Nuclear Synthesis

- All elements heavier than Helium are made inside stars

  up to Iron - fusion in Red Giants

  heavier than Iron (and some lighter) - Supernova explosions

- Stars lose matter at end of life-cycle

  becoming Red Giants (can detect)

  Supernova debris (can detect)

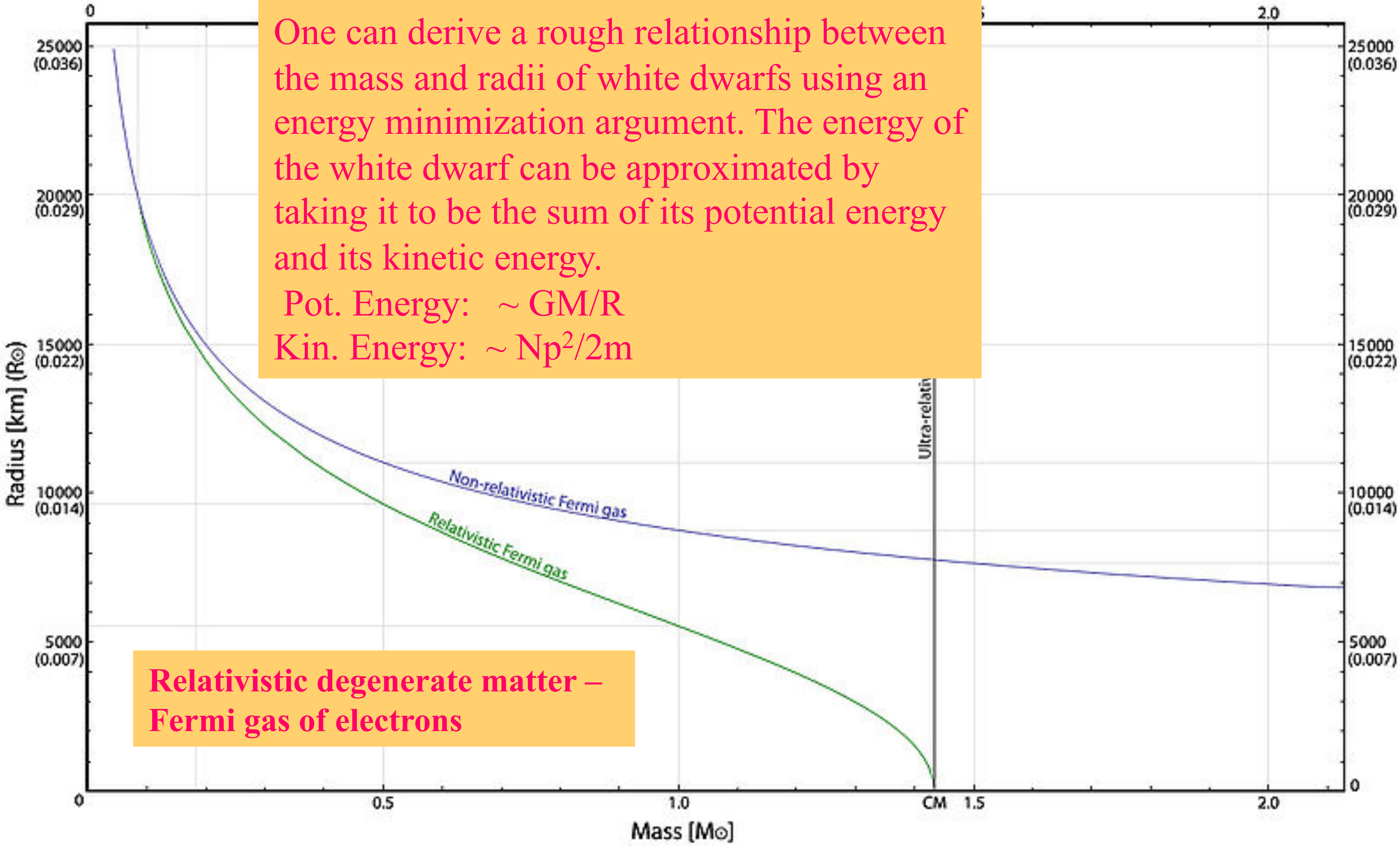
and this matter forms new stars (and planets and us)

White Dwarfs

No more fusion – only supported by electron degeneracy

Material	Density in kg/m^3	Notes
Water (fresh)	1,000	At STP
Osmium	22,610	Near room temperature
The core of the Sun	~150,000	
White dwarf star	1×10^{9} [1]	
Atomic nuclei	2.3×10^{17} [31]	Does not depend strongly on size of nucleus
Neutron star core	$8.4 \times 10^{16} – 1 \times 10^{18}$	
Black hole	2×10^{30} [32]	Critical density of an Earth-mass black hole

White Dwarfs Mass vs Radius



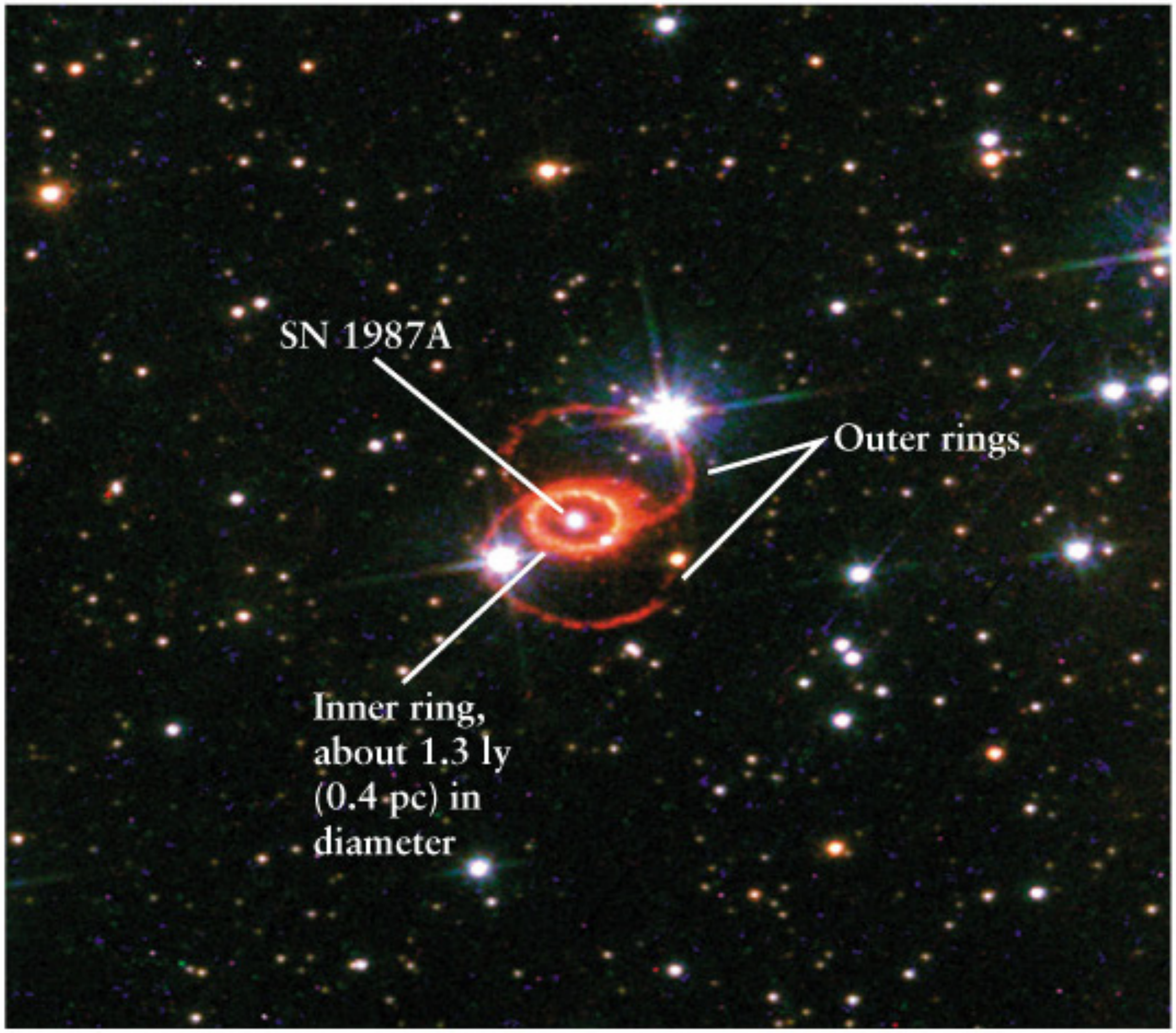
One can derive a rough relationship between the mass and radii of white dwarfs using an energy minimization argument. The energy of the white dwarf can be approximated by taking it to be the sum of its potential energy and its kinetic energy.

