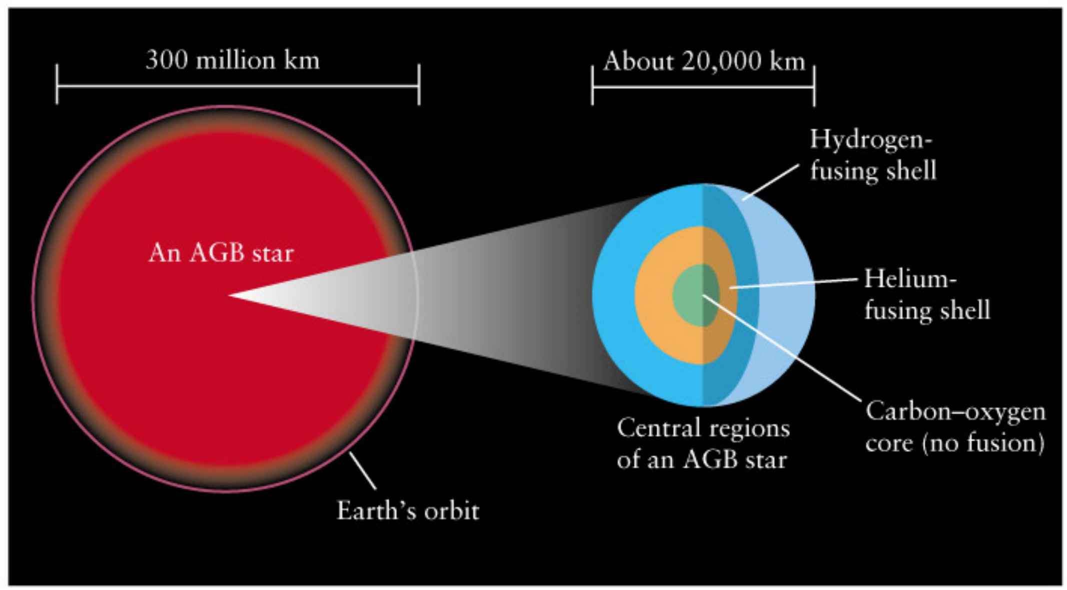
Fate of Stars

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

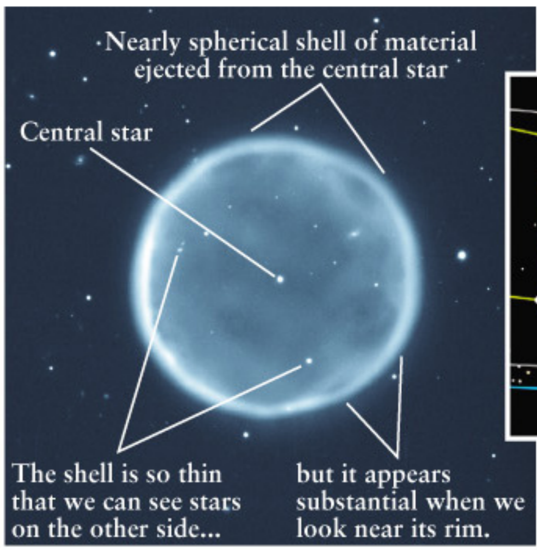
White Dwarves

- For “light” stars (less than about 10 times the mass of the Sun) the burning of He to Carbon (Oxygen) is final fusion stage
- electrons’ pressure resisting gravity
- Outer Layers keep expanding (or oscillating) losing matter. See as planetary nebula



Planetary Nebula

- NOT planets (historic term) material ejected by "pulsating" Red Giant.
- Can lose over half the star's mass



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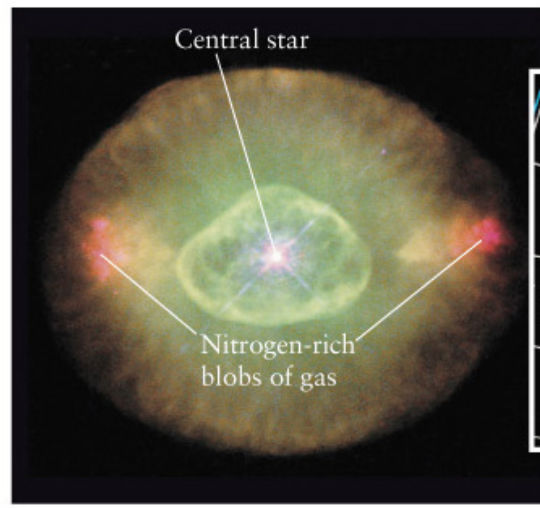
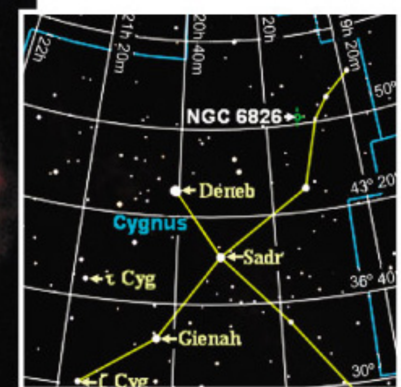
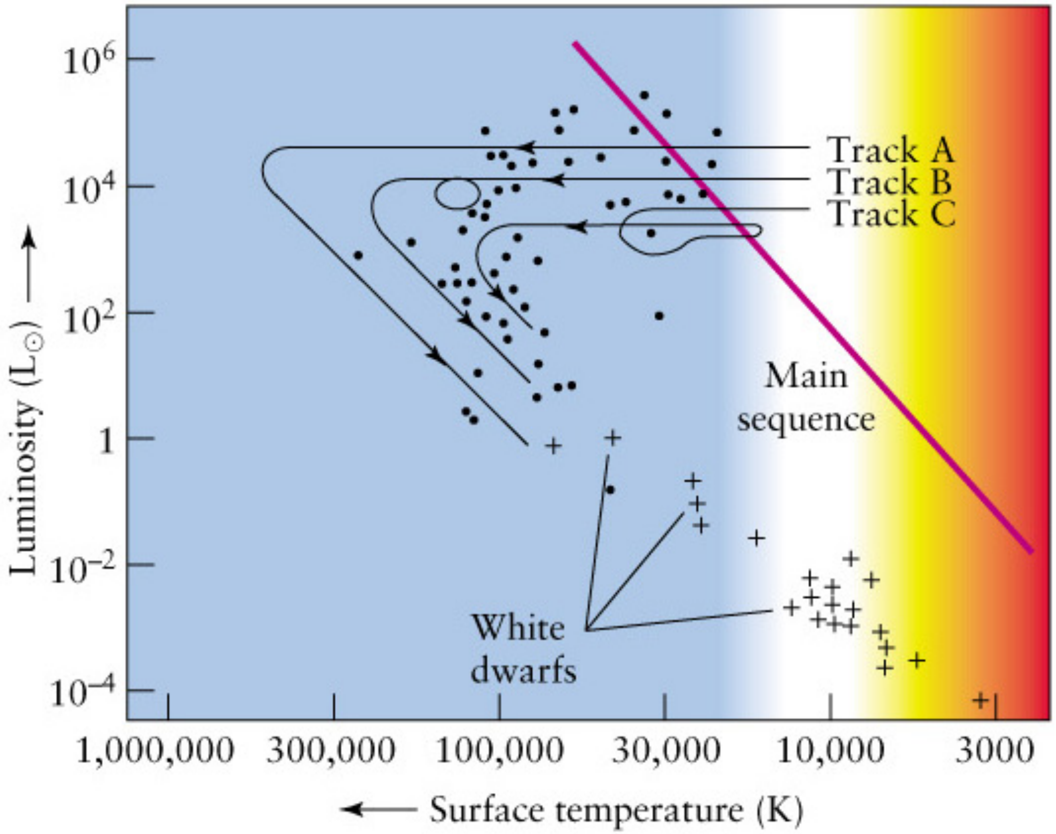
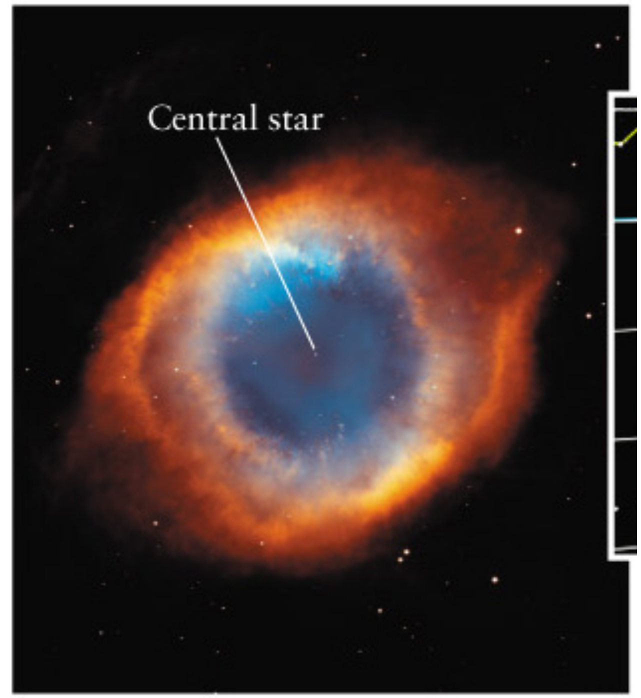




