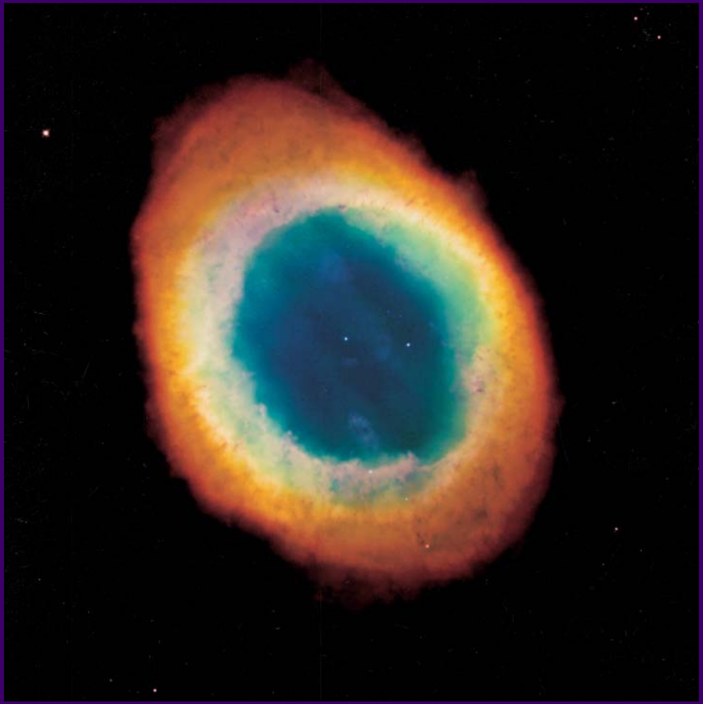
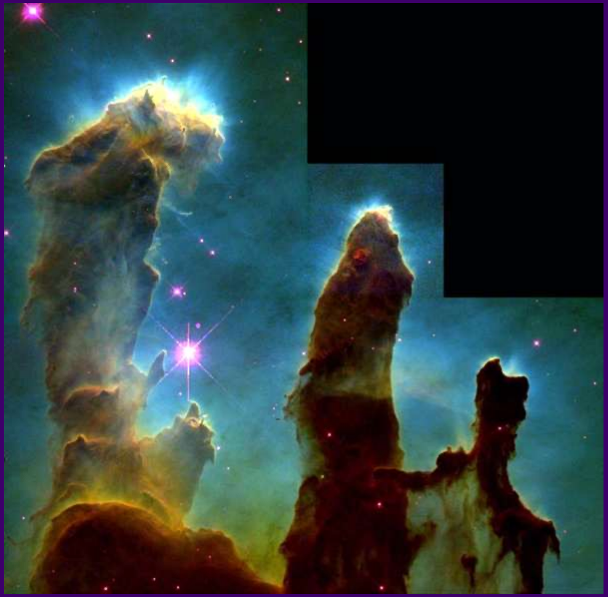


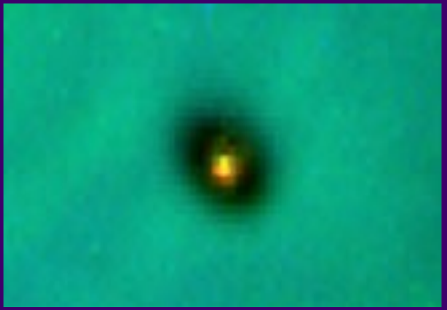
Red Giants and White Dwarfs

Today:

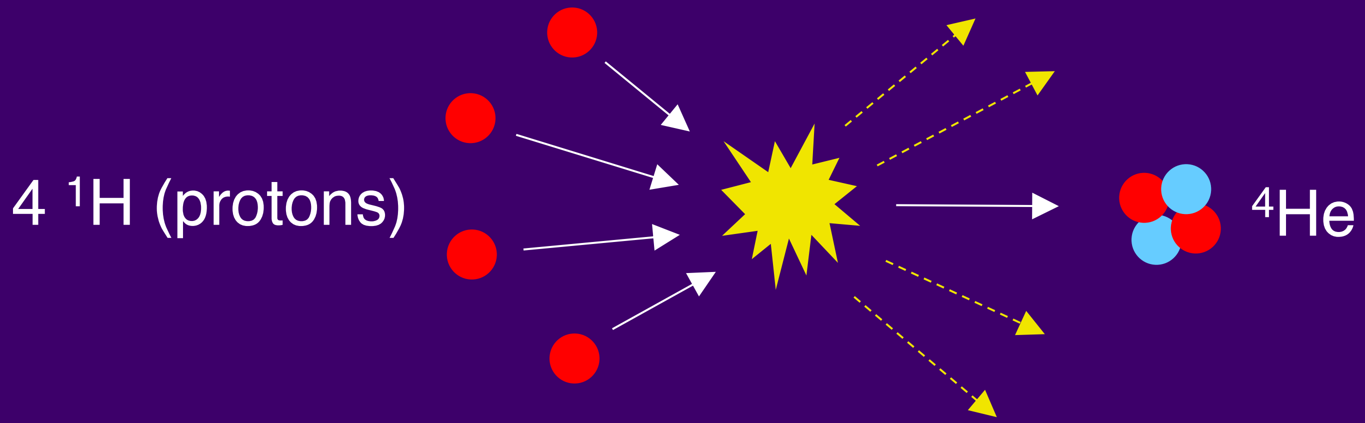
- Life cycles of stars
- Aging stars: red giants
- “Planetary” nebulae
- Spent stars: white dwarfs

Star Formation





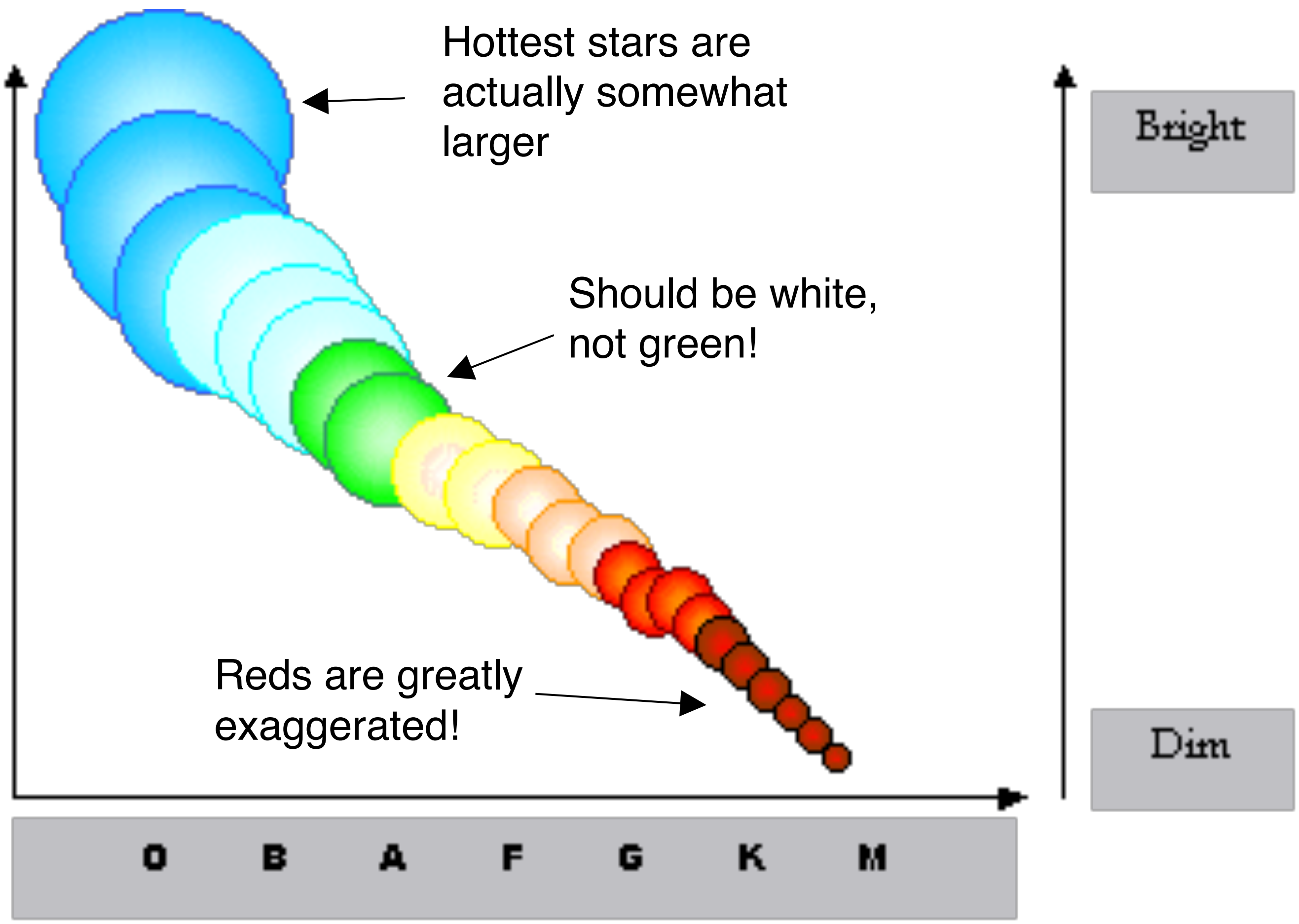
Fusion of Hydrogen into Helium



This reaction powers all main-sequence stars.

The more massive the star, the more pressure at its center and therefore the faster the reaction occurs.

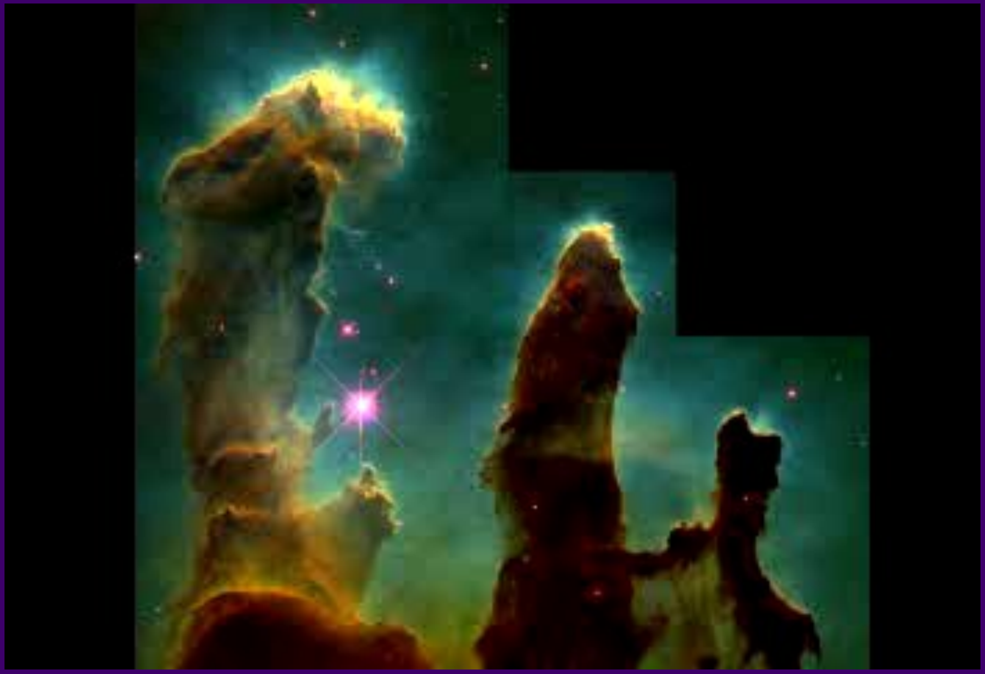
Sizes of Main-Sequence Stars



Main Sequence Lifetimes
(predicted)

Mass (suns)	Surface temp (K)	Luminosity (suns)	Lifetime (years)
25	35,000	80,000	3 million
15	30,000	10,000	15 million
3	11,000	60	500 million
1.5	7,000	5	3 billion
1.0	6,000	1	10 billion
0.75	5,000	0.5	15 billion
0.50	4,000	0.03	200 billion

A Star is Born!



Movie. Click to play.

