- the radius at which density is so great, no light escapes
- depends on the mass of an object – larger mass, larger R

Object	Mass	R_{sh}
massive star	10 M_o	30 km
mid-mass star	3 M_o	9 km
Sun-like star	1 M_o	3 km
Earth	3×10^{-6} M_o	9 mm
person	~60 kg (3×10^{-29} M_o)	10^{-28} m

Falling into a black hole:

- get stretched along axis parallel to the path of motion
- get stretched VERY severely in one direction, squeezed in the other direction: "spaghetti-fication"
- from observer's point of view, appear "redder" (gravitational redshift)
- because TIME slows, then you would appear to never really get there to an observer!

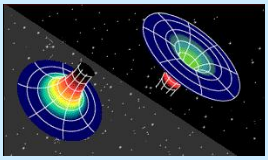


What would happen if you observed me fall into a black hole ???

- I would start to fall slowly because time appears to slow down due to the high gravity
- I would also appear to contract into a thin strand by tidal forces
- I would hover at the event horizon forever from the observer's perspective
- I would be shredded and stretched from my perspective (unpleasant!)

White holes, Wormholes, Parallel universes: do they exist?

- Einstein's equations of general relativity indicate their presence
- White hole: the mathematical "opposite" of a black hole
  matter is thought to flow OUT of a white hole
- Wormhole: the connection of a black hole and a white hole
  - usually collapse immediately (disintigrate) upon combination
  -however, with an outside pressure force, they could exist long enough to lead to space and time "travel" – 'future' tourists here on Earth!
- HOWEVER, none of these objects, ideas has ever been observed so at the moment, white holes, wormholes, parallel universes do not exist!



Types of Black Holes:

1. Remnant of Massive Star: stellar mass BH
   $M > 3\ M_o$
2. Supermassive BH (***millions*** of solar masses)
3. "Mid-mass" BH (100's of solar masses)
   coalescence of several black holes
4. Primordial BHs (less than 1 solar mass)
   evaporation : "Hawking Radiation"

Detecting Black Holes

- By definition, black holes are undetectable
- Have to infer their presence
  - large mass concentrated in a very small volume
  - mass itself is dark – no radiation coming from it

Detecting Black Holes – two main methods:

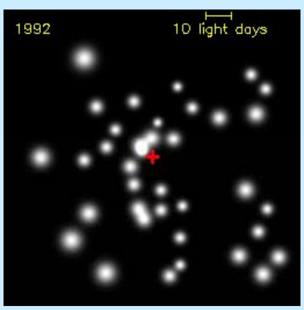
1. Rapid motions of stars around a dark object

   can use simple physics equations to deduce (calculate) the mass of "unseen" object

   - this can be a binary star system with one BH

   - or stars orbiting a supermassive BH

The 3 million solar mass black hole in our Galaxy center

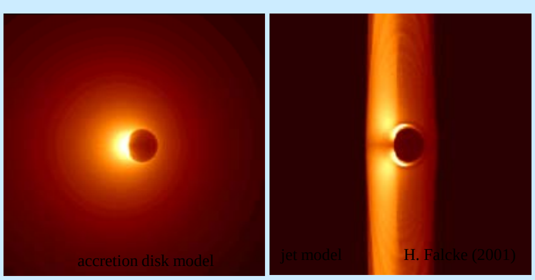


- study motions of stars near center of galaxy
- ~10 years of data
- closest star to SgrA*
  - "S2" passed within <u>17 light hours distance</u>
  - v ~ 5000 km/s (30 km/s) Sun orbits our Galaxy
  - elliptical orbit
  - stronger limits on M_{enc} 3.7+-1.5 million M_o

R. Schoedel, T. Ott, A. Eckhart, R. Genzel (MPE, Germany)

SgrA* - the black hole "shadow"

- if you get close enough, there will be a region (beyond the event horizon) where no light can escape – see a shadow against disk/jet light

