Astronomy 353

(Spring 2007)

ASTROPHYSICS: From Black Holes to the First Stars

(Lecture 6: Stellar Structure and Evolution)

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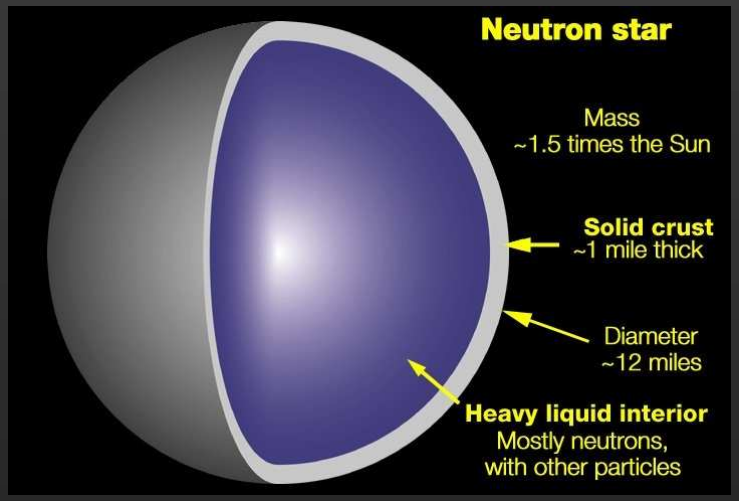
Stellar Remnants: How do they originate?

White Dwarfs

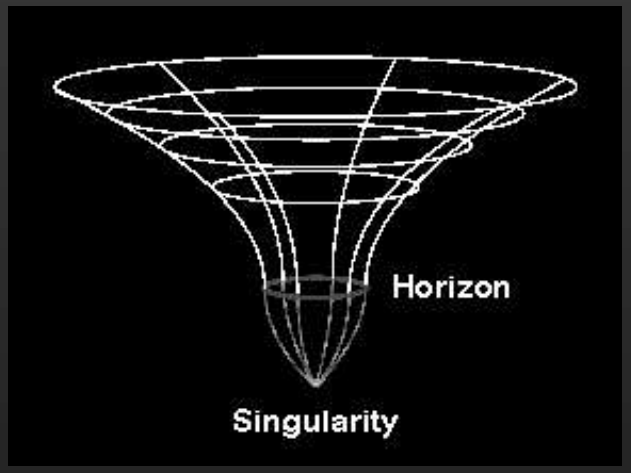
~ 10,000 km
(à Earth)

