Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

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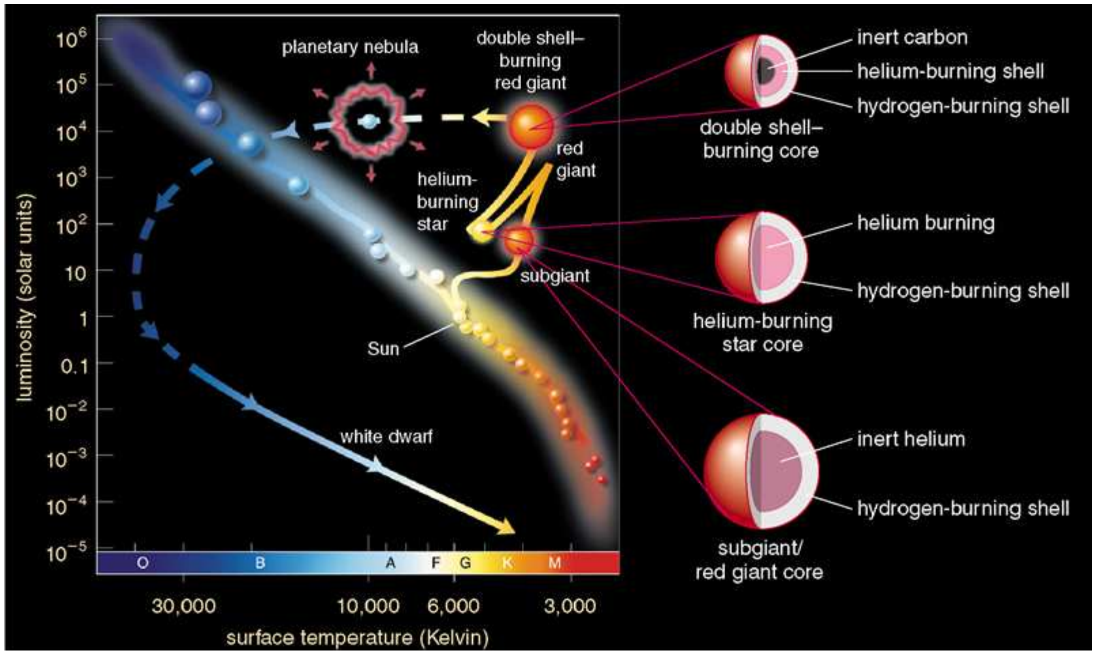
Lecture 16: Th Oct 26

Evolution of low-mass star on HR diagram after it fuses all H in its core

1) Stage 1: Main sequence star (core fusing H to He)

Stars in on main sequence and fusing H to He fusion in the core. This requires core temperature > 10^7 K

(4 H nuclei) à He nucleus + Fusion energy $T_c > 10^7$ K



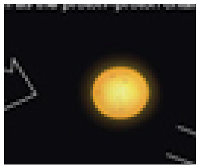
2) Stage 2: Subgiant /Red Giant star (inert He core and Hydrogen-fusing shell)

* All H in the core has been converted into He. Core cannot fuse Helium into Carbon as needs $T_c > 10^8$ K
  (4 He nuclei) à (Carbon nucleus) + Fusion energy $T_c > 10^8$ K

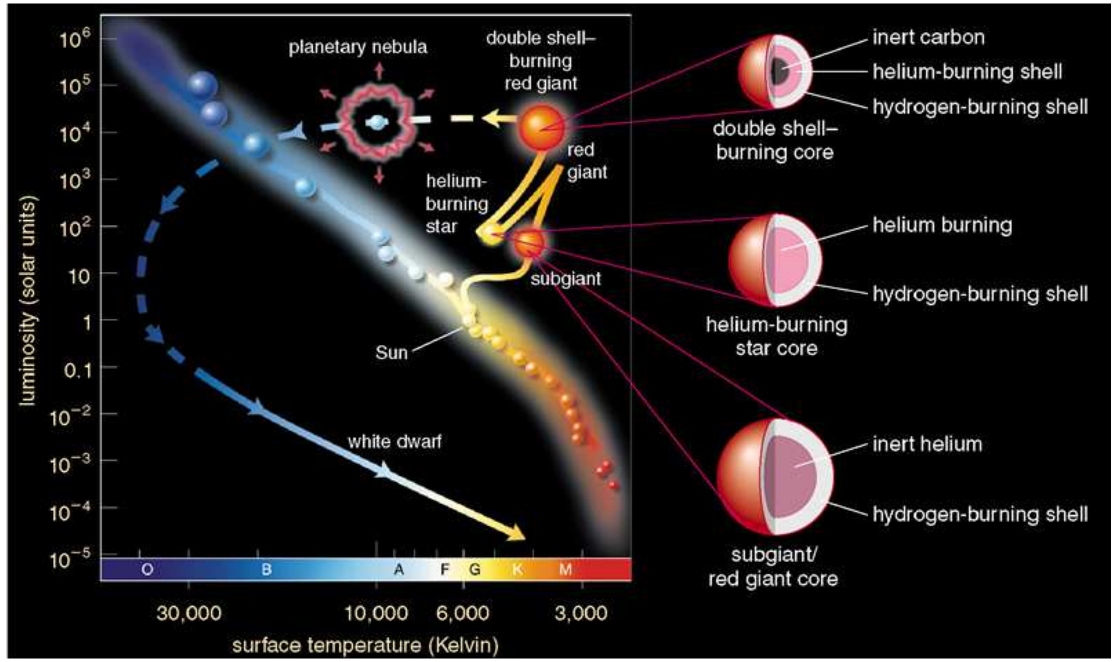
* The inert He core shrinks, and heats up
* Shells of H around the hot He core reach high temperature à fusion of H to Helium starts in the shell

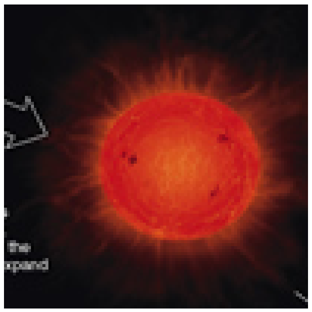
* The star's radius to expand à it enters subgiant/red giant phase : large and luminous

