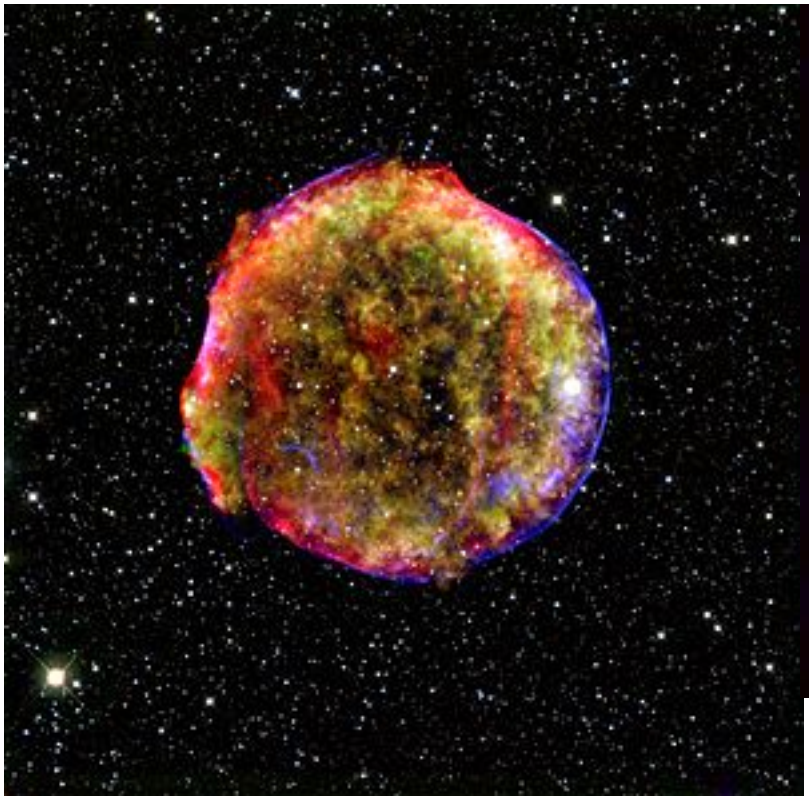
Supernovas

- 10-20 supernovas occur every1000 years in a galaxy the size of the Milky Way (~200 billion stars) with ~15% being type Ia
- 8 observed in last 2000 years (185, 386, 393, 1006, 1054, 1181, 1572, 1604)
- Hard to observe if on "opposite" side of Milky Way → all recent observed SN are in other galaxies

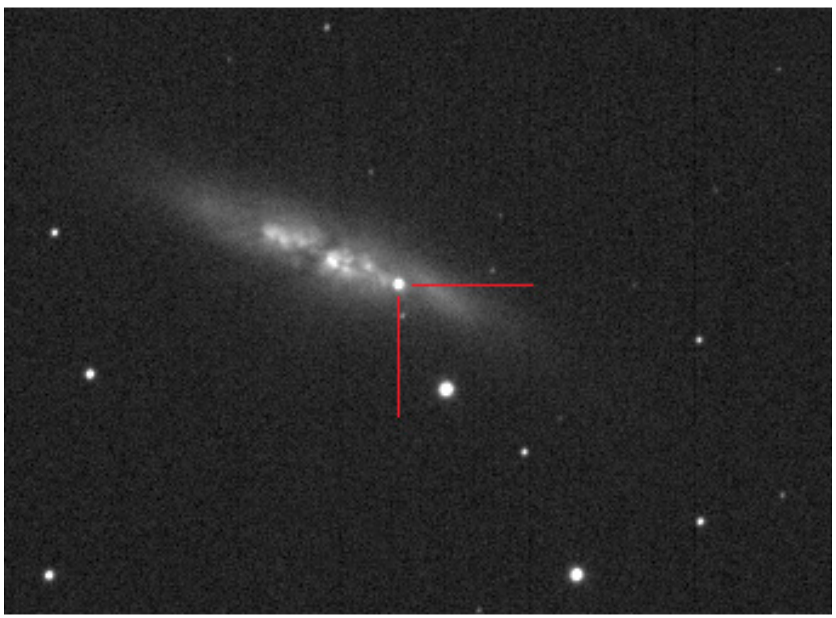
1572 (Tycho Brahe) and 1604 (Kepler)

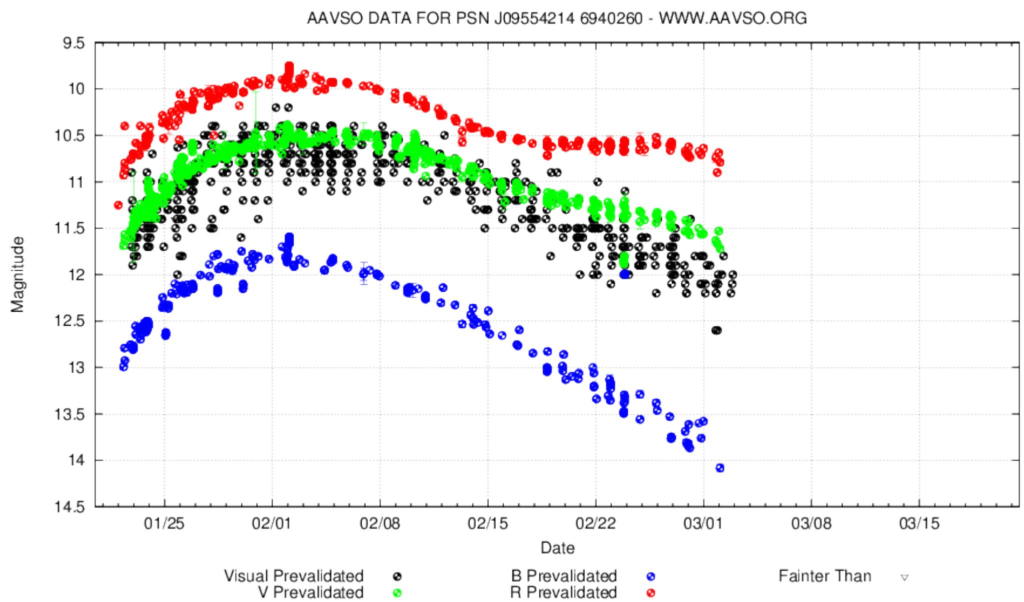
In Milky Way both probably Type Ia



Supernova 2014j – Jan 2014

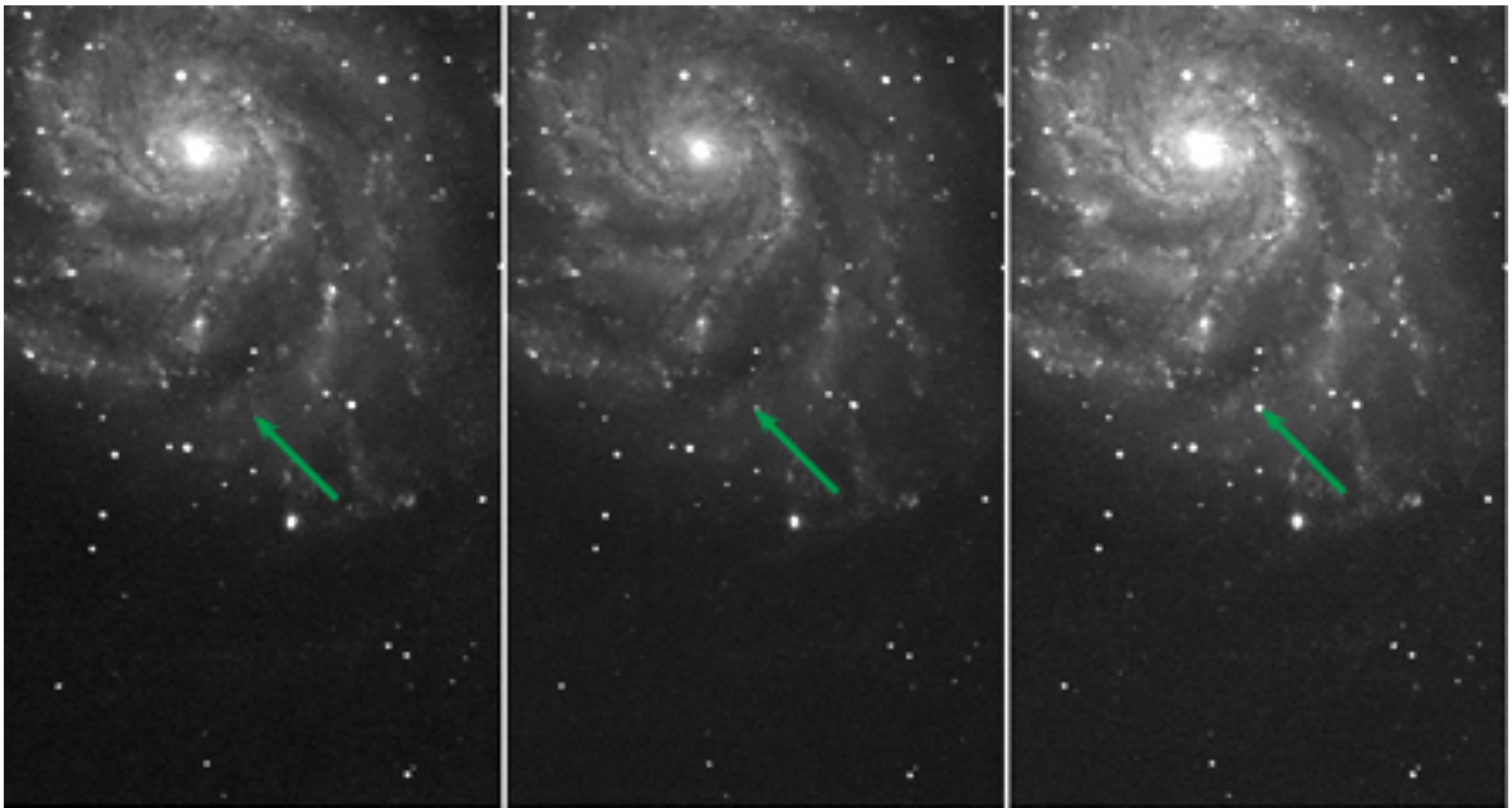
In M82 (Ursa Major). Type Ia. Closest of this type observed in modern times. 11.5 million LY away. Discovered at undergrad session Univ Coll London (SN1972 e was 11 MLY but pre "modern")