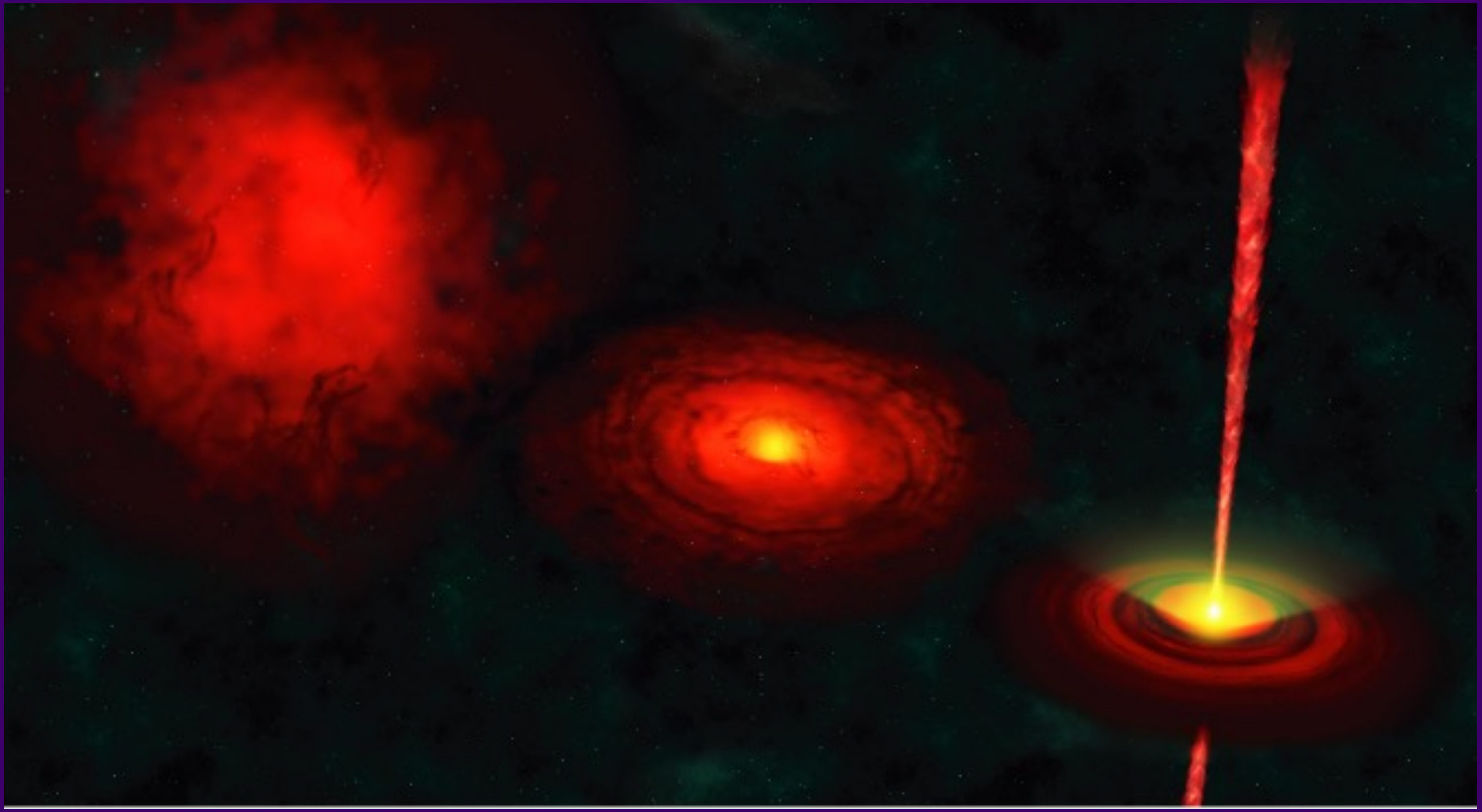
Eagle Nebula

Hubble Space Telescope

Pleadies

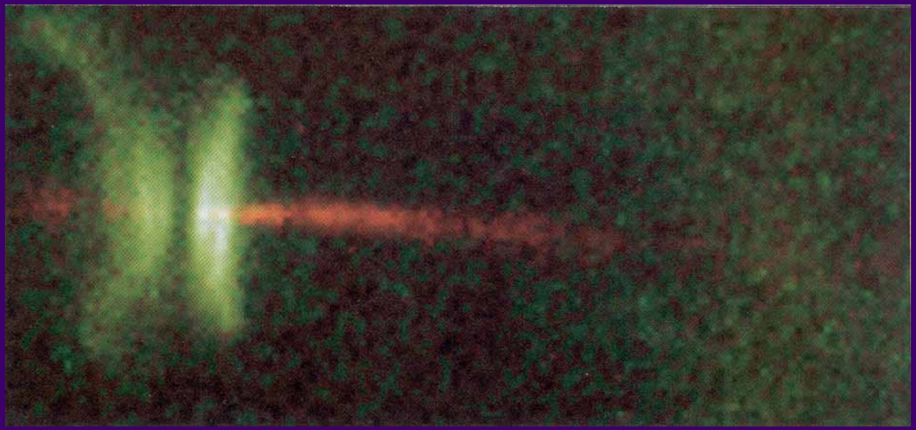
Star Formation

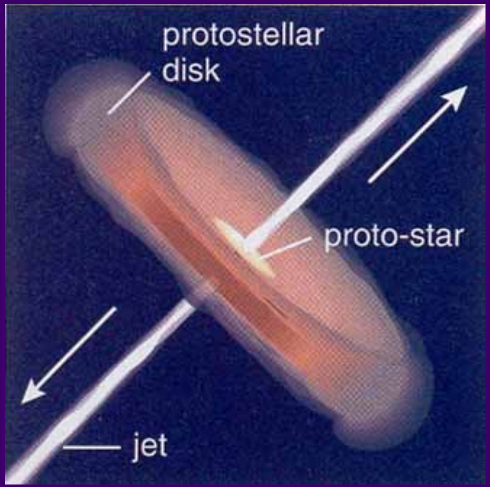
- As the protostar collapses, angular momentum is conserved
  - the protostar rotates faster
  - matter falling in to the protostar flattens into a (protostellar) disk
  - a planetary system could form from this disk



Direct Evidence of Disks & Jets

a disk forms

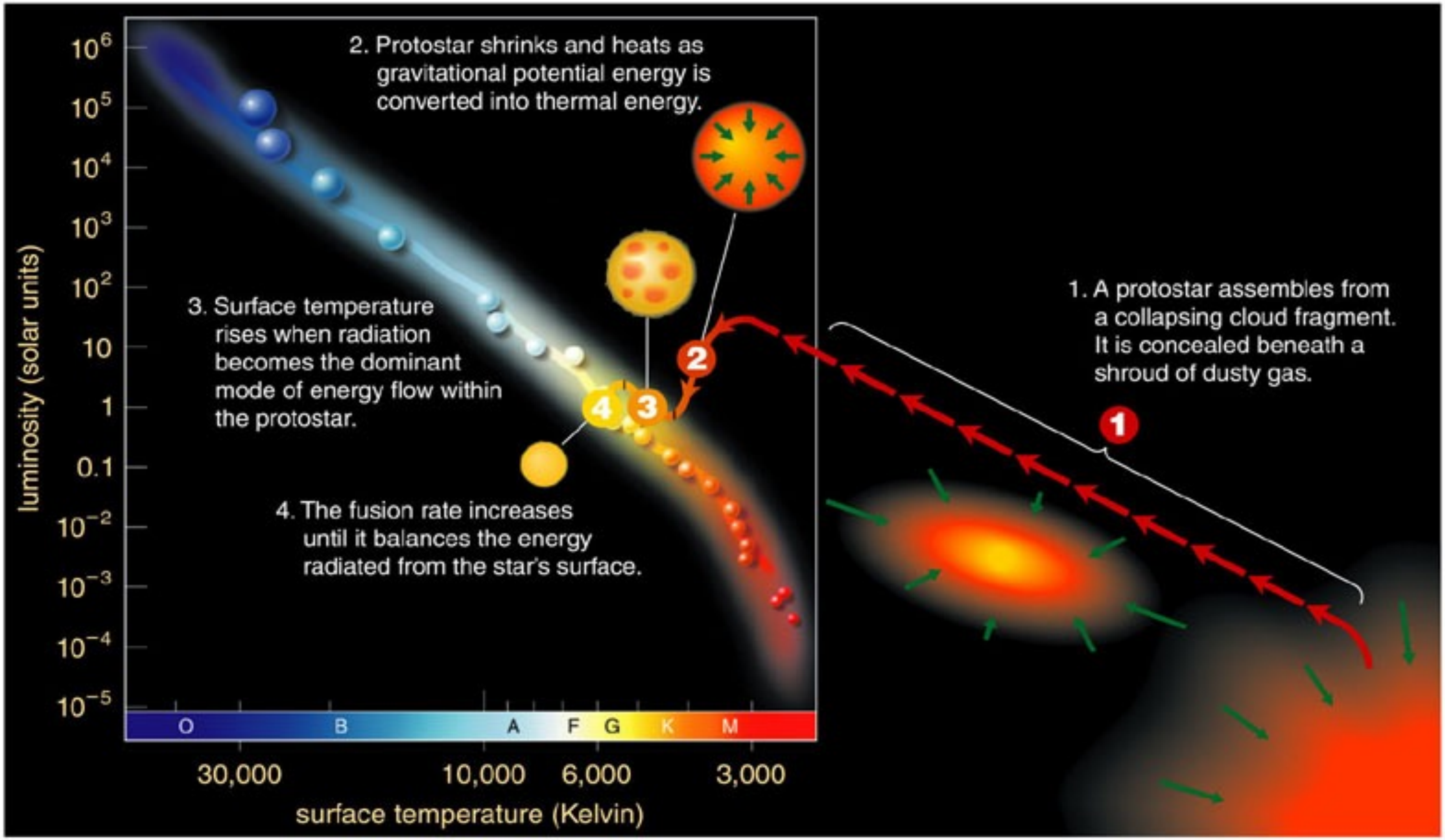




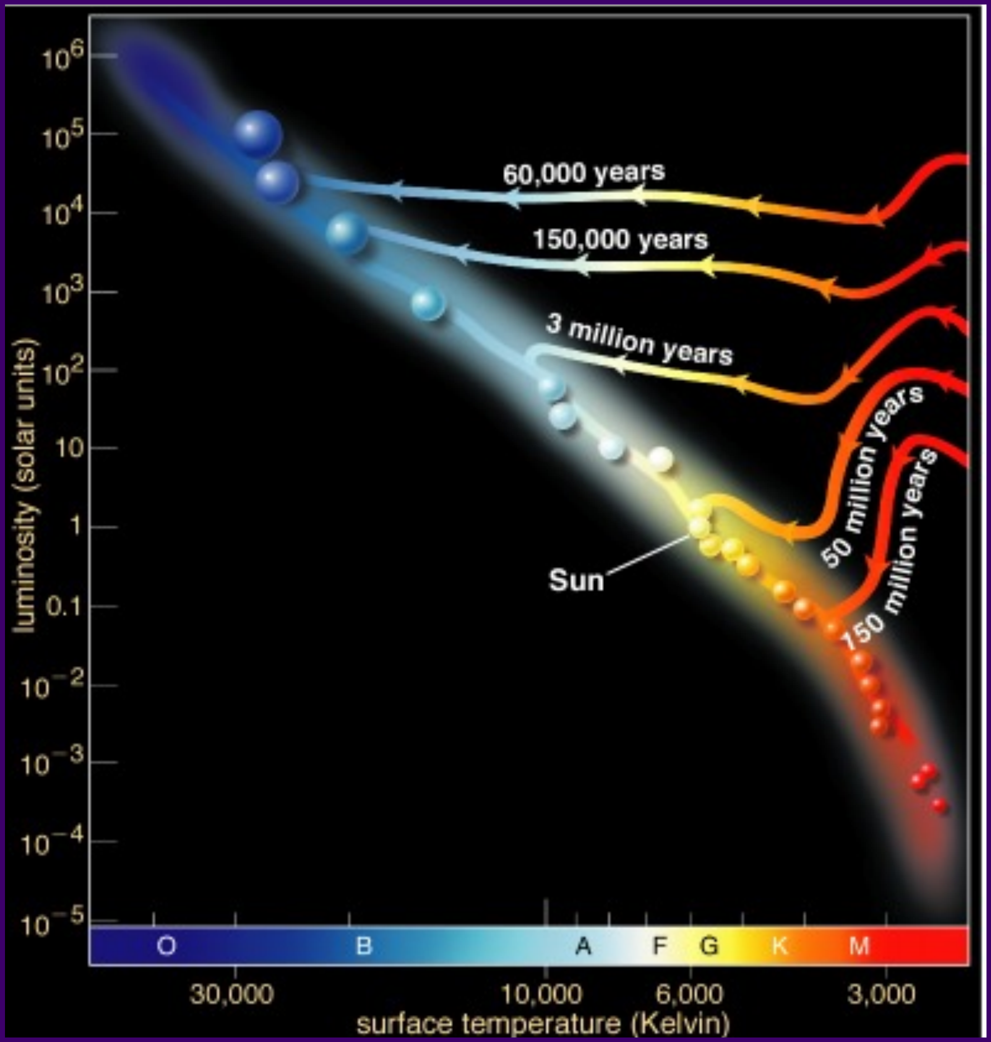
Star Formation

- As the protostar heats up, enough thermal energy is radiated away from surface to allow collapse to continue.
  - energy is transported to surface first via convection
  - as core gets even hotter, transport via radiation takes over
- The protostar must rid itself of angular momentum, or it will tear itself apart
  - magnetic fields drag on the protostellar disk
  - fragmentation into binaries
- Fusion reactions begin when core reaches 10^7 K