Pot. Energy: $\sim GM/R$

Kin. Energy: $\sim Np^2/2m$

Relativistic degenerate matter – Fermi gas of electrons

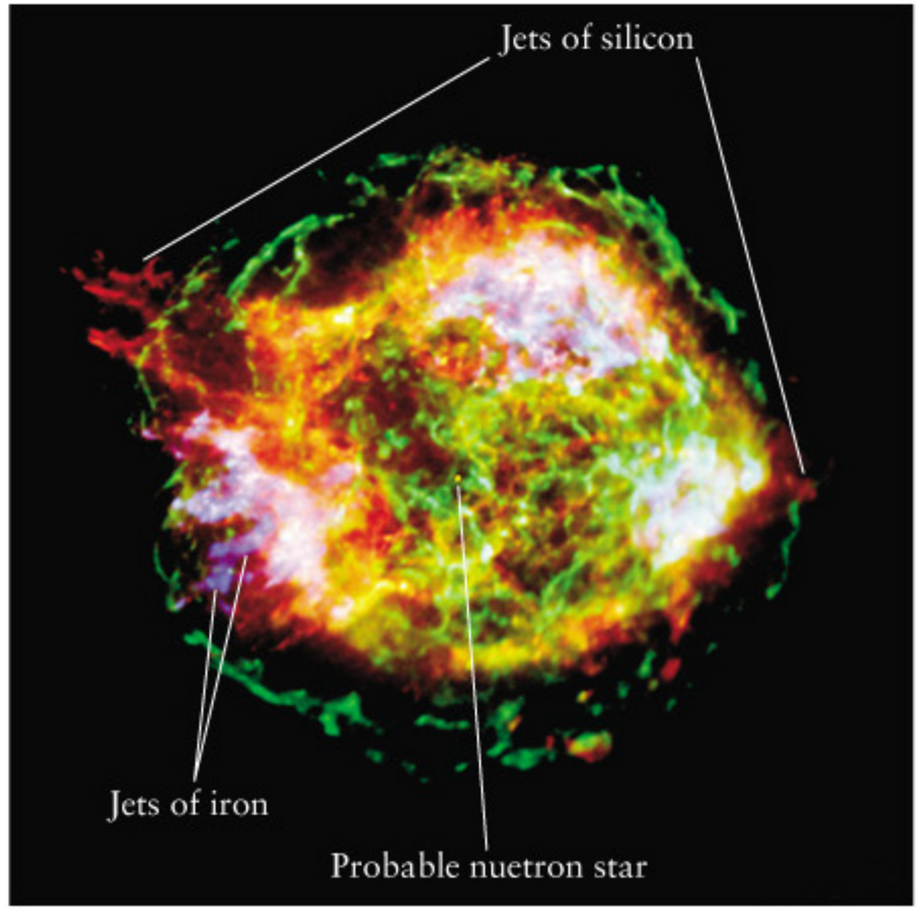
Supernova Debris   SN1987a



a Supernova 1987A seen in 1996

Supernova Debris

Crab Nebula M1
Supernova 1054
(observed by Chinese and Arabs) First neutron star



Cassiopeia A maybe observed in 1680

NEUTRON STARS

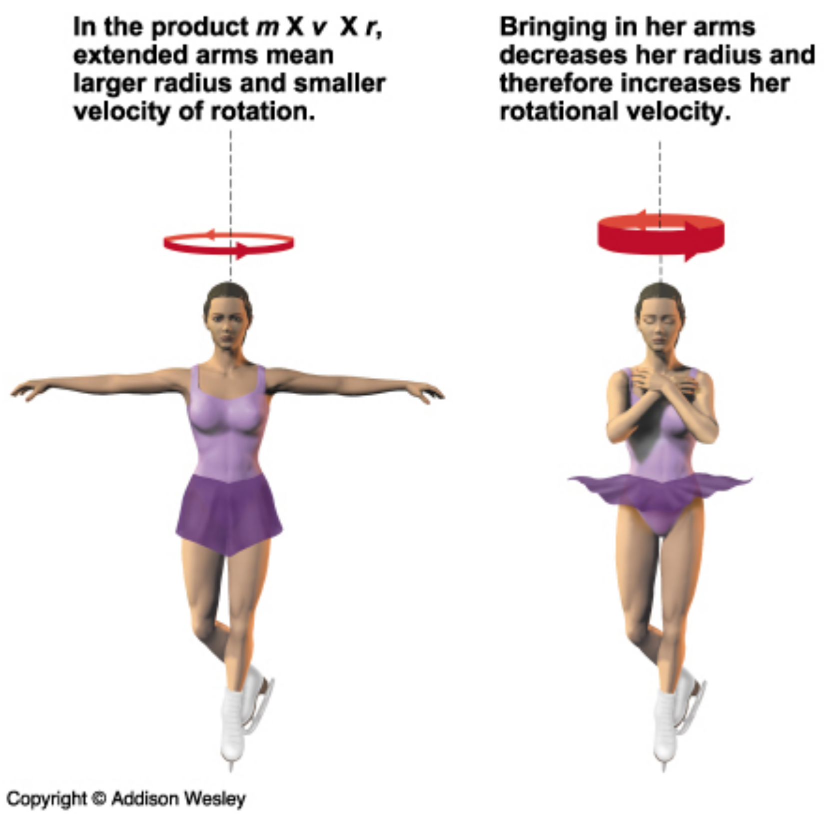
In supernova explosion core collapses

- $e^- + p \rightarrow n + \nu$
- packed neutrons remain giving neutron “star”
- 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