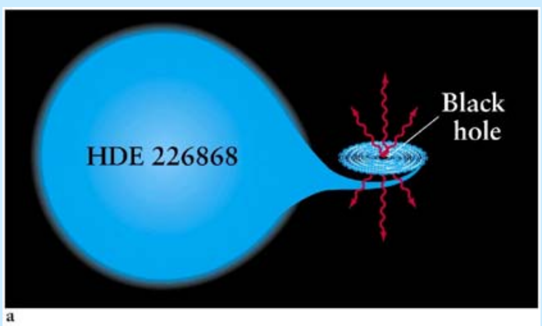


Detecting Black Holes – two main methods:

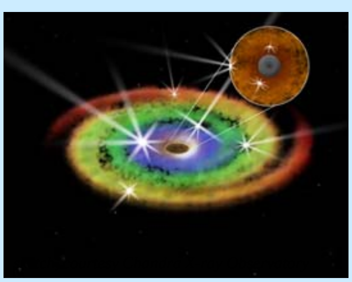
2. Detection of material falling into the curved spacetime near a BH – "accretion disk"

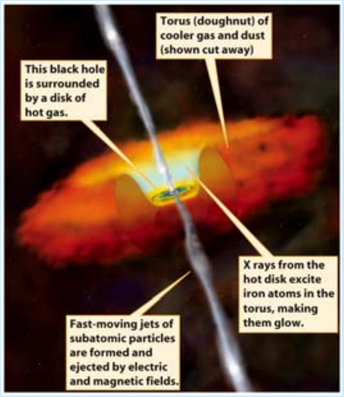
- ***friction between gas layers*** *heats the gas to very high temperatures*
- ***material ejected off the system in jets*** *(conservation of angular momentum)*

bright across the EM spectrum – X-rays to radio



Detecting Black Holes: accretion disk – hotter gas near BH



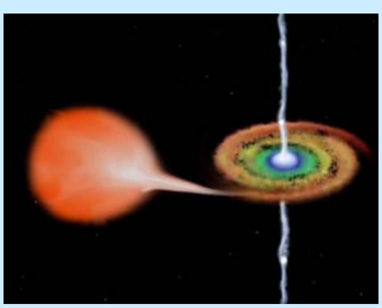


Detecting Black Holes – observational examples:

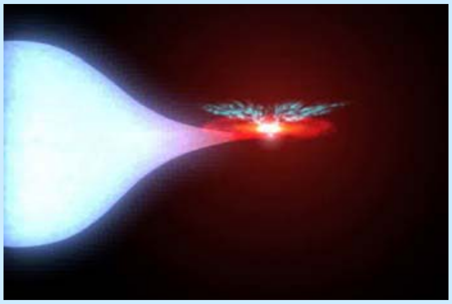
X-ray binaries – several in our Galaxy

Combination of the two methods:
- see bright X-rays but only one source
- infer the second source is "dark"
- calculate that the other source has mass > 2 solar mass ➔ BH!

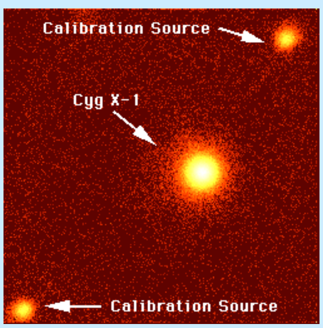
Detecting Black Holes: jets of material shoot off the disk