Neutron Stars



~ 10 km

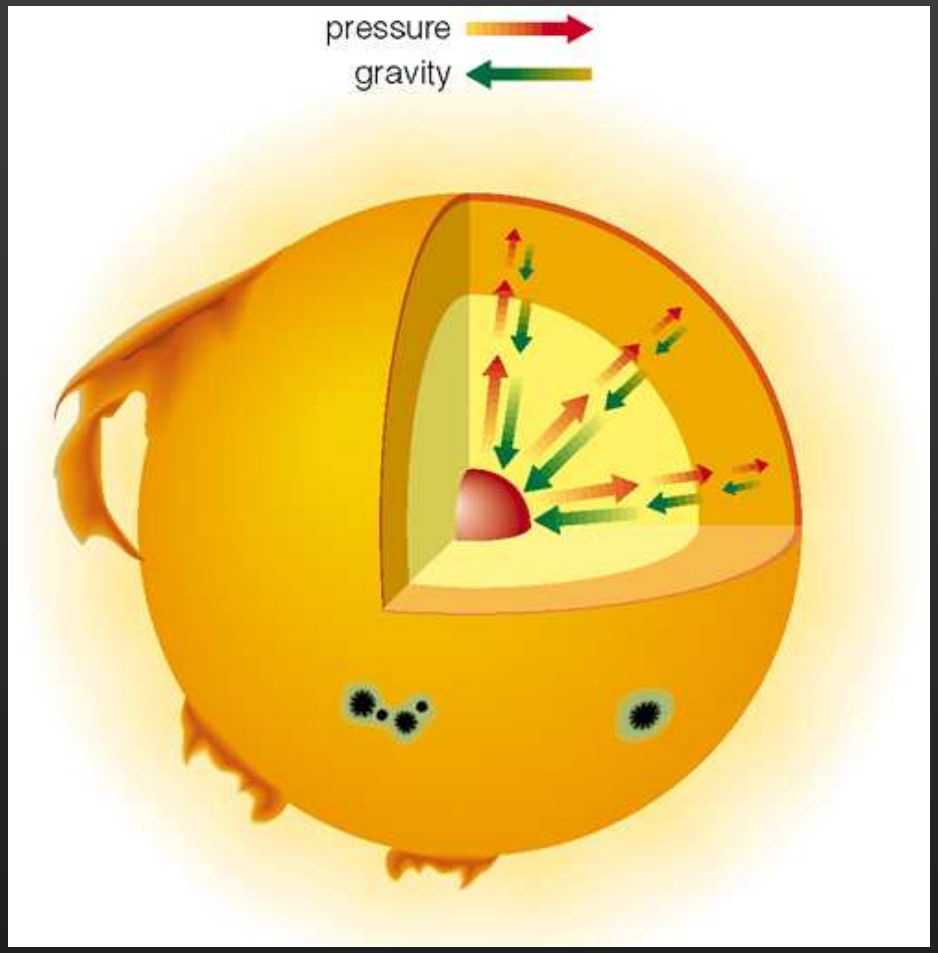
Black Holes



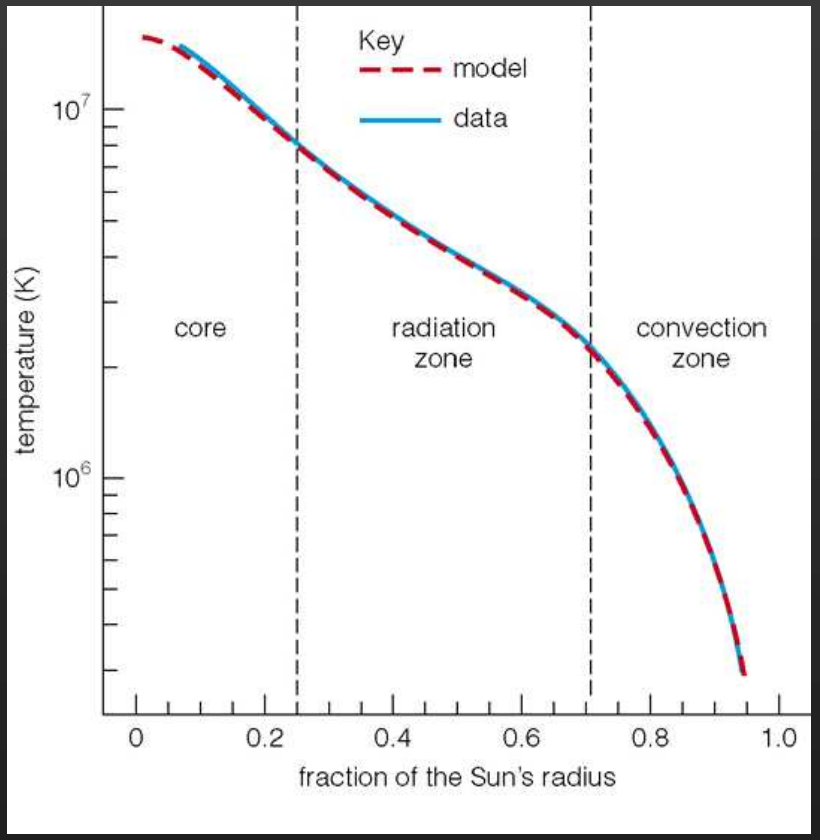
~ 3 km

Basic Structure of a Star

- in hydrostatic equilibrium (pressure = gravity)