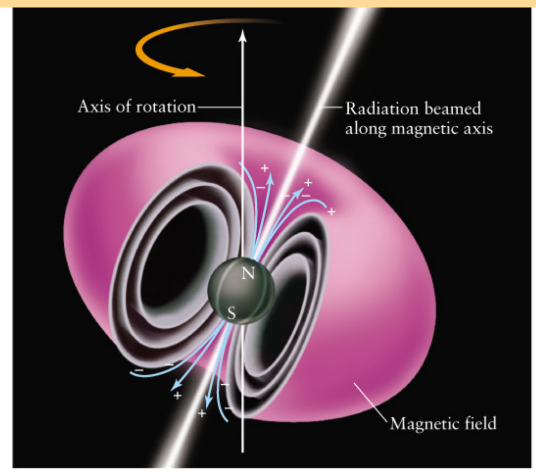
Angular Momentum and Neutron Stars

Angular momentum = MASS x VELOCITY x RADIUS

Decreasing RADIUS increases VELOCITY

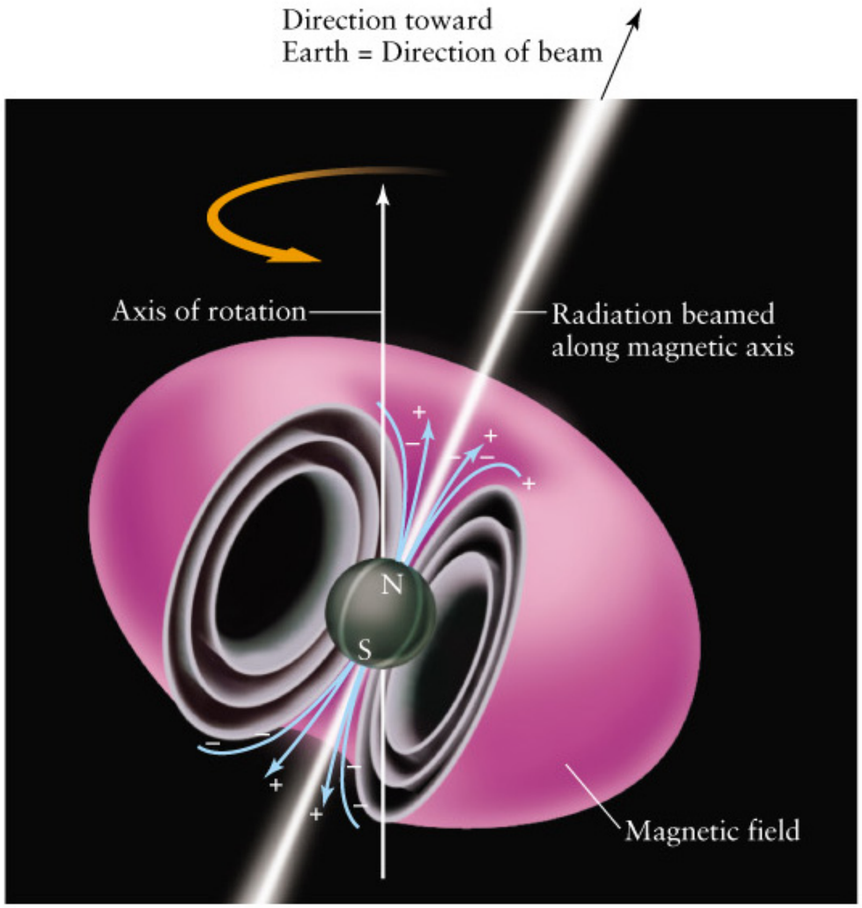


Angular momentum is conserved:
Spinning chair
Ice skater
Formation of neutron star in collapse of larger spinning star

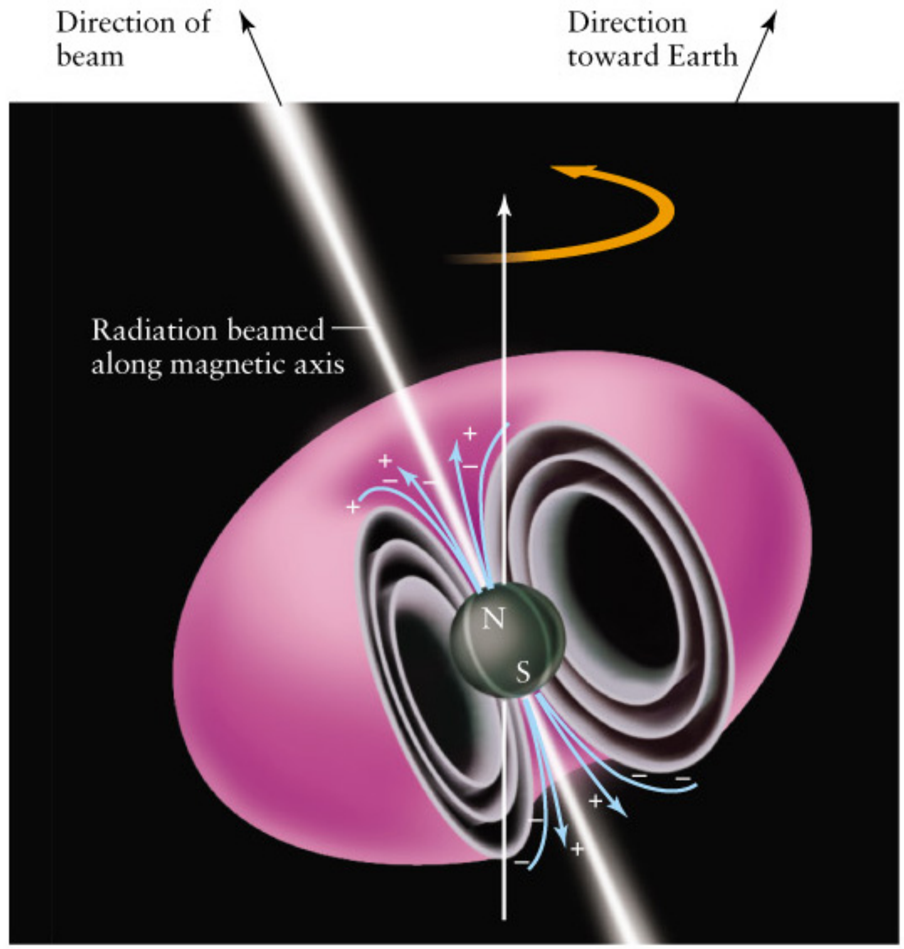


a One of the beams from the rotating neutron star is aimed toward Earth: We detect a pulse of radiation.

Rotating Neutron Star



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."

	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.