Stages of Star Formation on the H-R Diagram



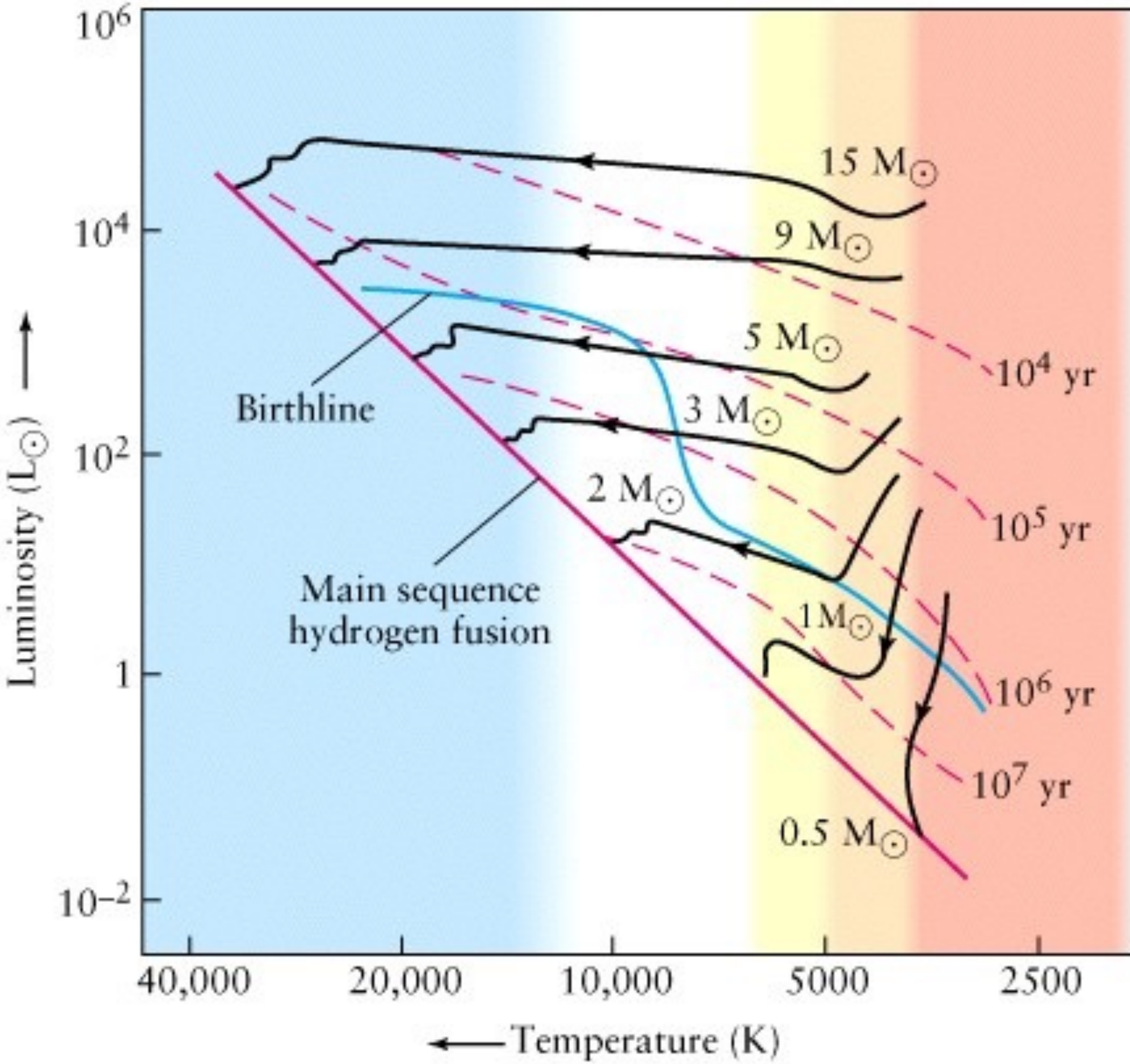
Arrival on the Main Sequence



- The mass of the protostar determines:
  - how long the protostar phase will last
  - where the new-born star will land on the MS

    i.e., what spectral type the star will have while on the main sequence

When a protostar ceases to accumulate mass, it, becomes a pre-main-sequence star.



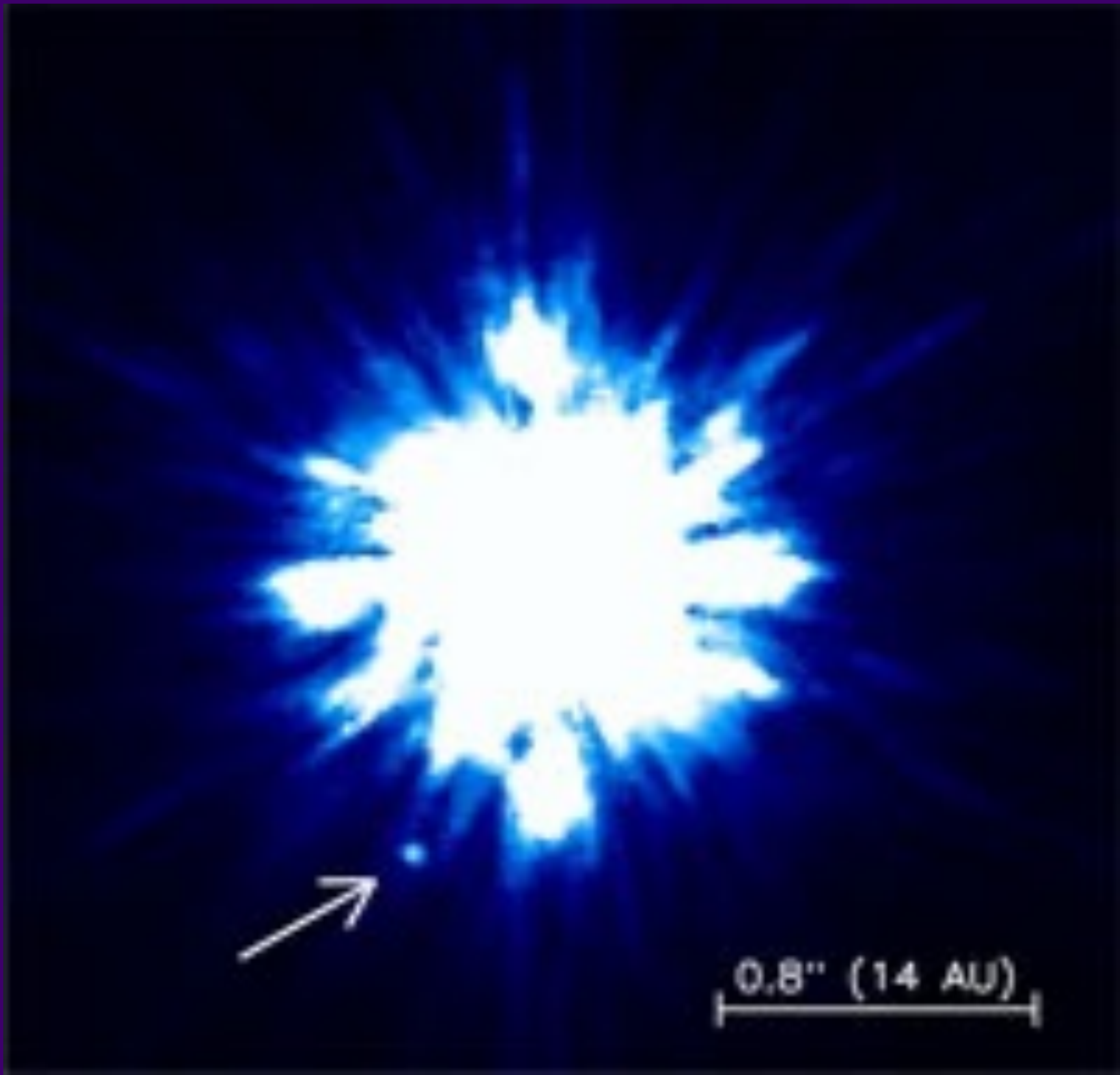
It's life path is forever determined by its initial mass

Missing the Main Sequence

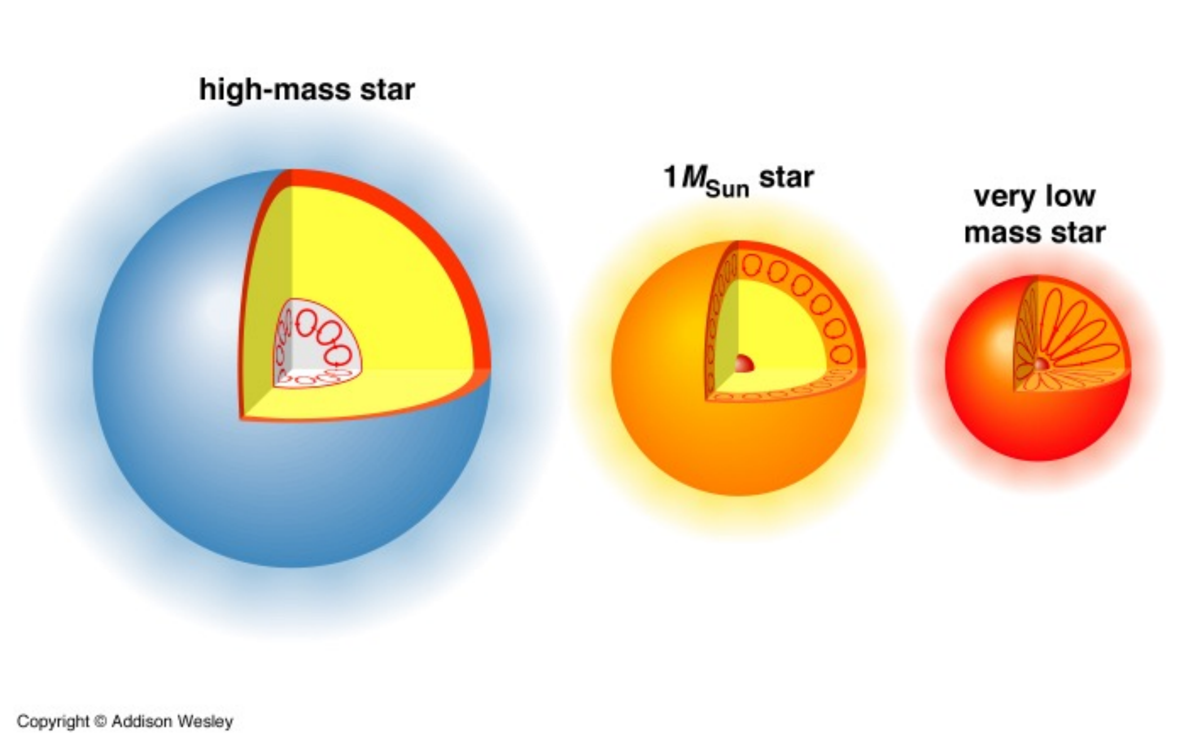
- If the protostar has a mass < 0.08 $M_\odot$:
  - It does not contain enough gravitational energy to reach a core temperature of 10^7 K
  - No fusion reactions occur
  - The star is **stillborn**!
- We call these objects Brown Dwarfs.
- They are very faint, emit infrared, and have cores made of Hydrogen
  - degenerate cores

Detection by
Michael Liu (IfA)
January, 2002

“Brown Dwarf”
orbiting a star
at same
distance as
Saturn in Solar
system



Life on the Main Sequence



The internal structure is different for MS stars of different masses.