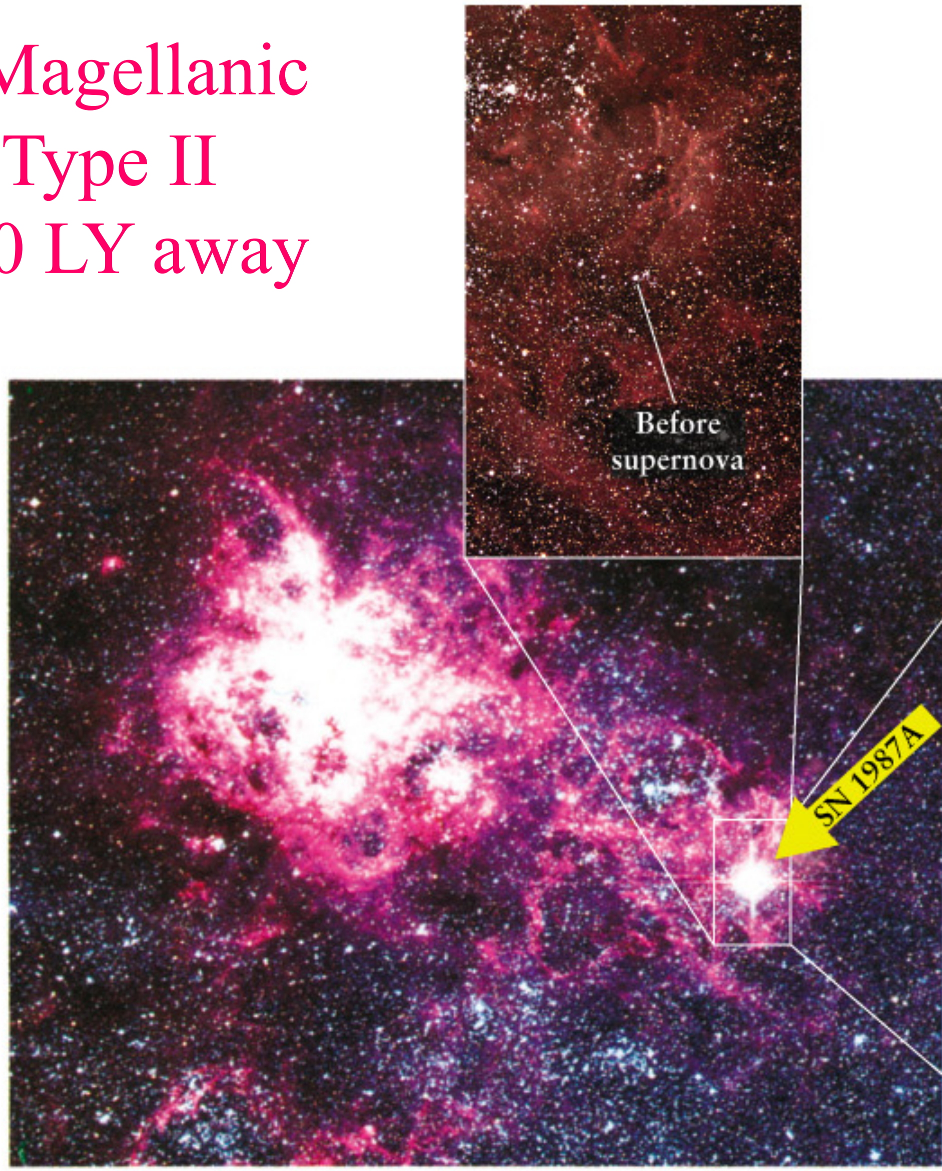
Supernova PTF 11kly – Sept 2011

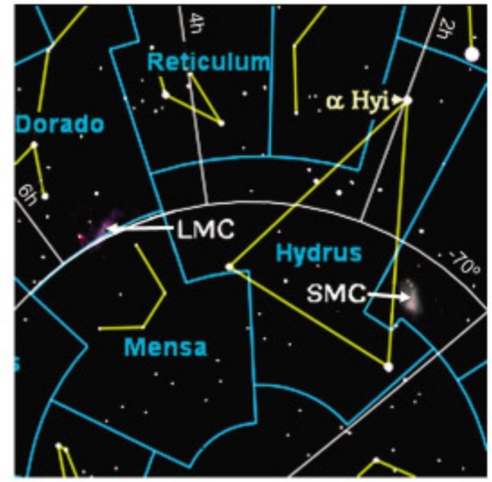
In Pinwheel Galaxy. Type Ia. 2nd closest Ia observed in modern times. 21 million LY away



Supernova 1987a (in movie)

Large Magellanic Cloud Type II
180,000 LY away

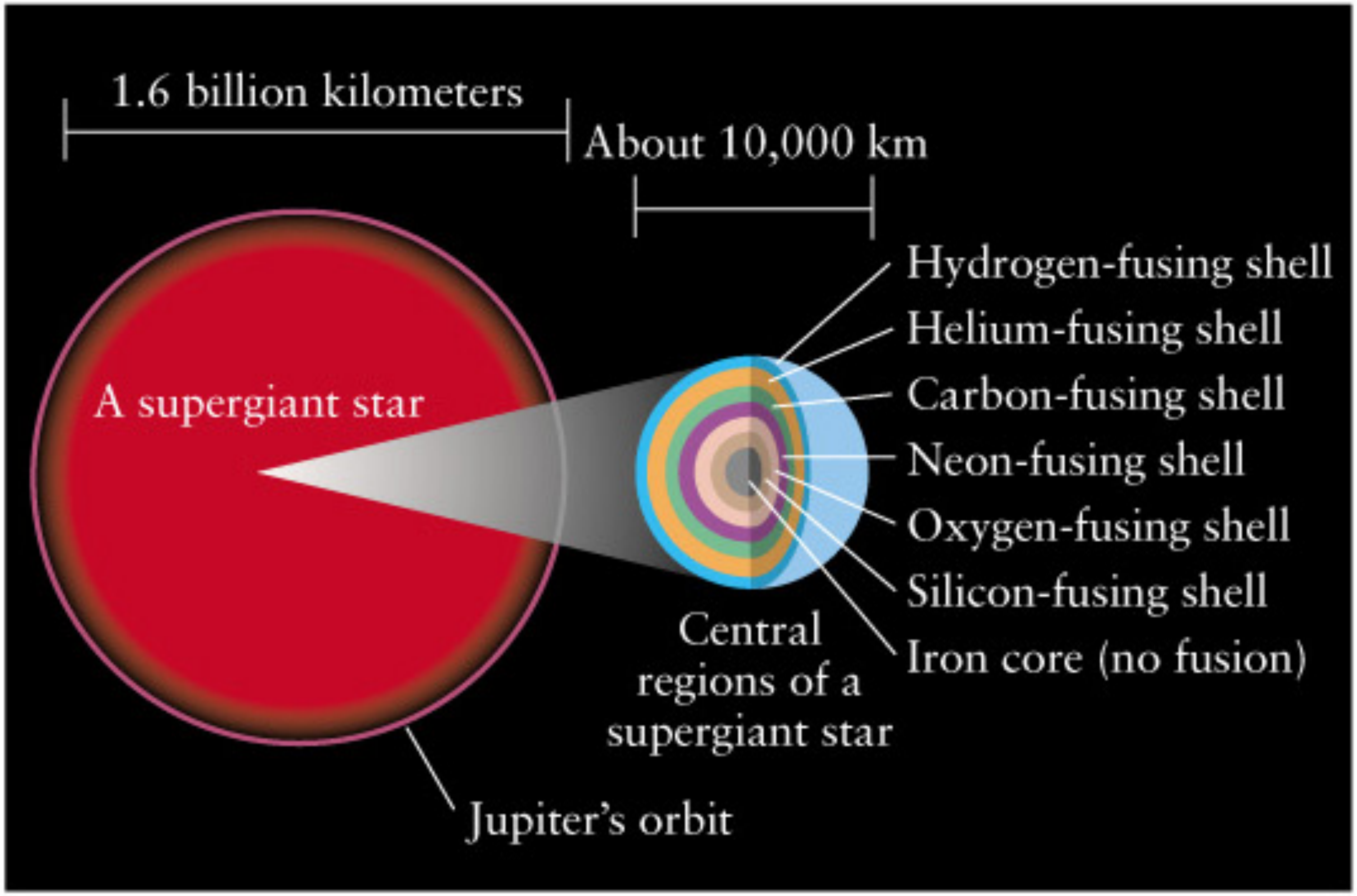




Supernovas and Core Collapse

- Massive stars have fusion to heavier nuclei (Neon, Silicon, Sulpher, etc)
- End up with core of Iron nuclei plus 26 unbound "free" electrons for every Fe
- Electrons are "degenerate" as so close together. This causes them to provide most of the pressure resisting gravity
- Enormous stress. If electrons "give way" leaves "hole" in center of star

Supergiant → Iron Core



During Supernova

- Core collapse gives 200 billion degrees → energetic photons
- Breaks up many nuclei

  Fe → 26p + 31n O → 8p + 8n
- New nuclei form → photons, n, and p strike shell around core
- p + e → n + neutrino