Evolution of low-mass star on HR diagram after it fuses all H in its core

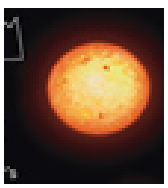


Yellow main sequence star.
H fusion in core at Tc> 10^7 K

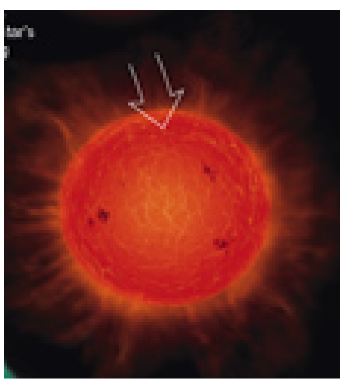




Red giant:
Inert He core
H-fusing shell

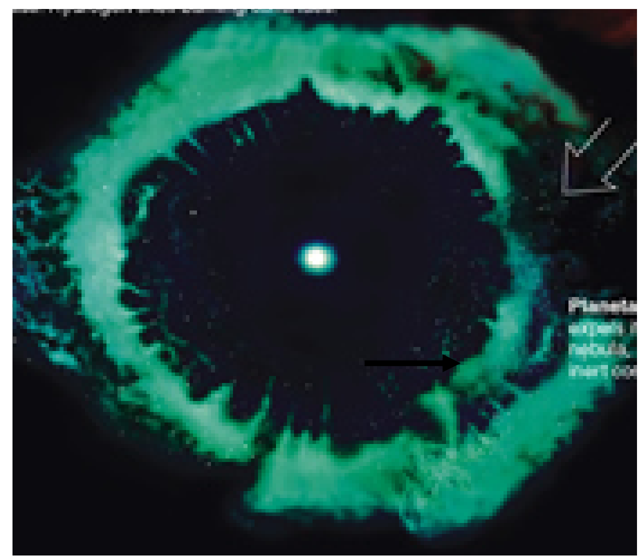


He-burning core at Tc> 10^8 K
+ some reduced H-fusing shell



Second red giant phase.
Inert C core + double shells fusing He, H

Core turns into a white dwarf and outer layers are ejected as a planetary nebula

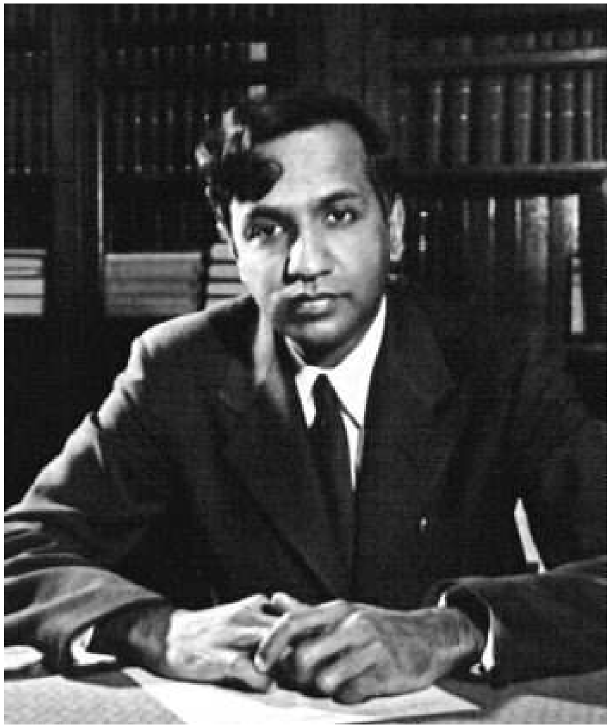


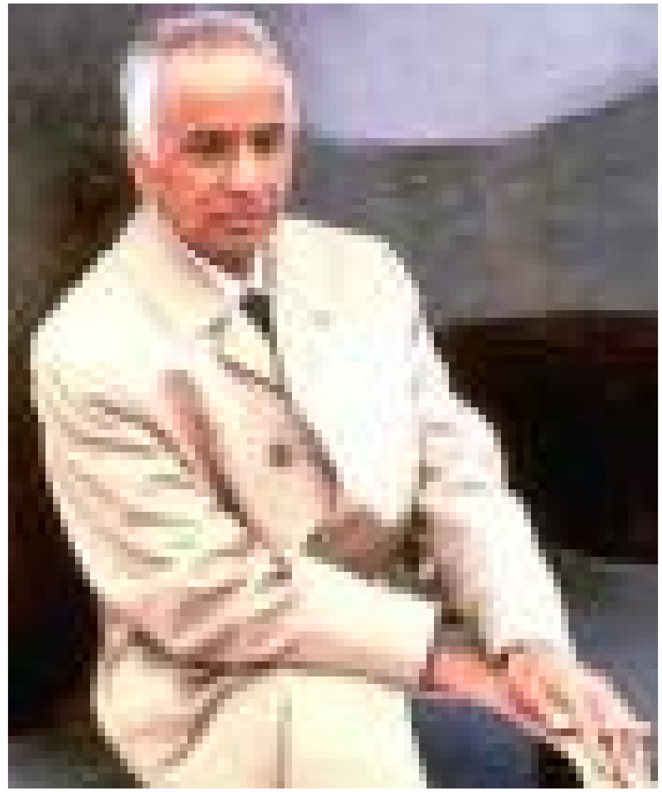
A white dwarf has very high densities

Type of Star	**Luminosity ($L_{/}$)**	**Radius ($R_{/}$)**		**Average Density (gm/cm^3)**
White dwarf	10^{-4}	0.01	(Earth Radius)	10^{6}
Main Sequence	1	1		1
Red Giant	10^{3}	50	(1/4 AU)	10^{-5}
Supergiant	10^{6}	1000	(5 AU)	10^{-9}

A white dwarf has very high densities and is supported against gravitational collapse by degeneracy pressure. This is a special type of pressure that kicks in only at extremely high densities

