6

The evolution of stars

Timescales

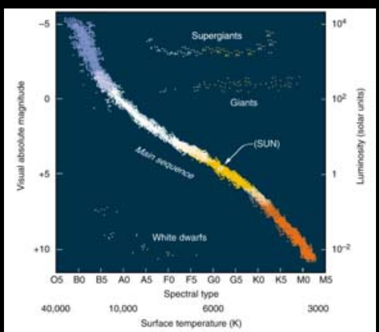
- Stars recycle matter
- No naked eye stars have disappeared
- Many stars have a variable light output

The Glowing Eye of NGC 6751 in Aquila courtesy NASA

Hertzsprung-Russell diagram

Ejnar Hertzsprung (1873 – 1967)

Henry Norris Russell (1877 – 1957)
Courtesy Margaret Olson, grand-daughter



Courtesy Kuhn & Koupelis fig 12.17

Stellar evolution

- Stars spend most of their life converting hydrogen to helium
- End game involves moving up and right
- Final state is a white dwarf

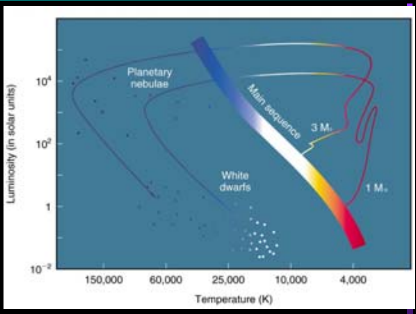
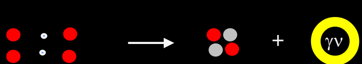


Fig 14.21 Courtesy Kuhn & Koupelis

Fusing hydrogen

- Proton - proton chain reaction results:

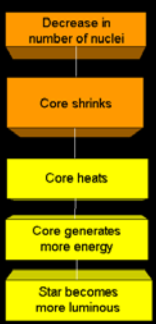


4 protons + 2 electrons → helium + 6 γ + 2 ν

Hydrogen → Helium

- Loss of mass is about 0.7% (26.7 MeV per reaction)
  - using $E = mc^2$, energy available for 1 kg of hydrogen converted is 6.3×10^{14} J

How long?



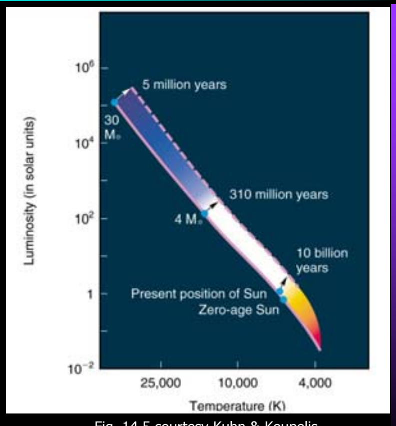


Fig. 14.5 courtesy Kuhn & Koupelis

Carbon cycle

- An alternative way of converting hydrogen to helium
- Faster than the proton-proton chain for stars more massive than 1.5 $M_\odot$
- Responsible for the short lives of massive stars
  - carbon 12 is converted by fusion and β^+ decay to nitrogen 15 before being recovered, along with helium 4

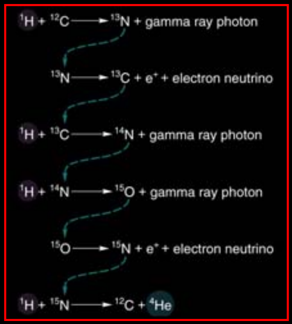


Fig 14.3 courtesy Kuhn & Koupelis

The beginning of the end

- Gravitational collapse
- Temperature increase
- Hydrogen fusing shell
- Expansion

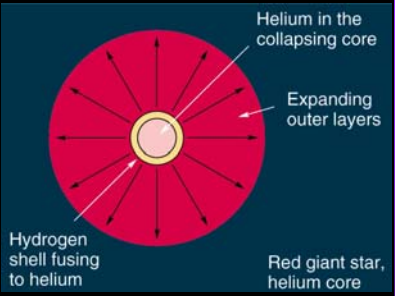


Fig 14.9 Courtesy Kuhn & Koupelis

A look ahead

- A $\rightarrow$ B becoming a red giant
  - inevitable for stars 0.4 $M_\odot$ to 4 $M_\odot$
- At B, the 'helium flash' for our sun