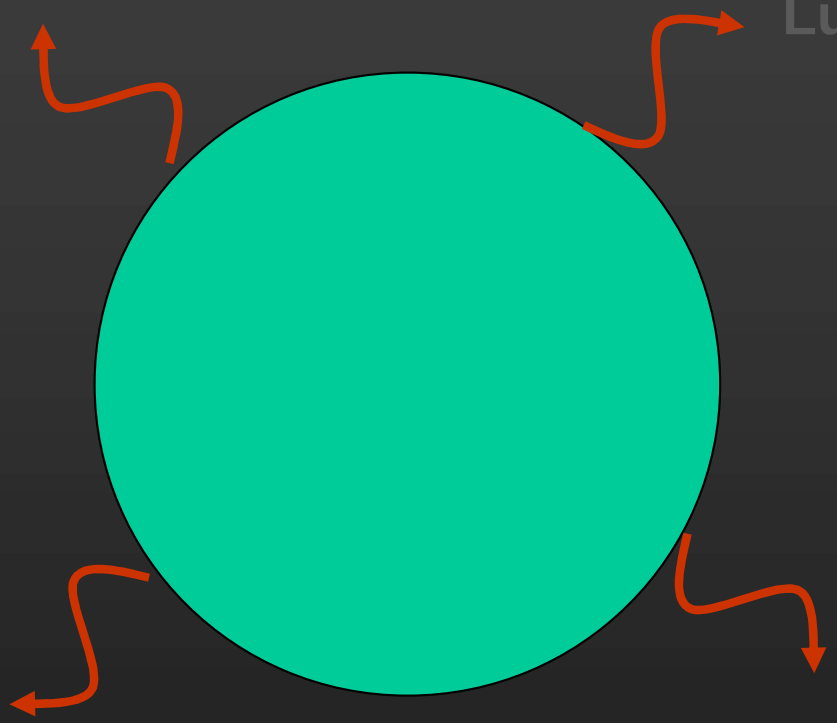
Temperature vs Radius



- High central pressure à high central temperature

Basic Structure of a Star

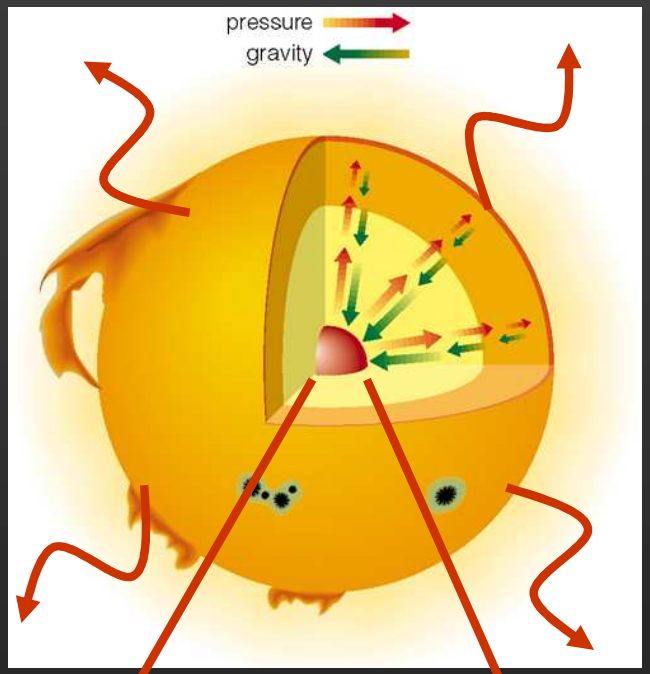
- Why does a star ***have*** to evolve?

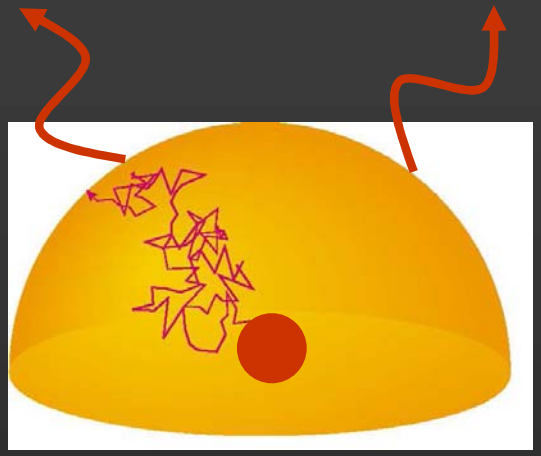


- A: Because it loses energy to radiation!