  1. Burst of neutrinos. 1000 times more energy than from light (photons)

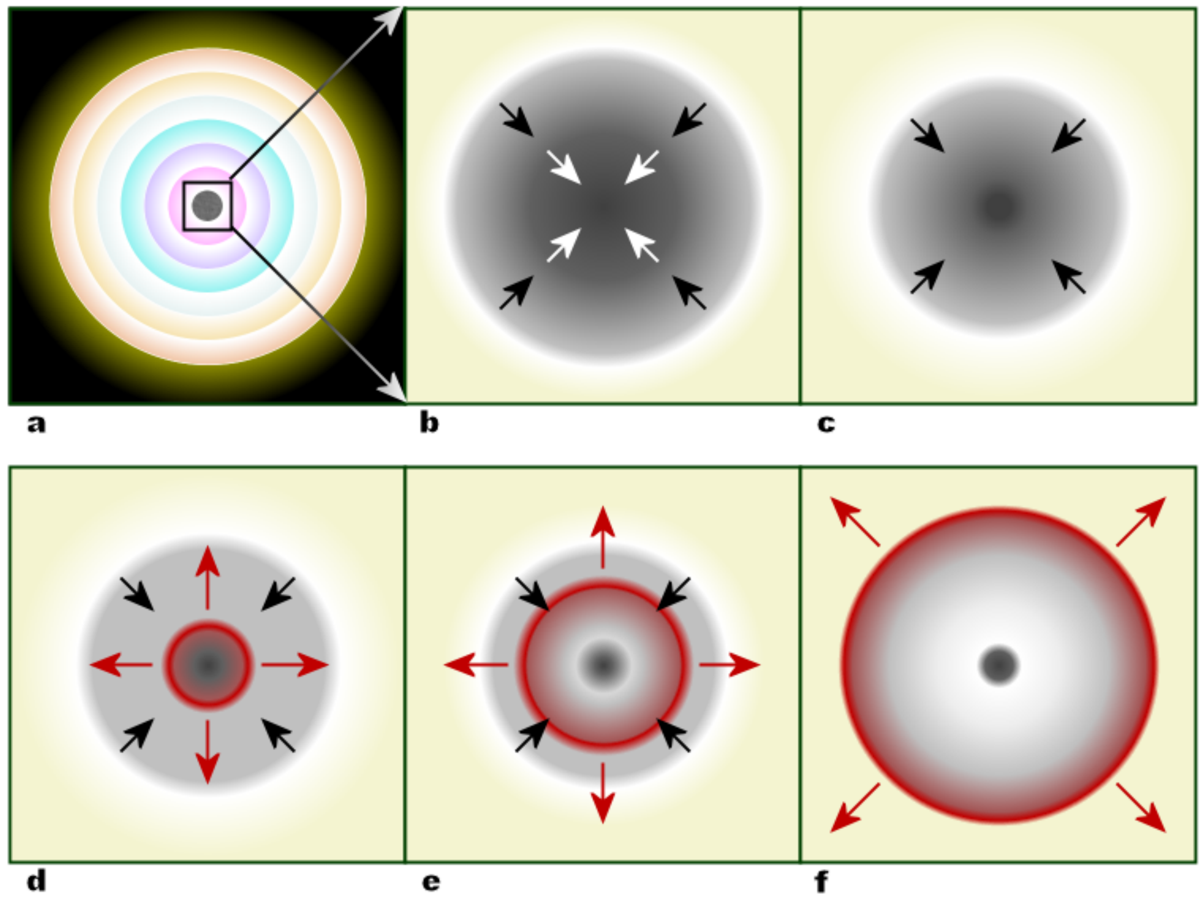
  2. Leftover neutron star

Core Collapse

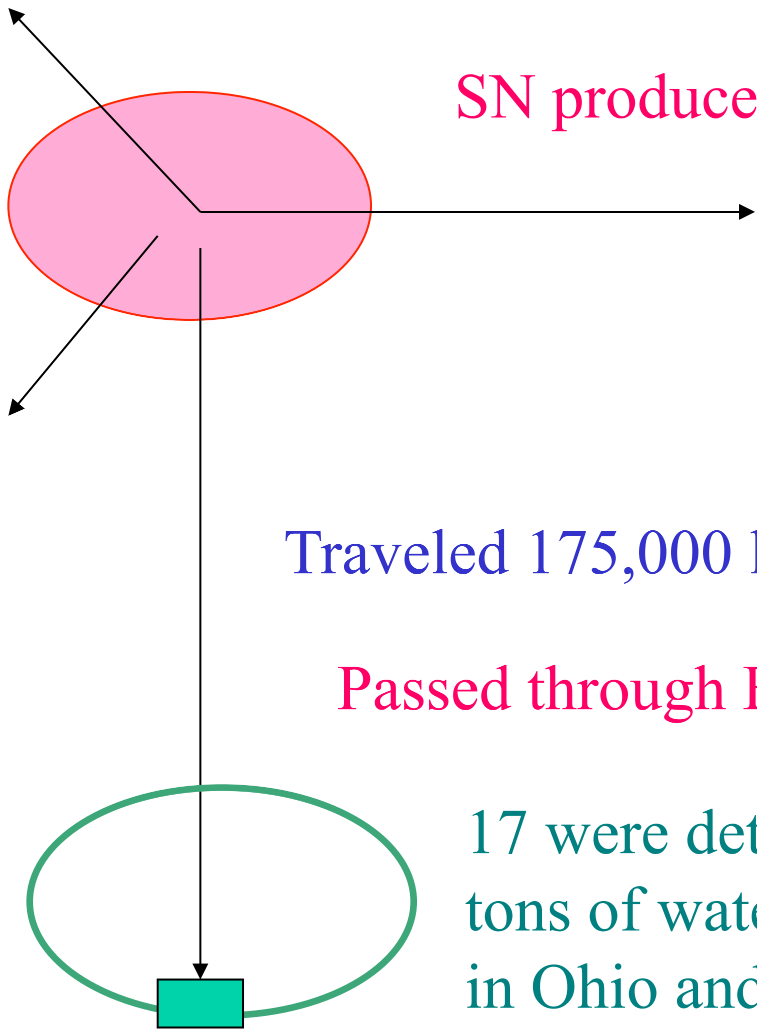
core collapses into mostly neutrons – very hot

outer layers rush into "hole" smashing into shock wave from core

happens when mass of core > 1.4 Mass Sun. Chandrashekar limit



Detection of neutrinos from SN1987A in Japan and Ohio



SN produced 10^{58} neutrinos

10^{15} ν/cm^2 at Earth

10^{18} neutrinos from SN passed through any person's body

Traveled 175,000 light years to Earth

Passed through Earth

17 were detected in detectors made from 100 tons of water located in underground mines in Ohio and Japan

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

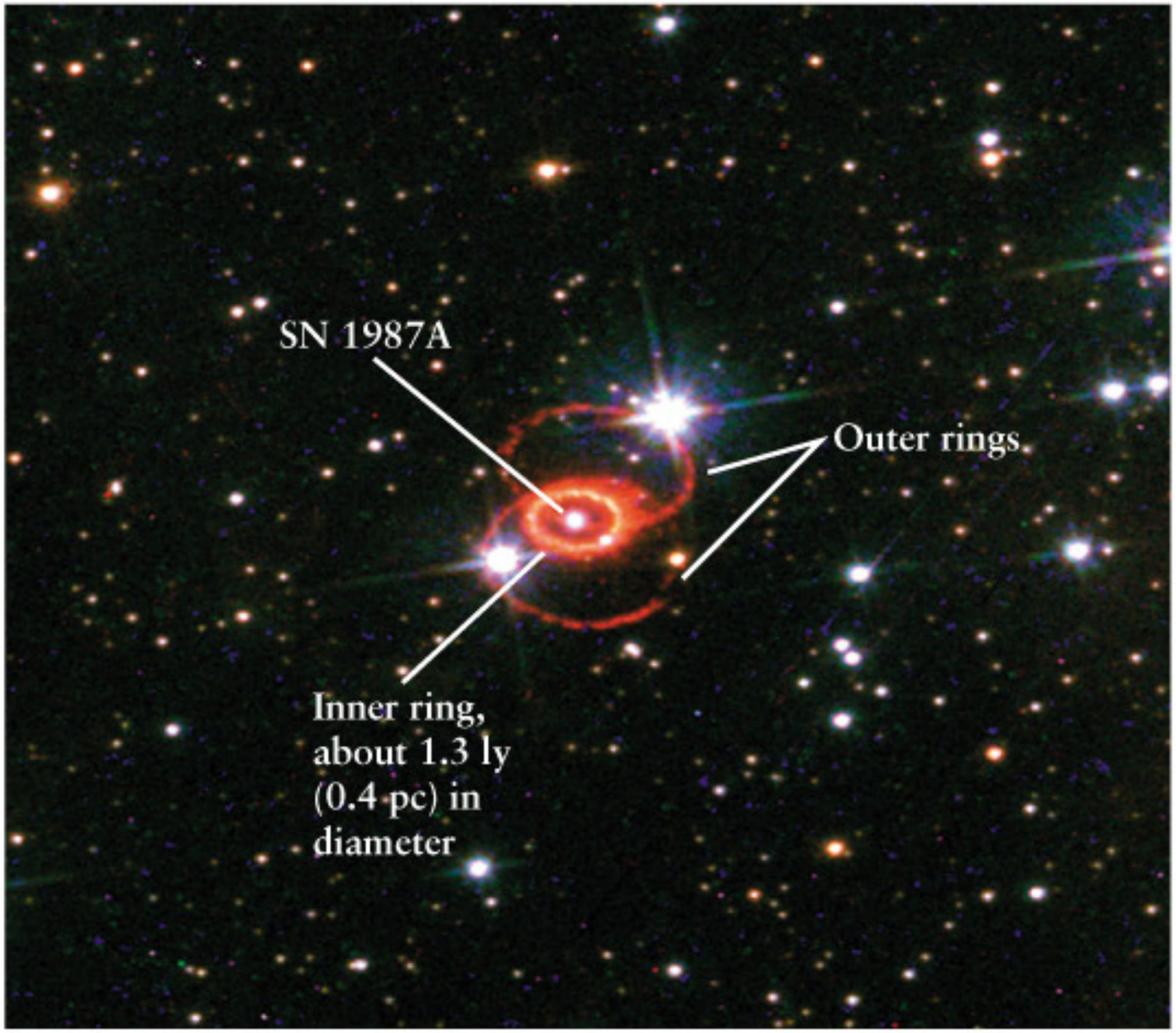
- Stars lose matter at end of life-cycle

  becoming Red Giants (can detect)

  Supernova debris (can detect)

