Fate of Stars

INITIAL MASS	Final State
relative to Sun's mass	
$M < 0.01$	planet
$.01 < M < .08$	Brown dwarf (not true star)
$0.08 < M < 0.25$	not Red Giant→ White Dwarf
$0.25 < M < 12$	Red Giant→White Dwarf
$12 < M < 40$	Supernova: neutron star
$M > 40$	Supernova: black hole

NEUTRON STARS

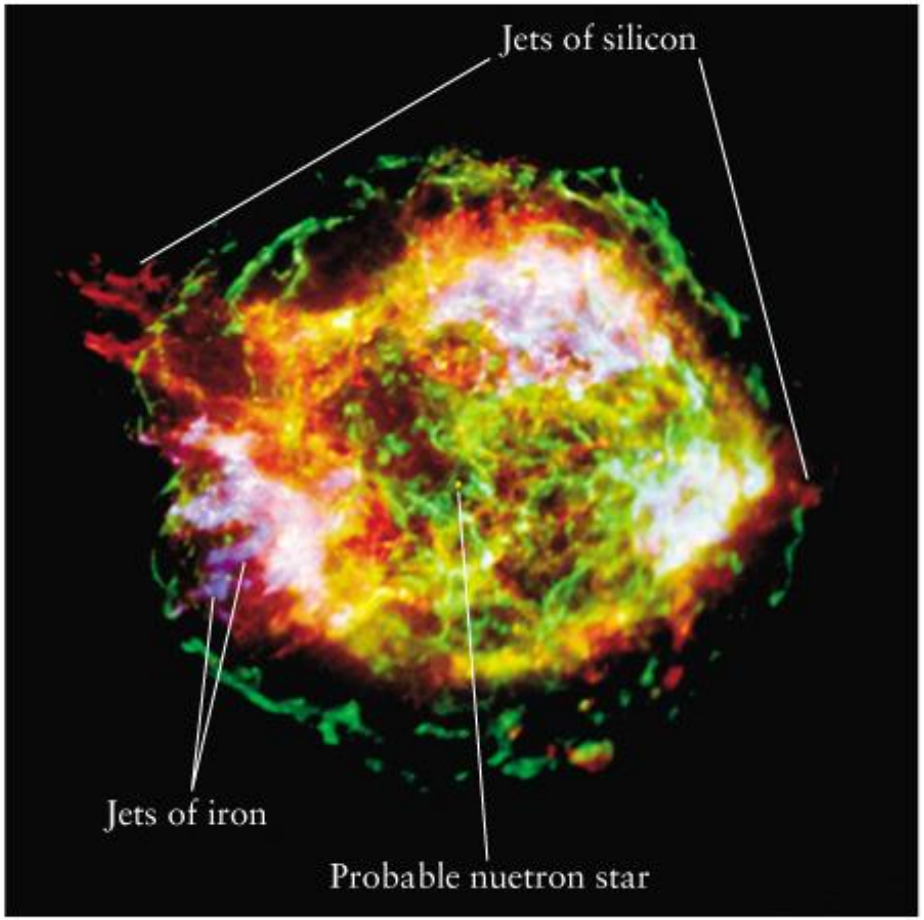
In supernova explosion core collapses

- $e^- + p \rightarrow n + \nu$
- packed neutrons remain giving neutron "star" about 1% protons/electrons (energy balance between neutrons and electrons)
- very hot (200 billion degrees) and very small (10-30 km - DeKalb County)
- so very, very dense. 1 cm^3 has mass of 100 million tons

See neutron stars in supernova debris

Crab Nebula M1

Supernova 1054 (observed by Chinese and Arabs). Has neutron star



Cassiopeia A maybe observed in 1680

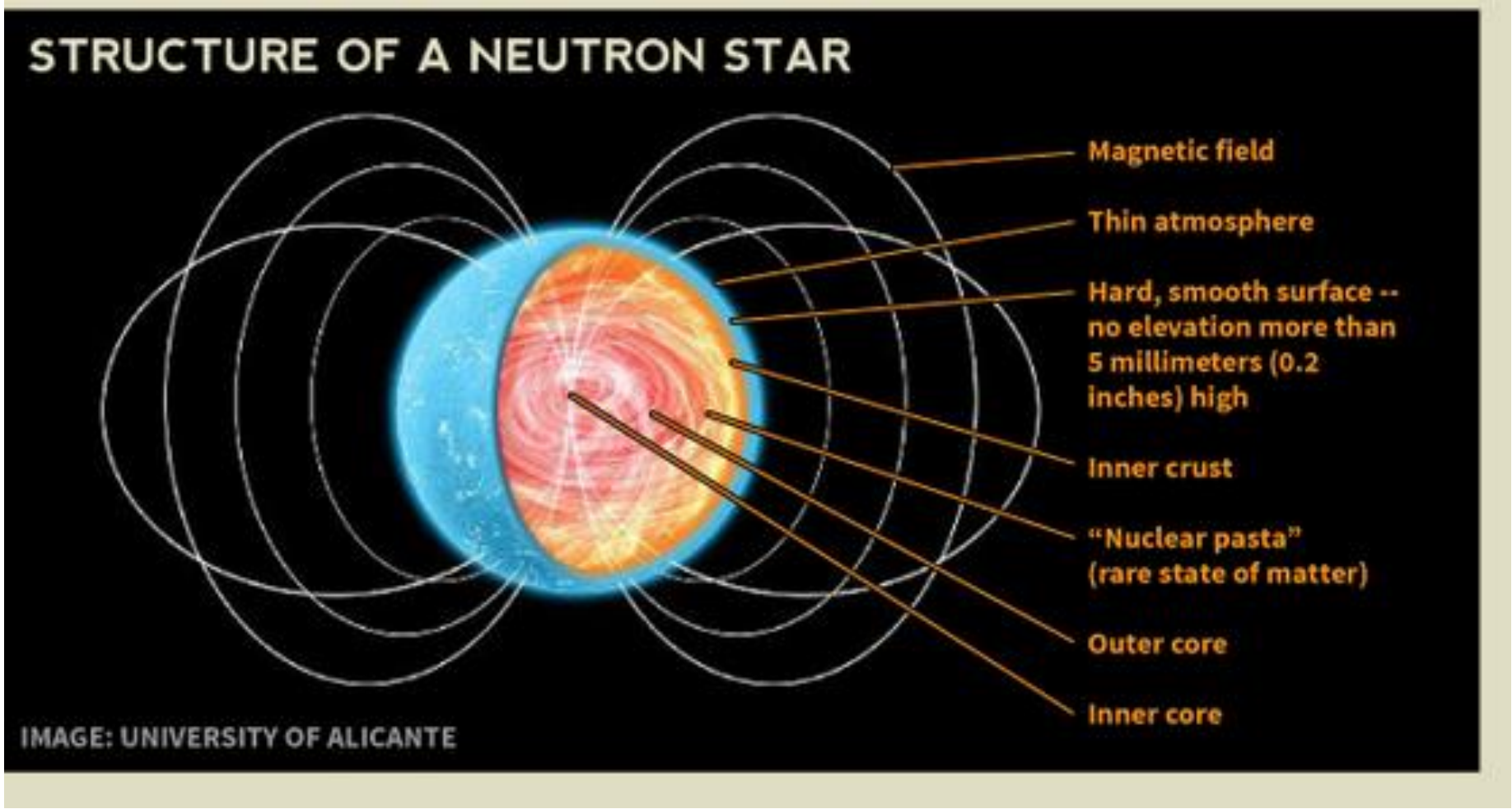
	White Dwarf	Neutron Star
Mass (relative to Sun)	1.0 (always < 1.4)	1.5 (always < 3)
Radius	5000 km	10 km
Density	10^6 g/cm^3	10^{14} g/cm^3