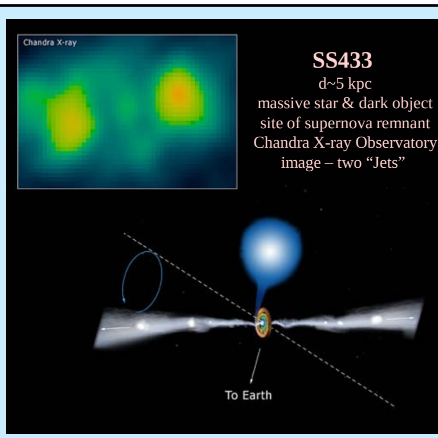


Detecting Black Holes:
jets of material shoot off the disk

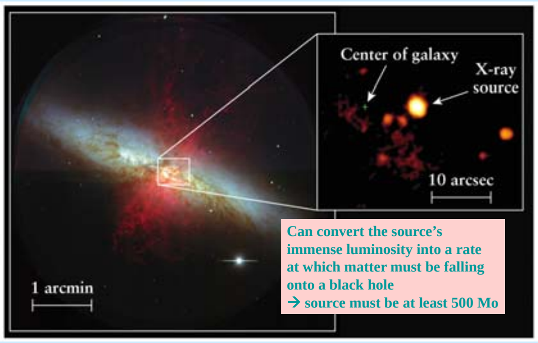


X-ray image of Cyg X-1

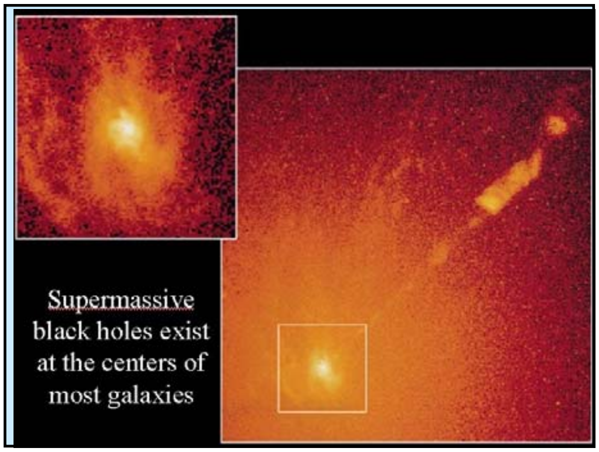




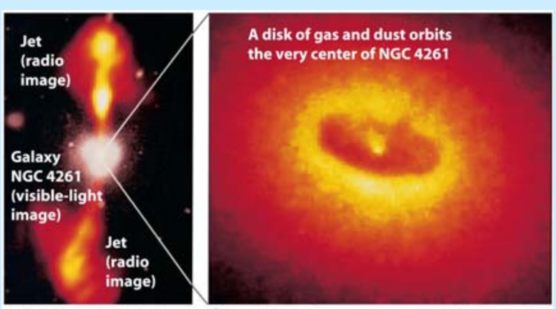
Mid-mass Black Hole in Galaxy M82



Can convert the source's immense luminosity into a rate at which matter must be falling onto a black hole
→ source must be at least 500 Mo



Supermassive black holes exist at the centers of most galaxies



(a) Galaxy NGC 4261 (b) Evidence for a supermassive black hole in NGC 4261

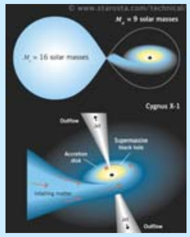
→ observe Doppler shifts in spectral lines from the disk
→ can use the rotation to get an idea of the "enclosed mass" of black hole

Myths about Black Holes #1:

Black holes exist only in theory

Detections of black holes:
Indirectly in X-ray binaries

Cygnus X-1 (1000 ly away)



Myths about Black Holes #2:

Black holes are giant cosmic vacuum cleaners which swallow everything up around them!

Gravity is so strong near a black hole because you can get much closer to it and still be exposed to that entire mass. DENSITY is so high – the black hole has almost no radius! ~10's km!

Different than on earth – the closest you can get to the earth's mass is the surface – that is ~6000 km from center.

If the Sun were to become a black hole today, we would feel no difference here on earth because we are so far away!

Myths about Black Holes #3:

The Sun will someday become a black hole.

The Sun will exhaust its hydrogen core and become a red giant. Then it will become a planetary nebula and white dwarf.

Its white dwarf mass will be less than 1 solar mass and thus, it will never have the density of a black hole.

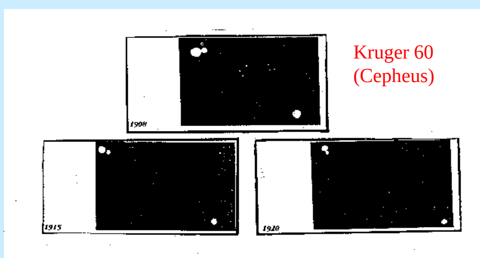
Myths about Black Holes #4:

Black holes can be detected visually.