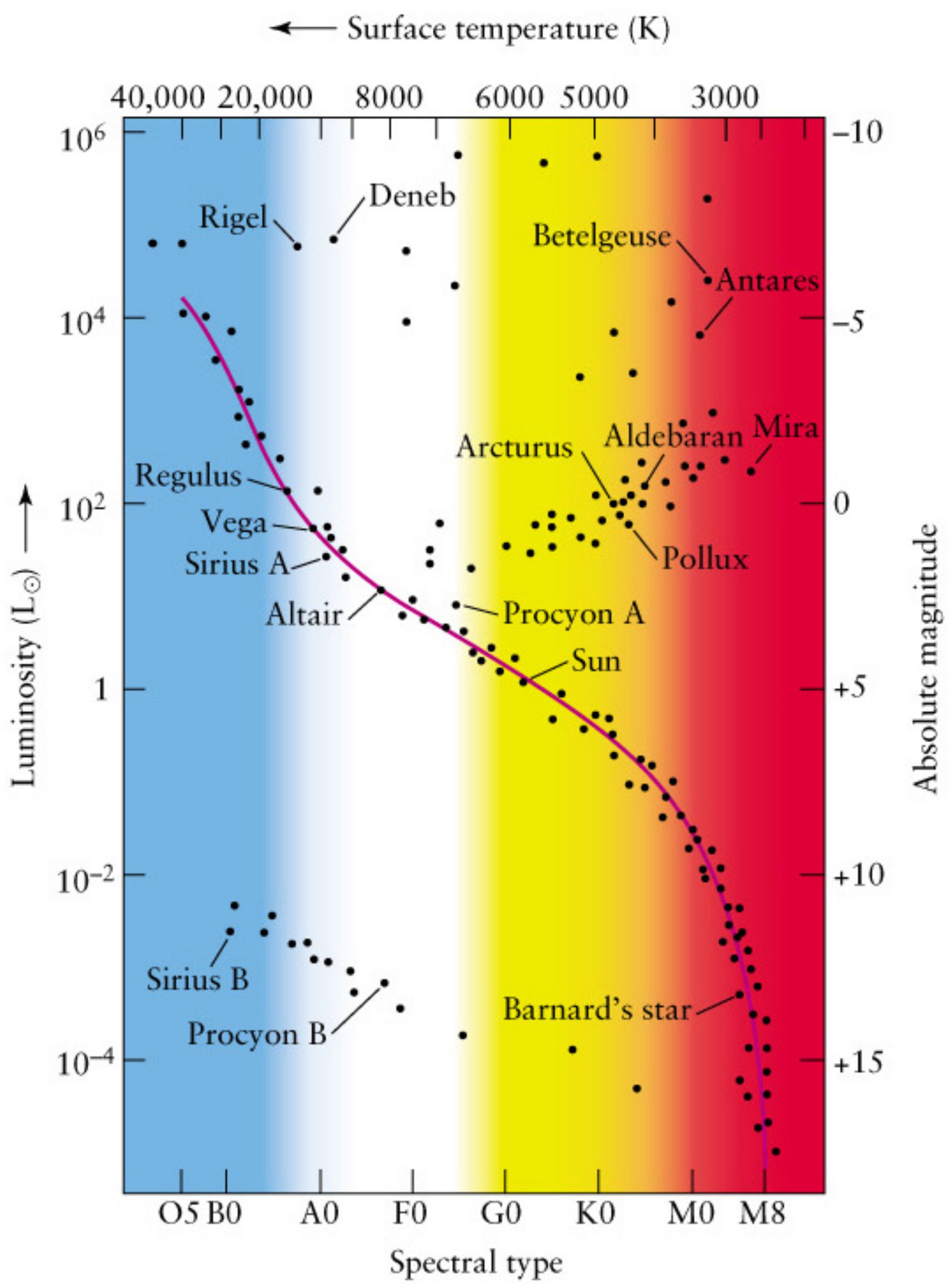
Helix nebula

Red Giant→White Dwarves



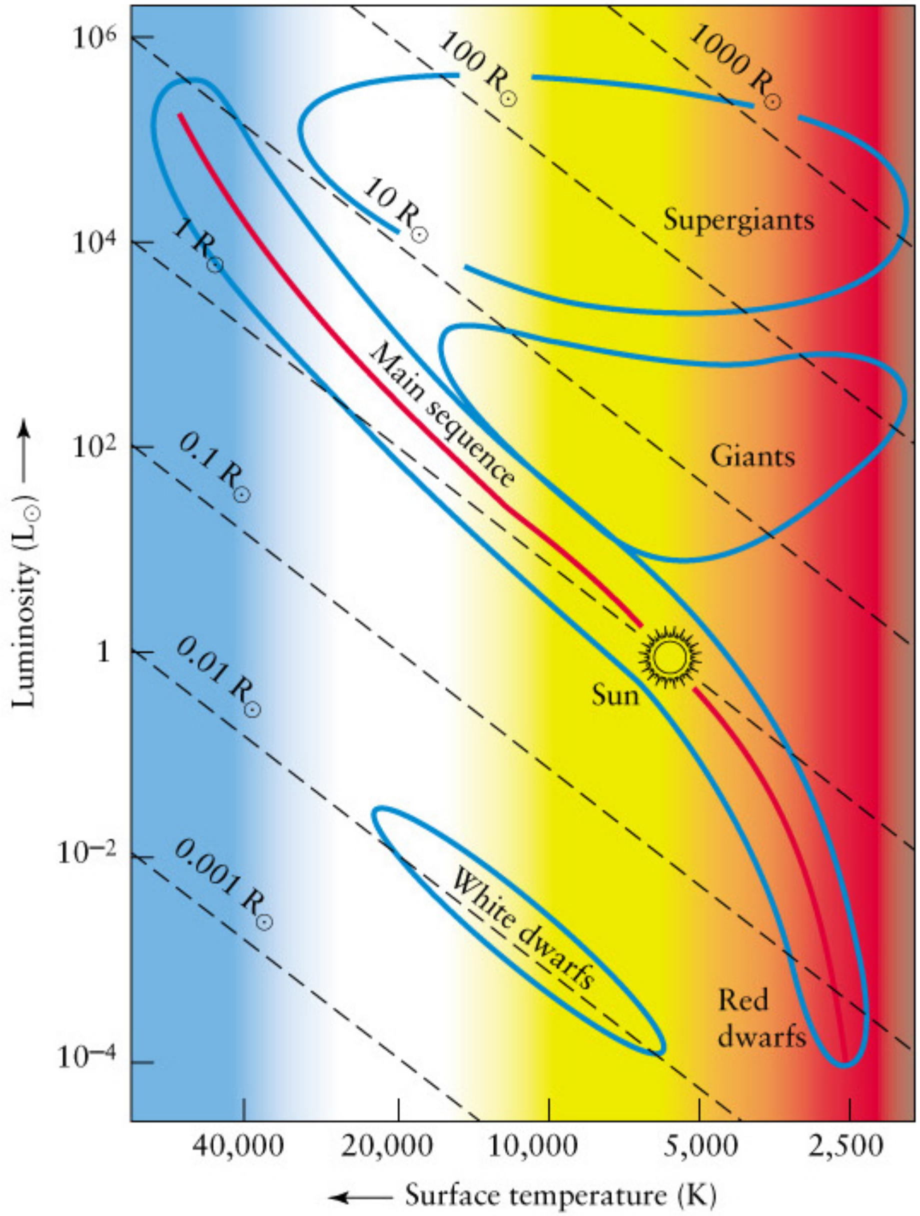


white dwarf at center of "planetary" nebula heats up surrounding gass



REMINDER Hertzprung-Russell Diagram

Plot Luminosity versus surface temperature

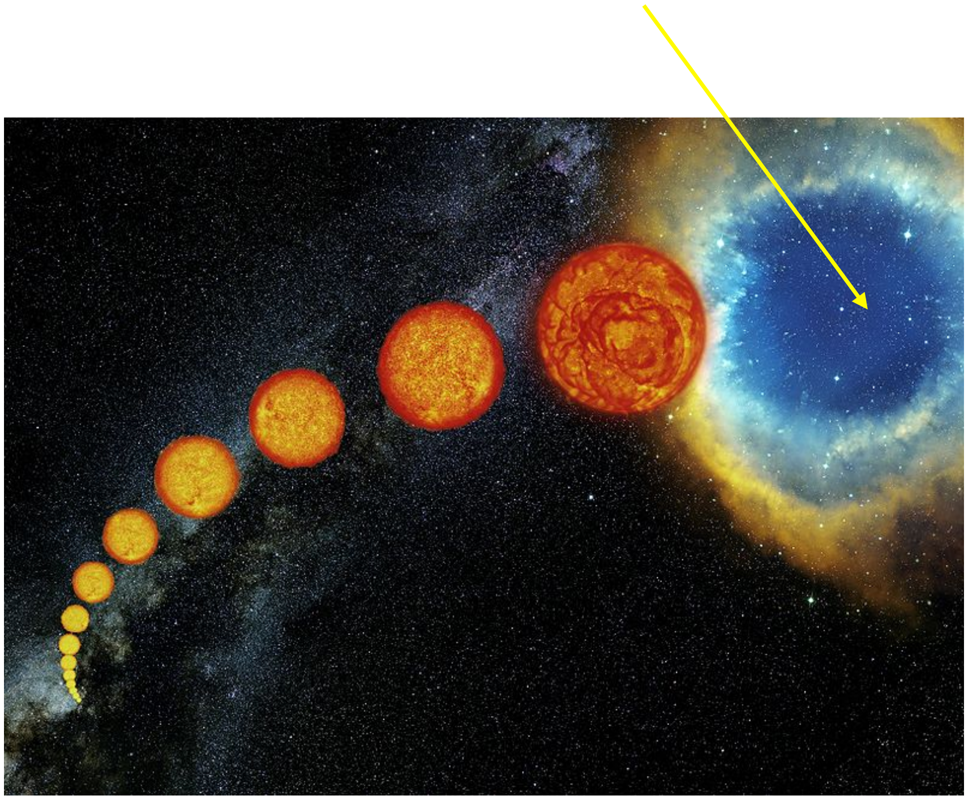


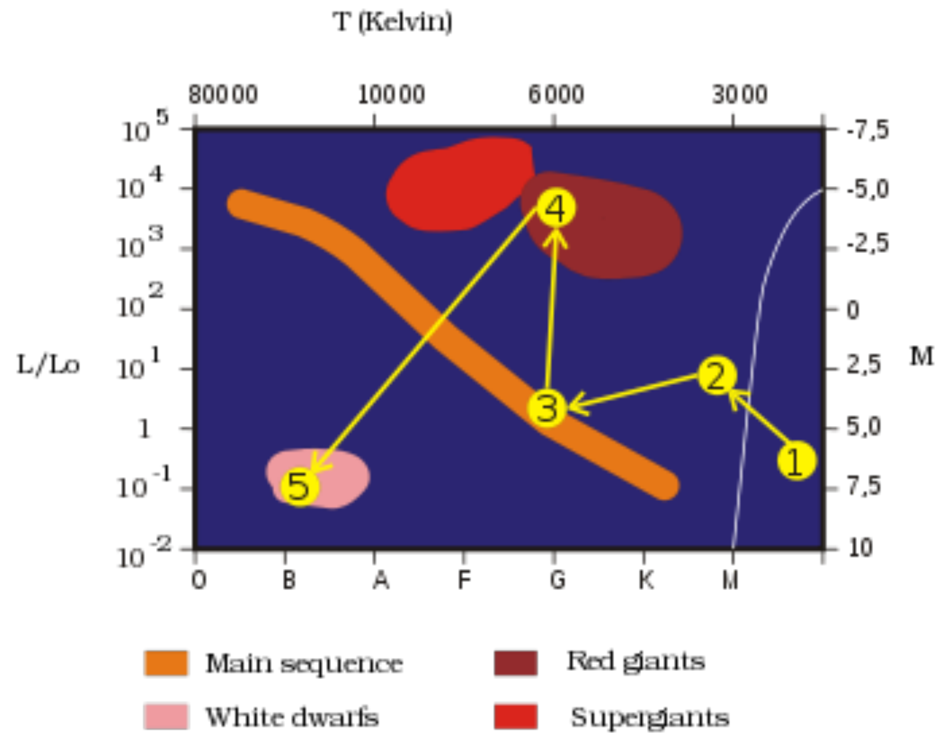
Hertzprung-Russell Diagram