Properties determined by "degenerate" electrons and neutrons.

NEUTRON STARS II

- spin rapidly → from >100 per second (Hz) to once per many seconds/minutes/hours/days
- EM radiation from protons/electrons + spin → large magnetic fields
- observe as repeating flashes of light PULSARS and seen in debris of known supernova explosions
- discovered in 1967 by grad student Jocelyn Bell. Her advisor Anthony Hewitt won Nobel prize. Found in PSR B1919. First called **LGM** for **"little green men"**

Neutron Star Structure: don't need to know

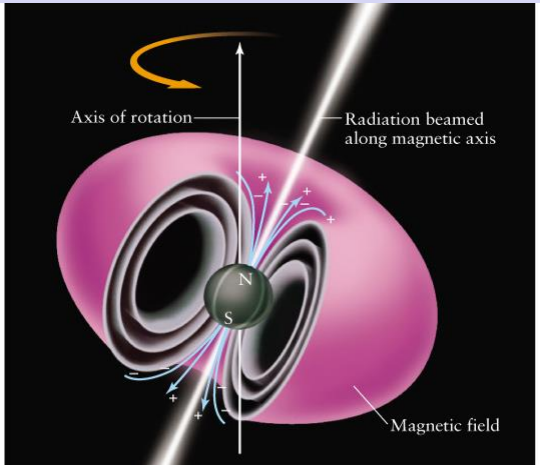


Angular Momentum + Neutron Stars

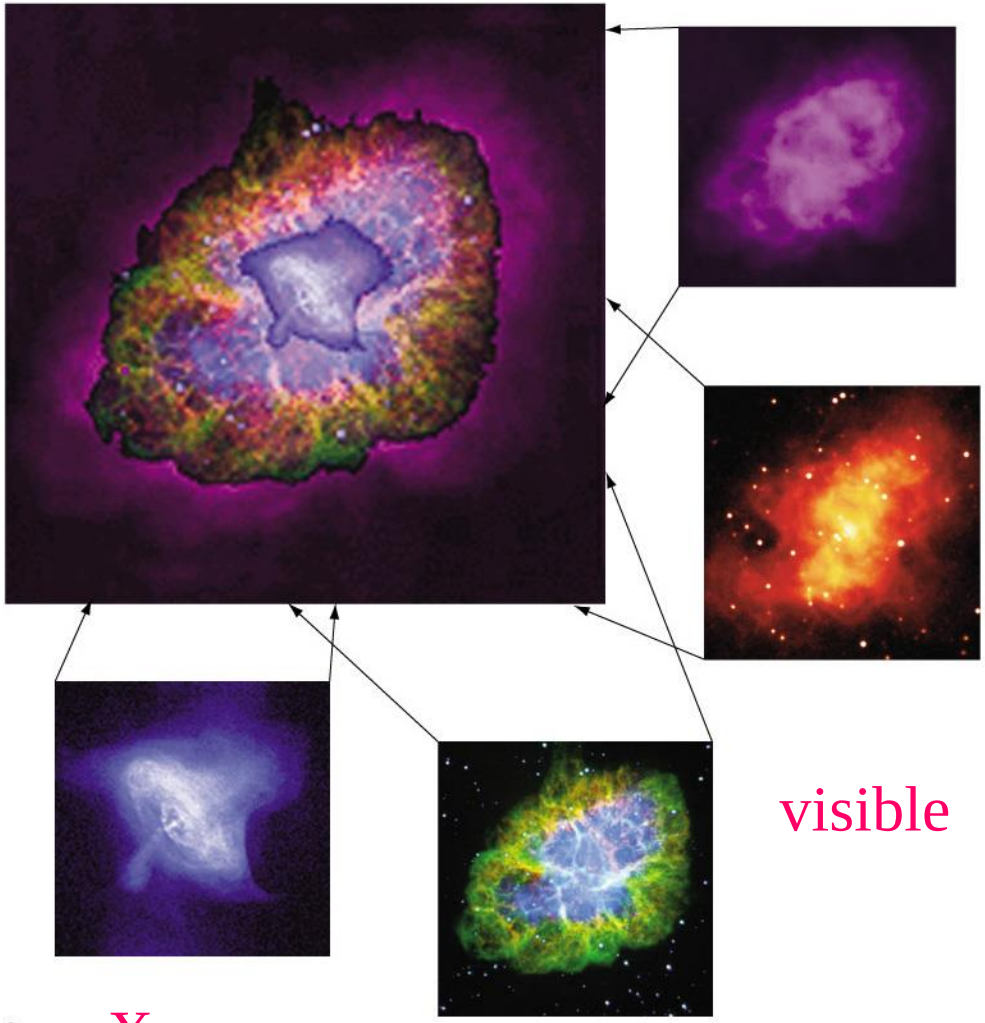
Angular momentum = MASS x VELOCITY x RADIUS

decreasing RADIUS increases VELOCITY

Angular momentum is conserved:
spinning chair
ice skater
formation of neutron star in collapse of larger spinning star