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

Supernova Debris SN1987a

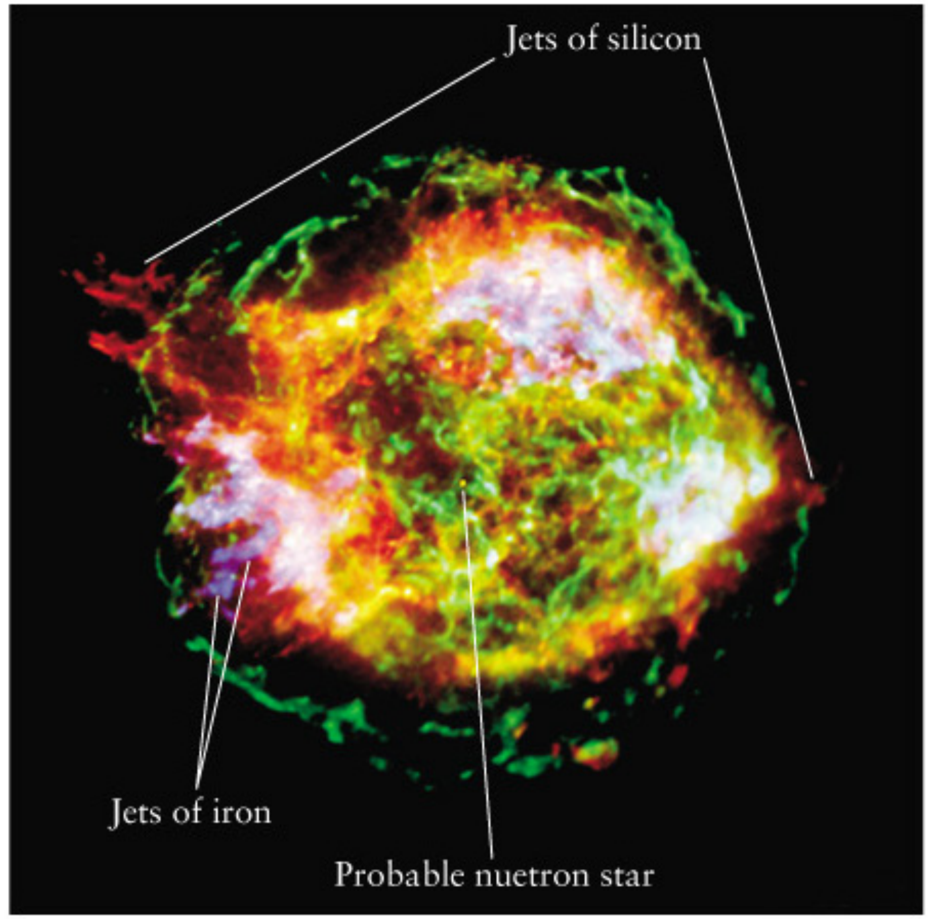


a Supernova 1987A seen in 1996

Supernova Debris

Crab Nebula M1

Supernova 1054 (observed by Chinese and Arabs). Has 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” about 1% protons/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

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

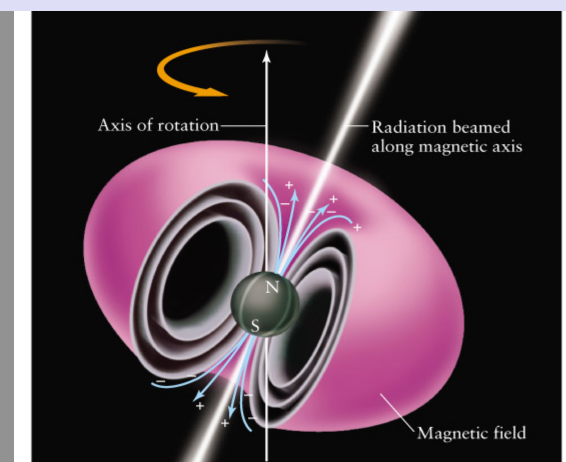
	White Dwarf	Neutron Star
Mass (relative to Sun)	1.0 (always $<$ 1.4)	1.5 (always $<$ 3)
Radius	5000 km	10 km
Density	10^6 g/cm^3	10^{14} g/cm^3

Properties determined by "degenerate" electrons and neutrons.

Angular Momentum + Neutron Stars

Angular momentum = MASS x VELOCITY x RADIUS
decreasing RADIUS increases VELOCITY

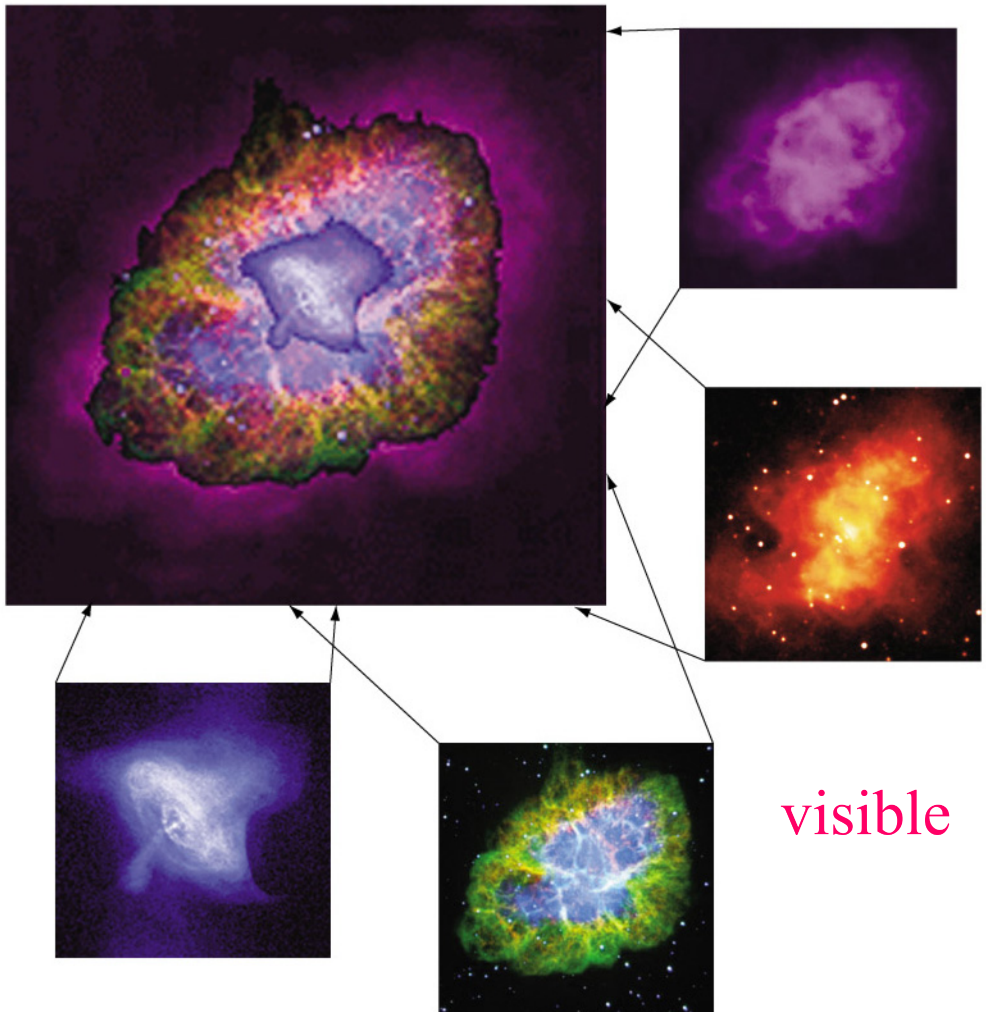
Angular momentum is conserved:
spinning chair
ice skater
formation of neutron star in collapse of larger spinning star



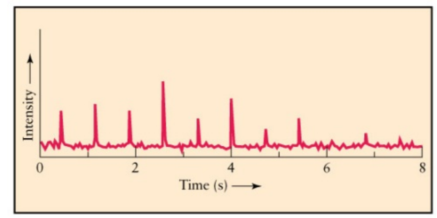
NEUTRON STARS II

- 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 Crab Nebula where Chinese had recorded a supernova in 1054. First called **LGM** for **"little green men"**