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

Sun: Main Sequence→Red Giant→White Dwarves

white dwarf

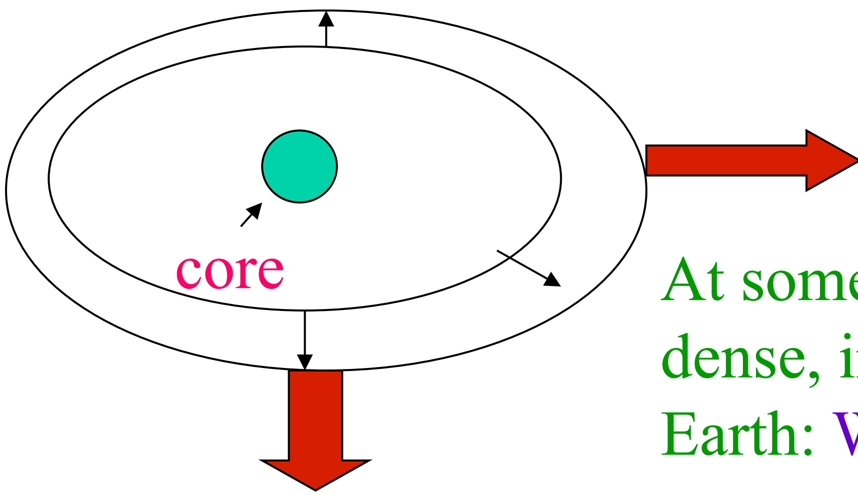




White Dwarves II

- loss of over 1/2 star's mass during Red Giant phase

Mass being lost

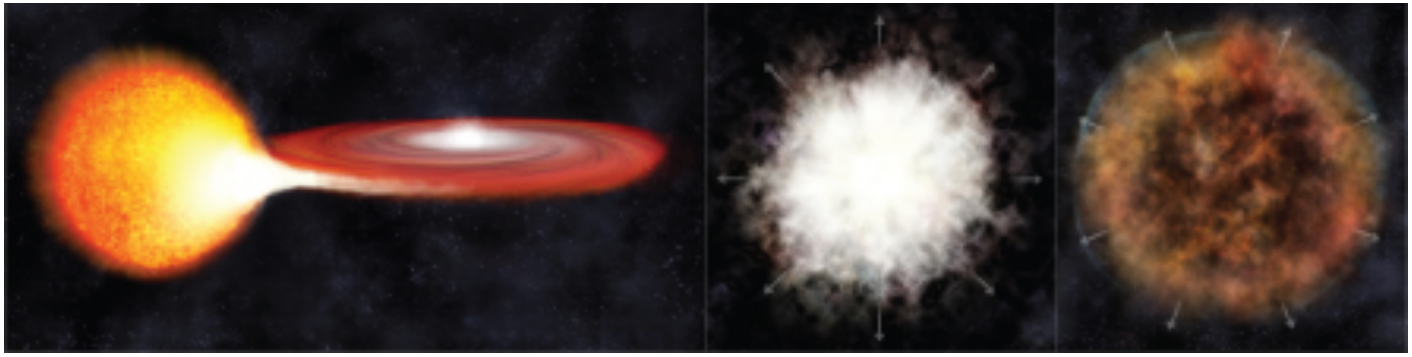


At some point all that is left is the hot, dense, inert C/O core about size of Earth: WHITE DWARF