Crab Nebula

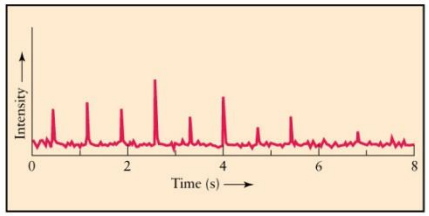


a

X-ray

visible

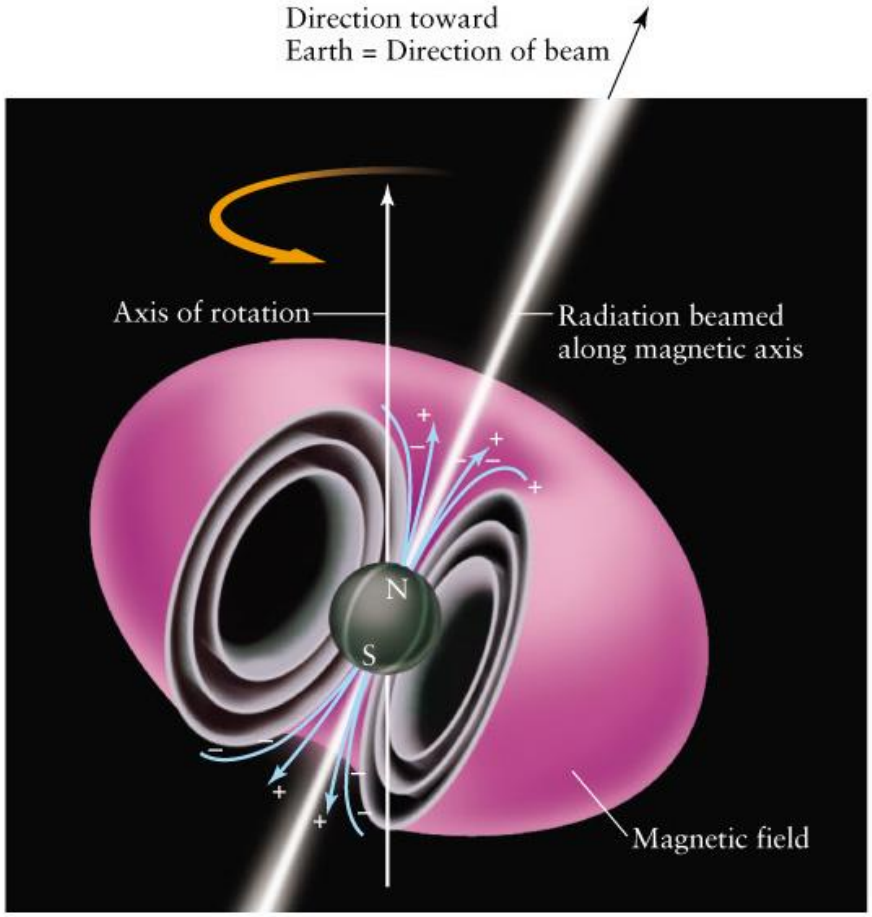
radio



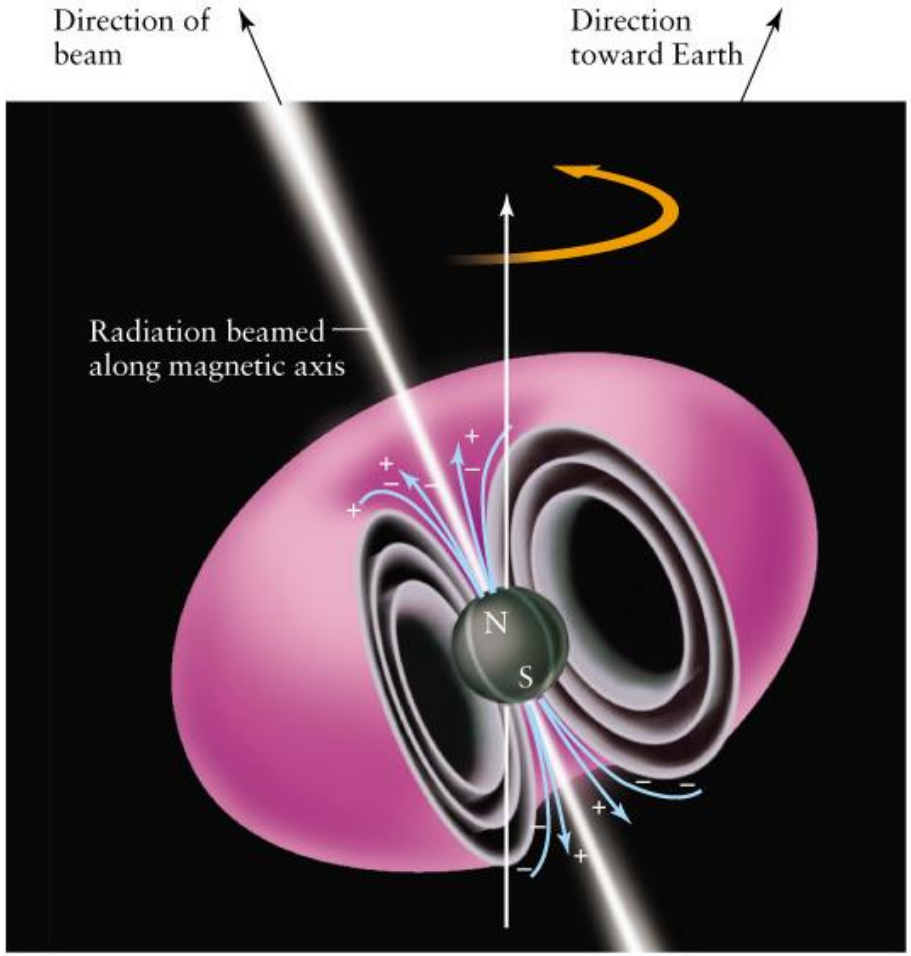
infrared

period = 30 Hz or 0.033 sec and can be “seen” in visible and X-ray

Rotating Neutron Star: not all point to Earth



a One of the beams from the rotating neutron star is aimed toward Earth: We detect a pulse of radiation.