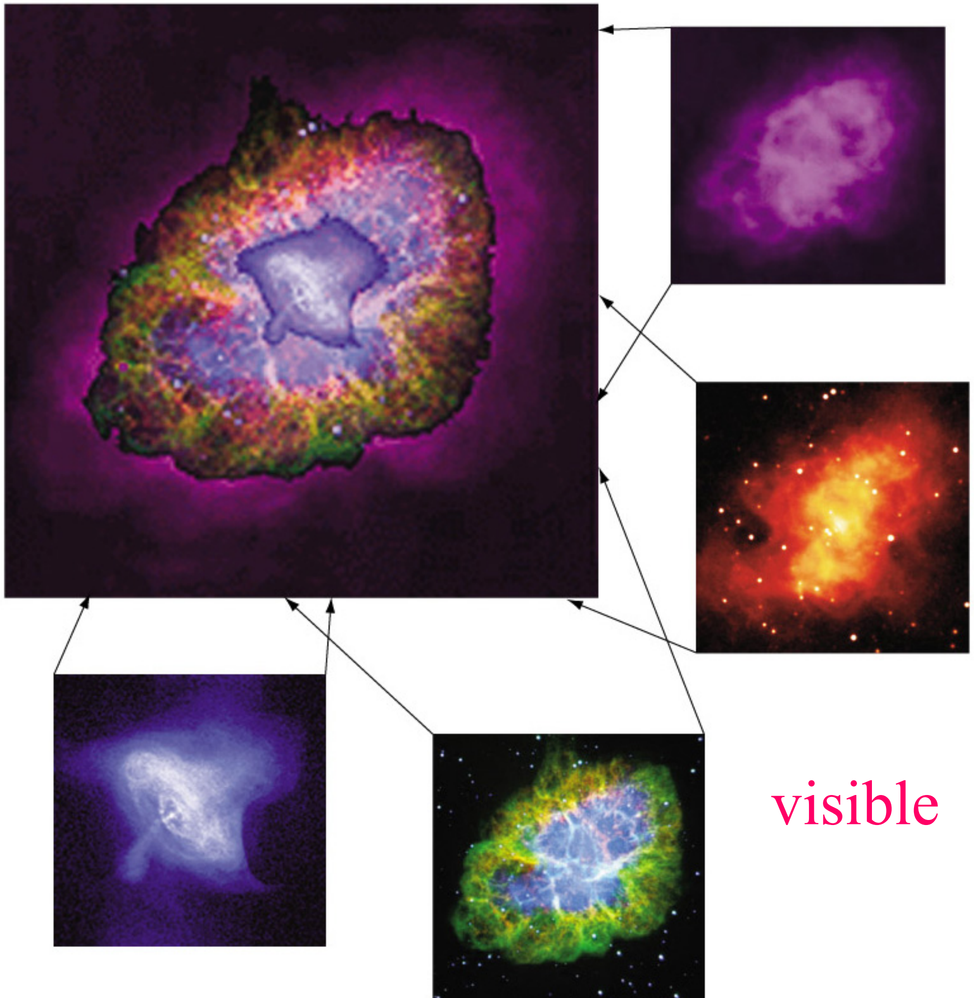
as neutron/electron mass ratio = 2000, neutron star much smaller and denser

Senior level physics classes do the quantum mechanics which predict radius versus mass

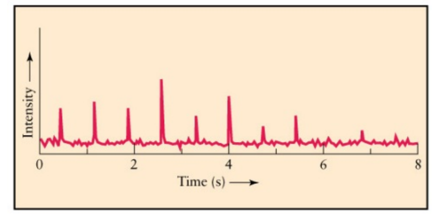
NEUTRON STARS II

- Very large magnetic fields
- Spin rapidly as small. Large range from >100 Hz to less than 1 Hz
- EM radiation from protons and electrons (have about one p or e for every 100 n)
- Observe as repeating flashes of light called PULSARS and are seen in debris of known supernova explosions
- Discovered in 1967 by grad student Jocelyn Bell. Her advisor Anthony Hewitt won Nobel prize. Found in Crab Nebula which was known to be where Chinese had recorded a supernova in 1054. First called LGM for "little green men"

Crab Nebula



radio



infrared

visible

a

X-ray

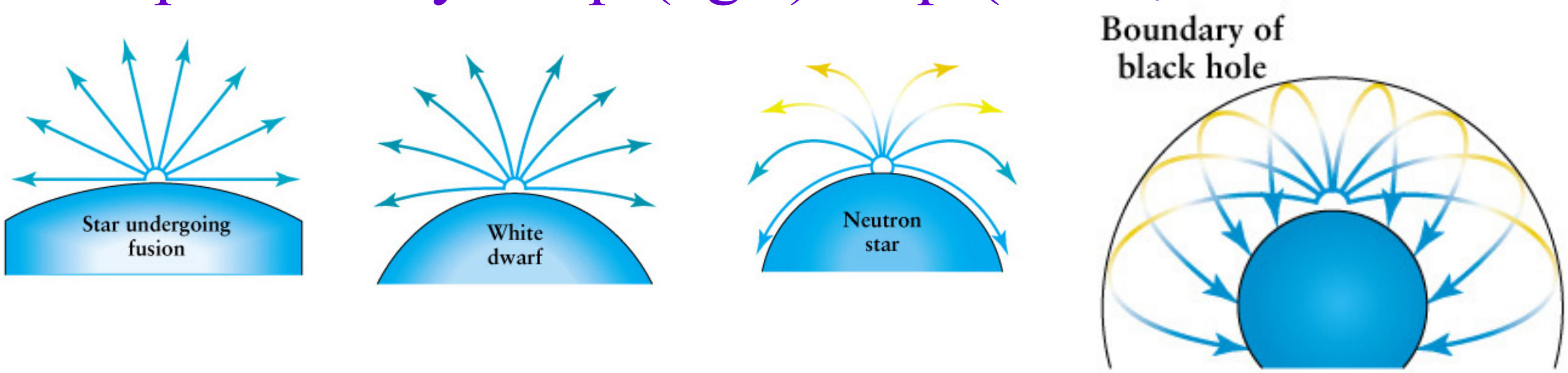
period = 30 Hz or 0.033 sec and can be “seen” in visible and X-ray

Surface Gravity

- $g = M/R^2$
- 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

BLACK HOLES

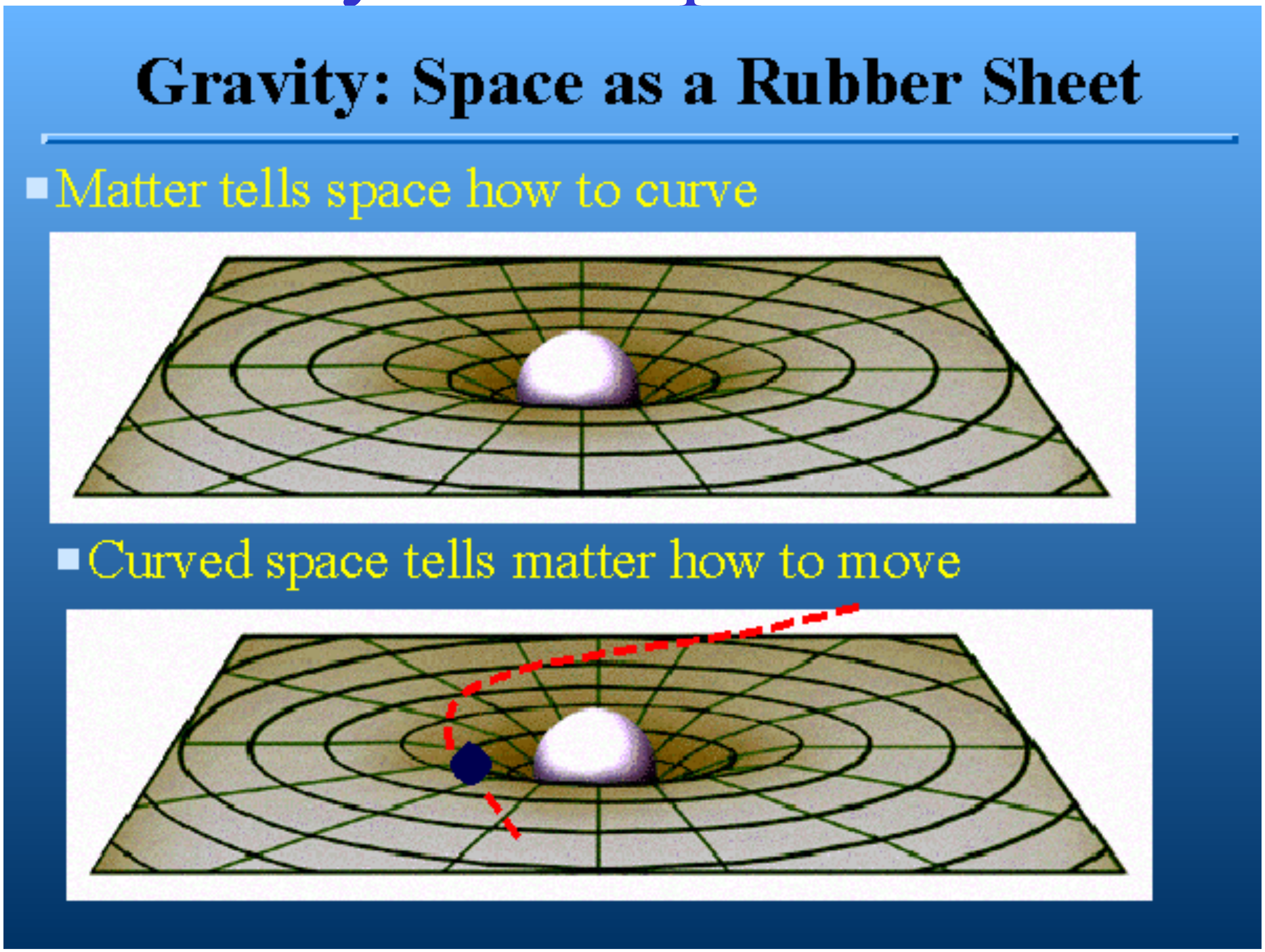
- Very small radius with mass >3x Mass(Sun) (and can be much, much more massive)
- So much gravitational force that not even light can escape --- escape velocity is greater than the speed of light
- Escape velocity = sqrt(2gR) =sqrt(2GM)/R