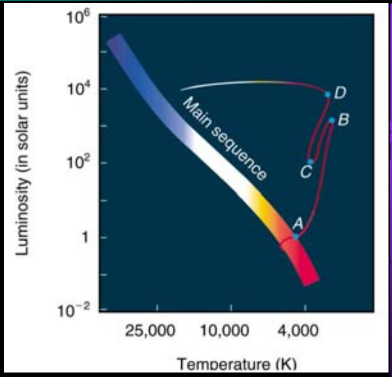
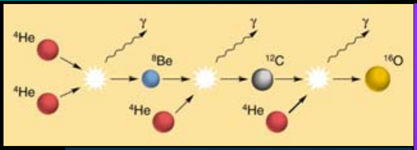
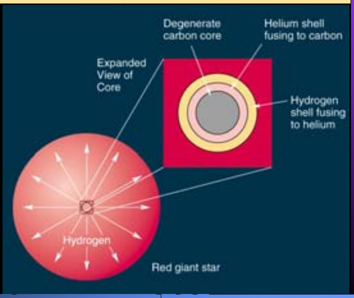


Fig 14.10 Courtesy Kuhn & Koupelis

Helium to carbon

- Essential for life
- Short life of beryllium makes this difficult
- Carbon 12 nuclear resonance helps

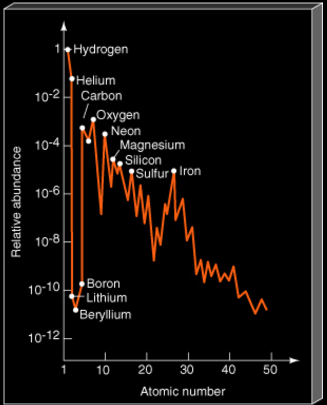




Figs 14.12 and 4.13
Courtesy Kuhn & Koupelis

Abundance of elements

- Formation abundance is dictated by conditions within the cores of dying stars
- Elements on Earth were formed in more than one star
- 10^8 K $\approx$ 10^4 eV
  - elements can be created in particle accelerators



Source: http://www.cfa.ustc.edu.cn/course/CHAISSON/AT421/IMAGES/AACHDEI0.JPG

The final red-giant phase

- ~100 million years for our Sun
- Red-giants are not intrinsically stable
  - escape velocity $v^2 = 2GM/r$
  - ~ 40 km s^{-1}
  - substantial continuous emission of matter
  - pulses of emission create *planetary nebulae*

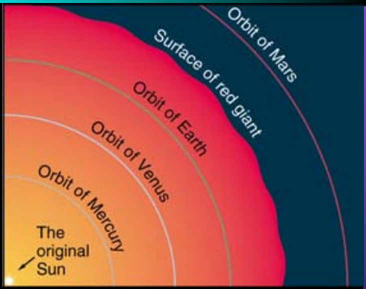
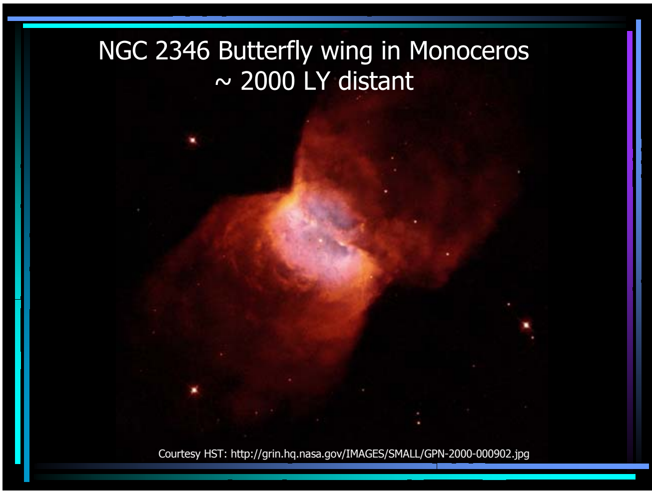