Will slowly cool down over time

White Dwarves Mass vs Radius

- In WD, gravity is balanced by pressure due to degenerate electrons
- A heavier WD will have smaller radius
- if Mass(WD) > 1.4 M(Sun) electrons can not resist gravity → called Chandrasekhar limit and no WD has a mass greater than this
- If WD can acquire mass from companion star and goes over this limit → Supernova and (usually) a Neutron Star



Degenerate electrons

not on tests

Same as Pauli exclusion - two electrons which are "close" to each other can not occupy the same quantum state. Causes:

- Periodic table and different chemical properties for different atoms
- Why metals conduct electricity
- Interior of stars and planets

electrons are forced to higher energy states and so exert more pressure than normal

Degenerate electrons

Being "close" depends on electrons energy. Easier for lower energy to be close (wavelength = h/p)

Classical relationship between temperature and pressure doesn't apply – i.e. pressure doesn't go down as star cools…

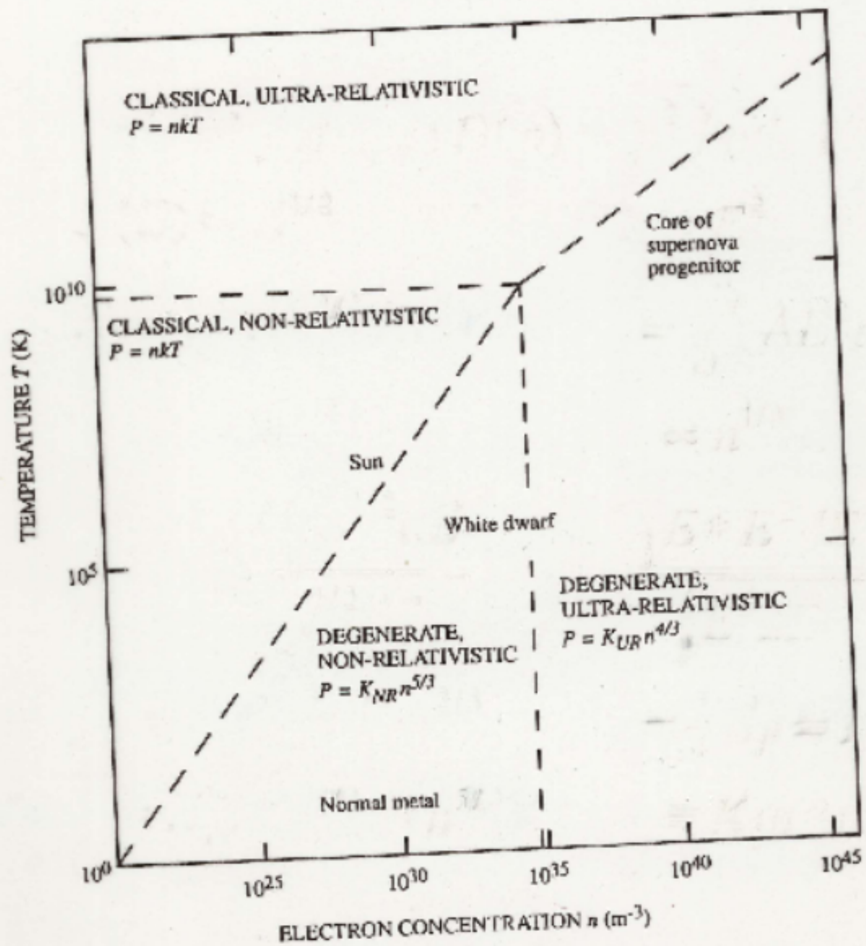
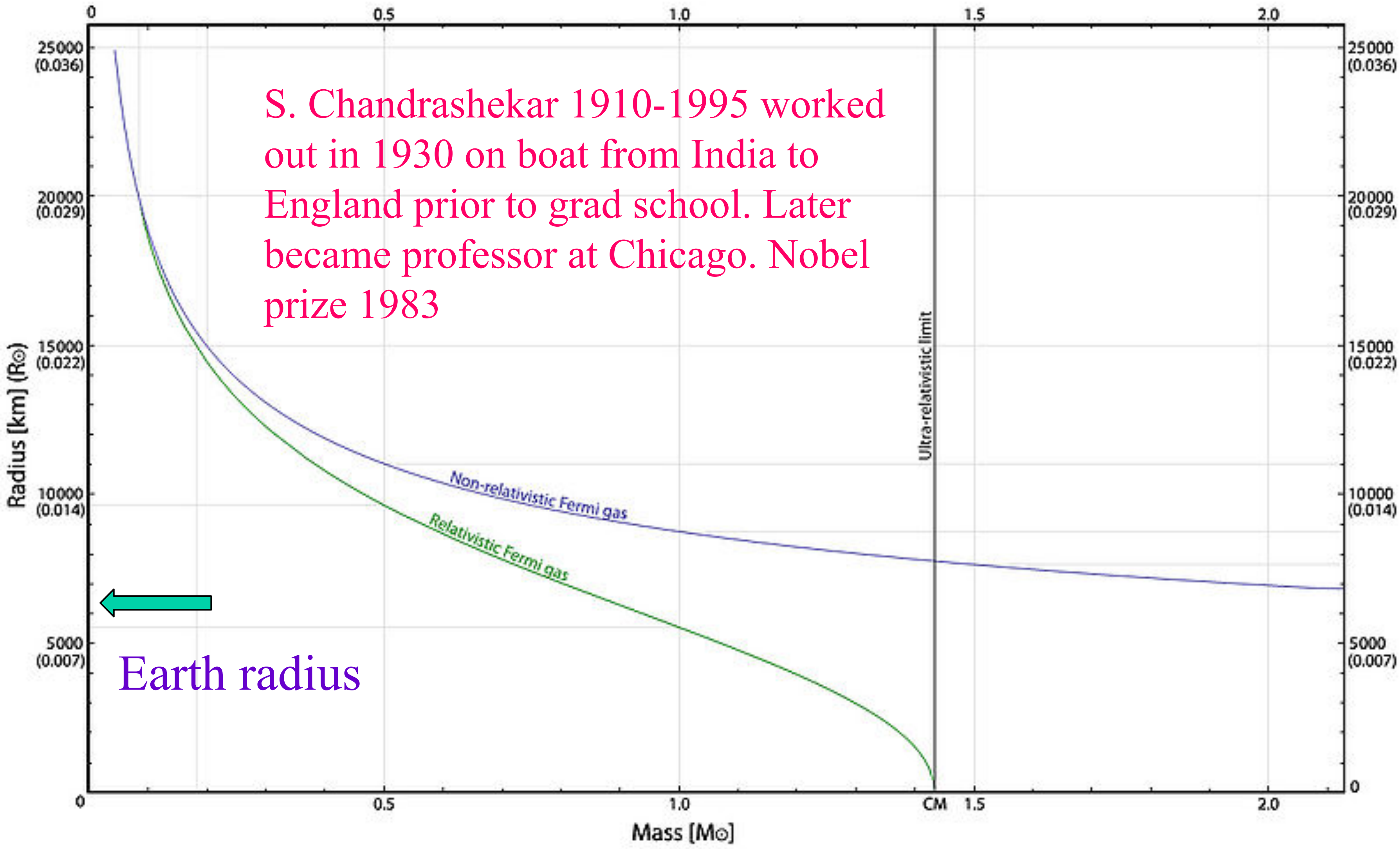


Fig. 2.2 Equation of state regimes for an ideal electron gas at a temperature T and at a density of n electrons per m^3. Typical values are shown for the temperature and density for electrons in a normal metal, in the sun, in a white dwarf and in the iron core of an evolved star just prior to a supernova.