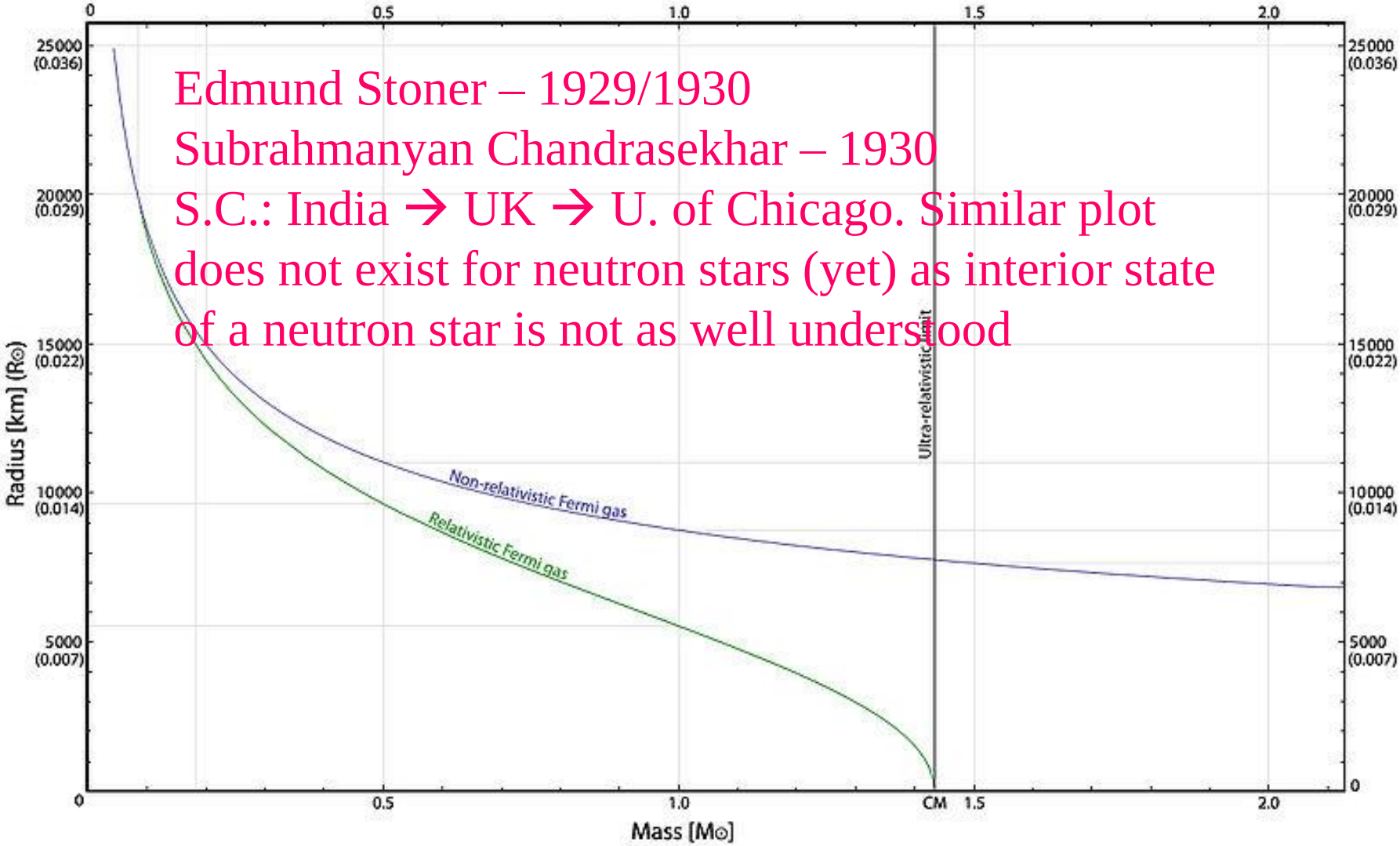


b Half a rotation later, neither beam is aimed toward Earth: We detect that the radiation is "off."

Surface Gravity of Neutron Star

- $g = M/R^2$
- for neutron star: mass is similar to Sun or 1,000,000 X Mass(Earth) while radius is 10 km or .002 Radius(Earth)
- surface gravity NS = 10^{11} Earth's
- force of gravity is resisted by degenerate neutrons
- If Mass(NS) > 3xMass(Sun), neutron star collapses into BLACK HOLE whose radius approaches 0
- Mass vs radius still not completely understood. Most massive neutron star observed is about 2xMass(Sun)

WD or NS: Mass vs Radius



Edmund Stoner – 1929/1930
Subrahmanyan Chandrasekhar – 1930
S.C.: India → UK → U. of Chicago. Similar plot does not exist for neutron stars (yet) as interior state of a neutron star is not as well understood

BLACK HOLES - history

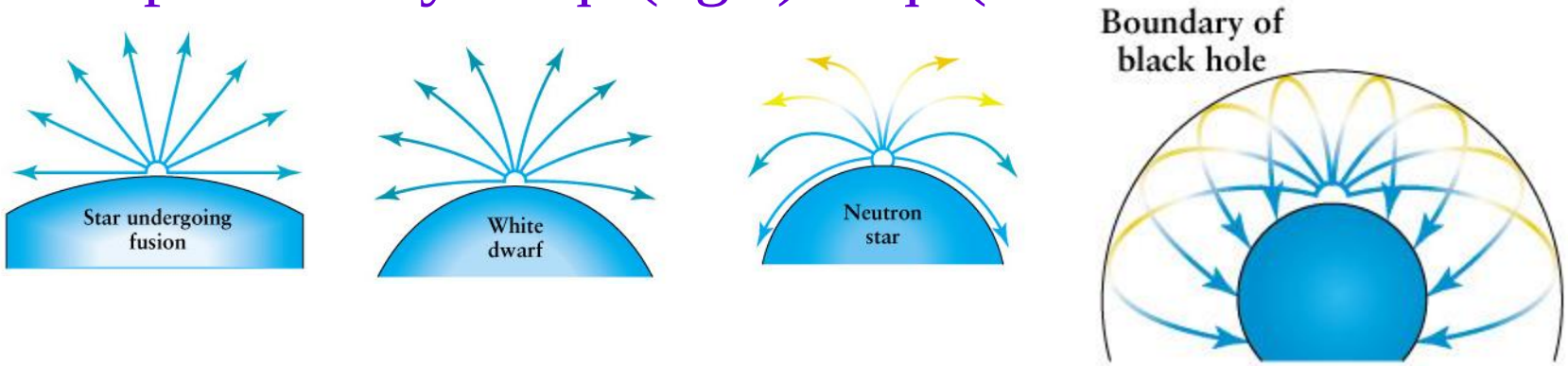
- Predicted by many back to 18th Century. Real effort followed Einstein's General Theory of Relativity in 1915 with early work by S. Chandrashenkar in the 1930s but rejected by many including A. Eddington.