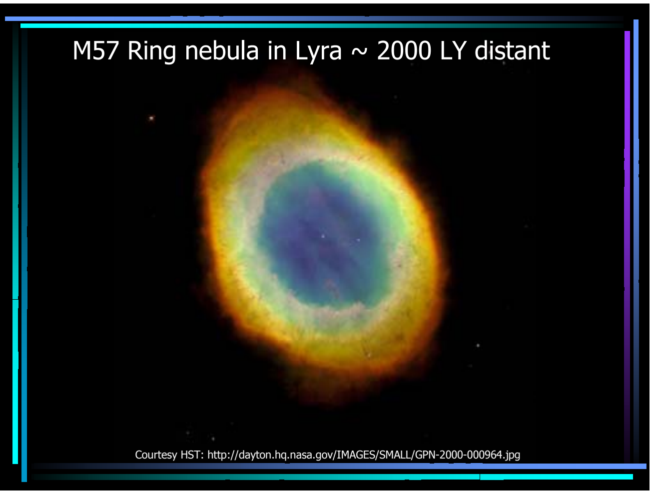
Fig 14.14 Courtesy Kuhn & Koupelis

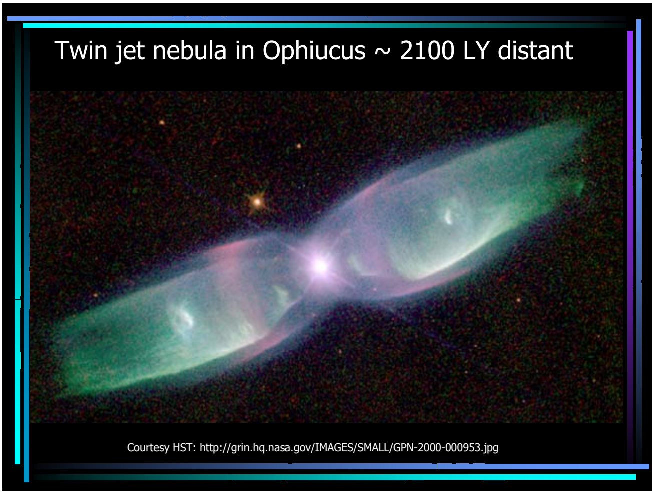

NGC 2392 Eskimo nebula in Gemini
~ 5000 LY away
Courtesy HST: http://dayton.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000882.jpg


NGC 6543 Cat's eye nebula in Draco
~ 3000 LY distant
Courtesy HST: http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000955.jpg


Stingray nebula in Ara ~ 18,000 LY distant
Courtesy HST: http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-001372.jpg


NGC 2346 Butterfly wing in Monoceros
~ 2000 LY distant
Courtesy HST: http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000902.jpg


M57 Ring nebula in Lyra ~ 2000 LY distant
Courtesy HST: http://dayton.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000964.jpg


Twin jet nebula in Ophiucus ~ 2100 LY distant
Courtesy HST: http://grin.hq.nasa.gov/IMAGES/SMALL/GPN-2000-000953.jpg

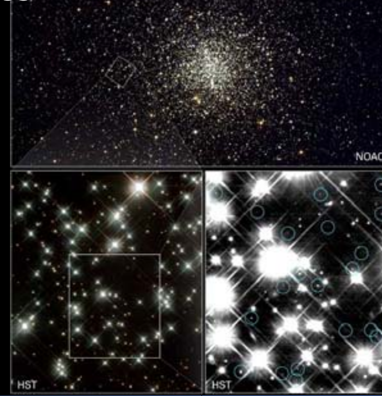
NGC 6369 Little Ghost nebula in Ophiucus ~3000 LY distant

Courtesy HST: http://www.jpl.nasa.gov/images/wfpc/wfpc_110702_browse.jpg

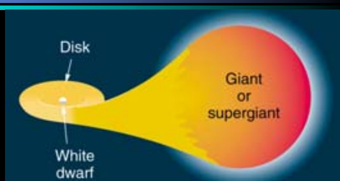
White dwarves

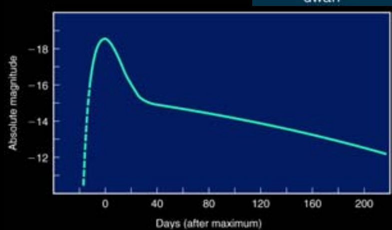
Courtesy HST: http://www.jpl.nasa.gov/images/wfpc/white_dwarf_stars_browse.jpg

- White dwarves in M4
- ~ 12.5 billion years old
- Bottom right HST 8 day exposure of a region ~ 1 LY across
  - white dwarves are circled in blue