Crab Nebula



radio



infrared

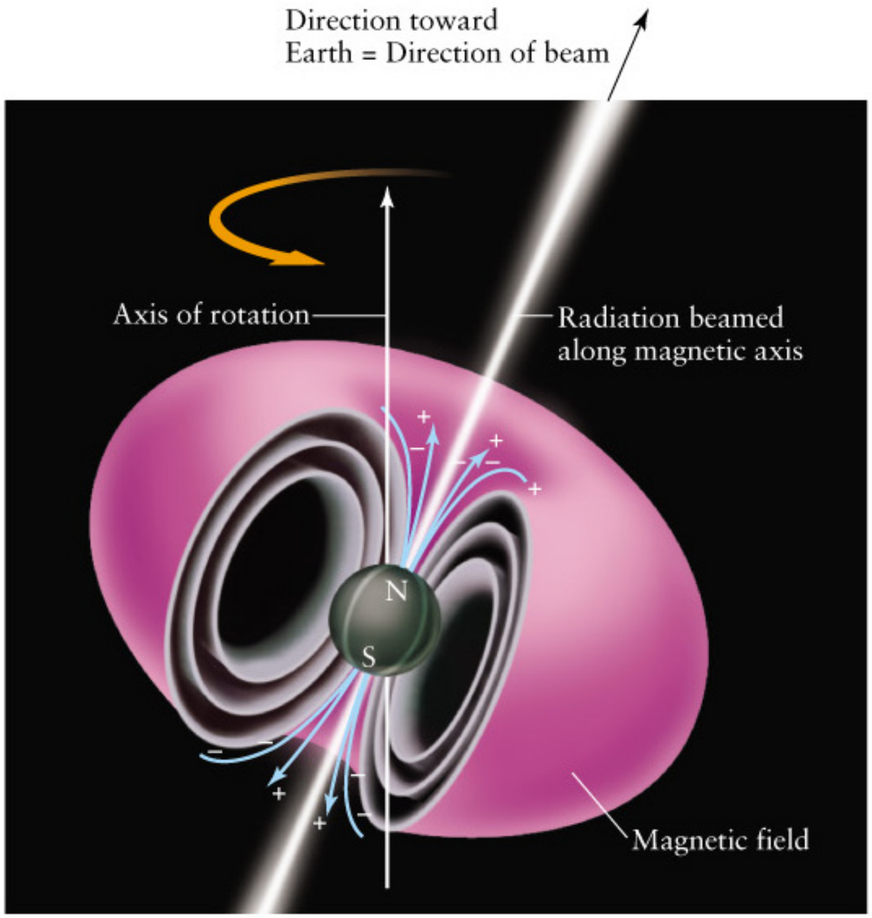
visible

a

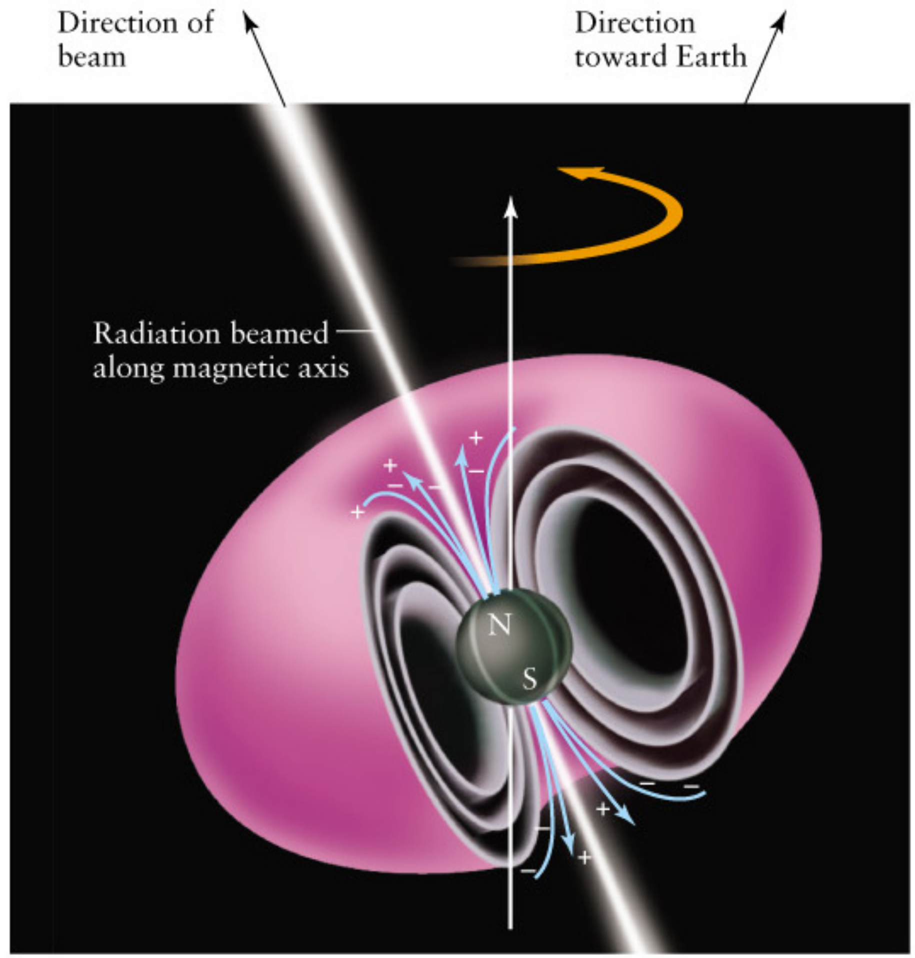
X-ray

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

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.



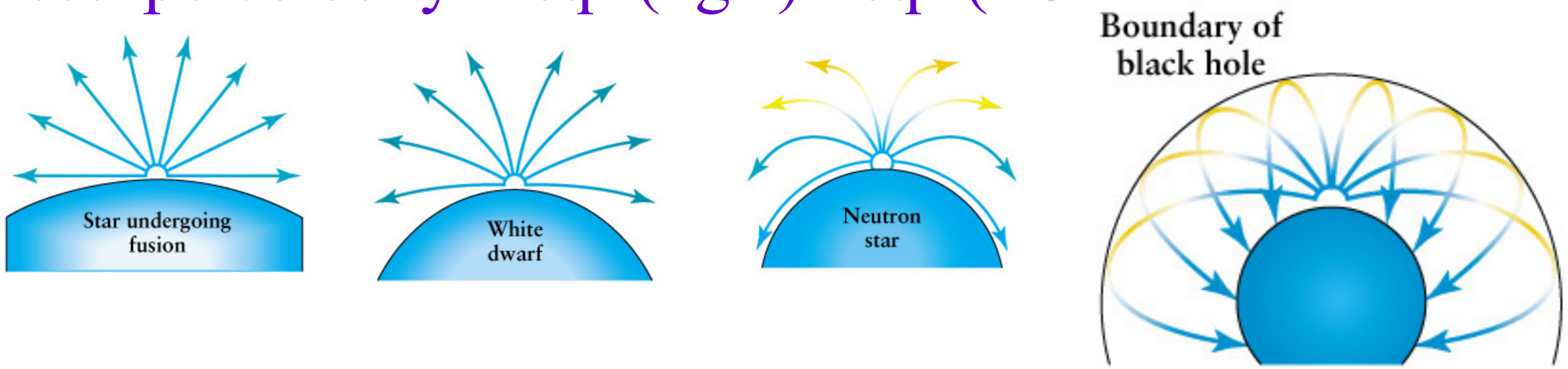
b Half a rotation later, neither beam is aimed toward Earth: We detect that the radiation is "off."

Surface Gravity

- $g = M/R^2$
- 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

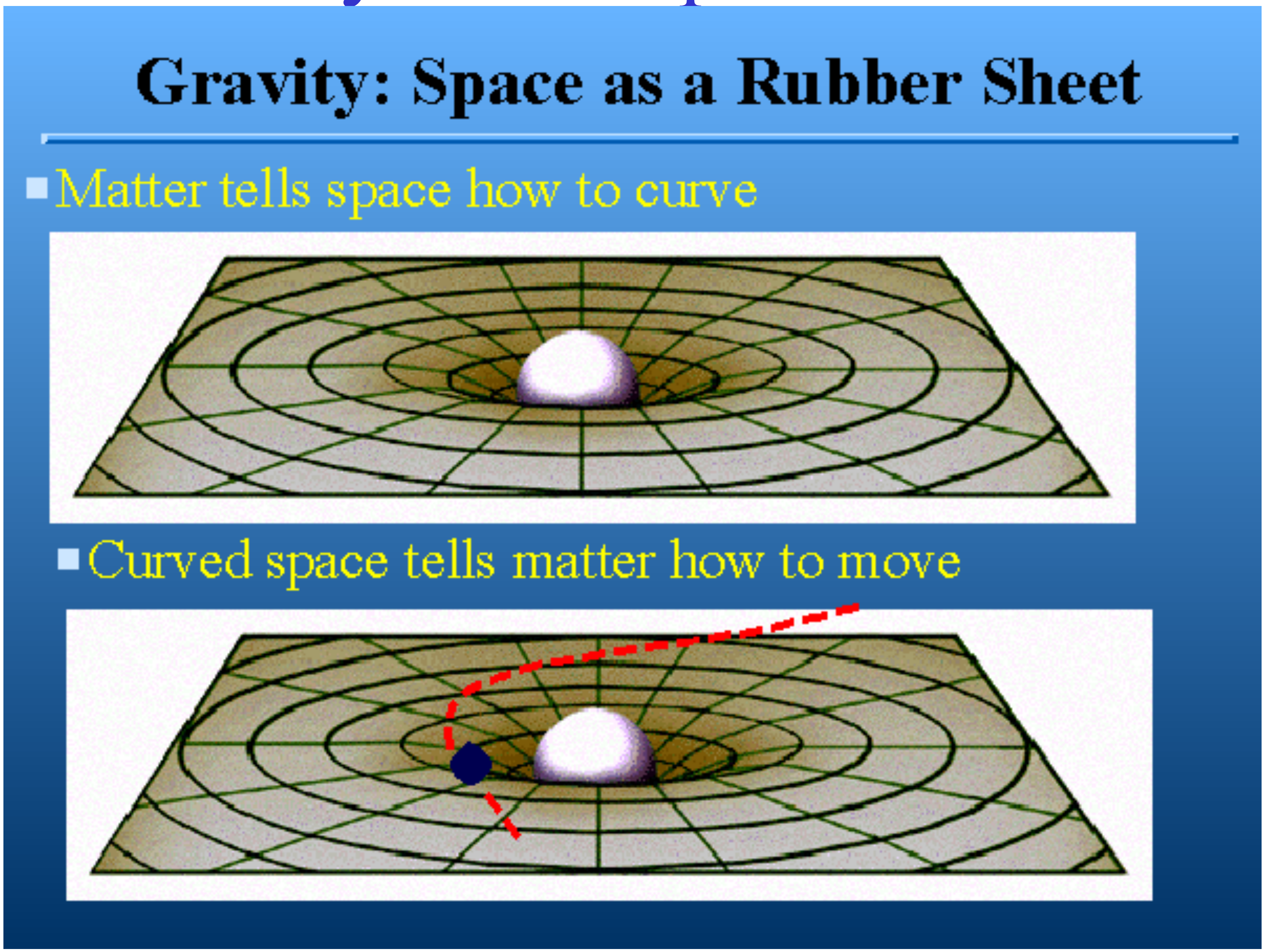
- very small radius with mass >3x Mass(Sun) (and can be much, much more massive)
- so much gravitational force that not even light can escape --- escape velocity is greater than the speed of light
- escape velocity = sqrt(2gR) =sqrt(2GM)/R