The more massive a star, the faster it goes through its main sequence phase

Table 11-1
Main-Sequence Lifetimes

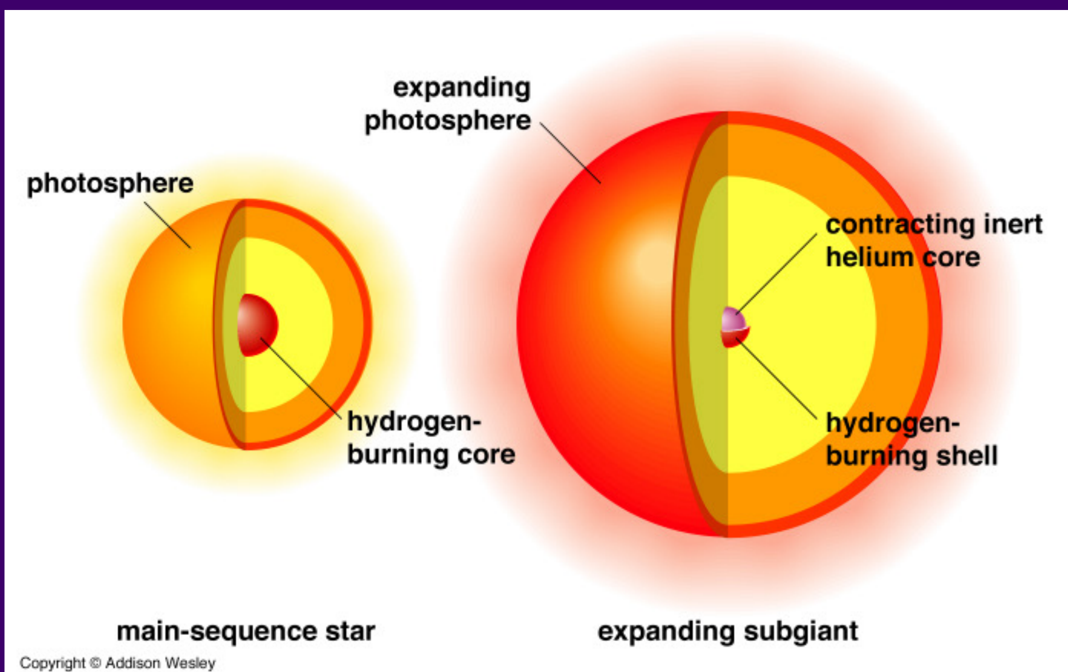
Mass ($M_\odot$)	Surface temperature (K)	Luminosity ($L_\odot$)	Time on main sequence (10^6 years)	Spectral class
25	35,000	80,000	3	O
15	30,000	10,000	15	B
3	11,000	60	500	A
1.5	7,000	5	3,000	F
1.0 (Sun)	6,000	1	10,000	G
0.75	5,000	0.5	15,000	K
0.50	4,000	0.03	200,000	M

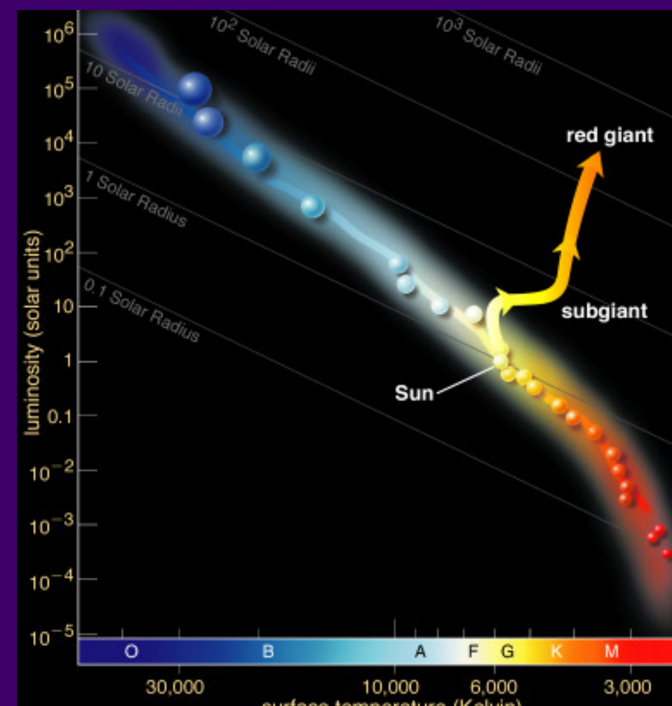
When core hydrogen fusion ceases, a main-sequence star becomes a giant

- The star can no longer support its weight
- The enormous weight from the outer layers compresses hydrogen in the layers just outside the core enough to initiate shell hydrogen fusion.
- This extra internal heat causes the outer layers to expand into a giant star.

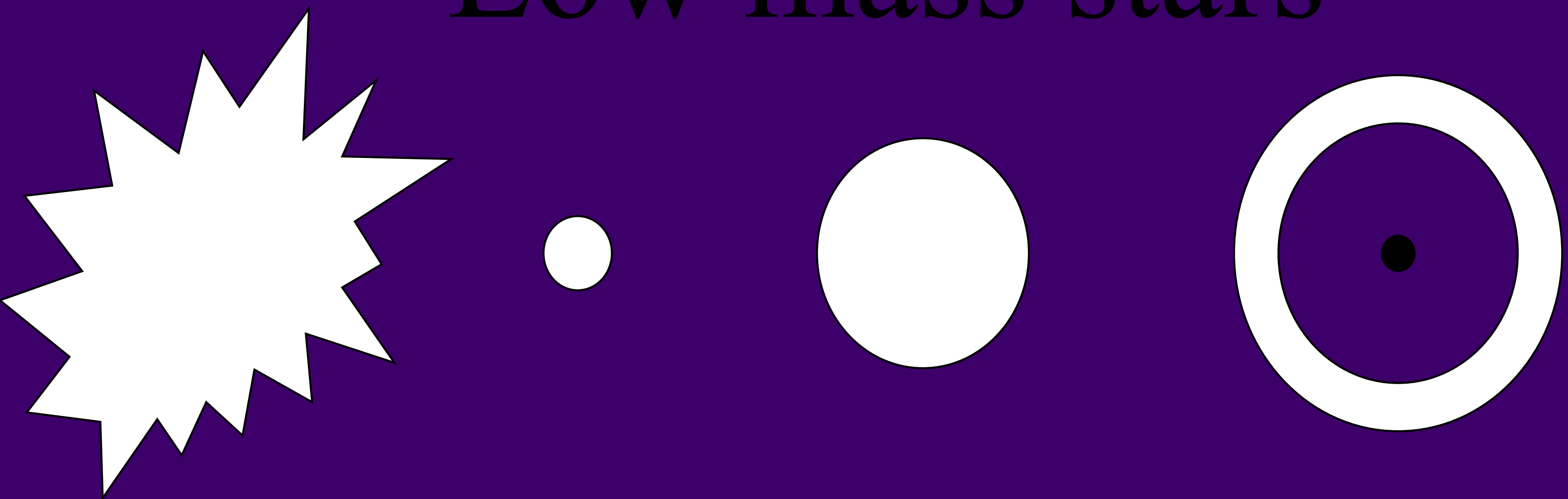
Leaving the Main Sequence

- The core begins to collapse
  - H shell heats up and H fusion begins there
  - there is less gravity from above to balance this pressure
  - so the outer layers of the star expand
  - the star is now in the **subgiant** phase of its life





Low mass stars



Interstellar Cloud

Main Sequence Star

Red Giant

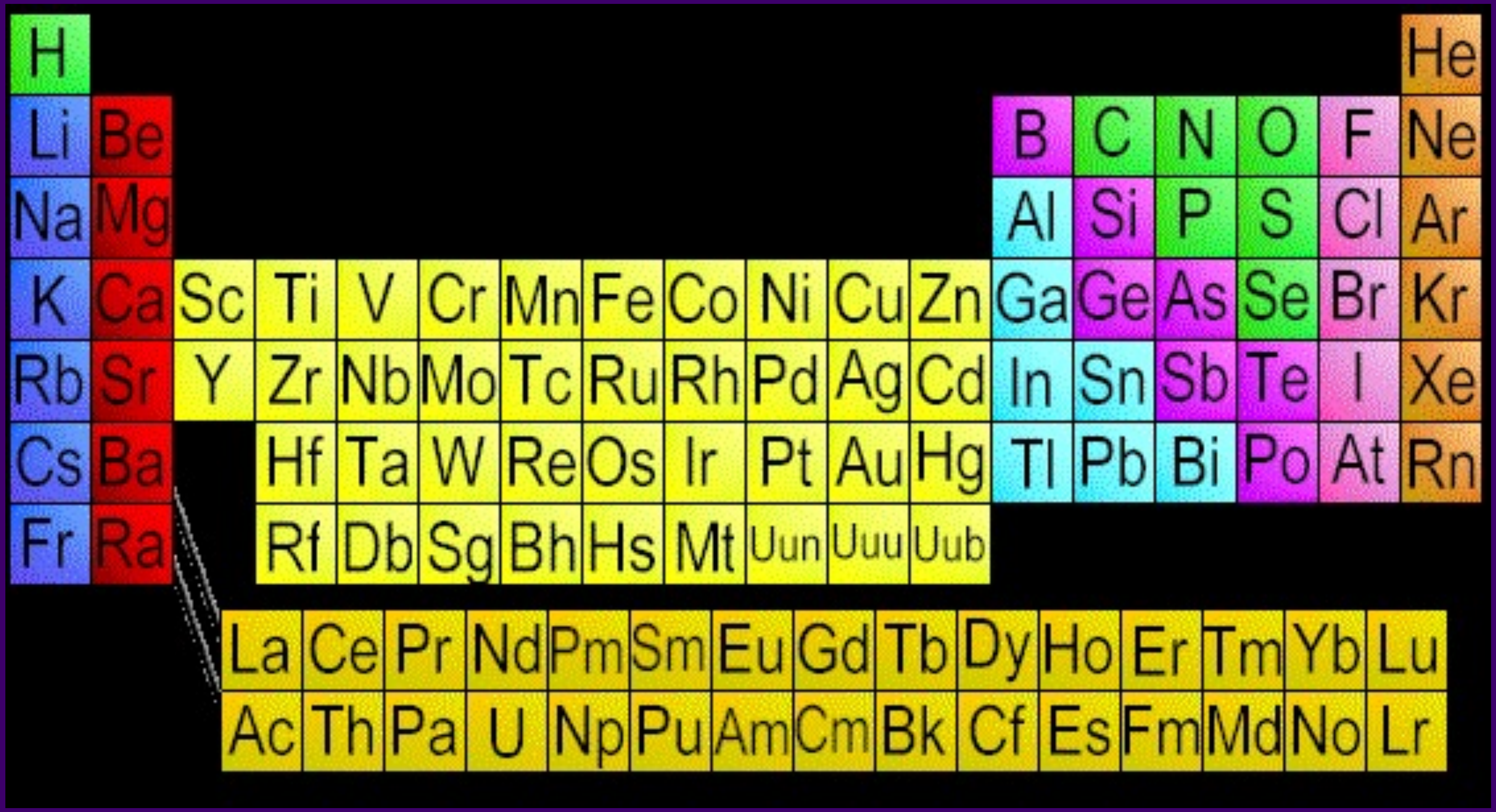
Planetary Nebula

White Dwarf

Fusion…

H fuses into He

What could He fuse into?