electron degeneracy pressure

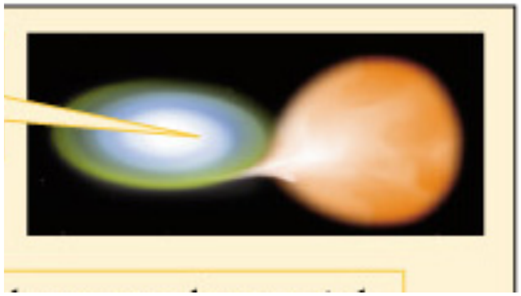
White Dwarves Mass vs Radius



Stellar Explosions

For heavy white dwarves with a companion star

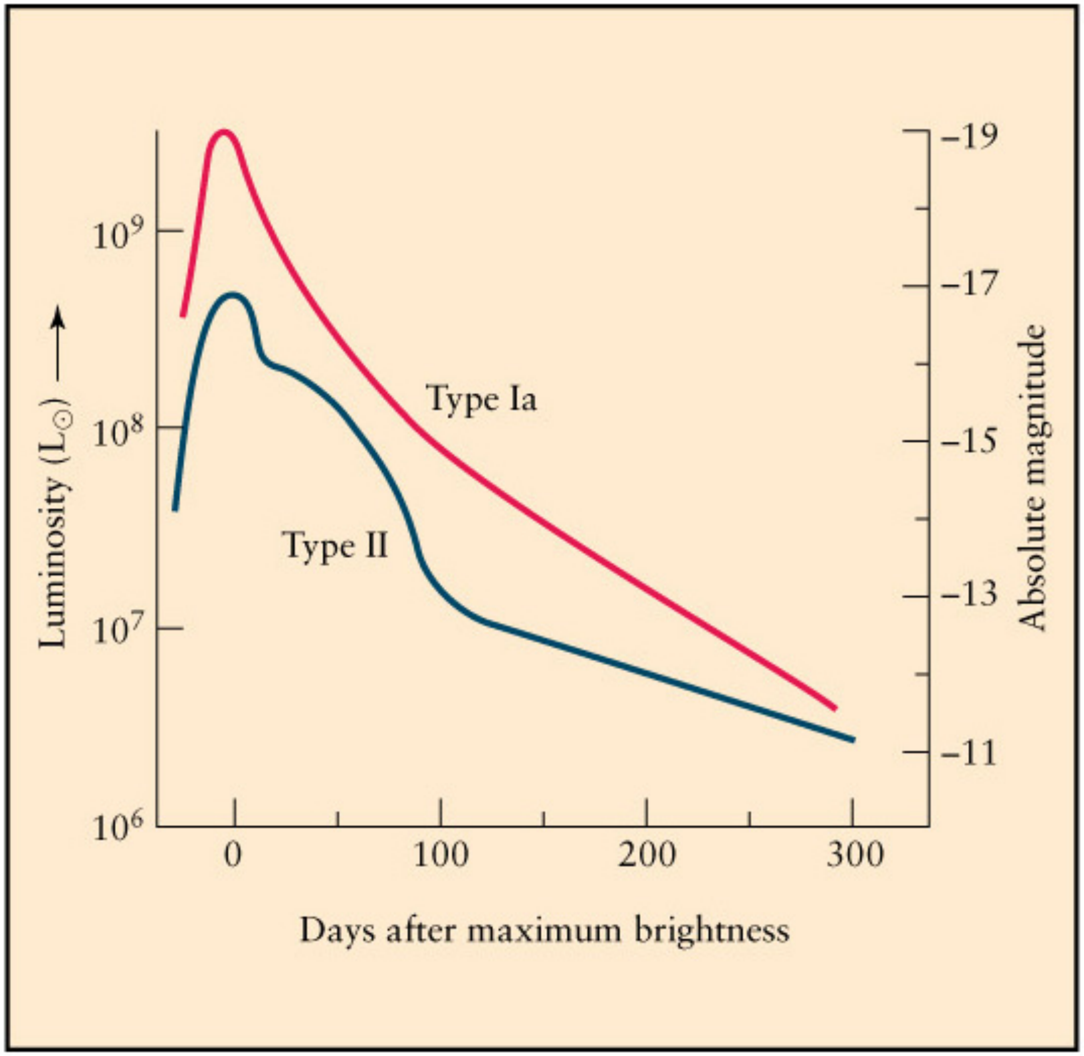
- Acquire mass, if becomes > 1.4 M(Sun) SUPERNOVA (Ia). p + e → n + neutrino
- Usually leaves neutron star



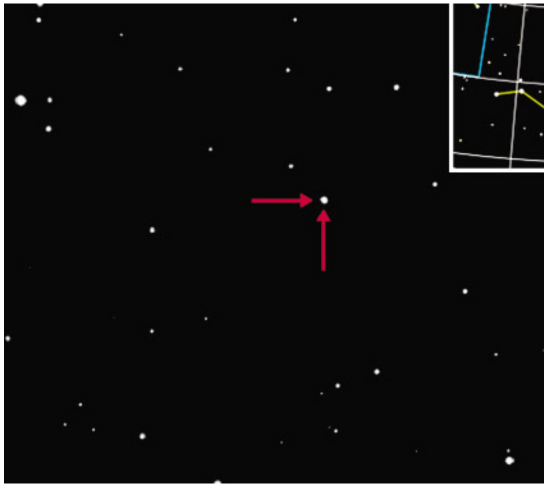
For high mass stars

- Fusion continues beyond C,O
- Core of degenerate electrons builds up - opposes gravity
- If Mass(core) > 1.4 M(Sun) core collapses in SUPERNOVA (II)
- Leaves either Neutron Star or Black Hole

Supernova Explosions



1 billion times brighter then the Sun for a few months

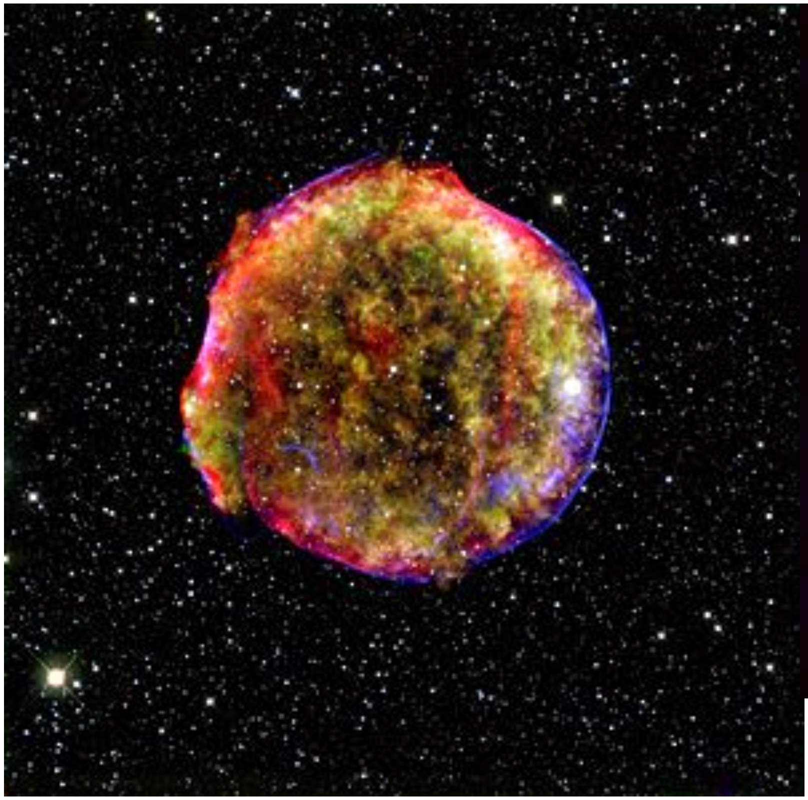


Supernovas

- 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

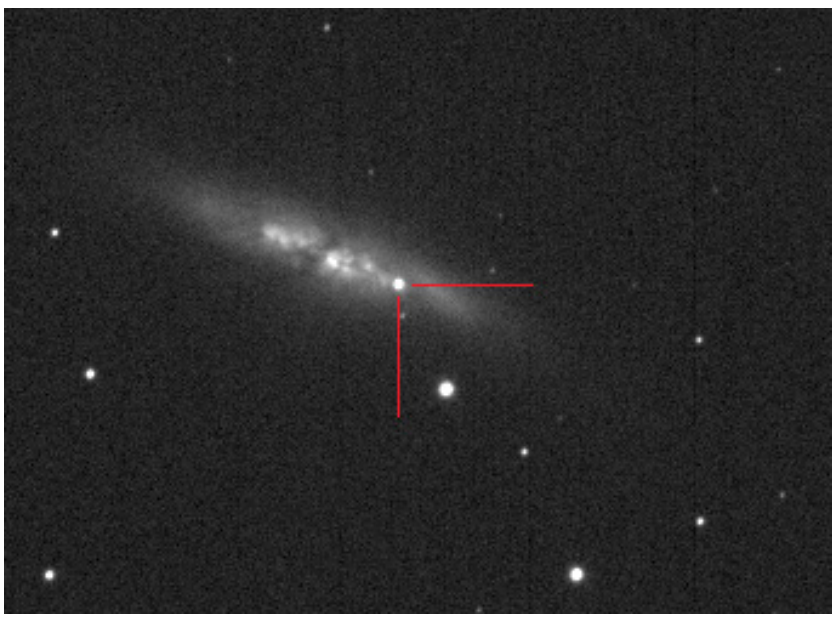
1572 (Tycho Brahe) and 1604 (Kepler)