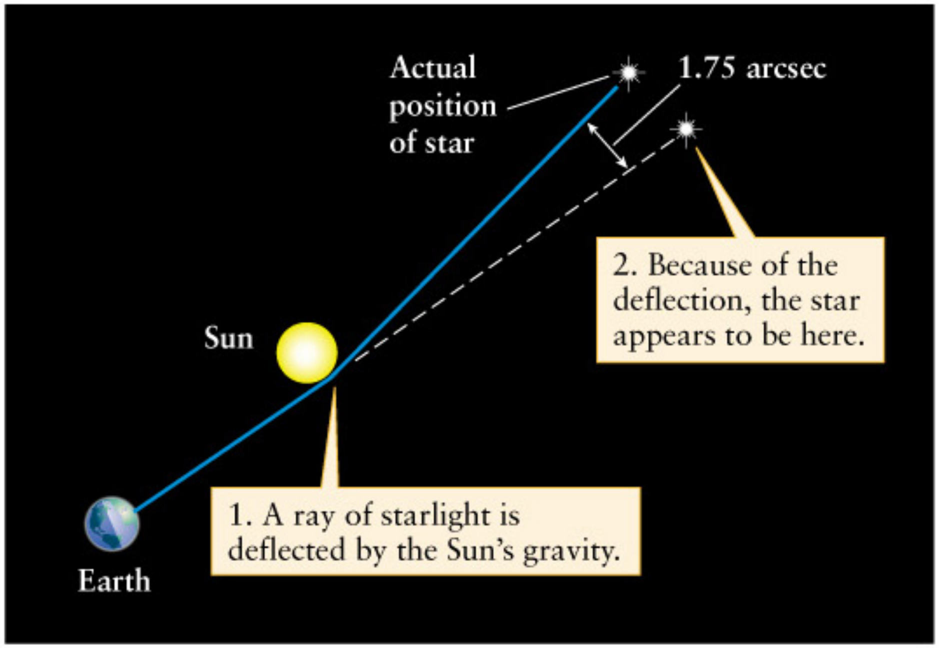
BLACK HOLES II

- 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 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

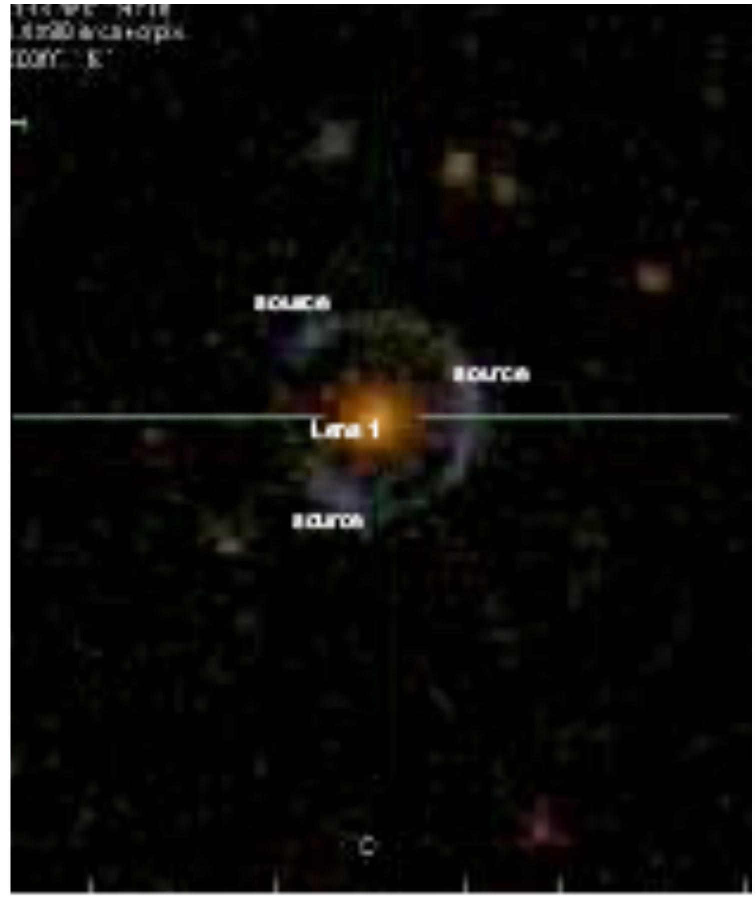
Gravity bends space-time



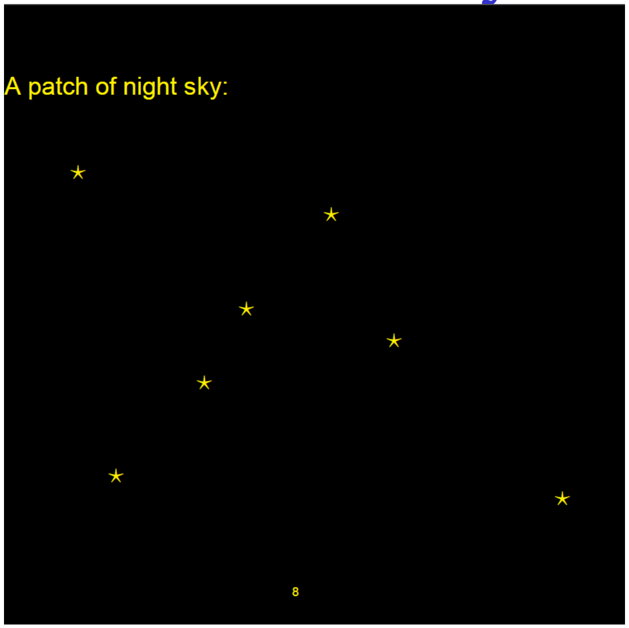
Gravity bends space-time

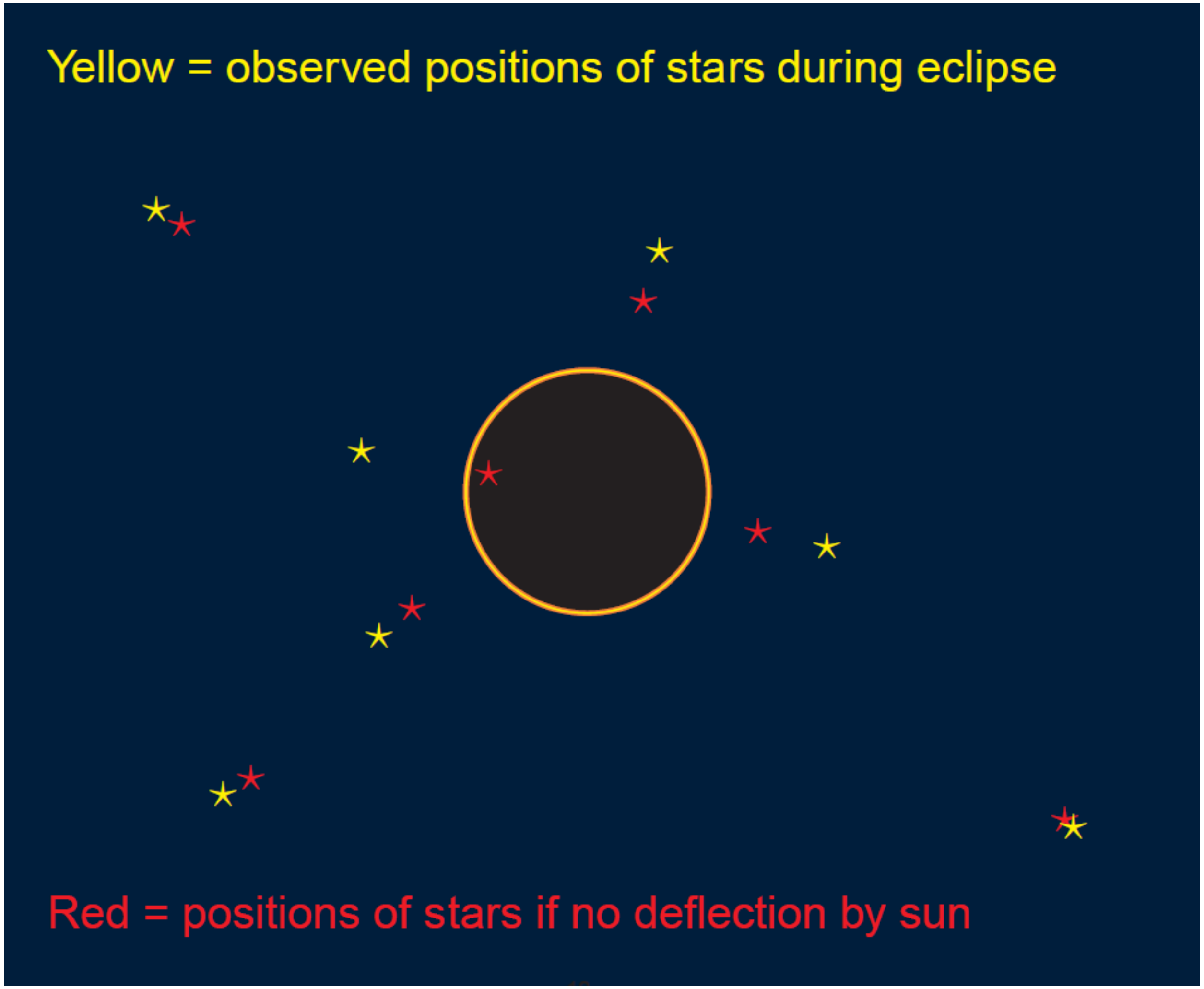


Einstein lens. Galaxy bends light from another galaxy further away (NIU student Donna Kubik thesis. Matt Wiesner also works on this)



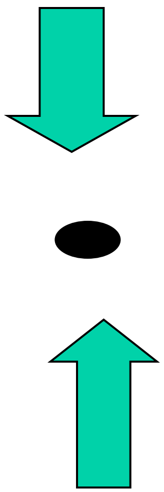
Gravity bends space-time: from S. Martin





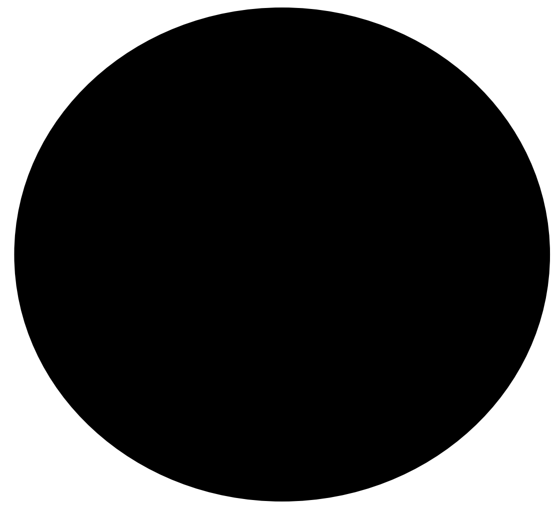
BLACK HOLES III

- 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)