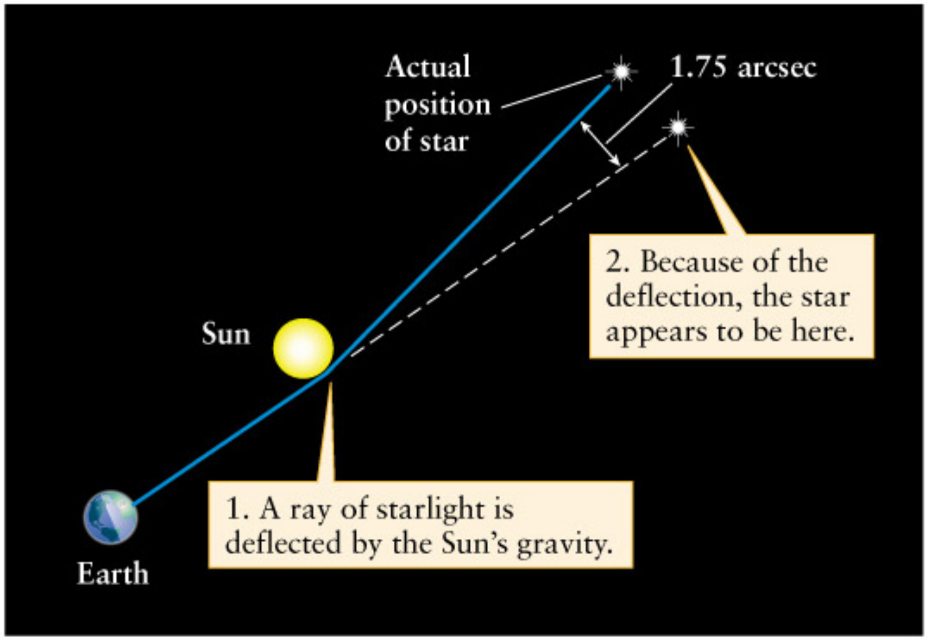
BLACK HOLES II

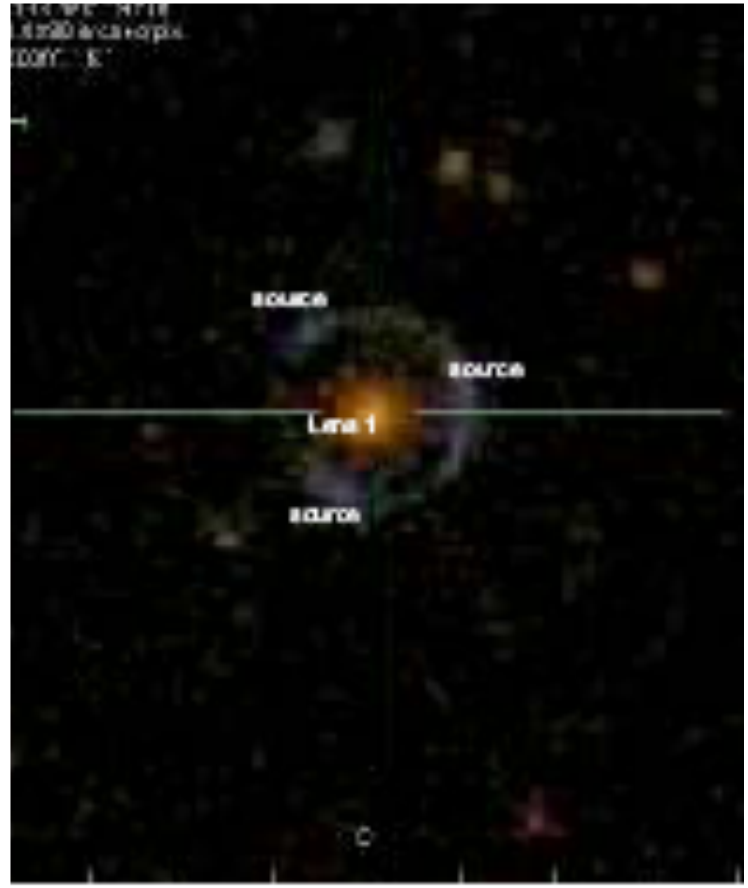
- Clearly "normal" matter can't escape surface but why light??
- Classical (Newton) gravity has force = Gm_1m_2/r^2. As mass(photon) = 0, and photon=light, then gravity should not effect
- But Einstein (in General Relativity) showed that light can be bent by large gravitational fields
- photons travel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

Gravity bends space-time



Gravity bends space-time



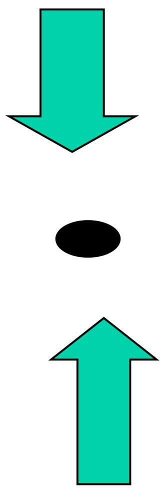


Einstein lens. Galaxy bends light from another galaxy further away (NIU student Donna Kubik thesis)

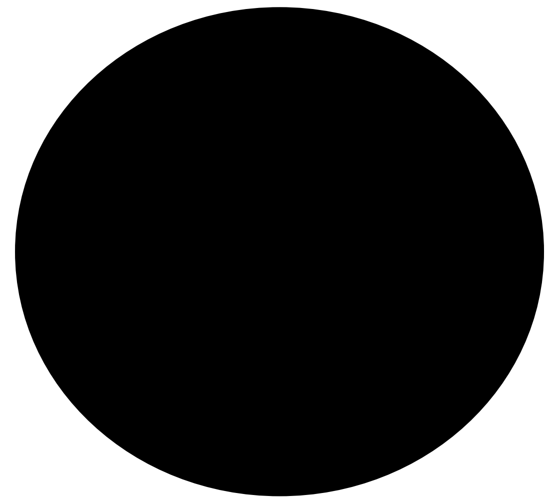
"Gravitational Lensing"

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 causing it to grow (and grow and grow)