- from Wikipedia "Chandrasekhar's work presaged the discovery of black holes, which at the time seemed so absurdly non-physical that Eddington refused to believe that Chandrasekhar's purely mathematical derivation had consequences for the real world. History clearly proved Eddington wrong, but his motivation remains a matter of some controversy. Chandrasekhar's narrative of this incident, in which his work is harshly rejected, portrays Eddington as rather cruel, dogmatic, and racist."

- 1939 Robert Oppenheimer ("father" of WW II atom bomb work) worked out with Tolman and Volkov the neutron star mass limit → collapses into black hole

BLACK HOLES

- very small radius with mass >3x Mass(Sun) (and can be much, much more massive)
- so much gravitational force that not even light can escape --- escape velocity is greater than the speed of light
- escape velocity = sqrt(2gR) =sqrt(2GM)/R



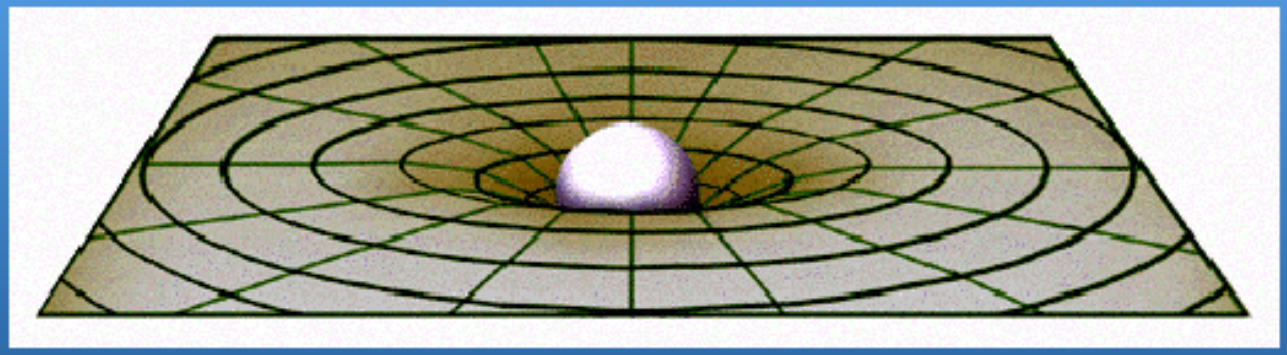
BLACK HOLES II

- "normal" matter can't escape surface but why light??
- classical (Newton) gravity has force = Gm_1m_2/r^2. As mass(photon) = 0, and photon→light, then gravity should not effect
- But Einstein (in General Relativity) showed that light is bent by large gravitational fields
- photons travel along space-time lines → curved near massive objects →near Black Hole light from BH is "trapped" → nothing can escape gravity's pull