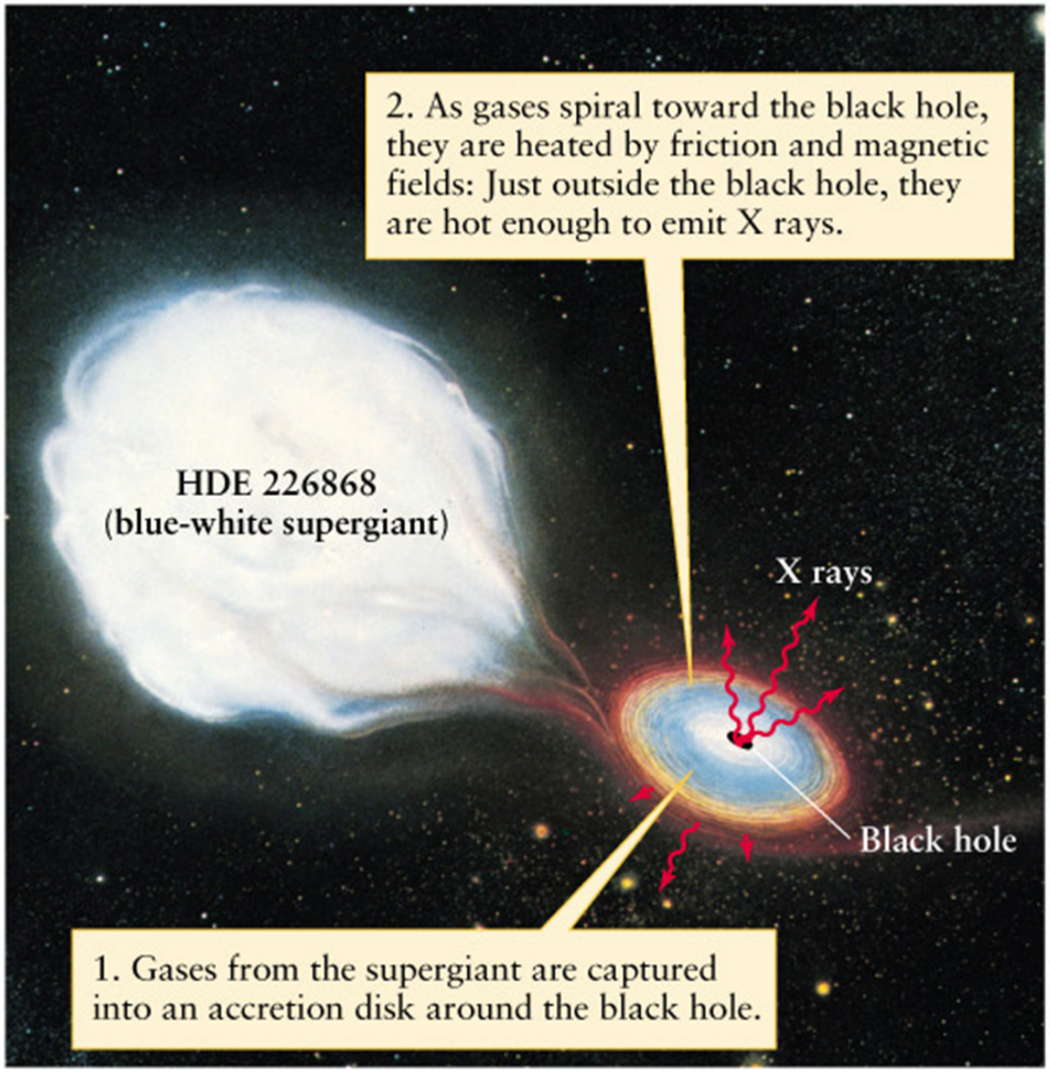
Matter falling in can also heat up and produce light



Millions (billions) of years later

Observing Black Holes

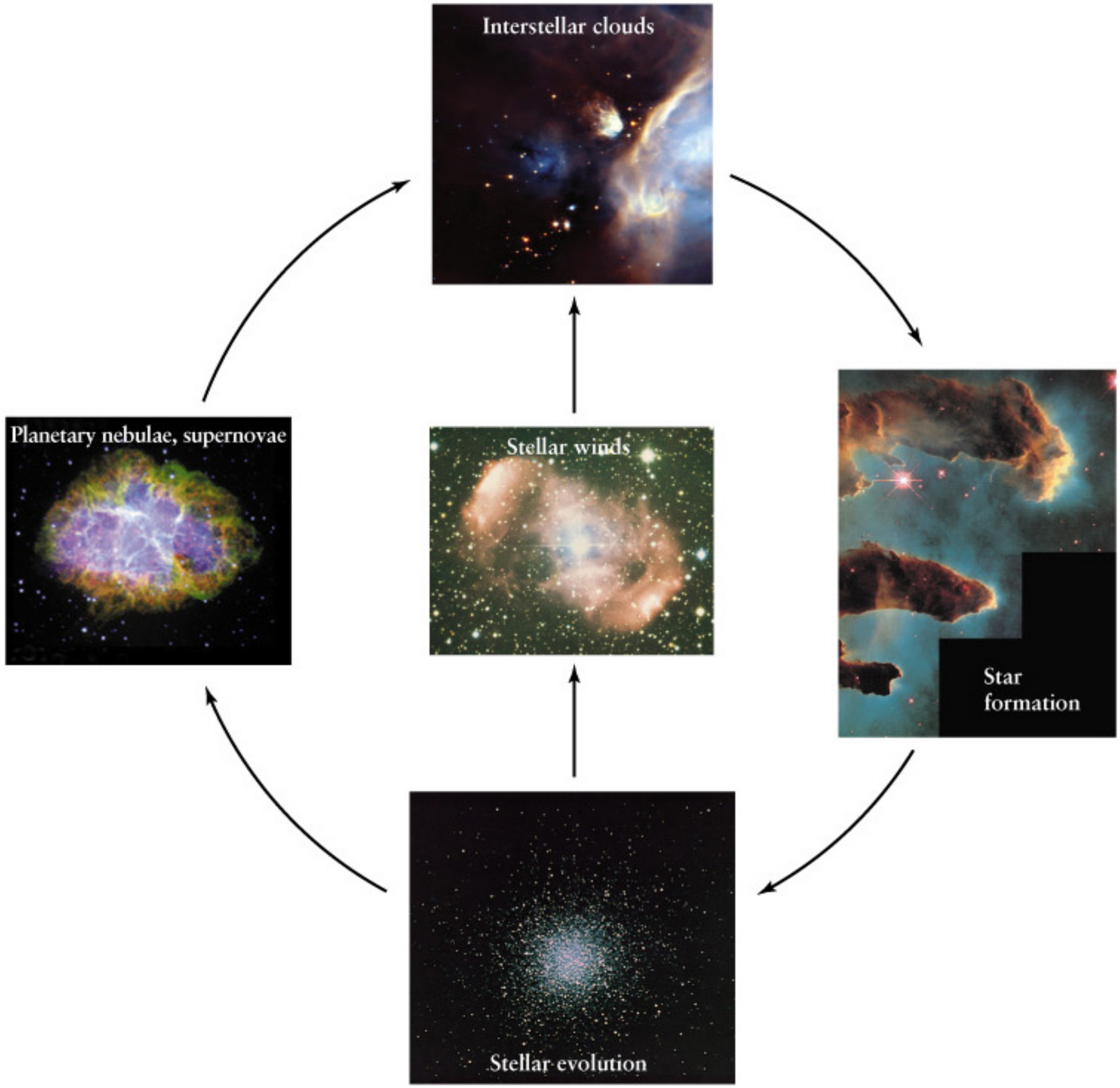
- observe radiation from hot matter falling into black hole
- observe orbit of normal star around "unseen" companion. Gives mass and if > 3xmass(Sun) then assume black hole (if smaller maybe neutron star)