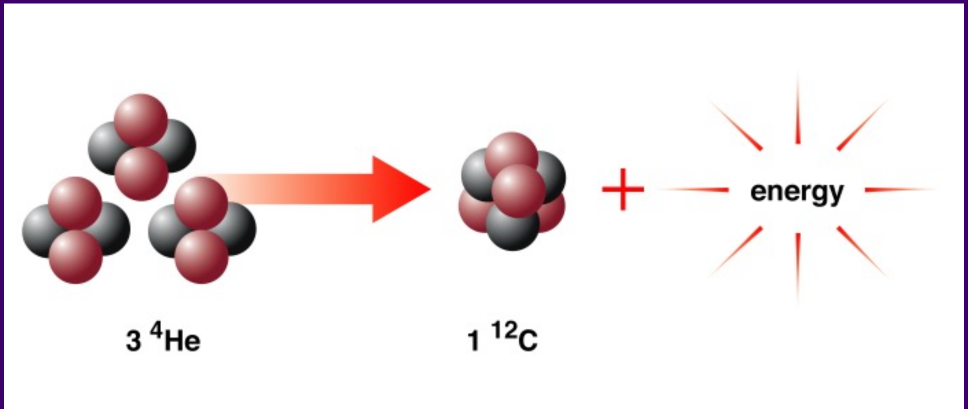


Helium fusion begins at the center of a giant

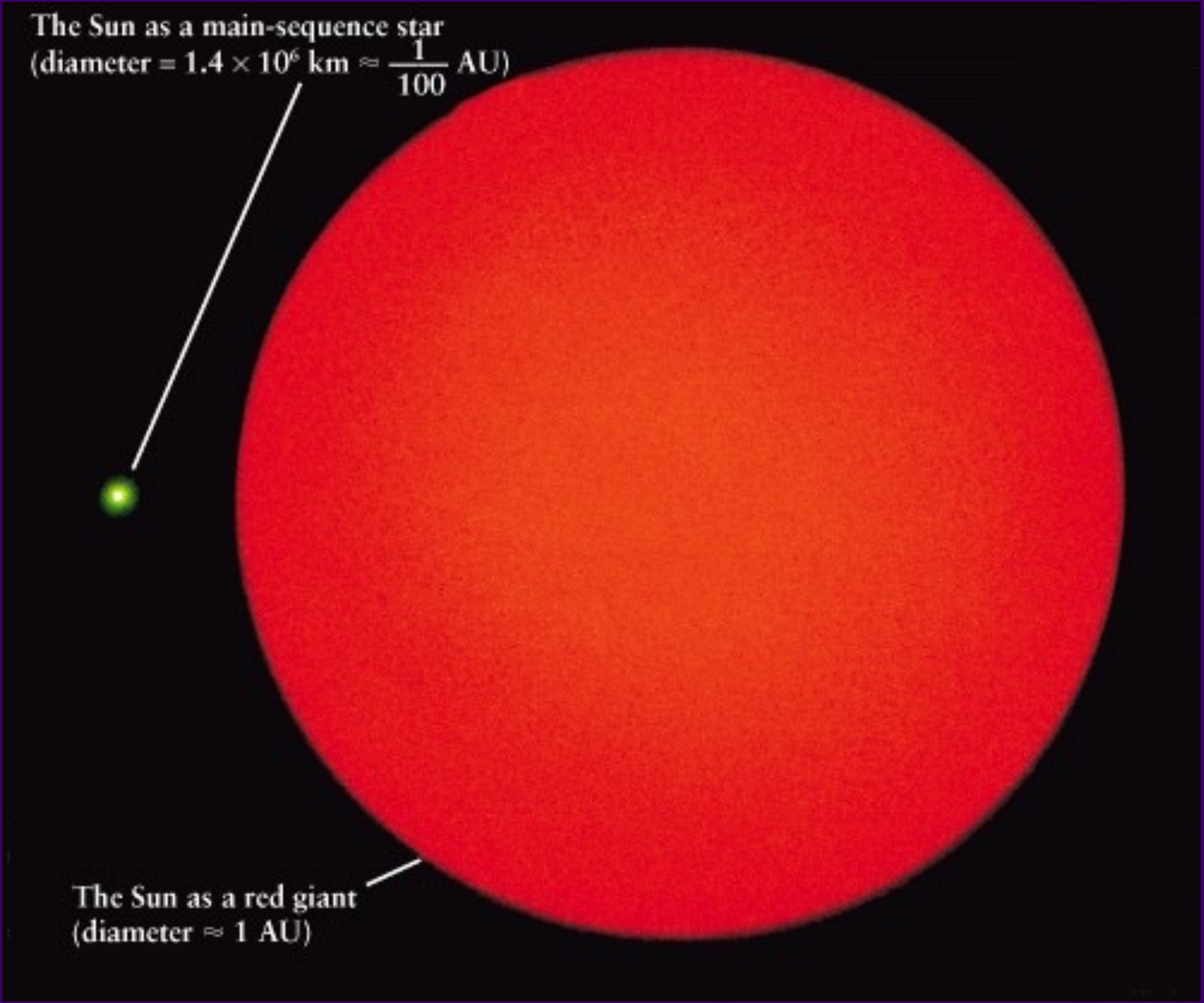
- While the exterior layers expand, the helium core continues to contract and eventually becomes hot enough (100 million kelvins) for helium to begin to fuse into carbon and oxygen
  - core helium fusion
  - 3 He ⇨ C + energy *and* C + He ⇨ O + energy
  - occurs rapidly - called the ***Helium Flash***

Red Giants

- The He core collapses until it heats to 10^8 K
  - He fusion begins (He ⇨ C)
  - called the "triple-α process"



- The star, called a Red Giant, is once again stable.
  - gravity vs. pressure from He fusion reactions
  - red giants create and release most of the Carbon from which organic molecules (and life) are made


The Sun as a main-sequence star
(diameter = 1.4×10^6 km ≈ $\frac{1}{100}$ AU)
The Sun as a red giant
(diameter ≈ 1 AU)

Low mass stars

Interstellar Cloud

Main Sequence Star

Red Giant

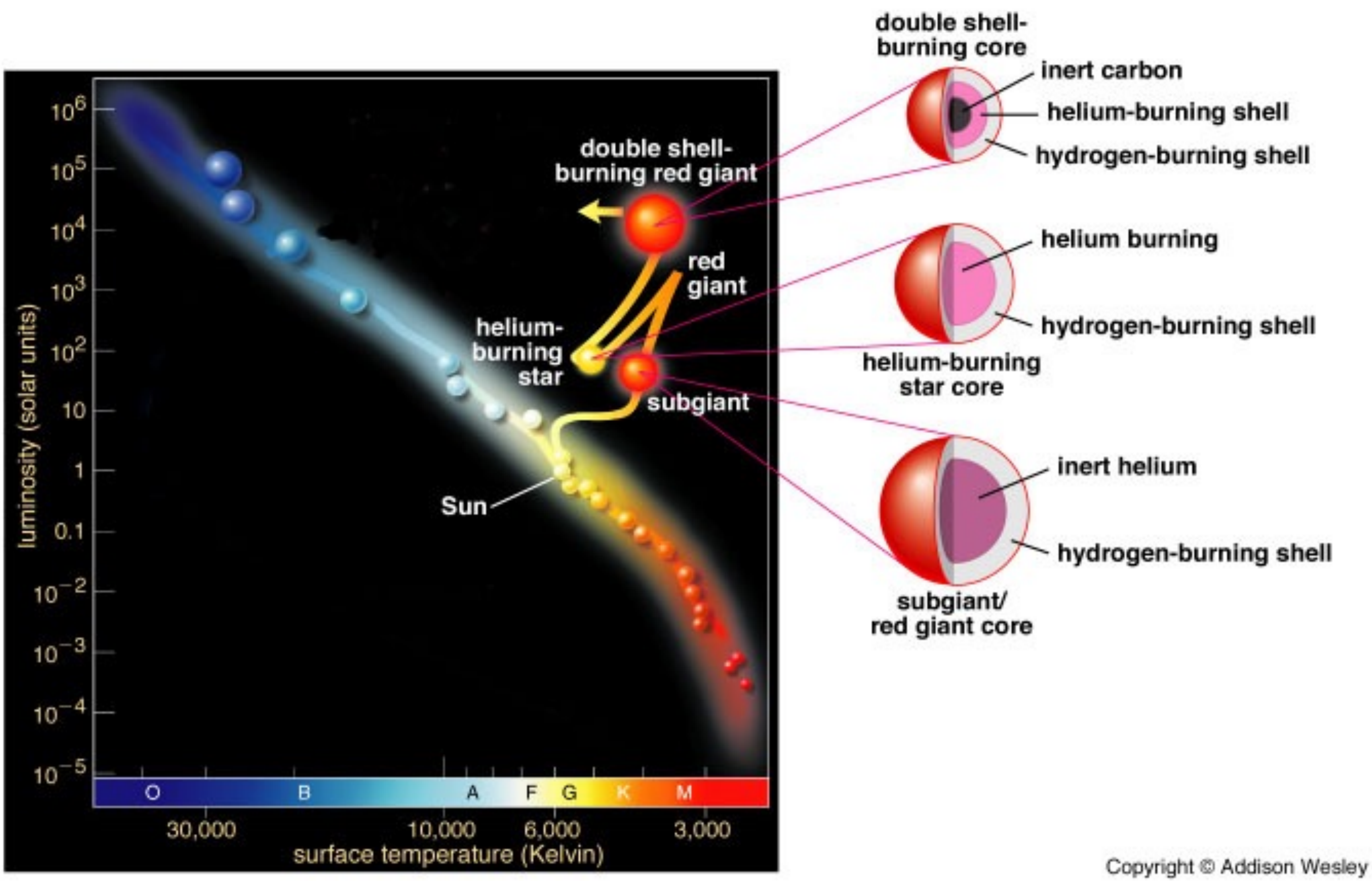
Planetary Nebula

White Dwarf

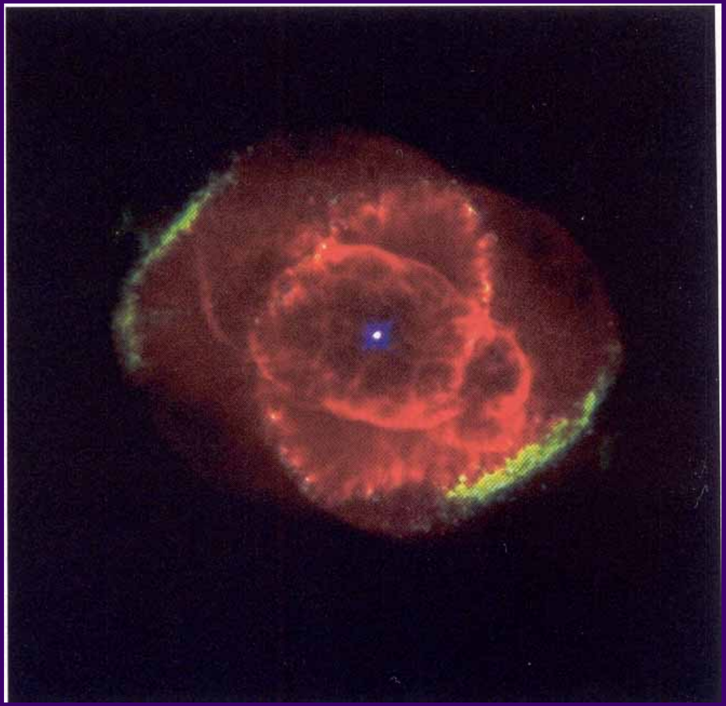
Planetary Nebulae

- When the Red Giant exhausts its He fuel
  - the C core collapses
  - Low & intermediate-mass stars don’t have enough gravitational energy to heat to 6×10^8 K (temperature where Carbon fuses)
- The He & H burning shells overcome gravity
  - the outer envelope of the star is gently blown away
  - this forms a planetary nebula