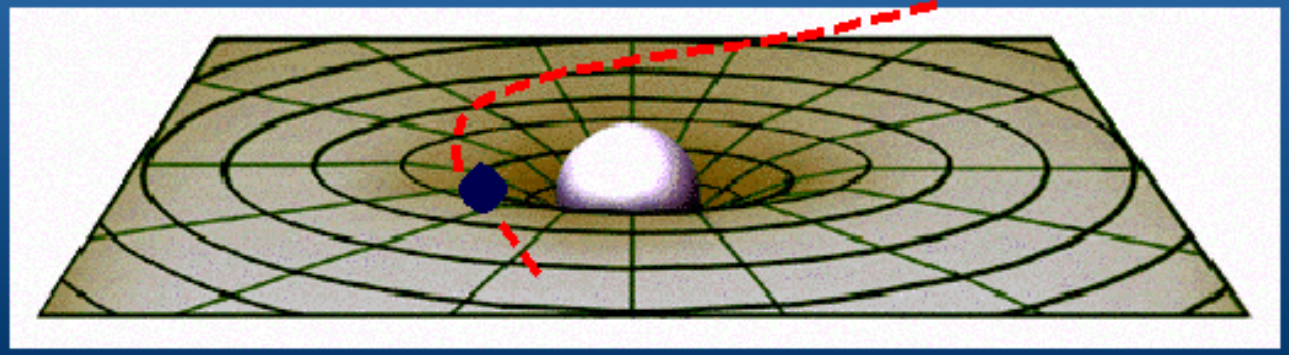
Gravity bends space-time

Gravity: Space as a Rubber Sheet

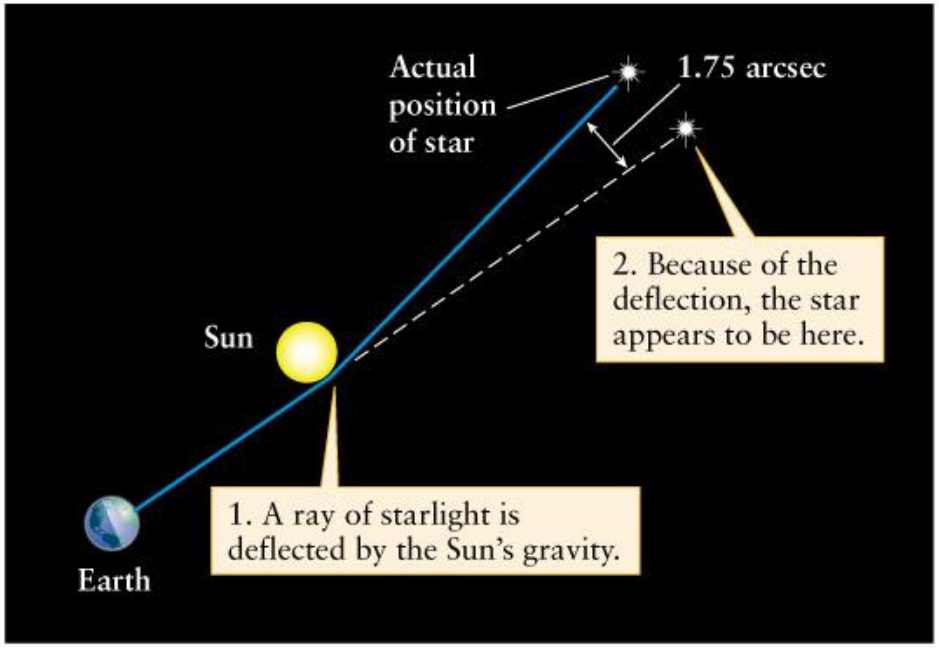
- Matter tells space how to curve

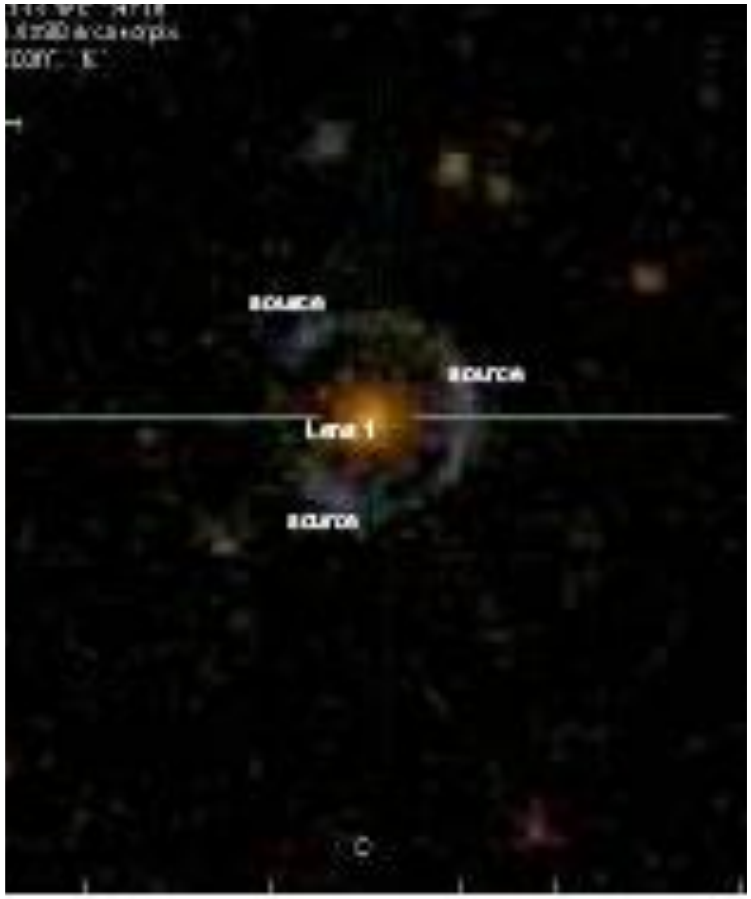


- Curved space tells matter how to move



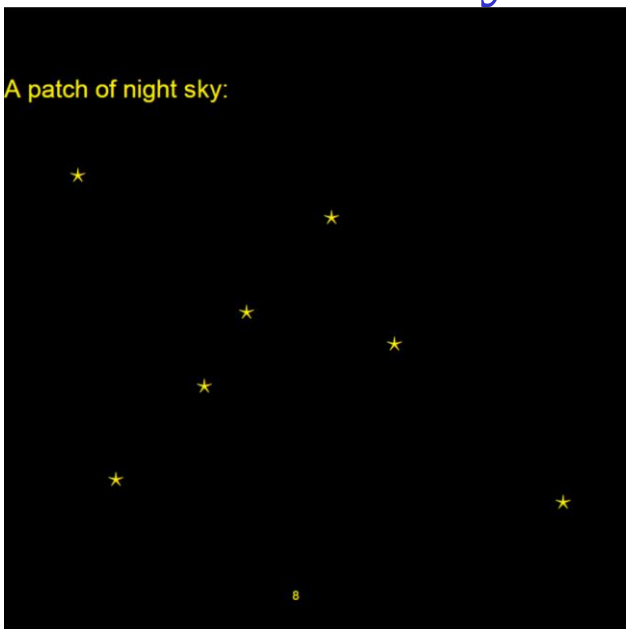
Gravity bends space-time

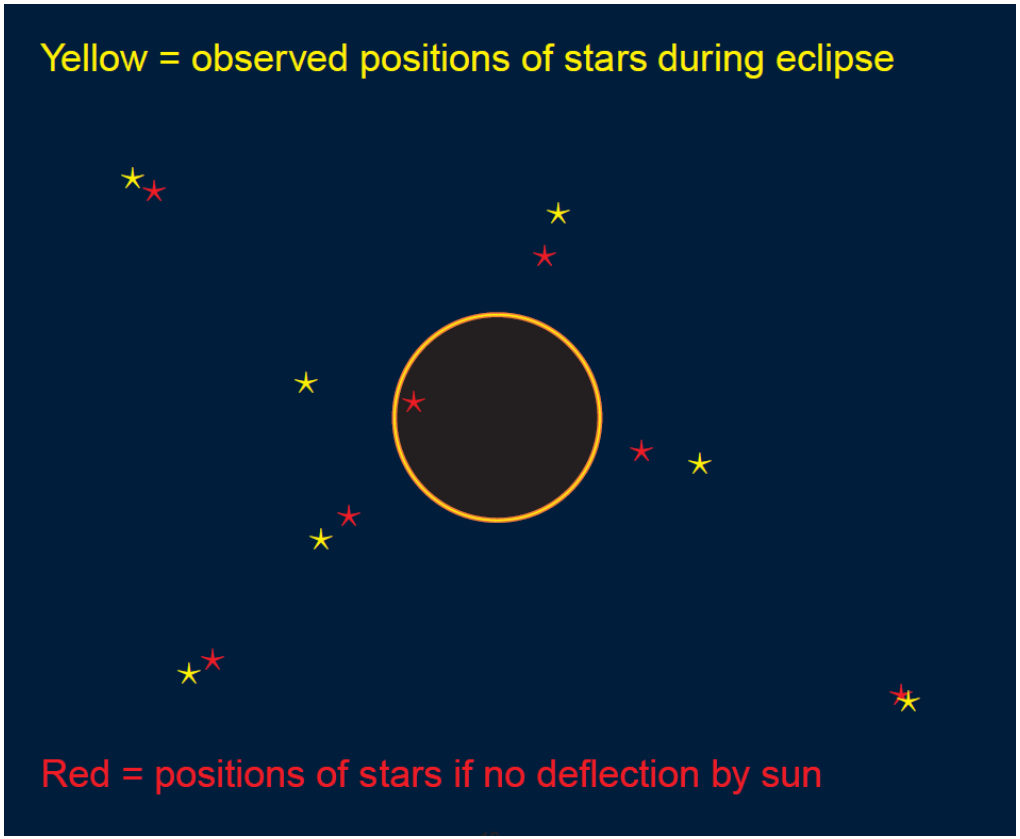




Einstein lens. Galaxy bends light from another galaxy further away (NIU student Donna Kubik thesis. Matt Wiesner also works on this subject)

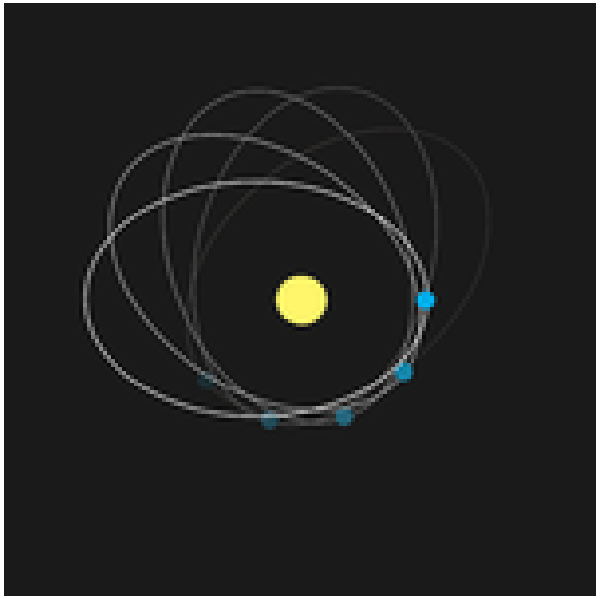
Gravity bends space-time: from S. Martin

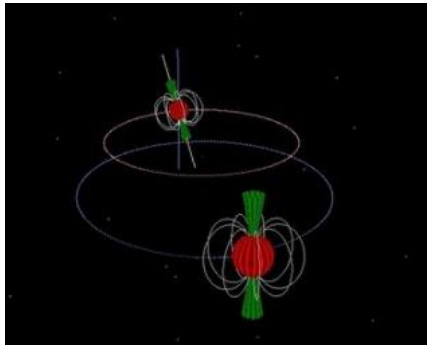


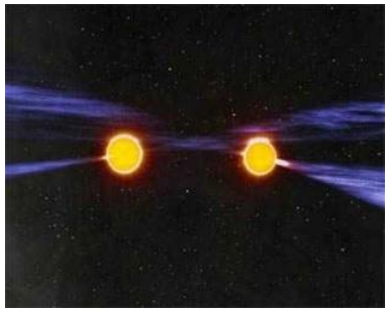