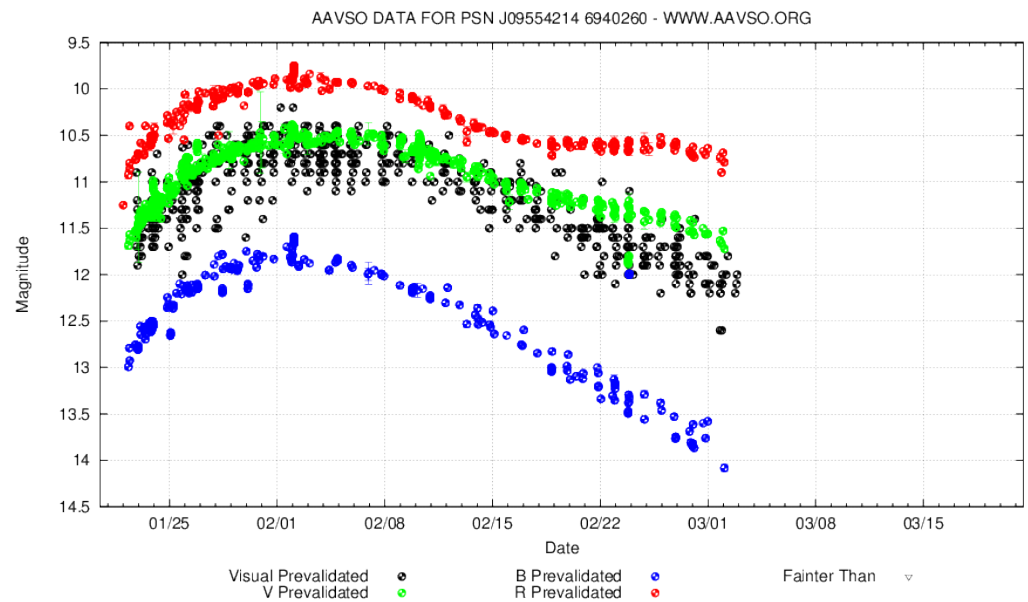
In Milky Way both probably Type Ia



Supernova 2014j – Jan 2014

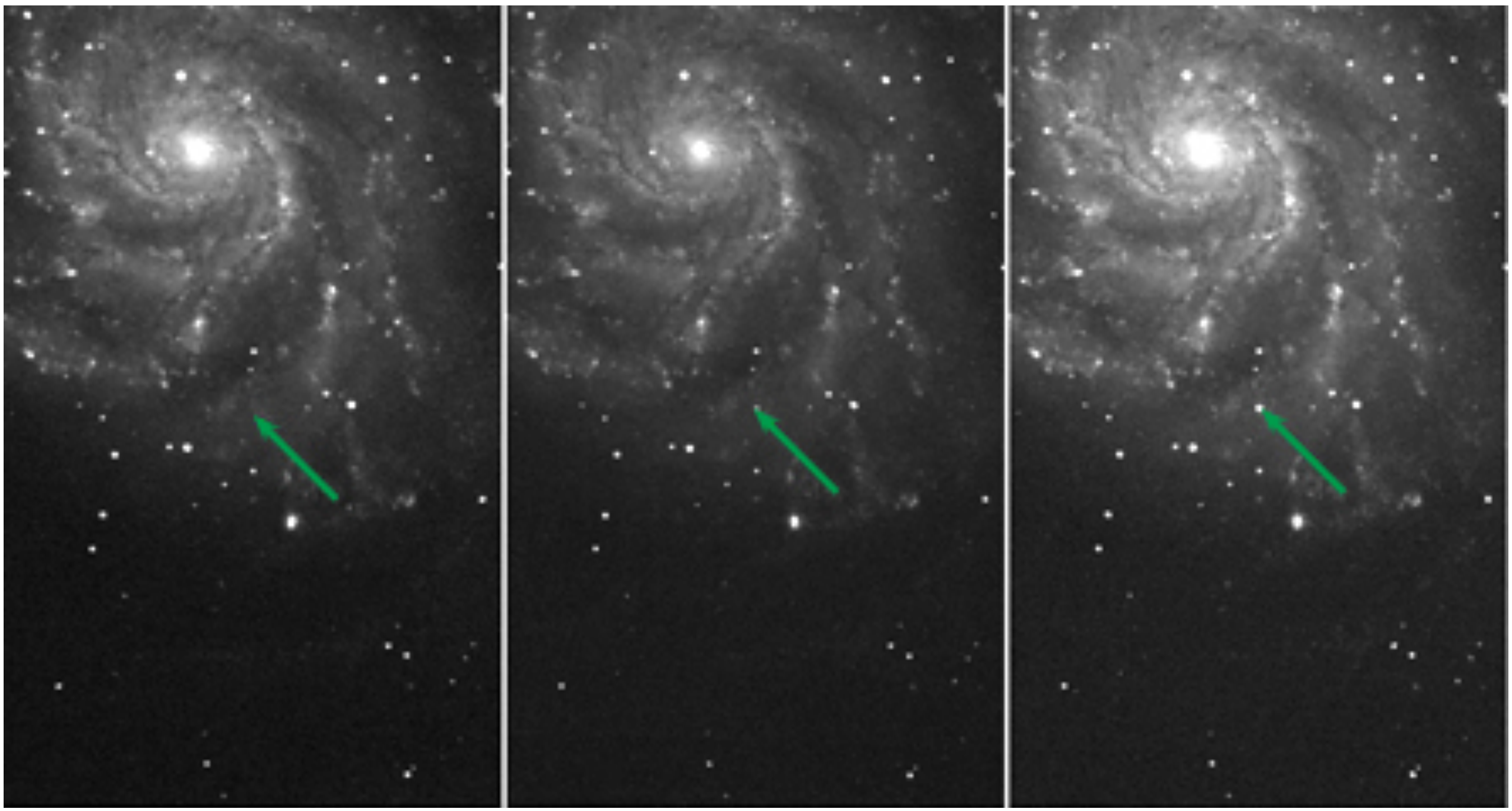
In M82 (Ursa Major). Type Ia. Closest of this type observed in modern times. 11.5 million LY away. Discovered at undergrad session Univ Coll London (SN1972 e was 11 MLY but pre "modern")





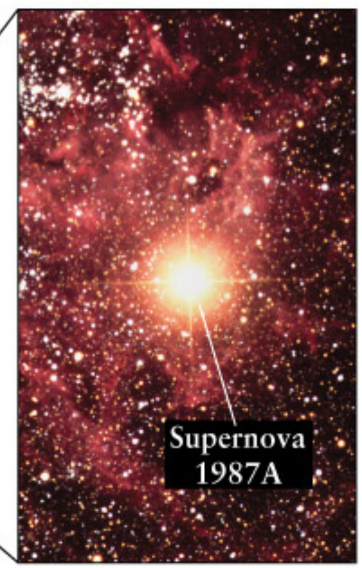
Supernova PTF 11kly – Sept 2011

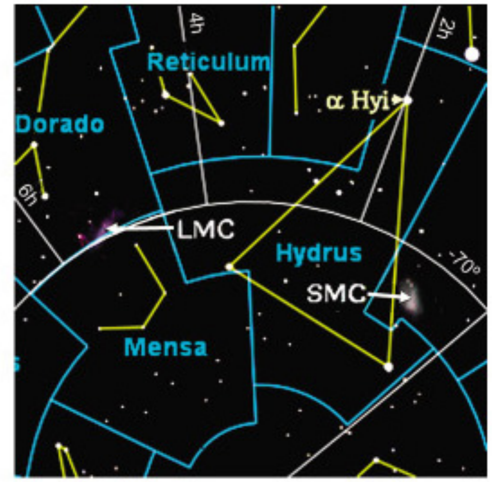
In Pinwheel Galaxy. Type Ia. 2nd closest Ia observed in modern times. 21 million LY away