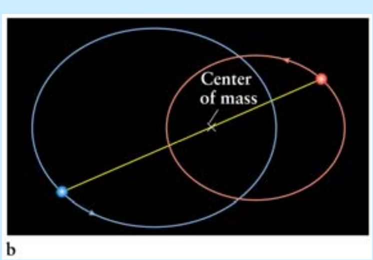
No!

We can only make INDIRECT measurements of the presence of black holes.

Stars usually do not live alone!
They come in pairs...
BINARY STARS



Binary stars orbit around a common
CENTER OF MASS



binary periods: a few hours (close stars) to 100's of years
→ can find masses if you know periods (using Kepler/Newton's laws)
binary separations: a few AU (!!) to 100's of AU

Types of Binary Stars

- Visual Binaries
  - Visible as two distinct stars
  - Most binaries are not visual binaries!
- Spectroscopic Binaries
  - Detectable in the stellar spectral lines
- Eclipsing Binaries
  - Detectable by changes in brightness (light curves)

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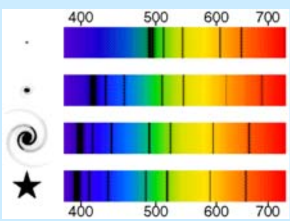
Doppler Shifts of nearby stars

most extreme motions of nearby stars in our Galaxy:

→ LHS52 moving at **+308 km/s** at distance of 82 ly

→ LHS64 moving at **-260 km/s** at distance of 78 ly

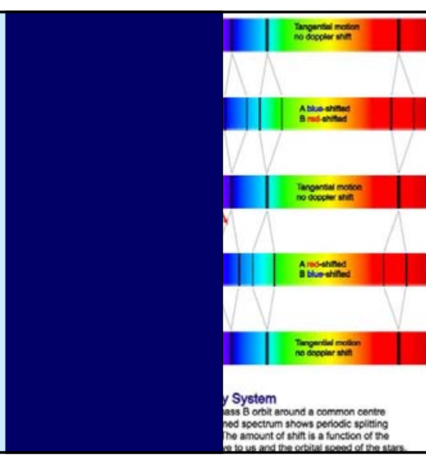


very distant galaxy: +75,000 km/s

distant galaxy: moving +16,000 km/s

nearby galaxy: moving +1000 km/s

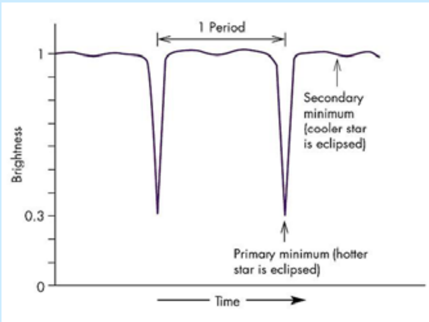
not moving enough for shift to be detectable

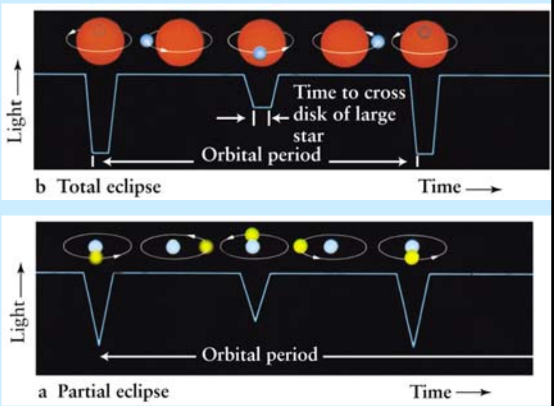


How do we know that a star is a binary system?

1. Spectroscopic – see changing Doppler shifts of two stars
2. VISUAL: actually SEE two stars!

See a change in brightness of a star





ALGOL: most famous eclipsing binary!

Beta (β) Persei

-first eclipsing binary star known

-every 2.9 days changes brightness by 6 x (minima)

-lasts about 2 hrs as the star passes in front of it

- next minima:

10/26/2010 @ 07:58 pm

11/10/2010 @ 04:03 am