First confirmation of Einstein predictions made in 1919 during solar eclipse (Arthur Eddington and others)

Gravitational Force: Newton vs Einstein



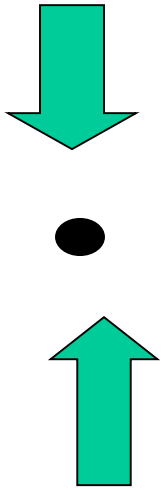




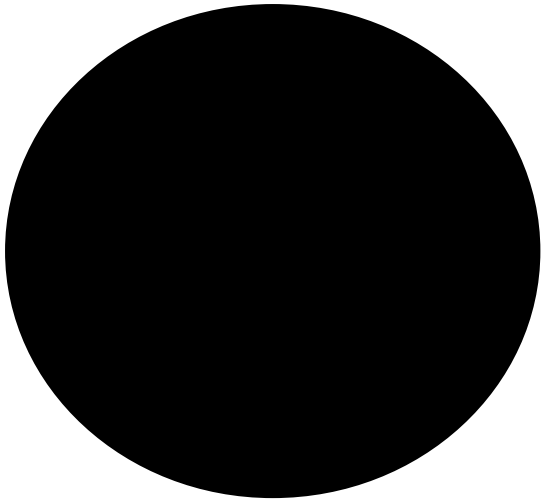
For large mass or short distances, the gravitational force from Newton is modified by Einstein's theory. See in the "precession of the perihelion" of Mercury's orbit around the Sun, or in orbits of 2 neutron star systems (1993 Nobel Prize)

BLACK HOLES III

- Black holes can keep accumulating mass…including "colliding" Black holes. Very massive (million times mass Sun) at center of many galaxies



Matter falls into BH → it grows (and grows and grows)