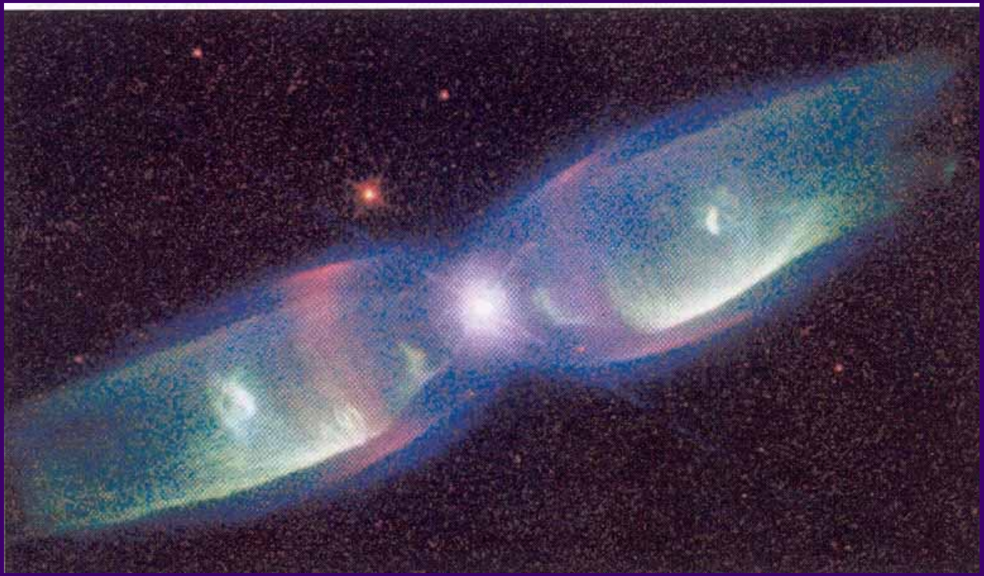
Planetary Nebulae



Planetary Nebulae



Cat's Eye Nebula



Twin Jet Nebula

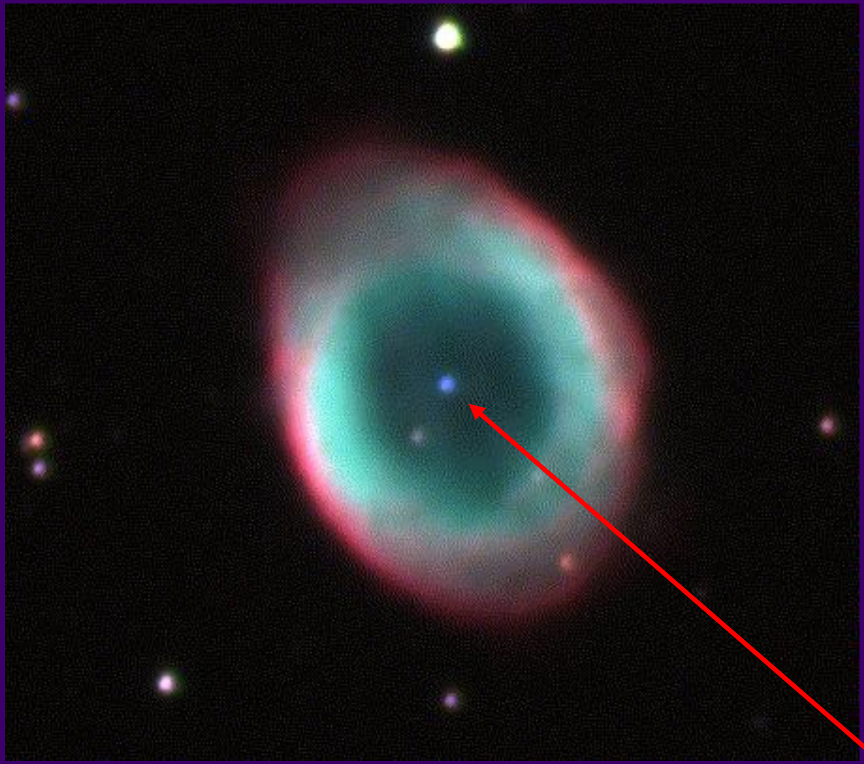
Helix Nebula--125 pc


© IAC/RGO/D. Malin
INT 11

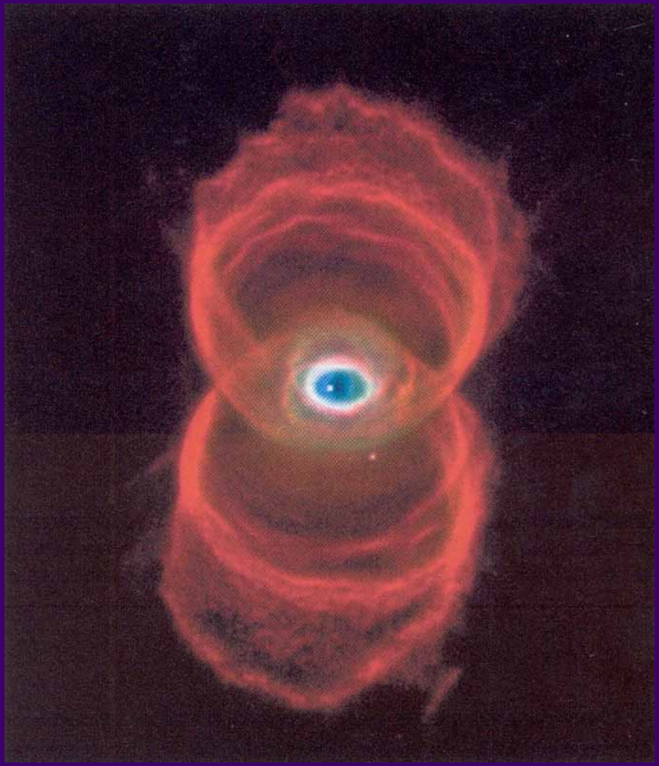
Henize 1357 • Stingray Nebula
Hubble Space Telescope • WFPC2

PRC98-15 • ST ScI OPO • April 2, 1998 • M. Bobrowsky (Orbital Sciences Corp.) and NASA

Planetary Nebulae



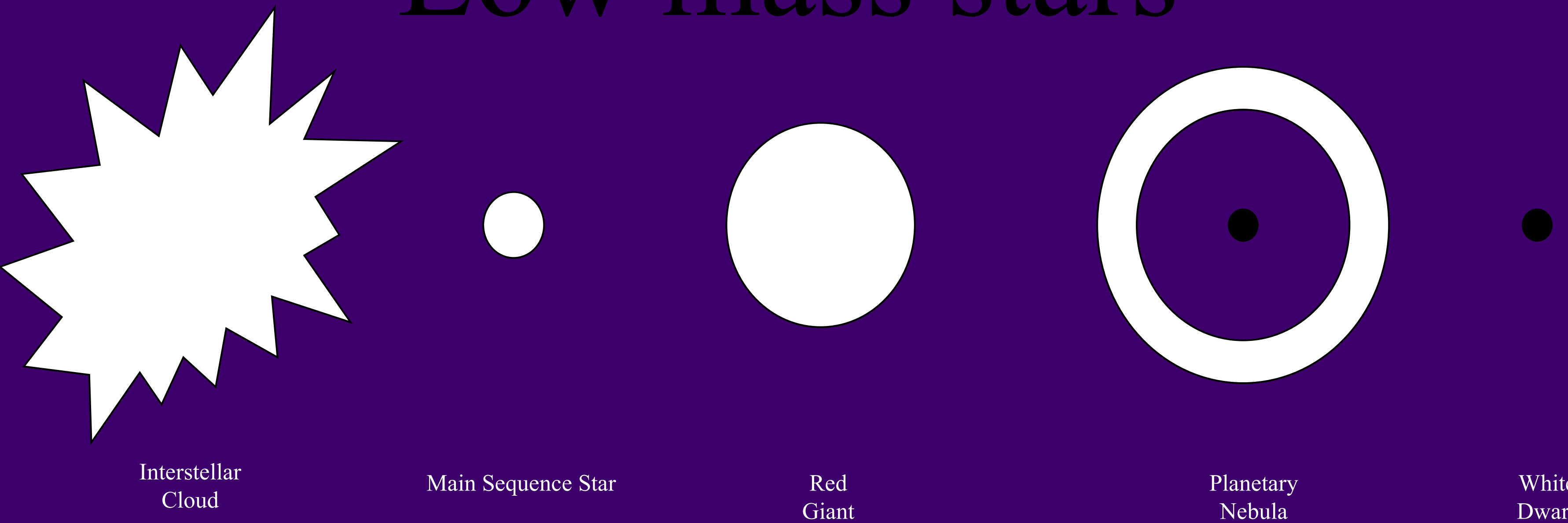
Ring Nebula



Hourglass Nebula

The collapsing Carbon core becomes a White Dwarf

Low mass stars



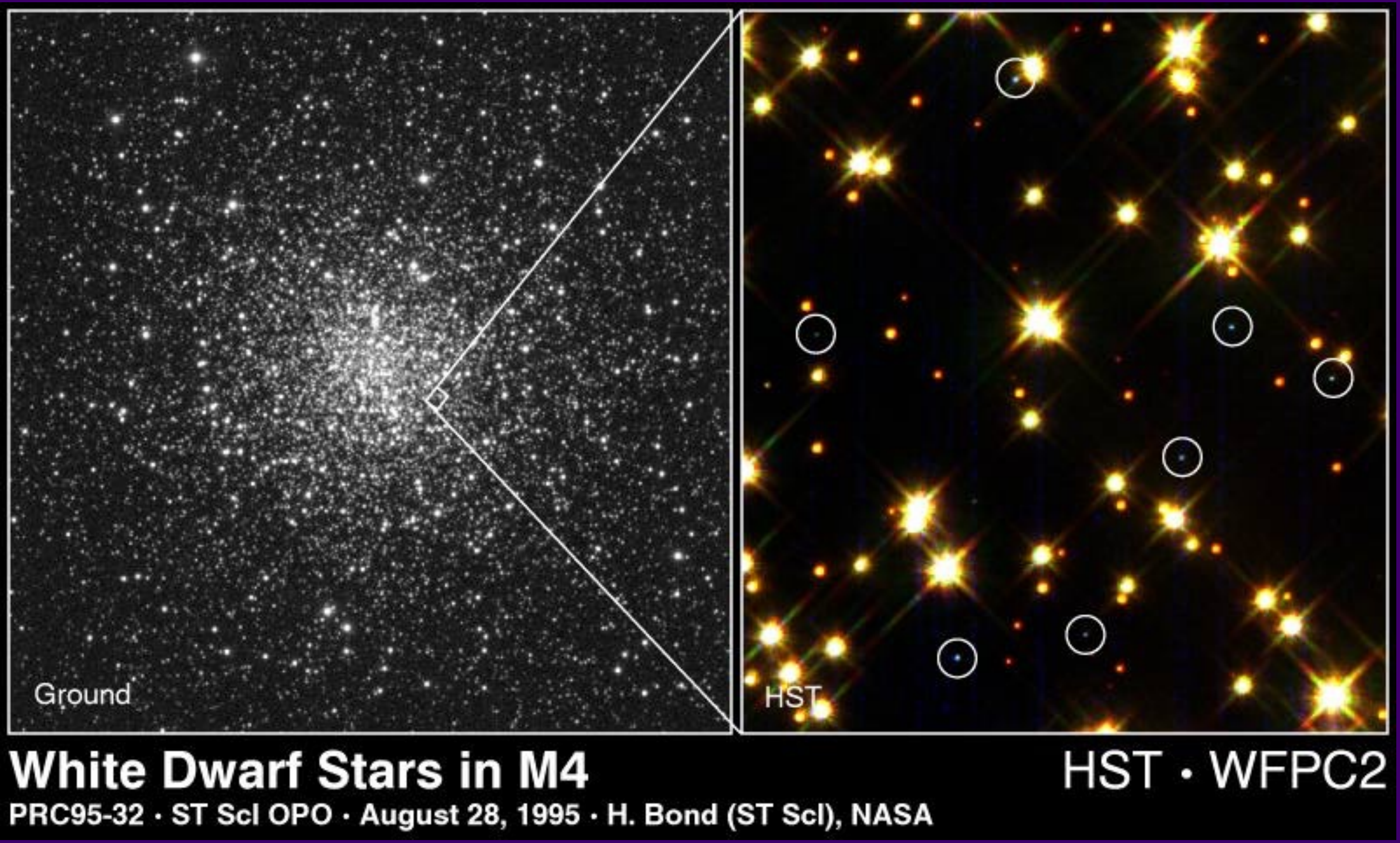
Interstellar Cloud

Main Sequence Star

Red Giant

Planetary Nebula

White Dwarf

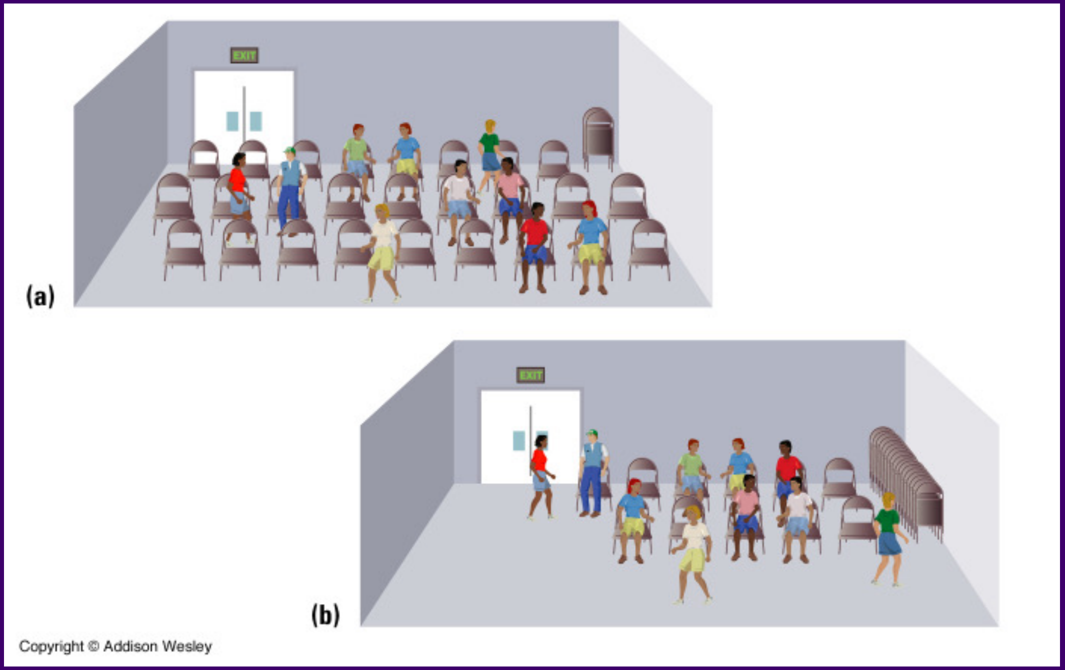

Ground
HST
White Dwarf Stars in M4
HST · WFPC2
PRC95-32 · ST ScI OPO · August 28, 1995 · H. Bond (ST ScI), NASA