A white dwarf cannot exceed a maximum mass of 1.4 solar masses





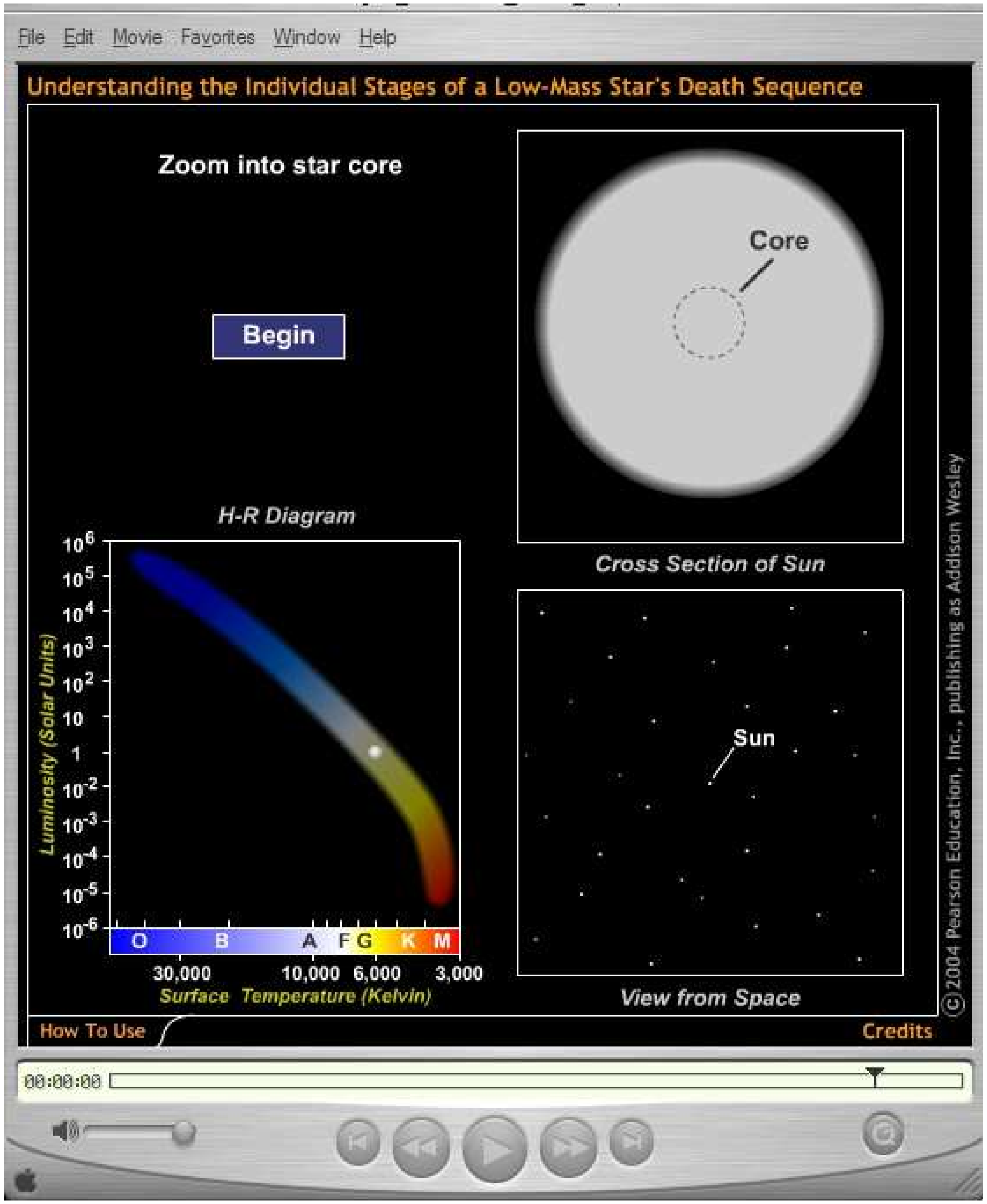
In 1931 Chandrasekhar at age of 19 presented calculations which showed that a white dwarf has a maximum mass limit of 1.4 M_o

He was ridiculed by Eddington at Cambridge. He moved to Uof Chicago in the USA

He was Awarded Nobel prize 30 years later in 1962

The mass limit of 1.4 M_o for a white dwarf is now called the Chandrasekhar mass

Evolution of a low-mass star

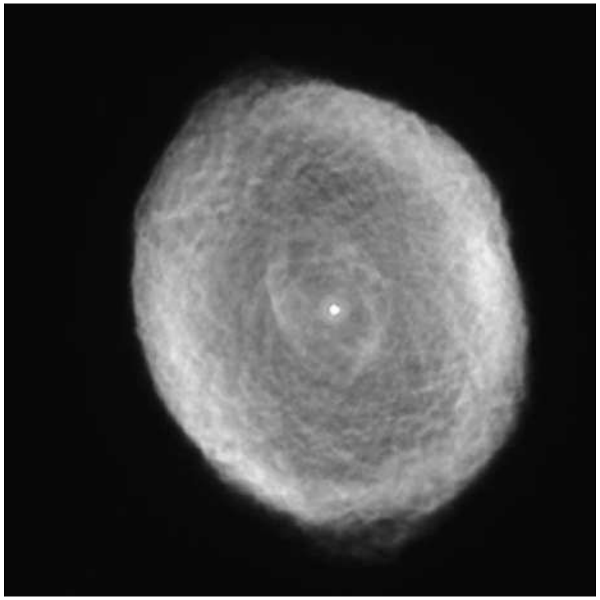


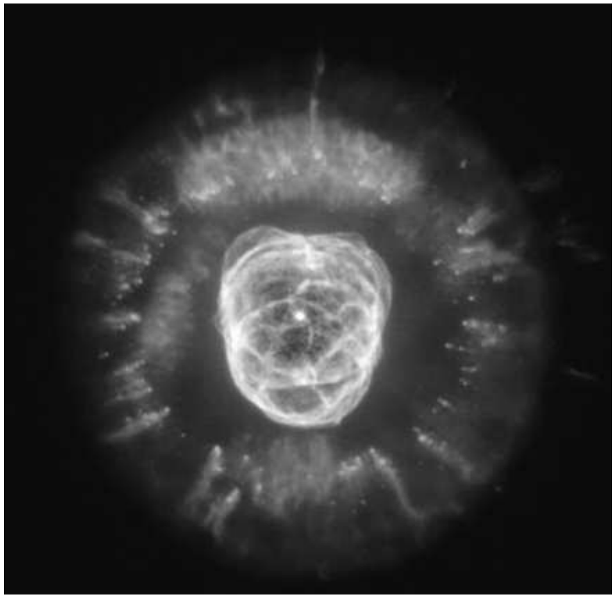
In class-movie
Stages of evolution
of low mass star