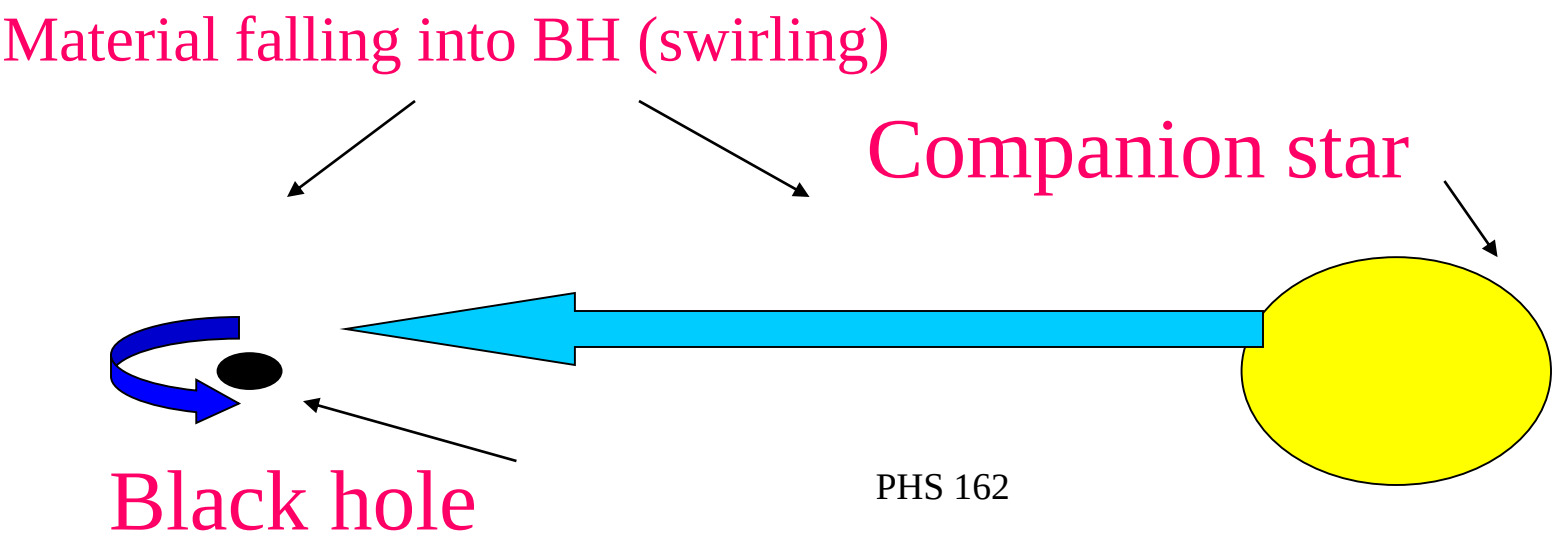


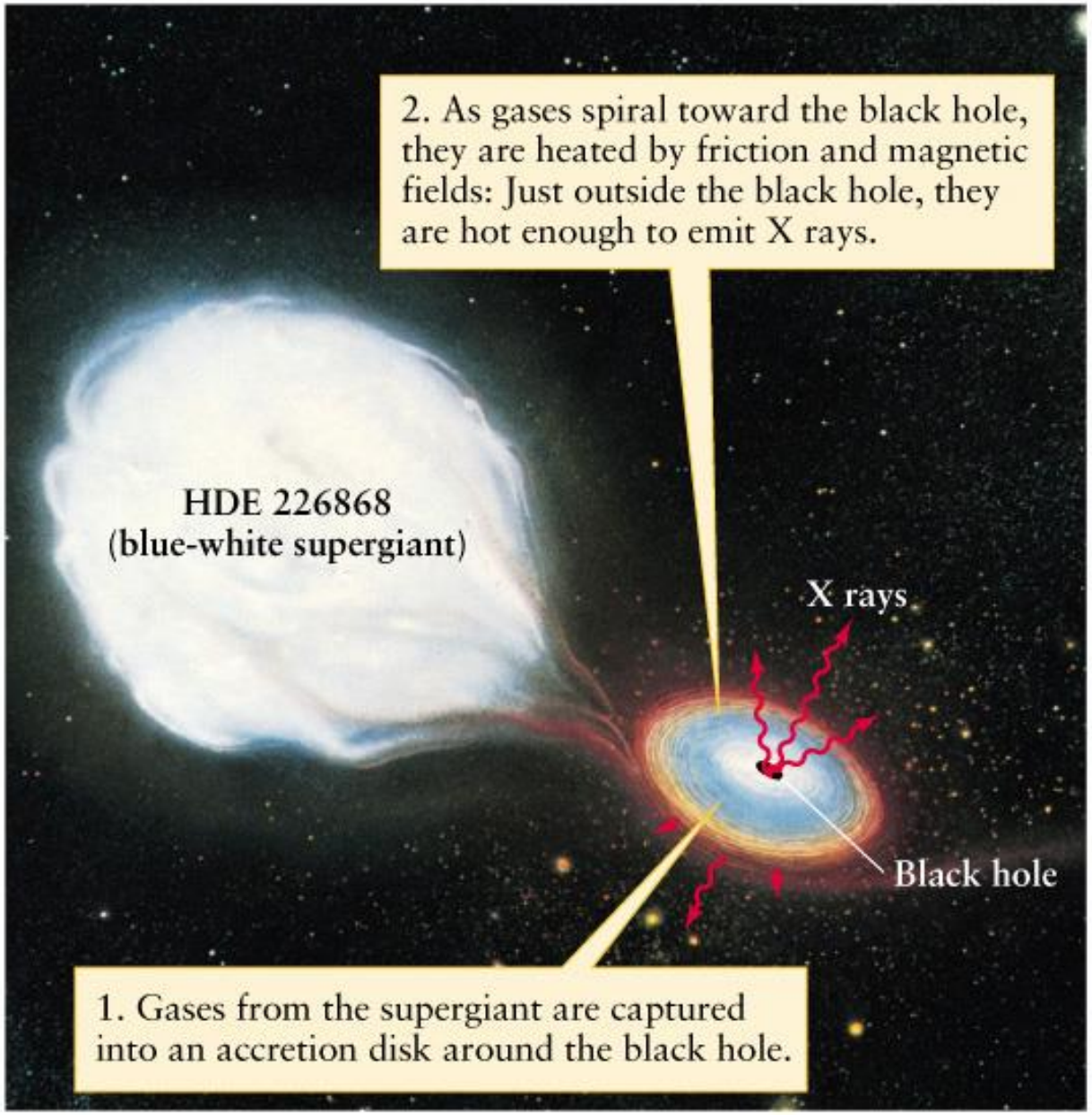
Millions (billions) of years later

Matter falling in can also heat up and produce light

Observing Black Holes

- observe radiation from hot matter falling into black hole
- observe orbit of normal star around “unseen” companion. Gives mass and if > 3xmass(Sun) then assume black hole (if smaller maybe neutron star)




2. As gases spiral toward the black hole, they are heated by friction and magnetic fields: Just outside the black hole, they are hot enough to emit X rays.
HDE 226868
(blue-white supergiant)
X rays
Black hole
1. Gases from the supergiant are captured into an accretion disk around the black hole.

BLACK HOLES IV

- perhaps new physics but lack quantum theory of gravity. Items like wormholes, breaks/tunnels in space-time, other dimensions….

Enter at one BH, exit at another