What provides the pressure in White Dwarf stars?

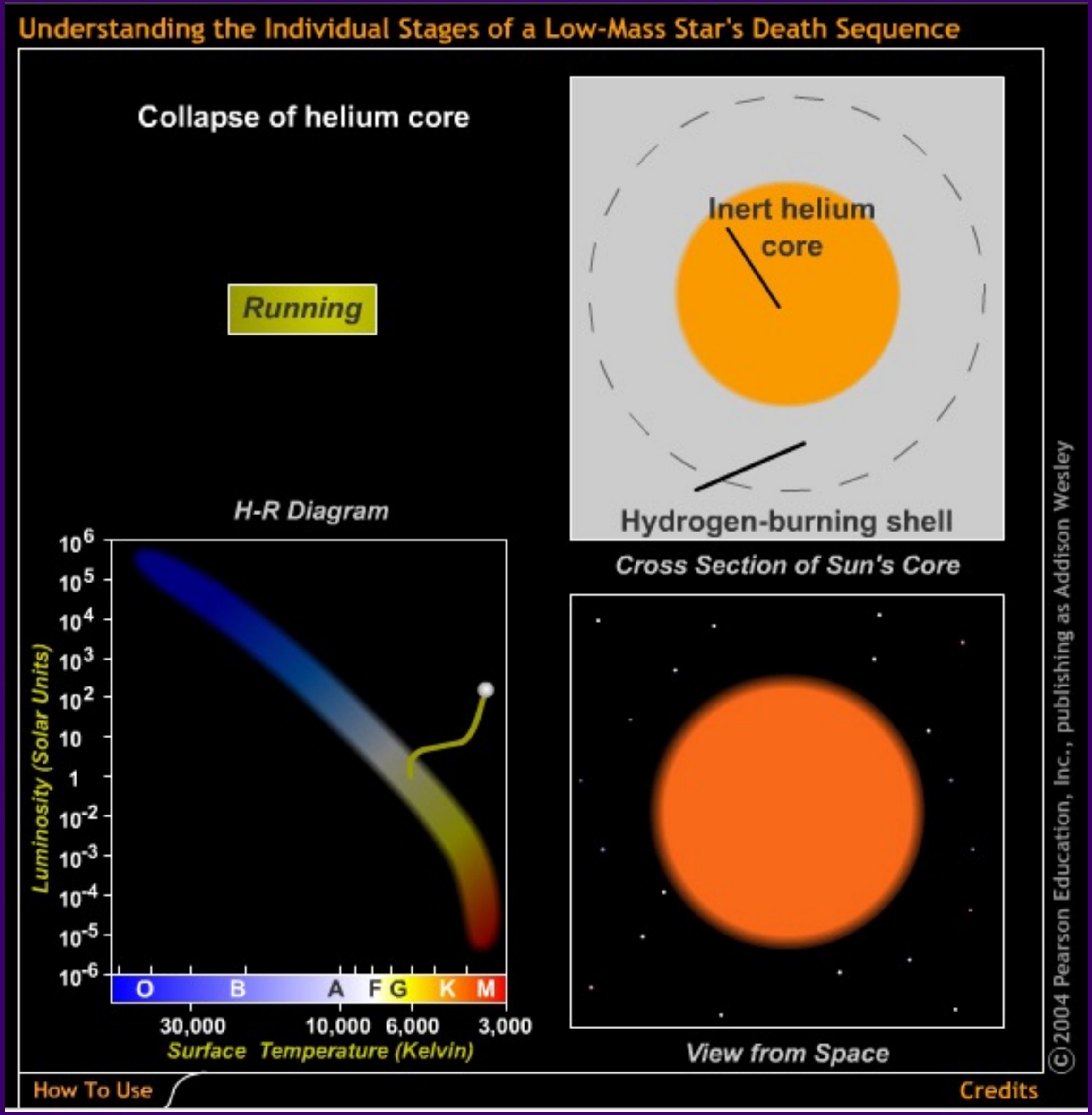
- Pauli exclusion principal
  - two identical particles cannot exist in the same place at the same time
  - this effect in stars is called ***electron degeneracy pressure*** and is not dependent on temperature
  - the star is supported by the fact that the electrons cannot get any closer together

Degeneracy Pressure

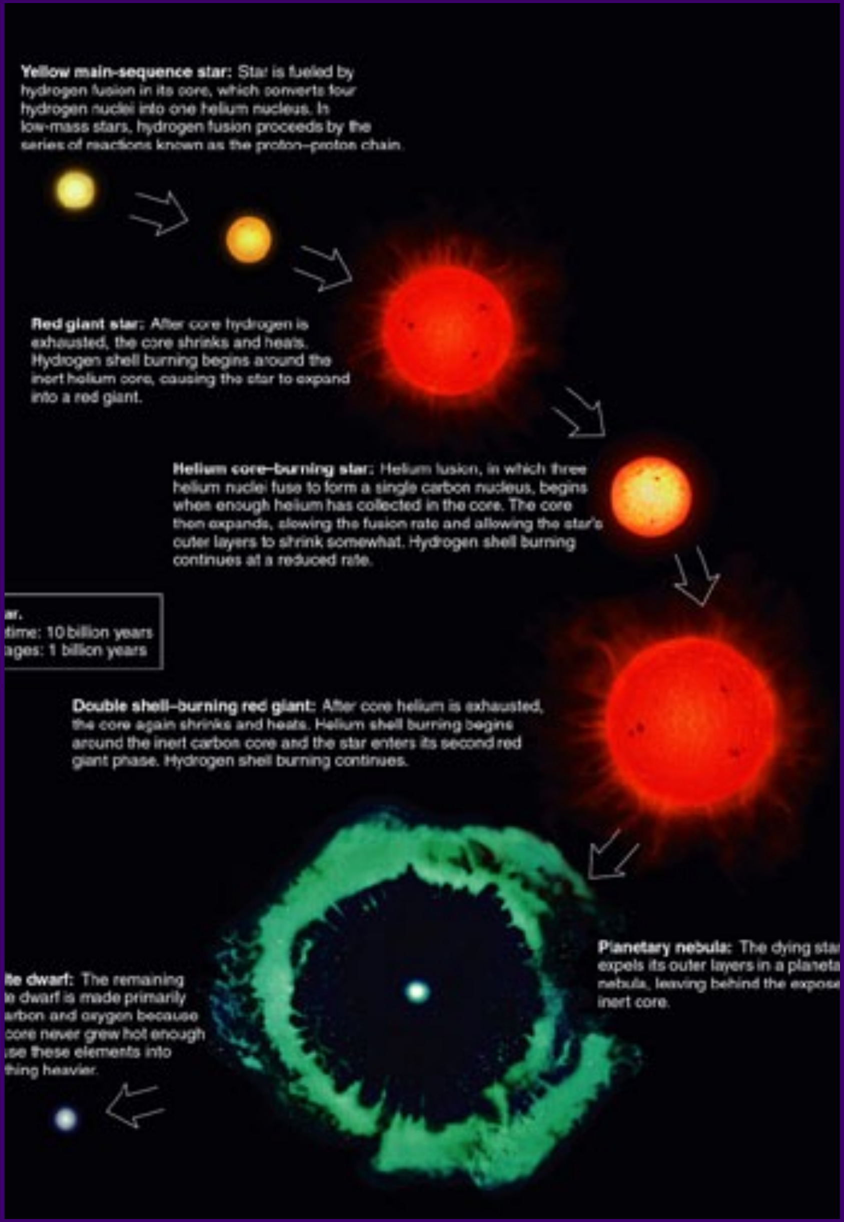
- Two particles cannot occupy the same space with the same quantum state (i.e., mass, energy, momentum etc.).
- For **very** dense solids, the electrons cannot be in their ground states, they become very energetic---approaching the speed of light.
  - the electrons play a game of musical chairs
- The pressure holding up the star no longer depends on temperature.



Low-Mass Stellar Evolution Summary

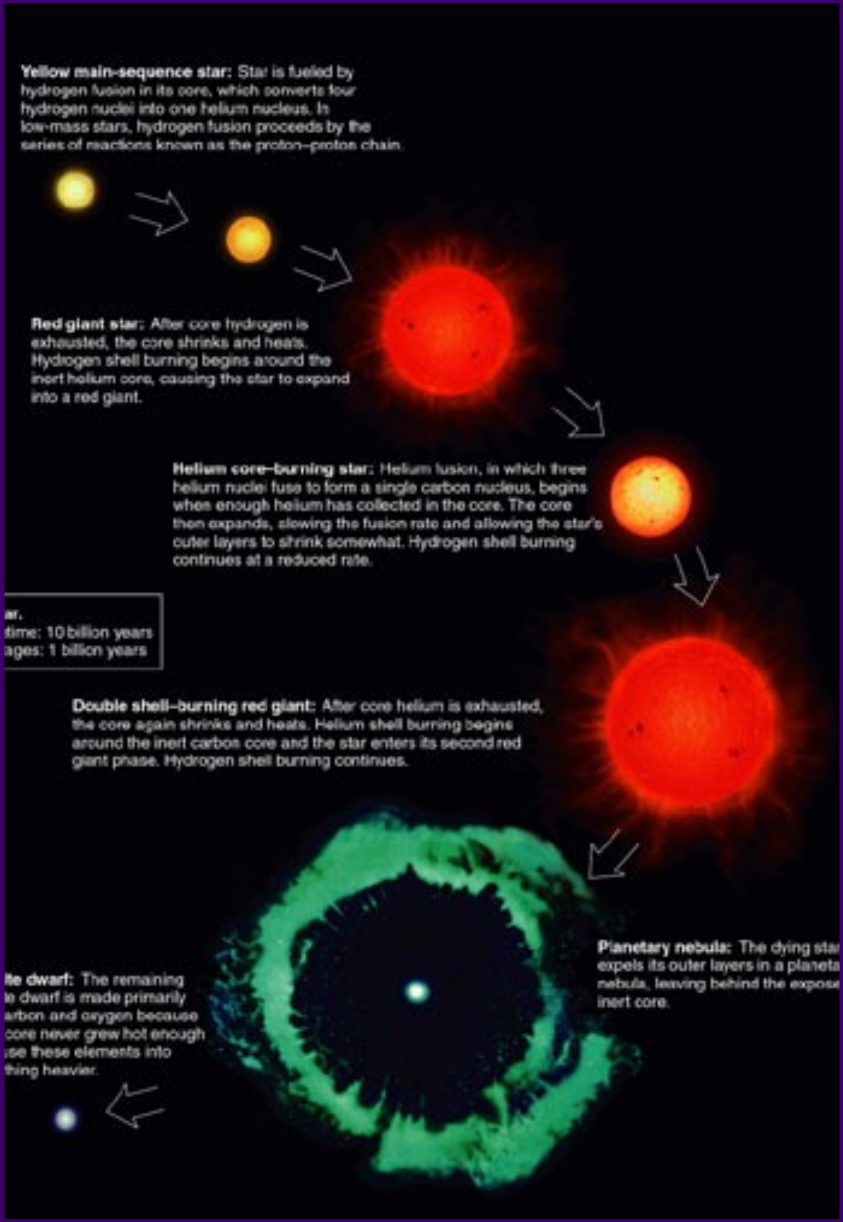


Low-Mass Star Summary



Not to scale!