Supernova 1987a (in movie)

Large Magellanic Cloud Type II
180,000 LY away

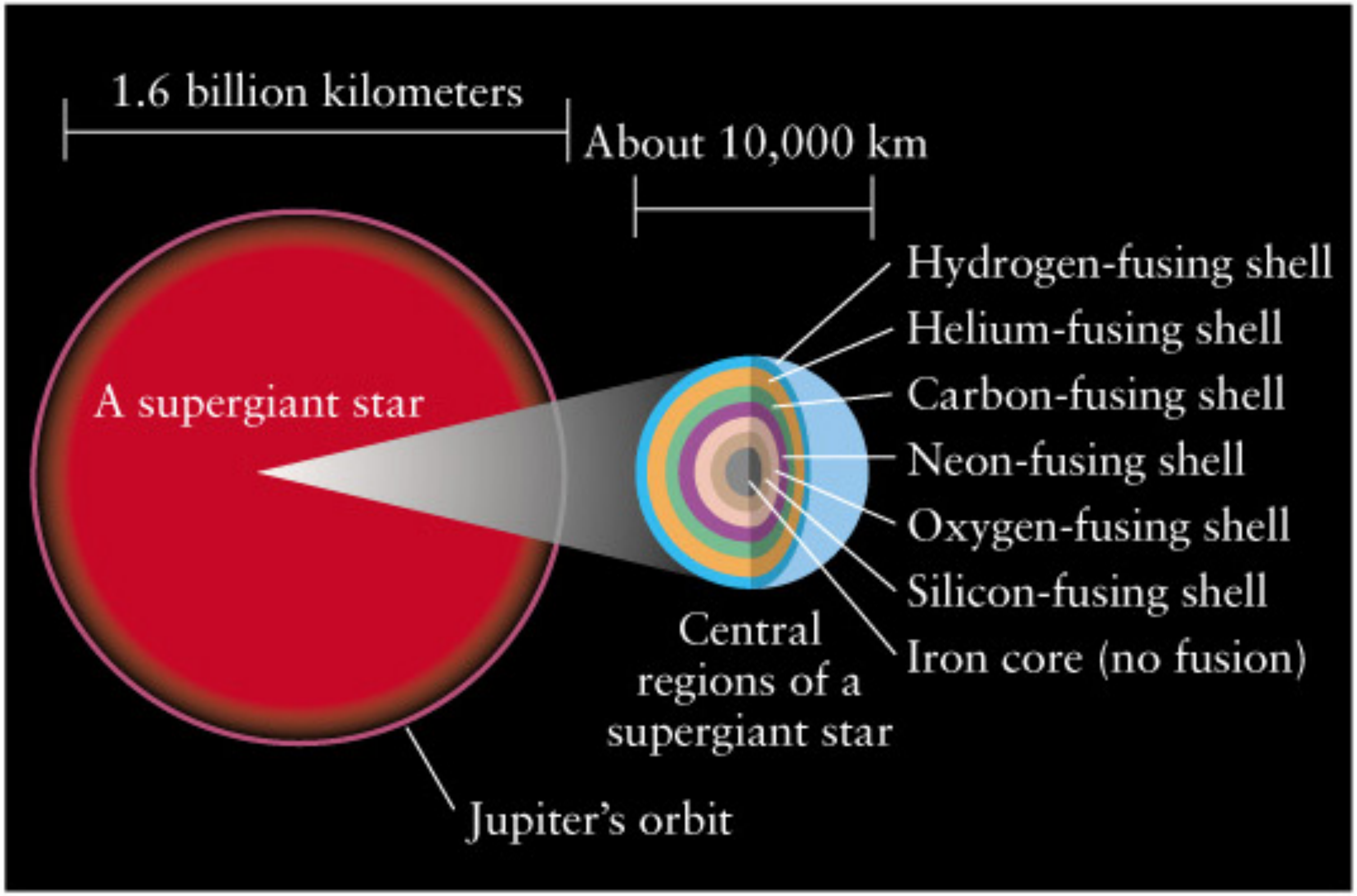




Supernovas and Core Collapse

- 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)

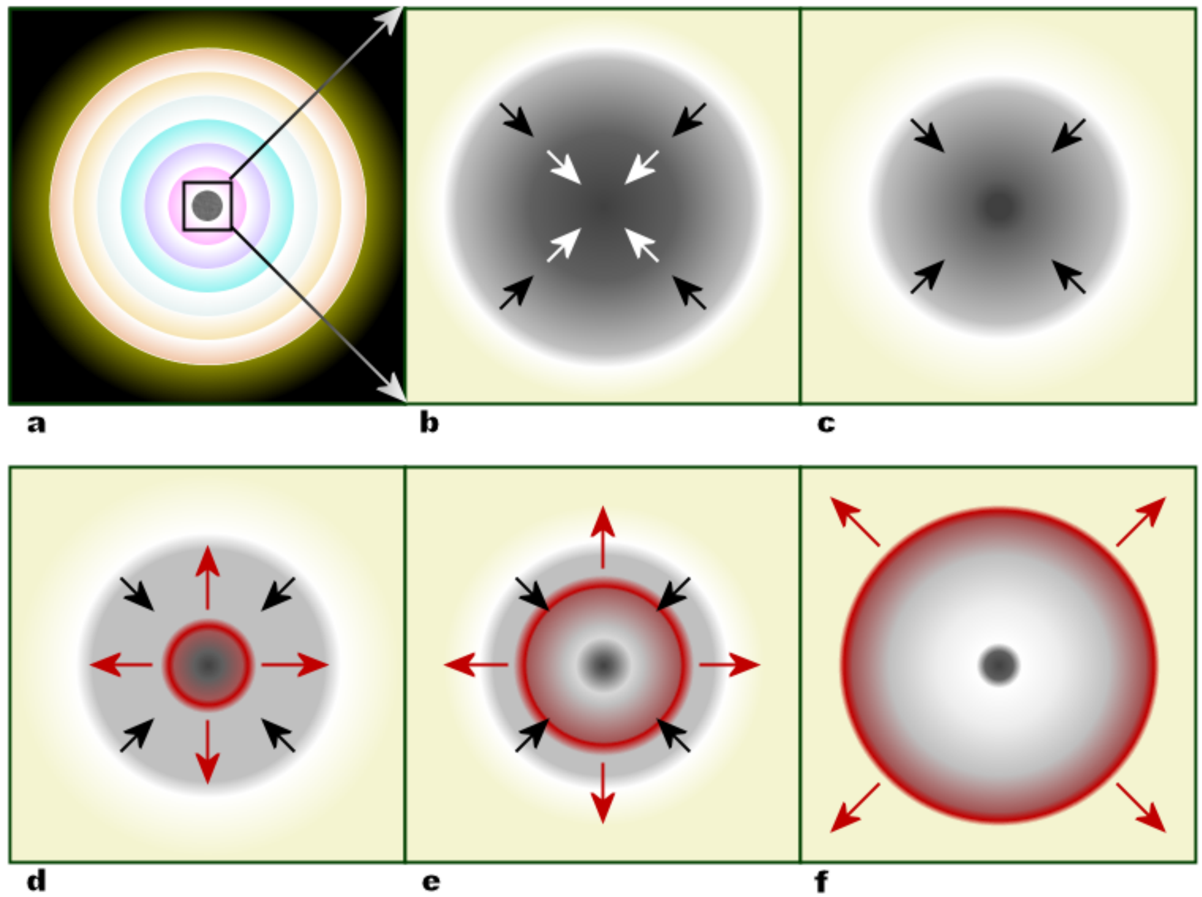
  2. Leftover neutron star

Core Collapse

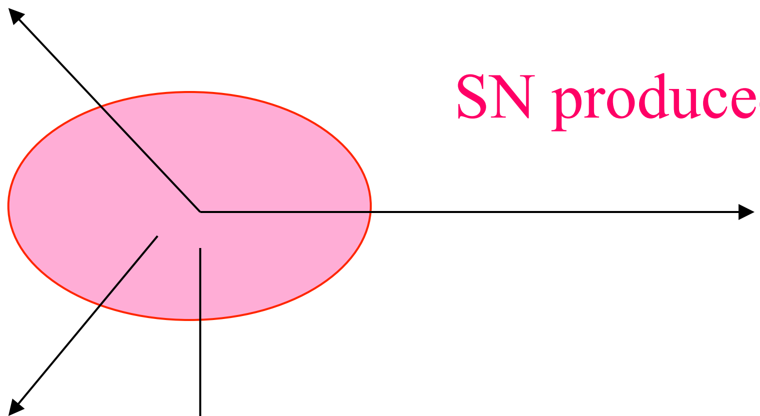
core collapses into mostly neutrons – very hot