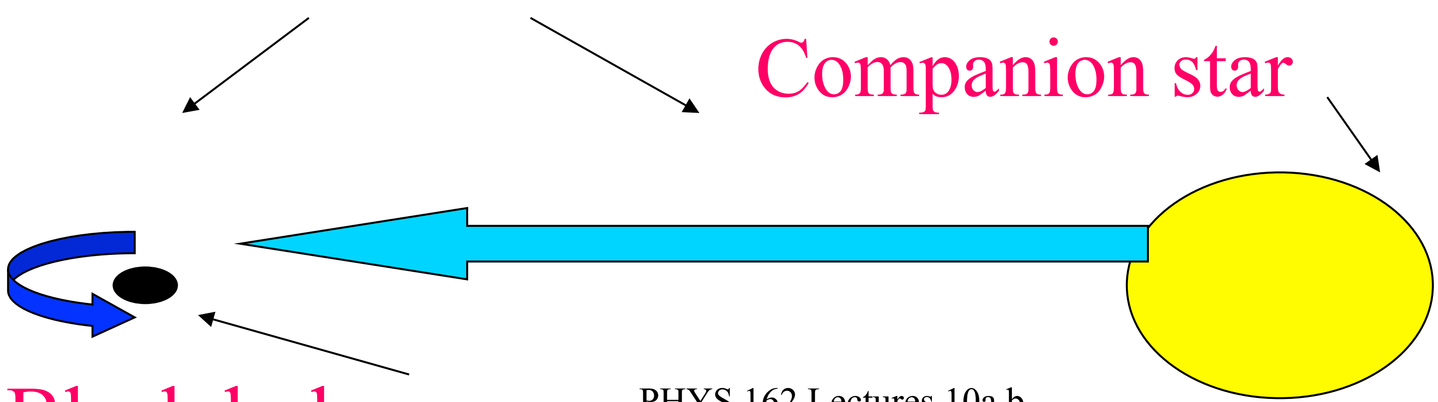


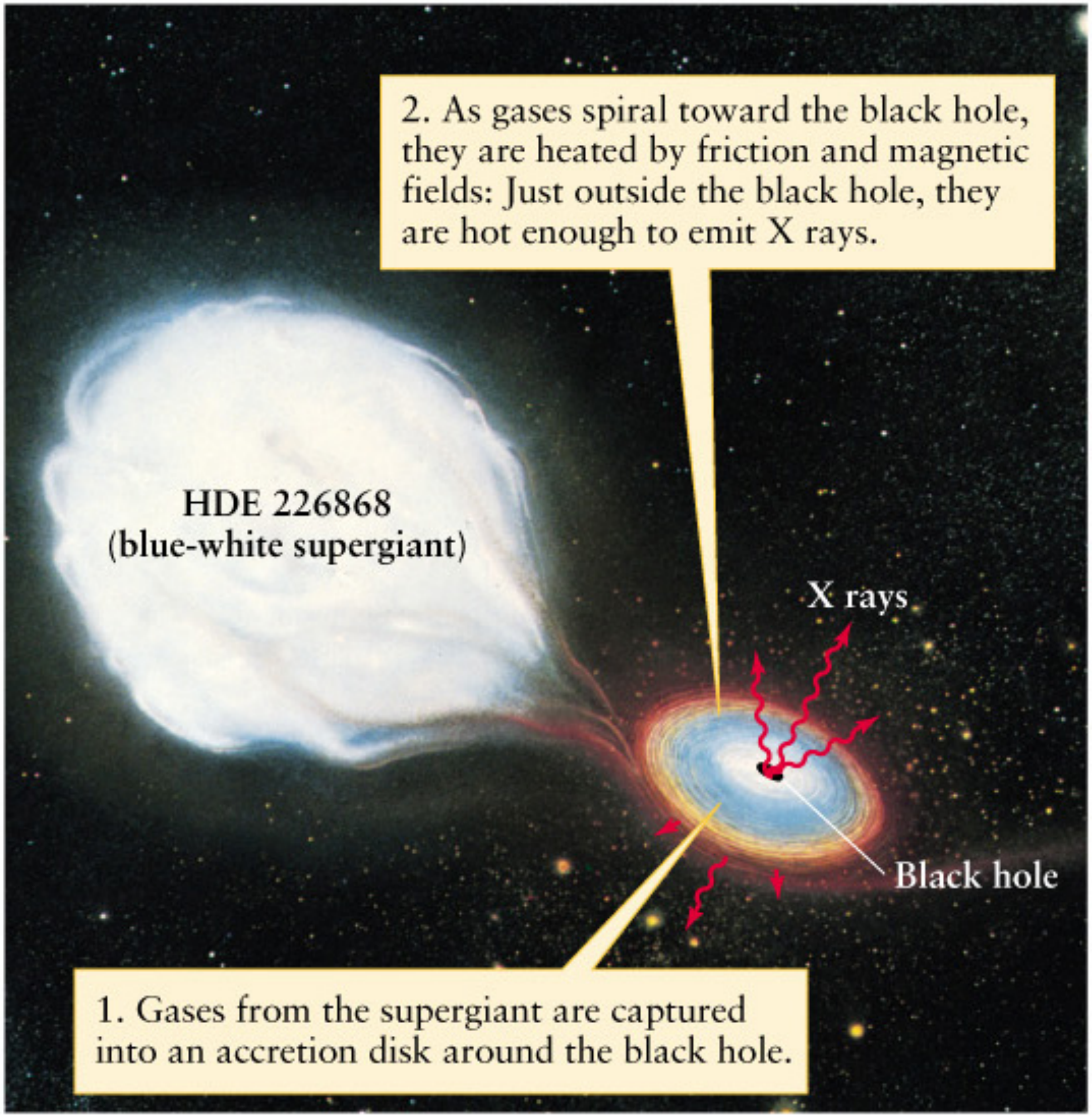
Millions (billions) of years later

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)
- Look for Hawking radiation --- never been observed by proposed e+e- pair production on edge of black hole (black hole evaporation)