1. Main Sequence: H fuses to He in core
2. Red Giant: H fuses to He in shell around He core
3. Helium Core Burning:
   He fuses to C in core while H fuses to He in shell
4. Double Shell Burning:
   H and He both fuse in shells
5. Planetary Nebula leaves white dwarf behind



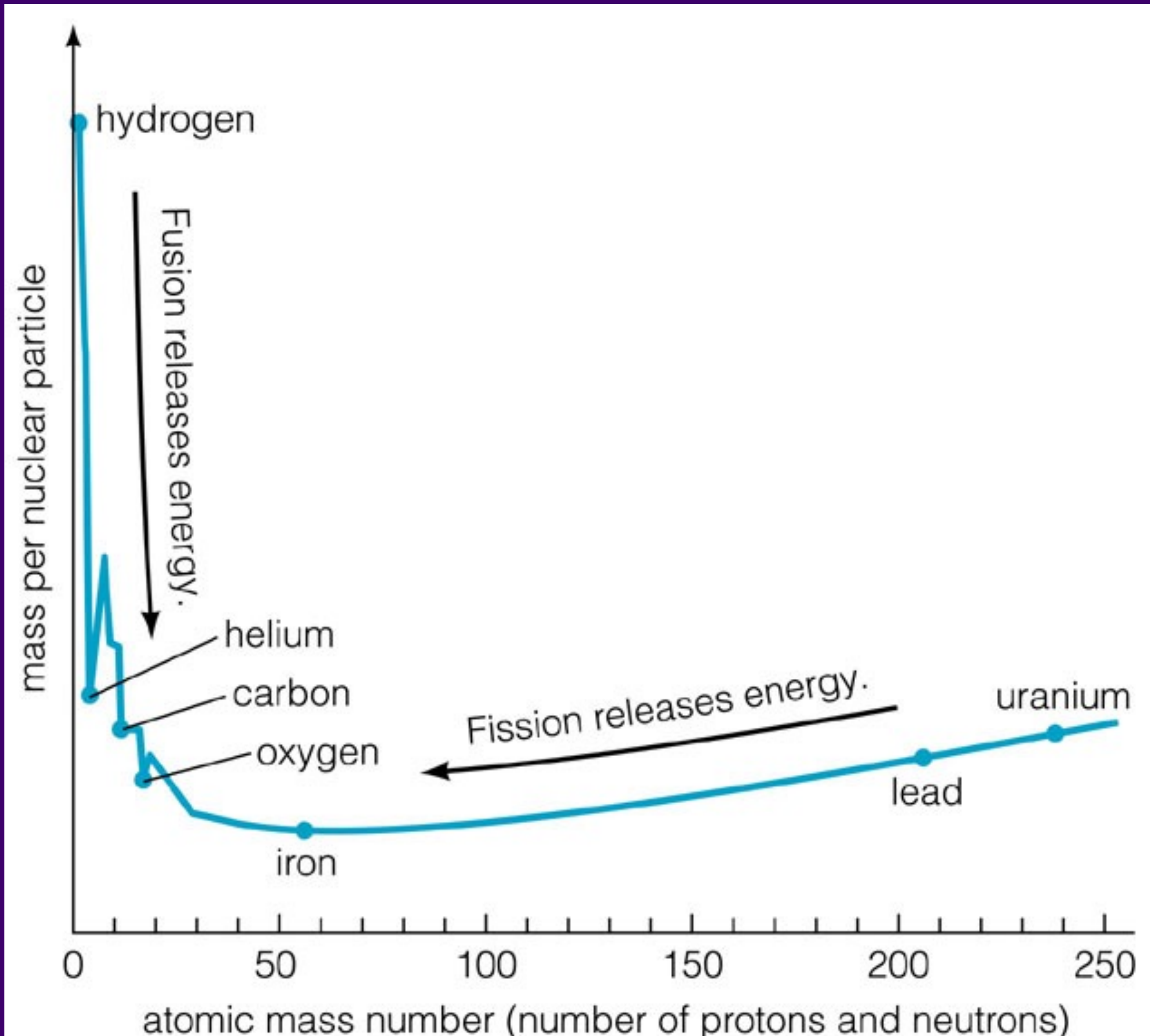
Not to scale!

___Reasons for Life Stages

- Core shrinks and heats until it's hot enough for fusion
- Nuclei with larger charge require higher temperature for fusion
- Core thermostat is broken while core is not hot enough for fusion (shell burning)
- Core fusion can't happen if degeneracy pressure keeps core from shrinking

Nuclear Fusion:

- star is mostly hydrogen
- pressure at core is enormous
- hydrogen combines to form helium and releases energy
- helium combines to form carbon and releases energy
- process continues to produce heavier elements--stops at iron

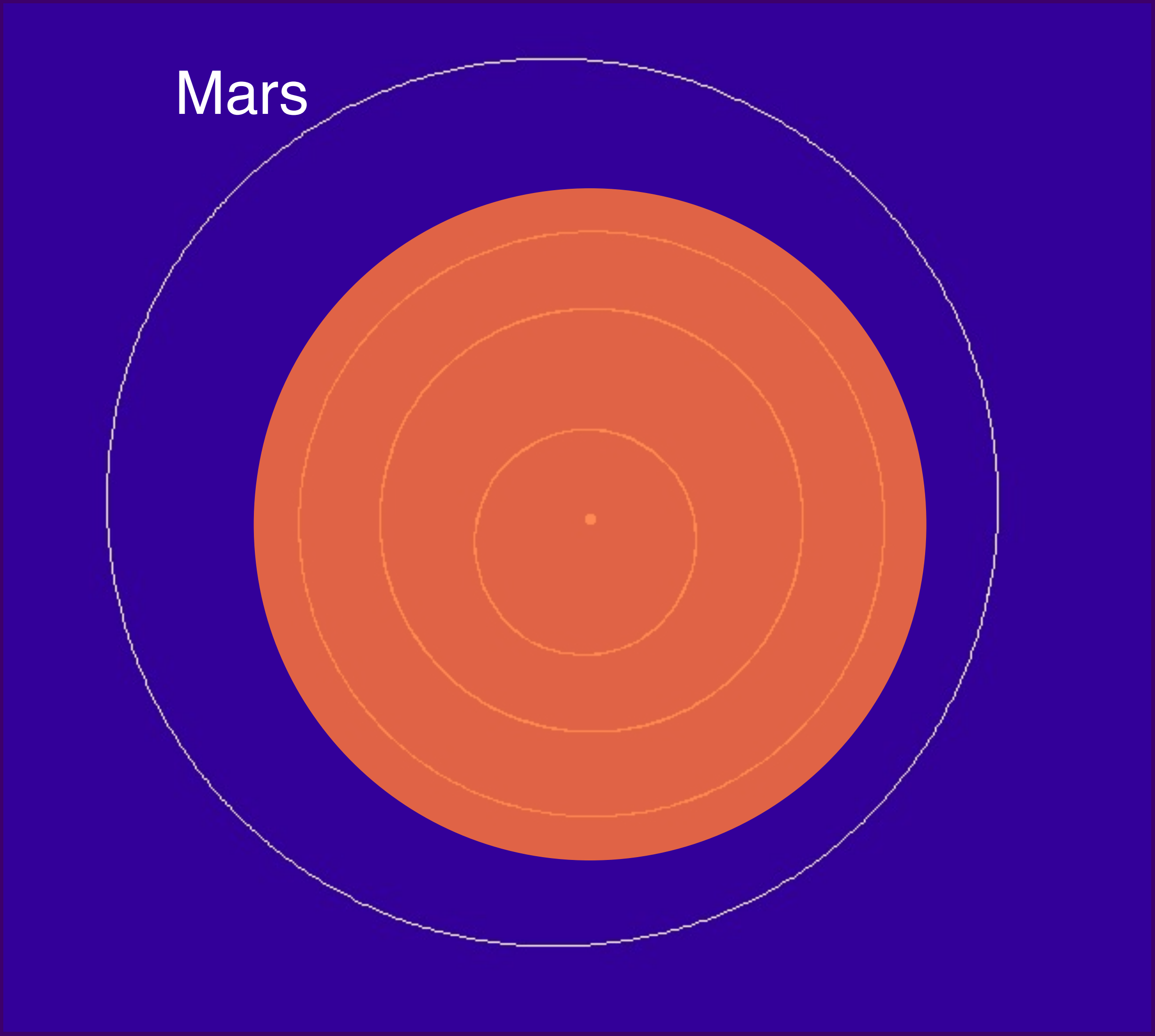


Iron is a dead end for fusion because nuclear reactions involving iron do not release energy

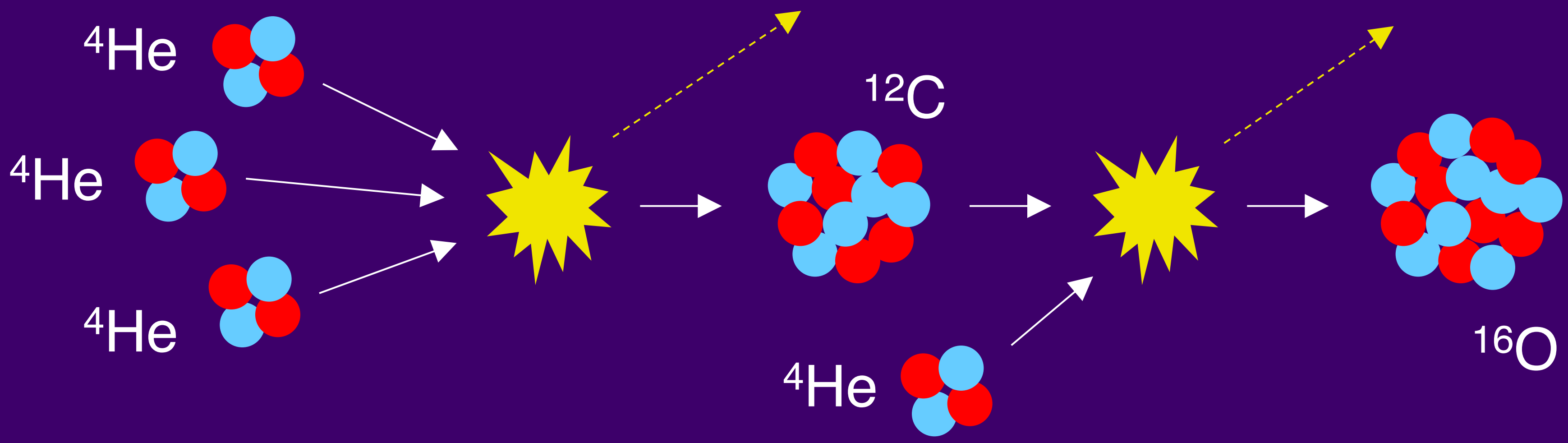
(Fe has lowest mass per nuclear particle)

So the Fe core continues to collapse until it is stopped by something new and different…

Red giants are big!



Fusion of helium into carbon, oxygen



- 3 He nuclei must merge quickly, since ^{8}Be is unstable
- Requires *very* high temperatures (100 million K) due to greater electrostatic repulsion
- Produces less energy per kg than hydrogen fusion
- Can continue in core of a star for about 20% of main-sequence lifetime

Final stages
in the life of a low-mass star

- Core runs out of helium, again collapses and heats up
- Helium burning continues (quickly) in a thin, hot shell surrounding the core; hydrogen burning continues in a larger shell
- Instabilities cause inner temperature to fluctuate, which causes outer layers of star to swell, pulsate
- Pulsations eject outer layers into space, gradually expanding into a "planetary nebula"
- Eventually, energy production stops and a very dense "dead" star is left behind: a "white dwarf"