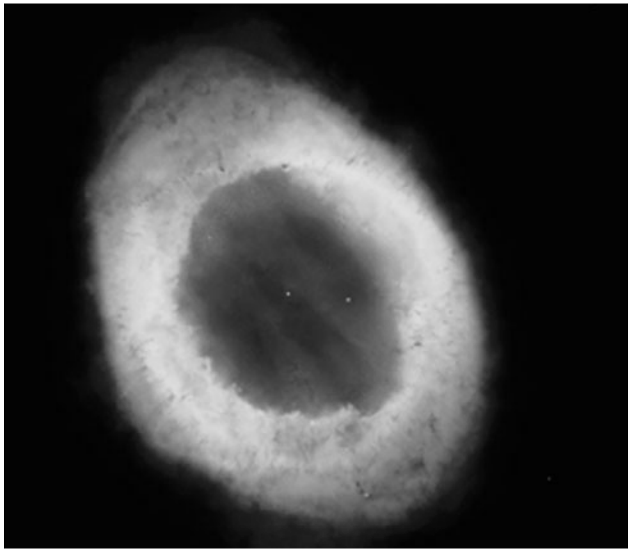
When a low mass star dies

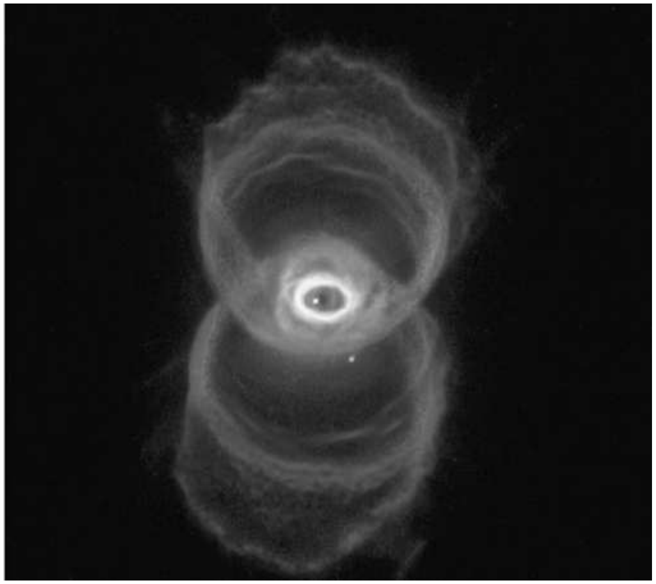
- **its core turns into a white dwarf**
- **its outer layers are ejected as a planetary nebula**