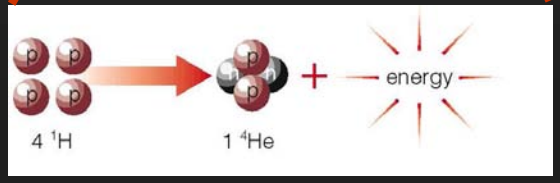
Basic Structure of a Star

- How does star replace lost energy?





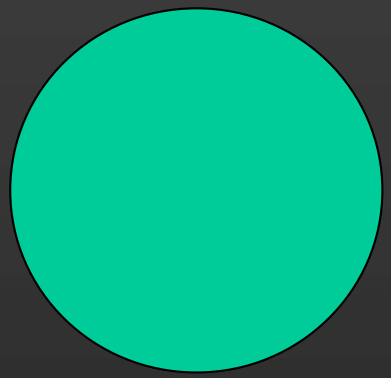
- Radiation (photons) random walk to the surface!



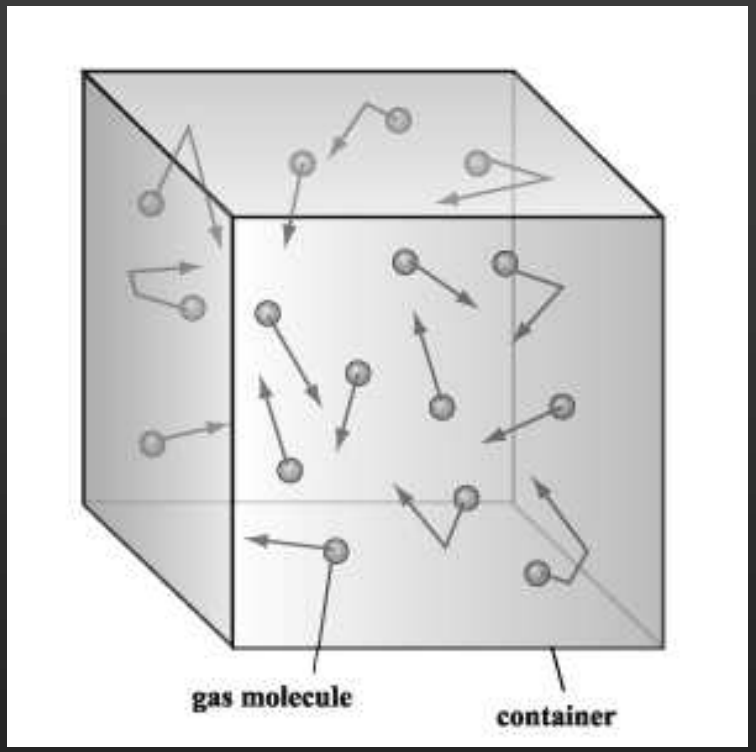
Nuclear fusion (hydrogen burning)

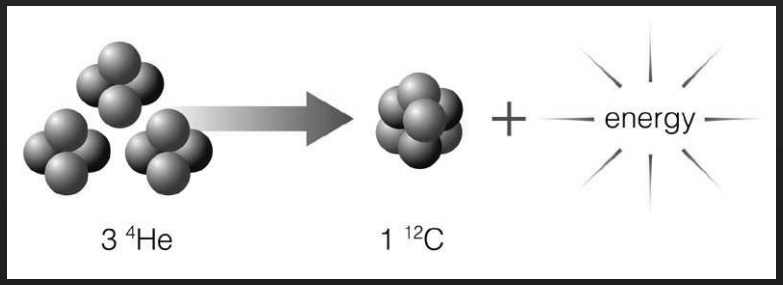
Basic Structure of a Star

- What happens when nuclear fuel is exhausted?



A: Stellar core contracts!