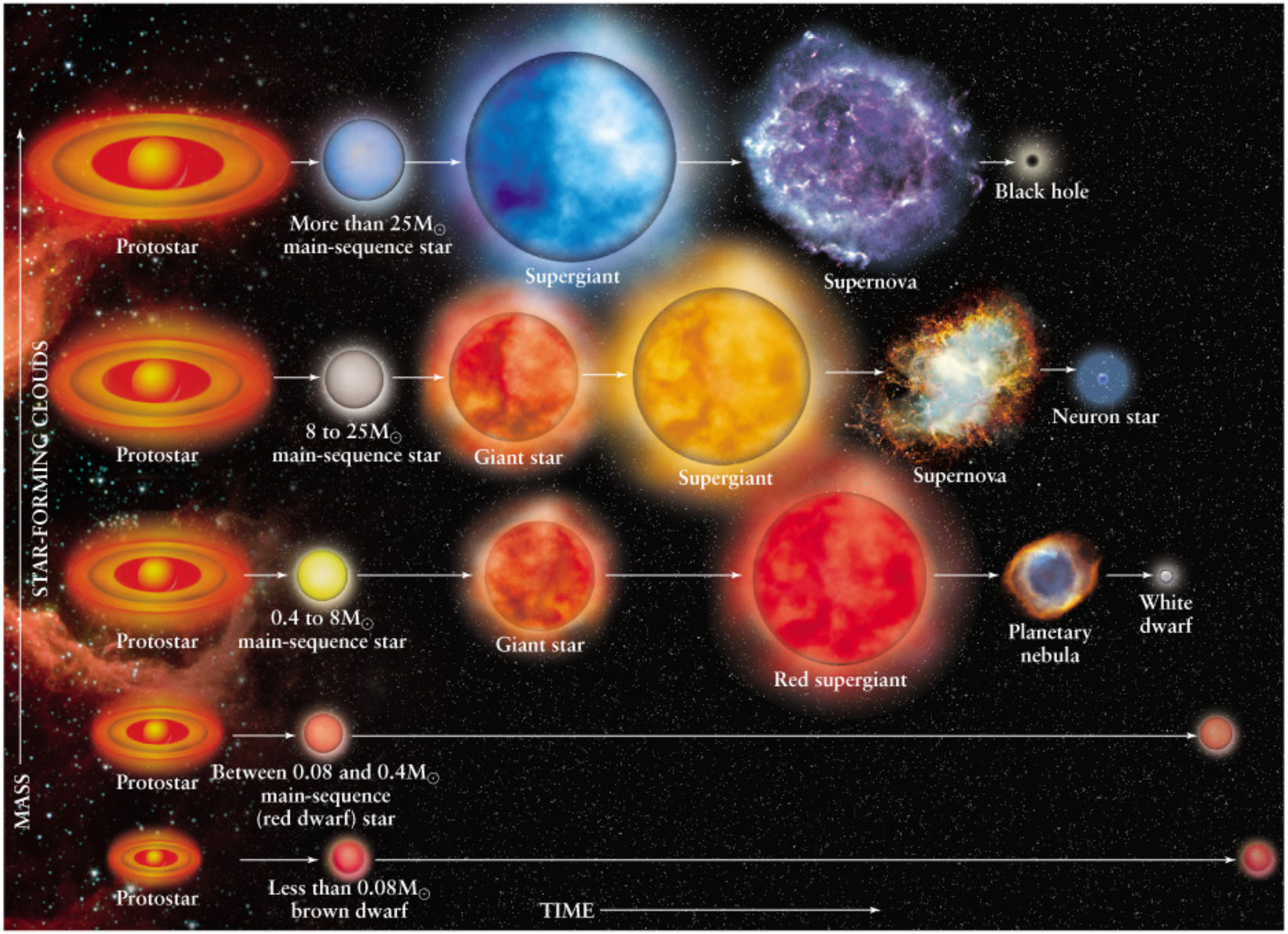
BLACK HOLES IV

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

Star Life Cycles

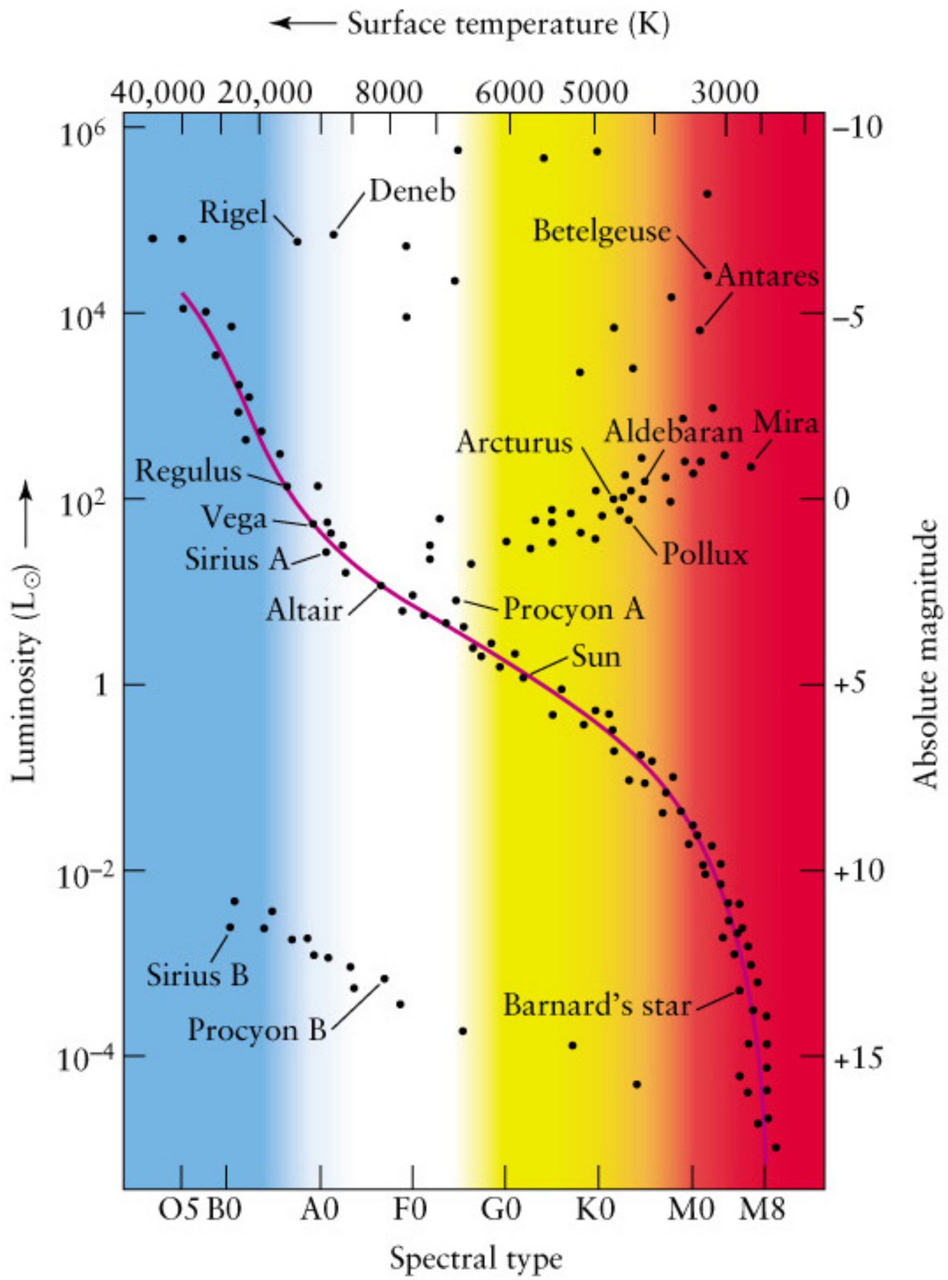


Star Life Cycles - Summary



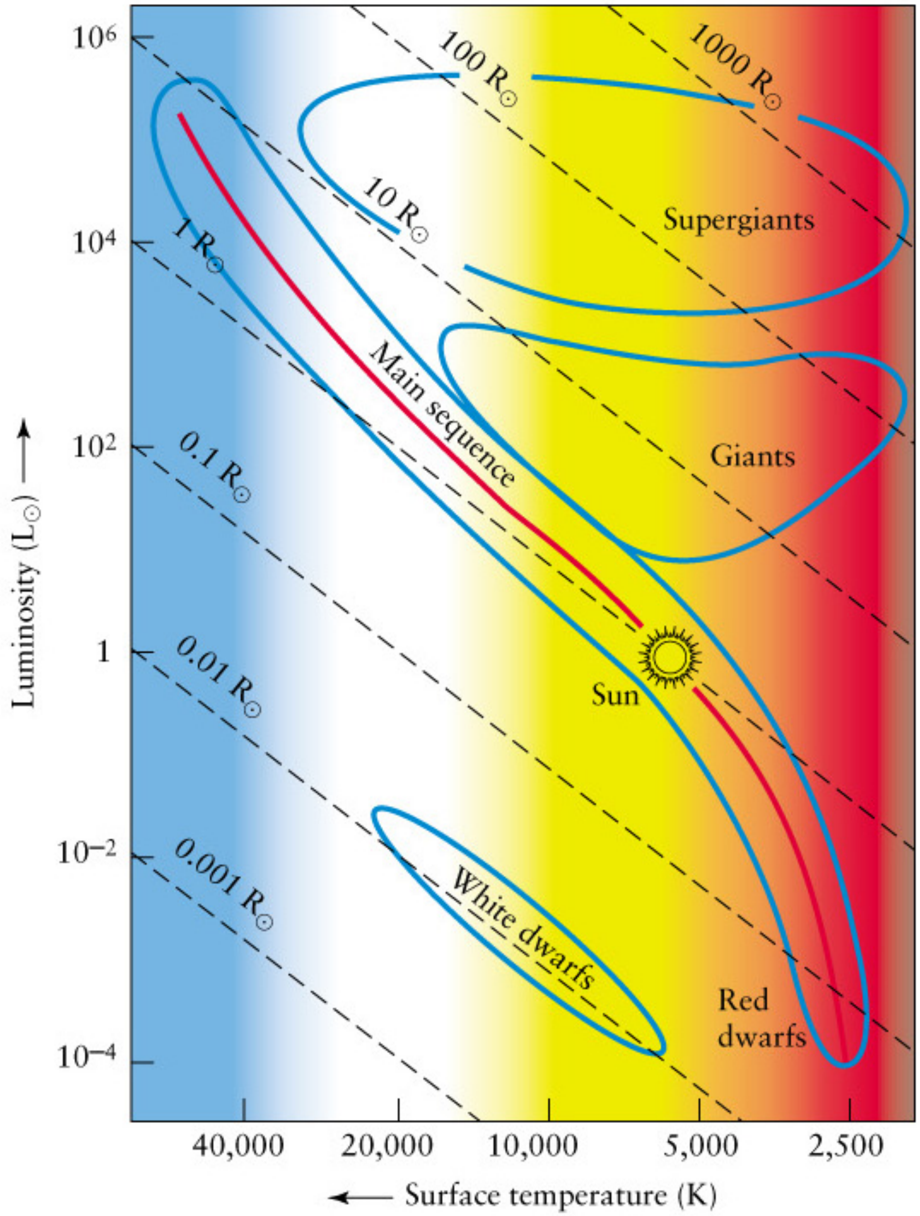
Test 2 Study Guide

- 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) and what happens during supernova
- difference between white dwarf, neutron star, black hole



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

Temperature vs Luminosity vs Radius of Stars

Energy emitted by surface of star due to EM radiation is Energy/area = σT^4. Examples

- Two stars. Same temperature and radius → same Luminosity
- Two stars. Same temperature. Radius(B) = 2xRadius(A). So surface area(B)= 4xsurface area(A) → Luminosity(B)= 4xLum(A)

Radius = 1 radius = 2

Temperature vs Luminosity vs Radius of Stars

Energy emitted by surface of star due to EM radiation is Energy/area = σT^4. Examples

- Two stars. Same radius. Temperature(B) = 2xTemp(A). (Energy/Area)B = 2^4(Energy/Area)A or (Energy/Area)B = 16x(Energy/Area)B → Luminosity(B) = 16xLum(A)

Temp = 6000 Temp = 12,000