Evolution of low-mass stars: Planetary Nebulae



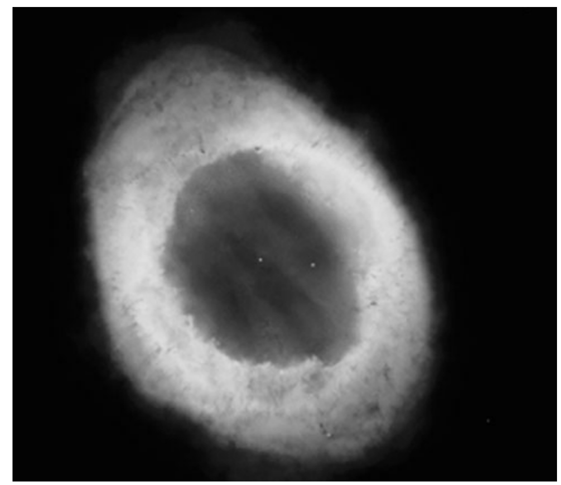






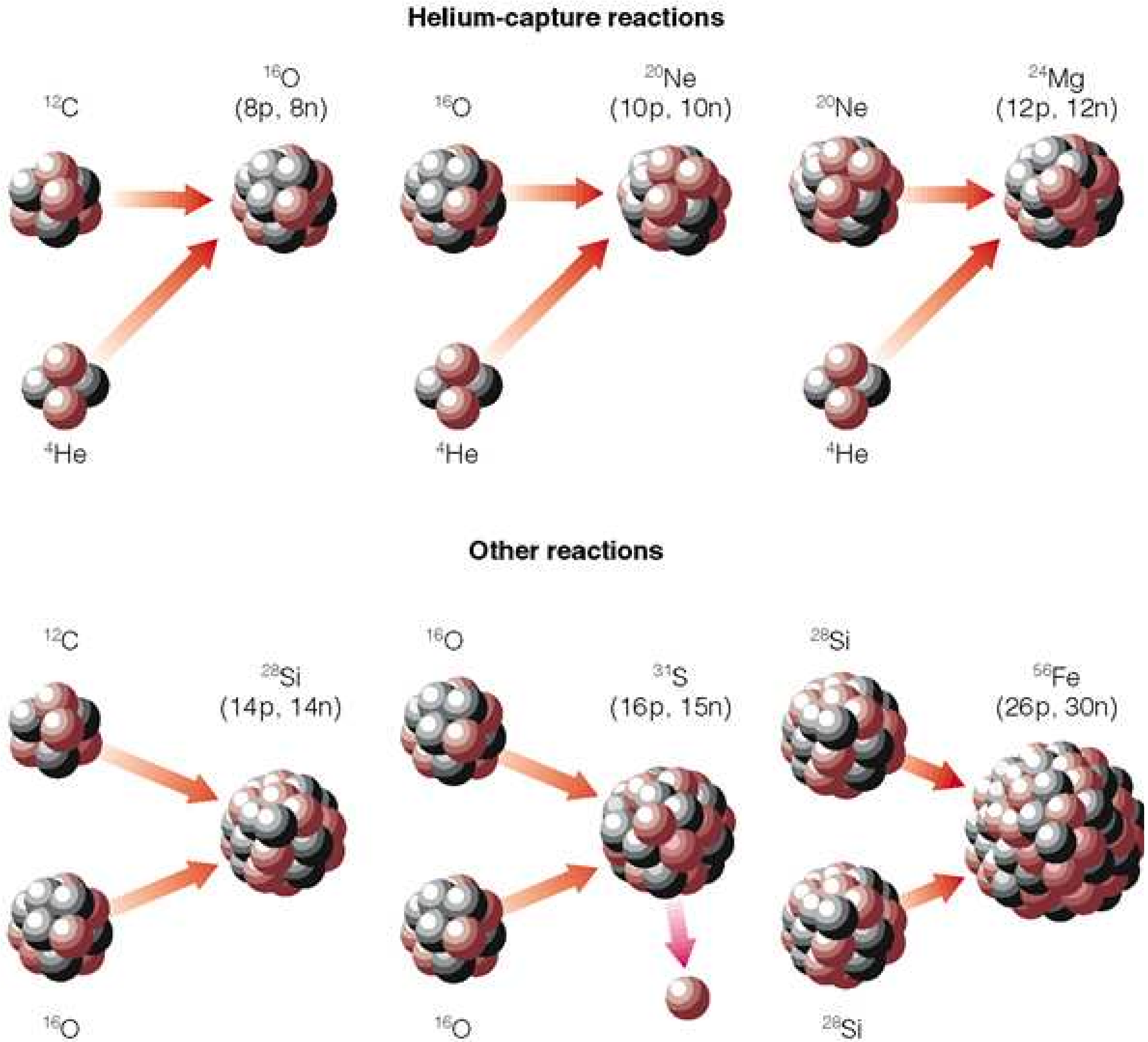
Evolution of low-mass star

In class-movie: Formation of planetary nebula, the Helix Nebula



<u>Evolution and Death of High Mass Stars</u>

Successive episodes of more advanced fusion in core of massive stars



Hydrogen à Helium;
Helium à Carbon

This is last fusion stage in low mass stars, but in high mass stars, fusion proceeds further:

<u>Helium capture reaction</u>

C + He à Oxygen; Oxygen + He à Neon

Neon + He à Mg

<u>Other reactions</u>

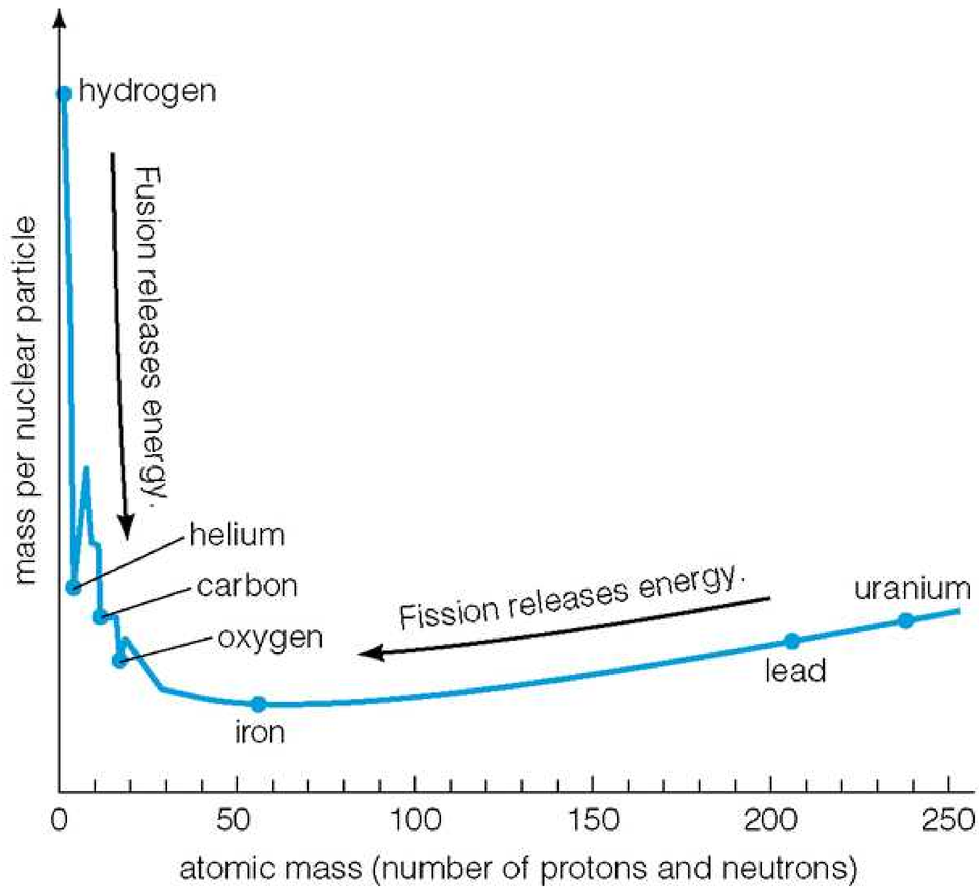
C + O à Silicon

O + O à Sulphur

etc

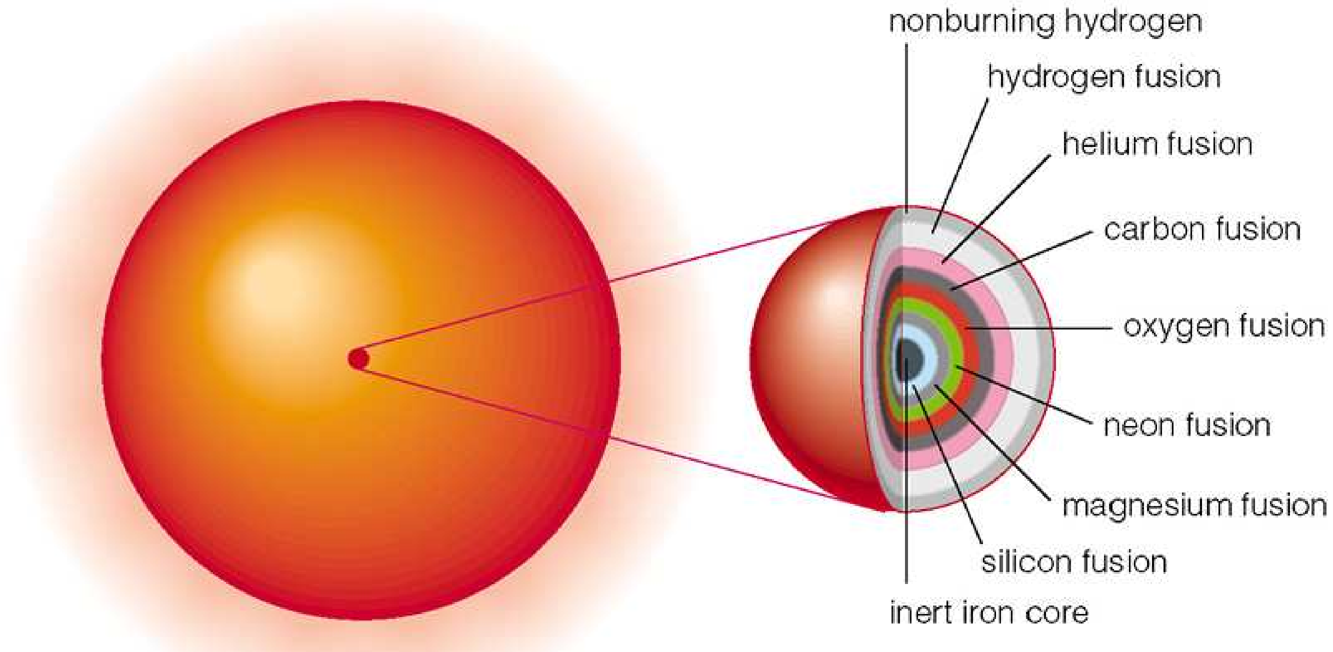
Si + Si à Iron (last gasp)

Why is fusion of Si into iron the last fusion reaction ?



- Recall fusion energy E = (starting mass M1 – final mass M2) c^2
  Need starting mass M1 > final mass M2 for energy to be released!
- Note that on the plot, the difference dM = (starting mass M1 – final mass M2) becomes smaller and smaller at each successive stage of fusion…

A massive star near the end of its lifetime has "onion ring" structure

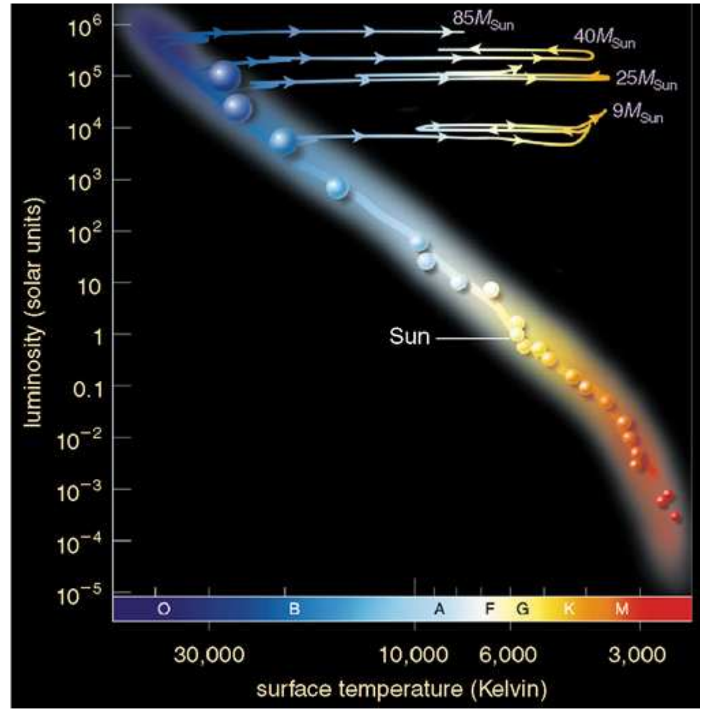


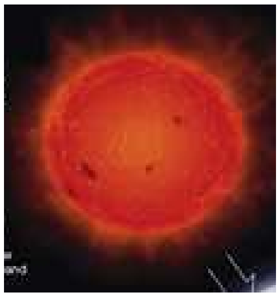
Onion ring structure from nuclear fusion:

à Inert iron core and outer rings fusing Si, Mg, Ne, O, C, He, H

Evolution of a high-mass ($M>8M_o$) star on HR diagram

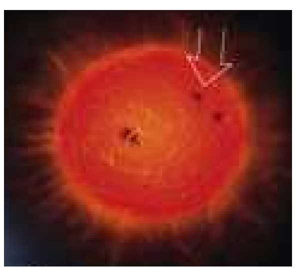
Blue main sequence star. H fusion in core via CNO cycle





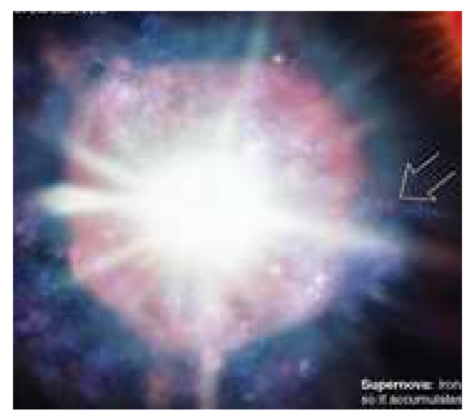
Red supergiant:
Inert He core
H-burning shell