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



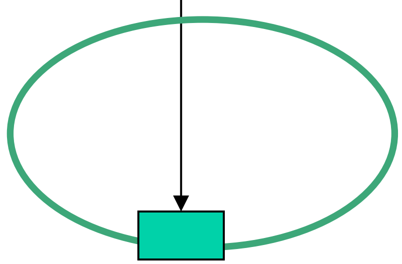
SN produced 10^{58} neutrinos

$10^{15}\ \nu/cm^2$ 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

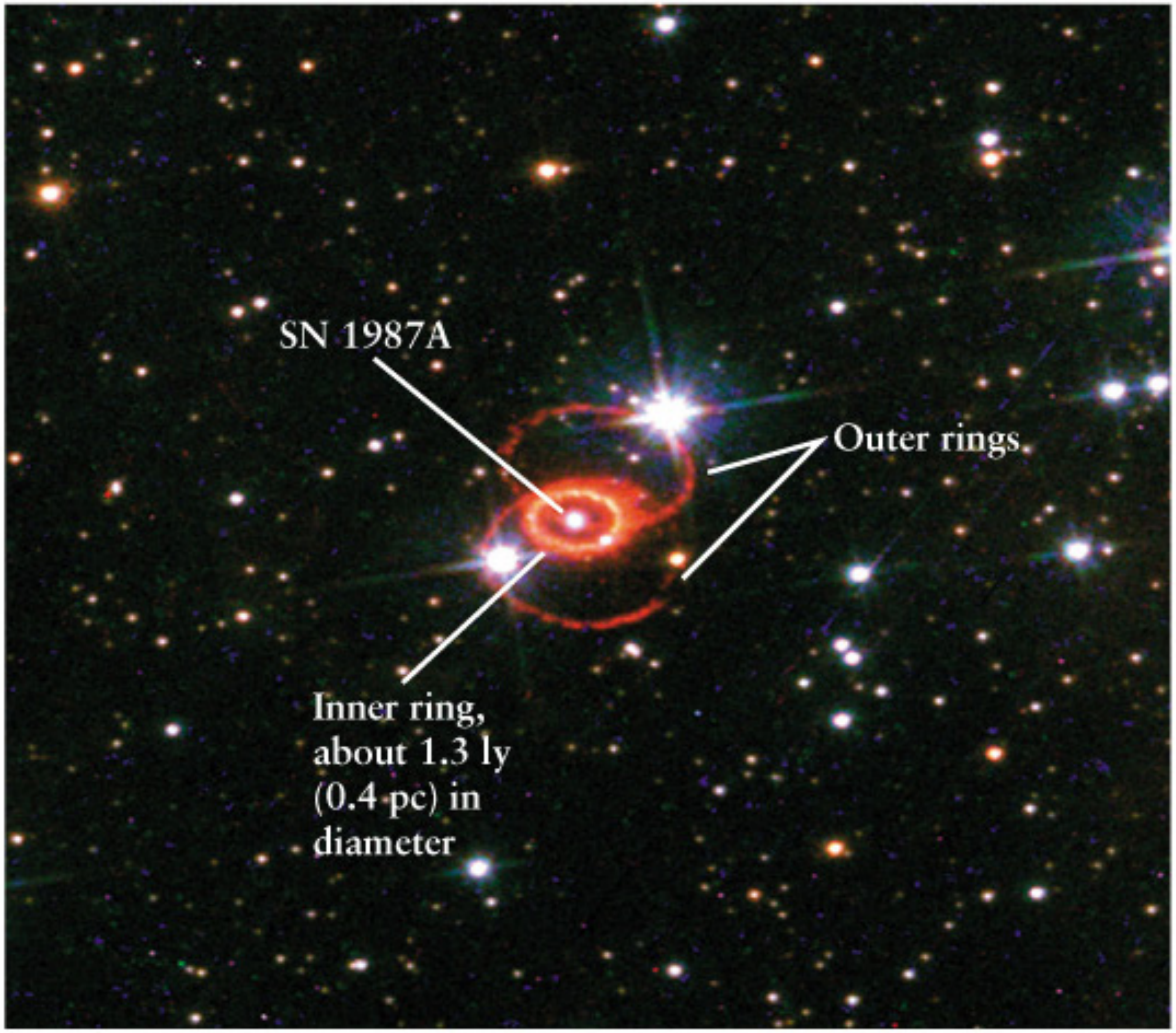
- Stars lose matter at end of life-cycle

  becoming Red Giants (can detect)

  Supernova debris (can detect)

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

Supernova Debris SN1987a

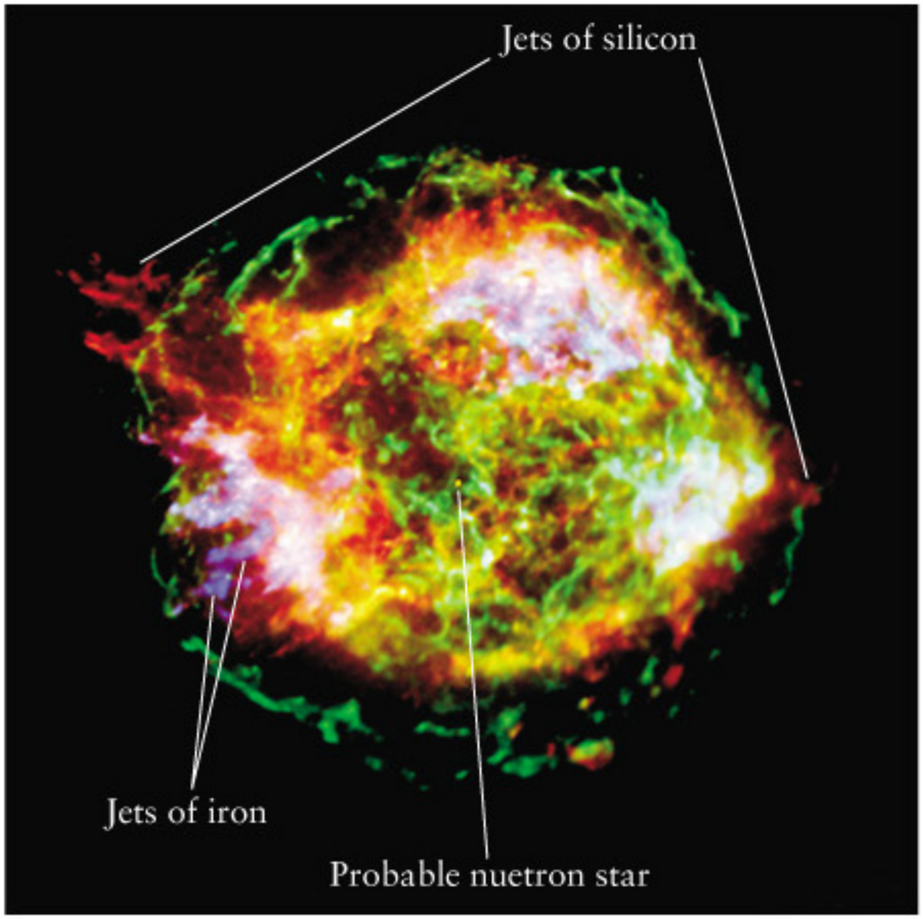


a Supernova 1987A seen in 1996

Supernova Debris

Crab Nebula M1

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



Cassiopeia A maybe observed in 1680