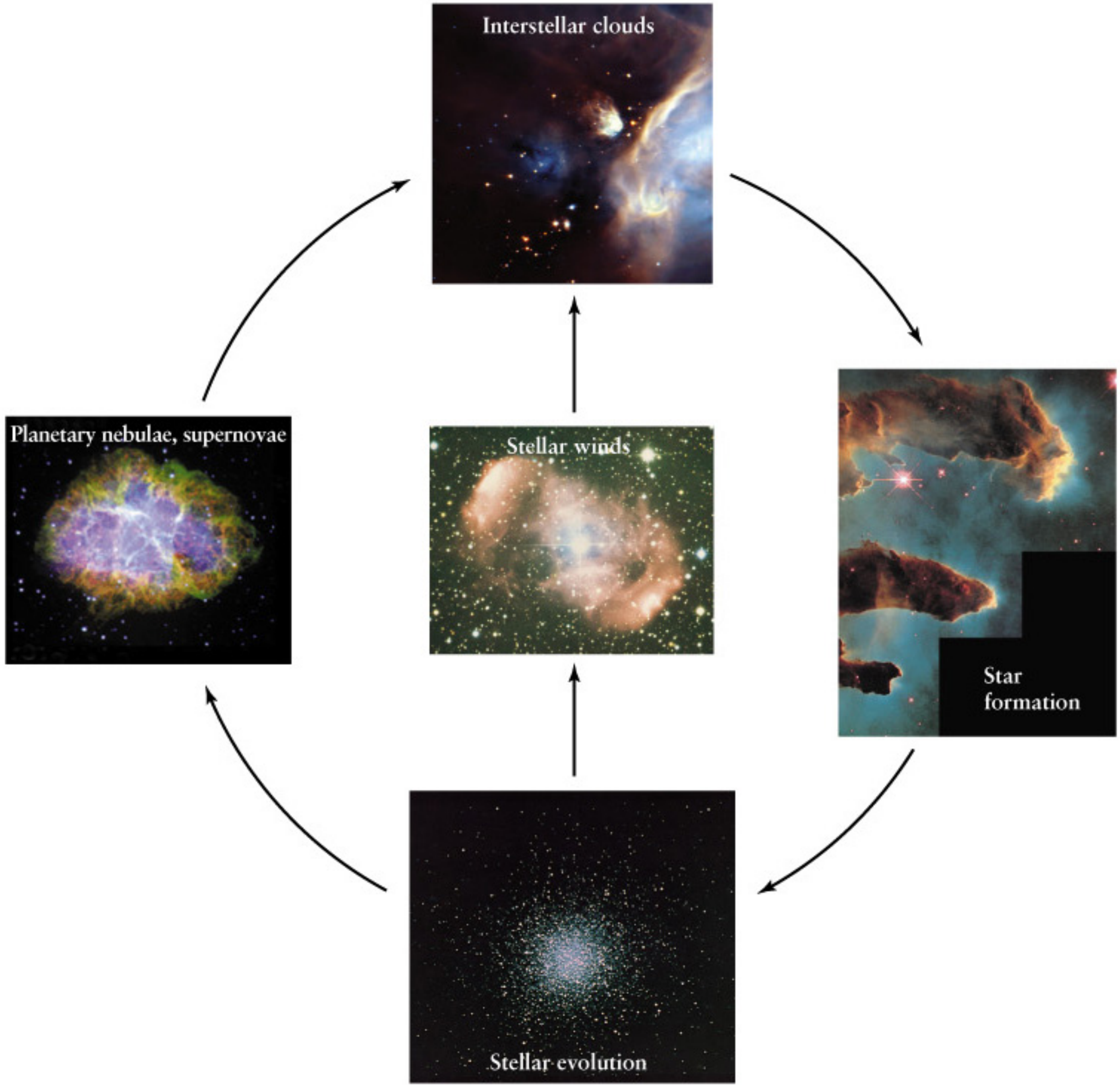

2. As gases spiral toward the black hole, they are heated by friction and magnetic fields: Just outside the black hole, they are hot enough to emit X rays.
HDE 226868
(blue-white supergiant)
X rays
Black hole
1. Gases from the supergiant are captured into an accretion disk around the black hole.

BLACK HOLES IV

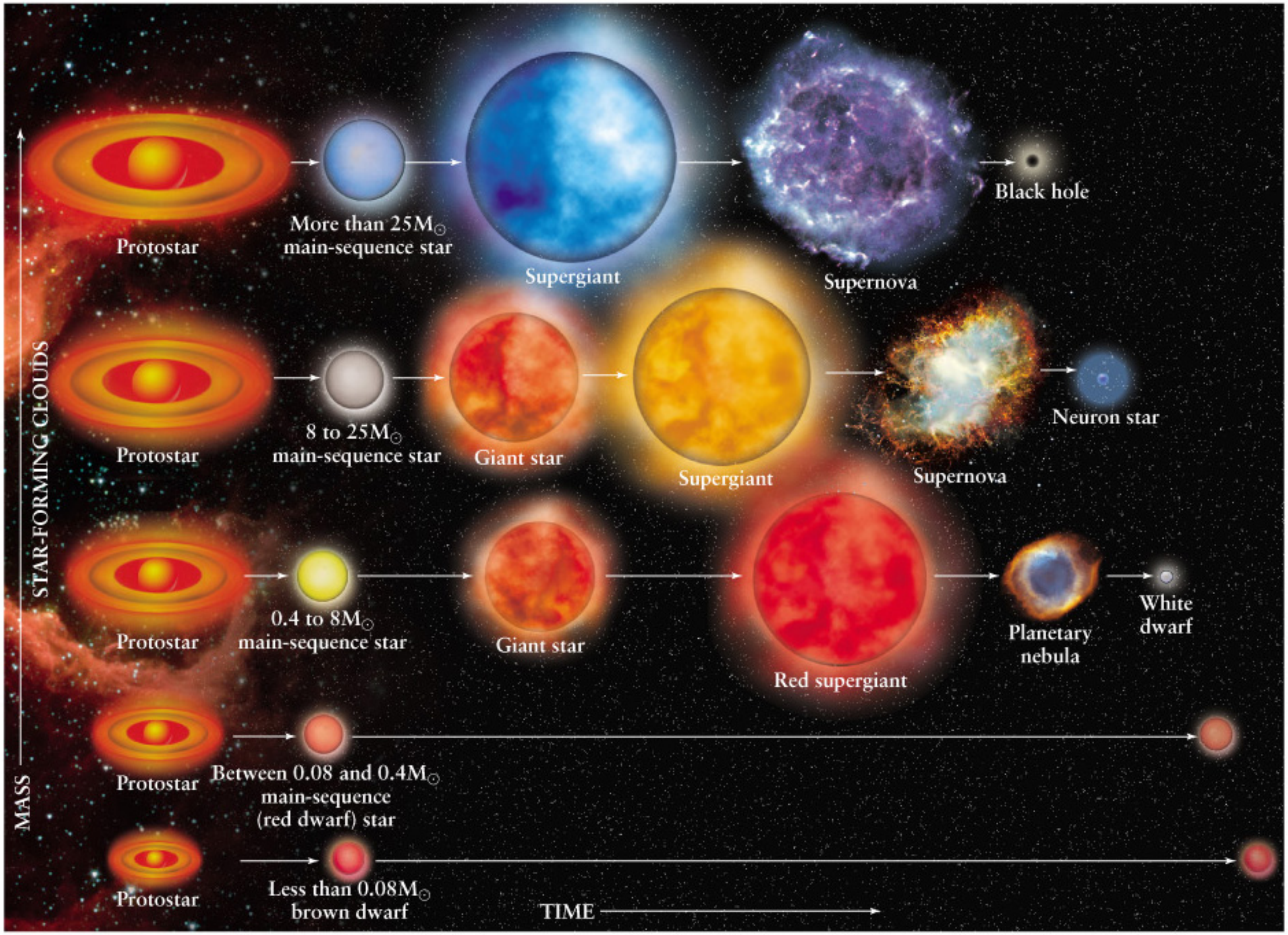
- Perhaps new physics but lack quantum theory of gravity. Items like wormholes, breaks/tunnels in space-time, other dimensions….