'Blue' supergiant:
He-burning core +
reduced H-burning
in shell



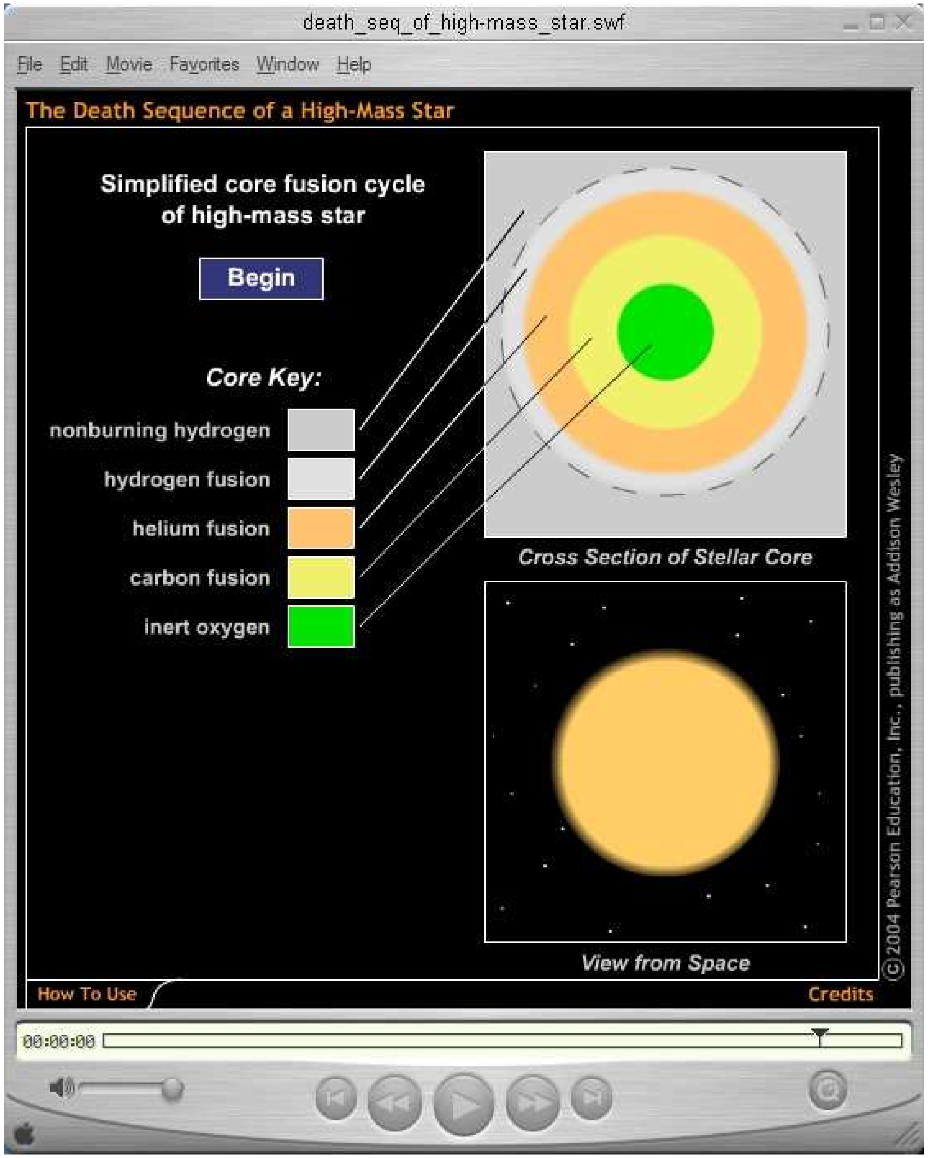
Superrgiant phases. Inert C core shrinks till fusion of C starts, then of O, then…of Si until iron collects in core. Multiple shells burning C, O, He, H

When it is no longer supported by deg-pressure, iron core collapses, and e- p+ combine to form a neutron star or BH. Star explodes outer layers into SN



Evolution of a high-mass star

In class-movie
Stages of evolution
of high-mass star



When a high mass star dies
- its core turns into a neutron star or a black hole,
- its outer layers are ejected as a supernova remnant