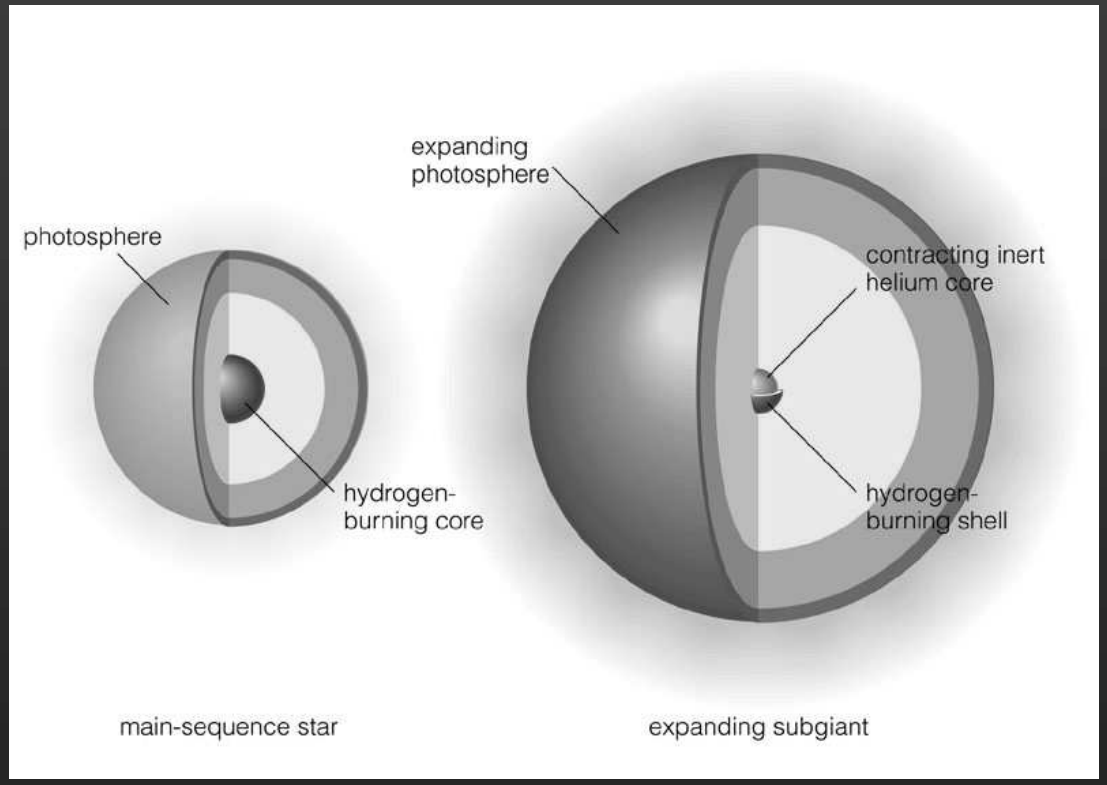


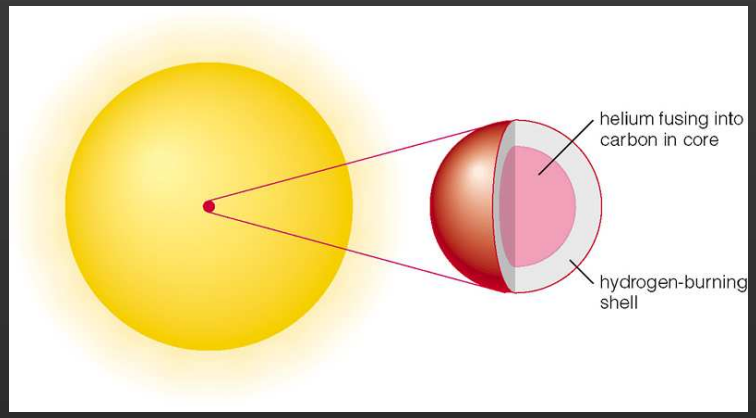
- Compressional heating!
  à central temperature goes up!