- Finally: Mythology that BH move through space “destroying” planets, stars, etc-- force due to gravity same as normal star of same mass

Star Life Cycles

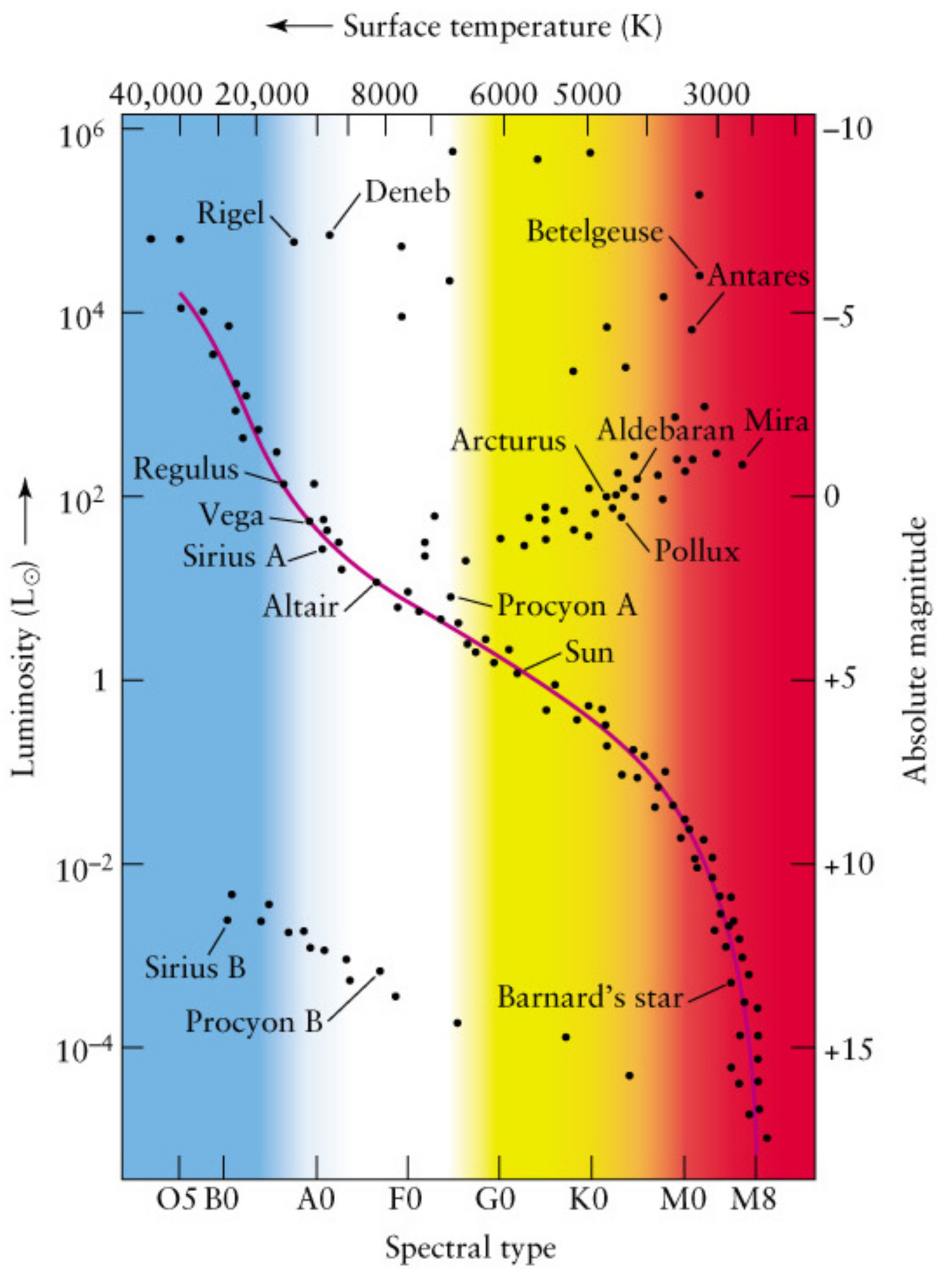


Star Life Cycles - Summary



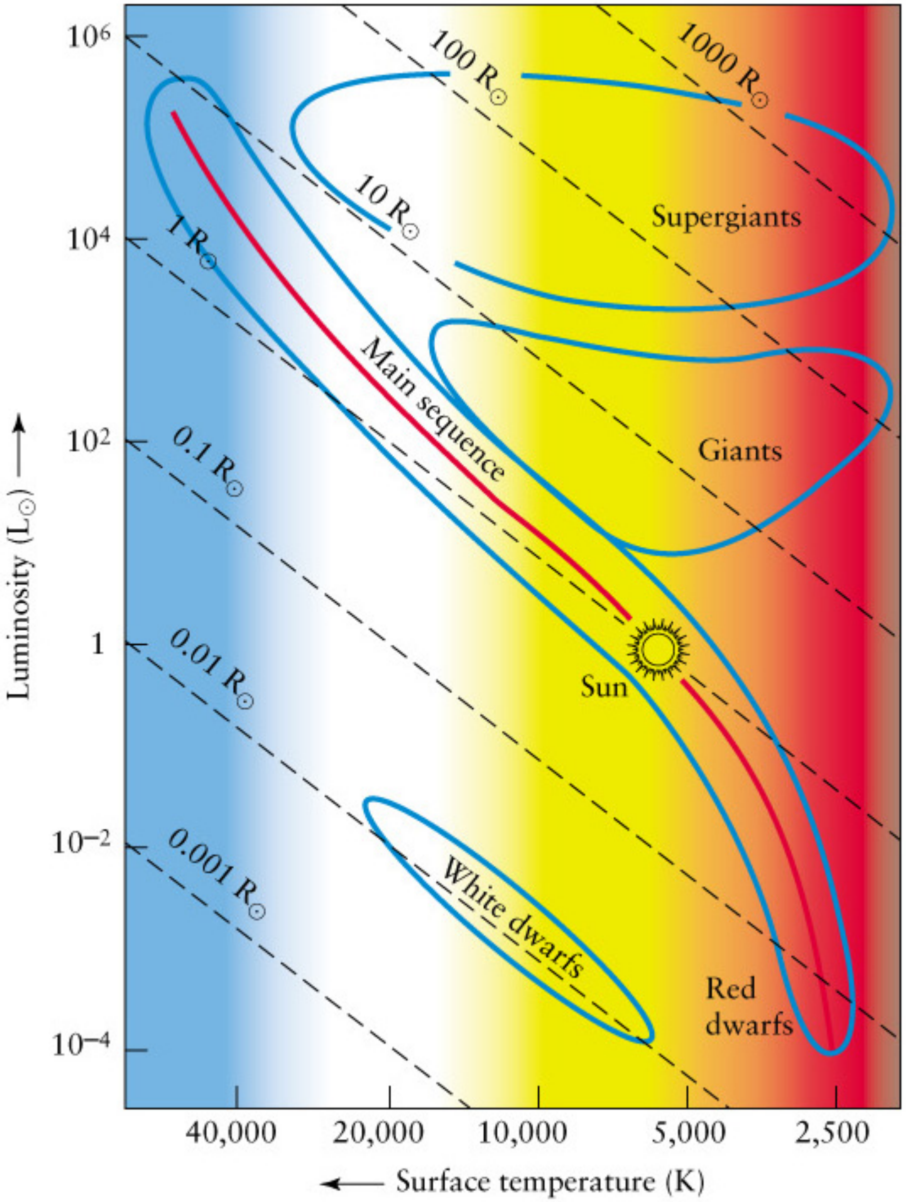
Test 2 Study Guide

- How to measure distances to stars (1) helio-centric parallax and (2) spectroscopic parallax
- Hertzprung-Russell diagram identifiers (main sequence, red giant, white dwarf)
- luminosity vs radius vs surface temperature for stars
- star clusters and how they are used to study star aging
- steps leading from gas cloud to main sequence star
- steps leading from Red giant to supernova (or white dwarf to SN)
- difference between white dwarf, neutron star, black hole
- four forces and examples from star's lifecycle: gravity pulls material in raising temperature allows fusion to start. Electric force resists gravity and causes light to be emitted. Strong nuclear force causes fusion to release energy. Weak nuclear force involved in some fusion reaction and aids in core collapse and neutron star formation



REMINDER Hertzprung-Russell Diagram

Plot Luminosity versus surface temperature



Hertzprung-Russell Diagram

Stars with larger sizes are brighter then a smaller star with the same surface temperature