Death of a high mass star leads to a SN remnant and a neutron star

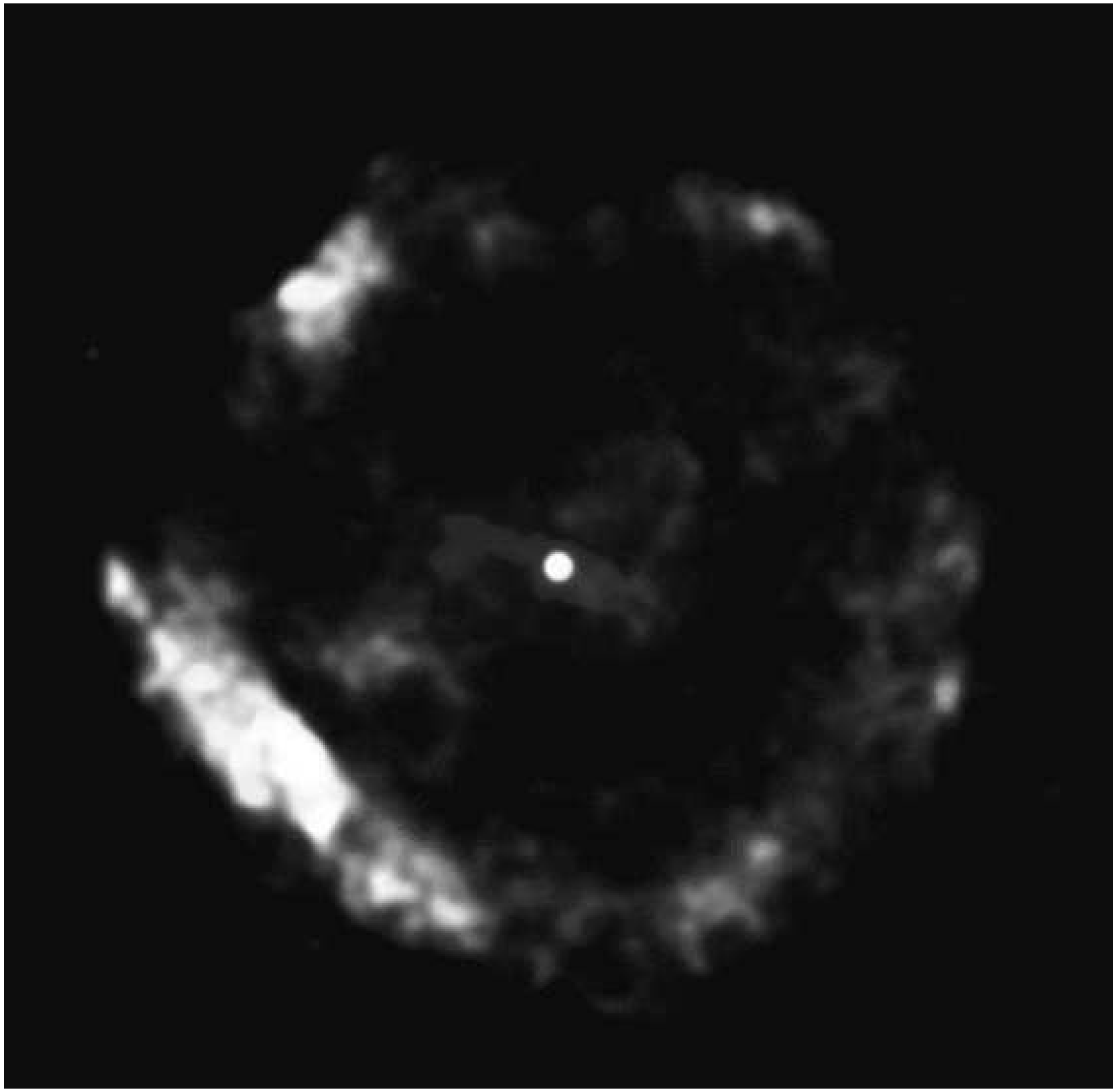
This image at optical wavelengths shows the Crab nebula, a supernova remnant.

The remnant is made of expanding hot gas full of heavy elements like C, N, O, Si, S, Mg, Fe

Where is the neutron star?

At the center of the supernova remnant…. radio images show a spinning neutron star

Death of a high mass star leads to a SN remnant and a neutron star



X-ray image from CXO of a neutron star at center of old supernova remnant

before

after

Visible image of Supernova remnant 1987A in the LMC galaxy

Neutron Stars

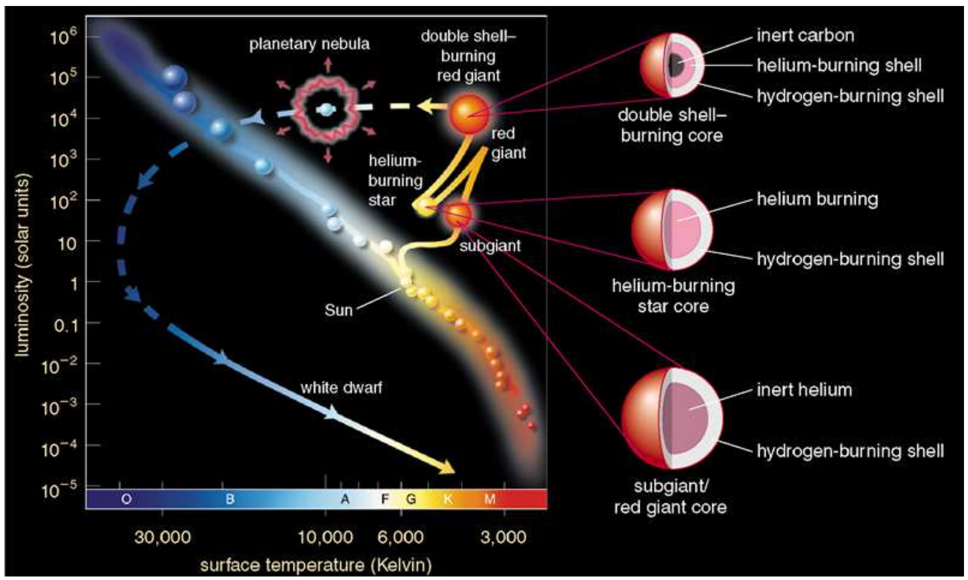
Fritz Zwicky ; 1934: suggested supernova forms when star collapses into neutron star

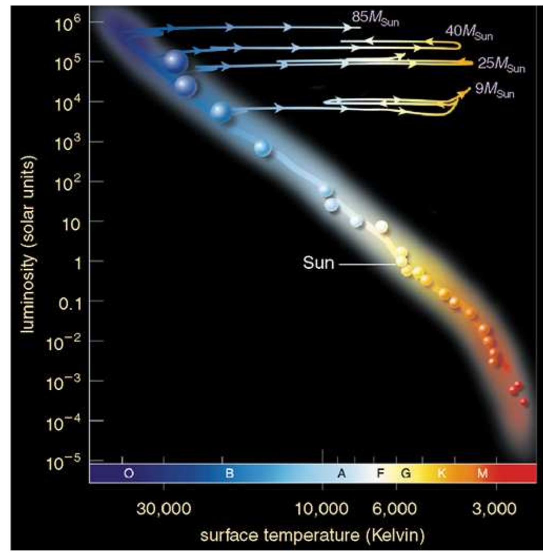
Jocelyn Bell . Discovered first rotating neutron star or pulsar in 1967.

Lifetime of low-mass versus high-mass stars

1) A star spends over 80% of its lifetime on the main sequence, fusing H to He in its core. Subsequent stages of evolution are very swift.

à **The lifetime of a star is approximately equal to its main sequence lifetime.**





2) A high mass star has more H in its core for fusing into He than a low mass star, Yet its main sequence lifetime is   MUCH SHORTER !   Why?