Type Ia supernovae





- White dwarf reaches Chandrasekhar limit
- Standard candle M = -19

Figs 4.25 and 4.27 Courtesy Kuhn & Koupelis

Supergiants

- Massive stars create supergiants
- E.g. Betelgeuse

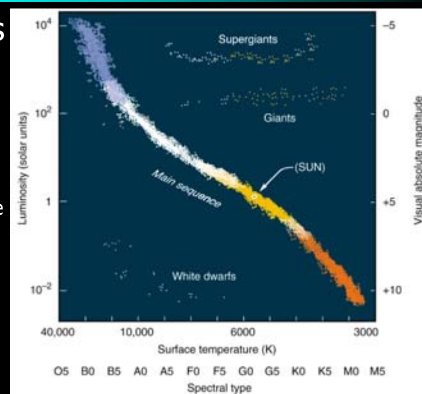


Fig 15.2 Courtesy Kuhn & Koupelis

Supergiant evolution

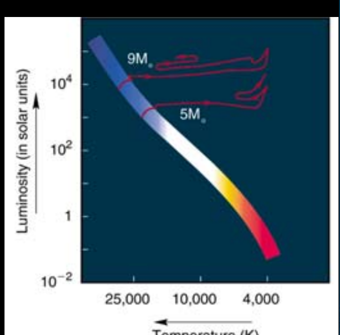
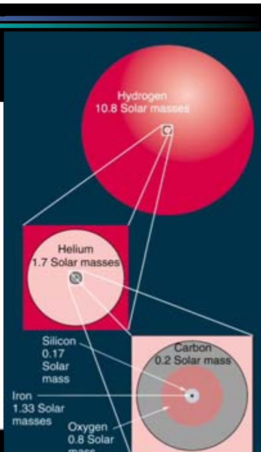


Fig 15.3 courtesy Kuhn & Koupelis



Evolution of a 15 solar mass star

Table 15-2

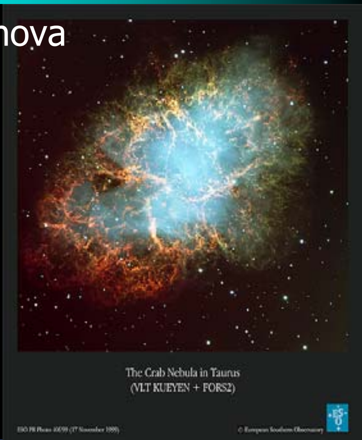
The Evolution of a 15-Solar-Mass Star

Element Fused	Fusion Products	Time	Temperature
Hydrogen	Helium	10,000,000 years	4,000,000 K
Helium	Carbon	>1,000,000 years	100,000,000 K
Carbon	Oxygen, neon, magnesium	1000 years	600,000,000 K
Neon	Oxygen, magnesium	A few years	1,000,000,000 K
Oxygen	Silicon, sulfur	1 year	2,000,000,000 K
Silicon	Iron	A few days	3,000,000,000 K

Table 15.2 courtesy Kuhn & Koupelis

Type II supernova

- Collapse of iron core
- Protons → neutrons + neutrinos
- Rebound wave creates heavy elements + disperses ~ 5 $M_\odot$
- Crab nebula
  - ~ 6500 LY
  - supernova visible by daylight in 1054



Neutron stars

Table 15-5 A Typical Neutron Star

Courtesy Kuhn & Koupelis

Mass	1.5 solar masses
Diameter	20 km (width of a small city)
Density	10^{15} g/cm^3
Temperature	10,000,000 K

- The remnant core of a type II supernova explosion
- Between 1.4 and 3 $M_\odot$
- Too small to be seen in a telescope

Pulsars

- Discovered by Jocelyn Bell in 1967

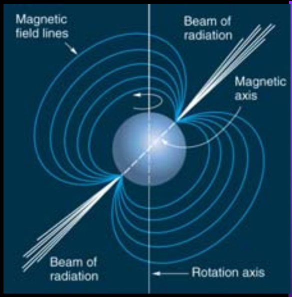


Fig. 15.13 Courtesy Kuhn & Koupelis

← Image of the crab pulsar in X-rays by Chandra probe
Source: http://chandra.harvard.edu/photo/0052/0052_xray_lg.jpg

Black holes, again

Cygnus X-1 graphic, a binary with a massive B0 giant and a black hole

- Black holes are the end game of supermassive stars
- Cores greater than about 3 $M_\odot$ are too massive to form neutron stars
  - neutron degeneracy pressure cannot support the weight
- The core collapses to a black-hole
  - a 5 $M_\odot$ black-hole has a Schwarzschild radius of 15 km
    - this is not much smaller than a neutron star
  - Cygnus X-1, the first X-ray star discovered, behaves as a binary with one component a black hole

The end of PX2512 lectures

Hubble Deep Field HST · WFPC2
PRC96-01a · ST ScI OPO · January 15, 1996 · R. Williams (ST ScI), NASA