- further stages of nuclear burning!
  (e.g., Helium burning)

Stellar Evolution

- core contraction à envelope expansion (“mirror principle”)



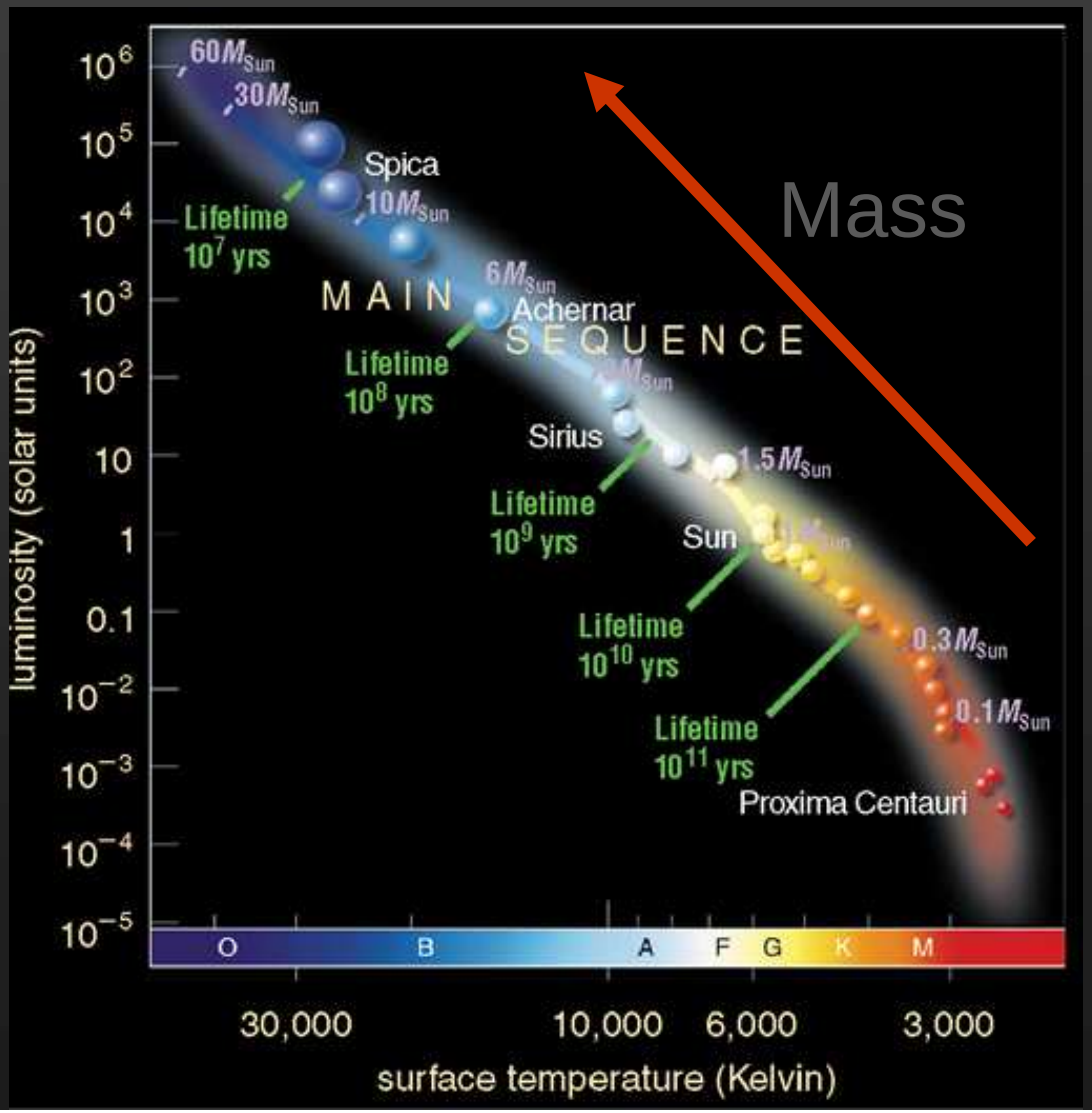


- stars evolve to become giants!

The Hertzsprung-Russell Diagram (HRD)

- **hydrogen burning stars (main-sequence, MS)**

Luminosity vs Surface temperature



Stars are ~ black-body radiators

$$L = 4 \cdot \pi \cdot R^2 \cdot \sigma \cdot T^4$$

Stars obey virial theorem

$$k_B T \sim G M m_H / R$$

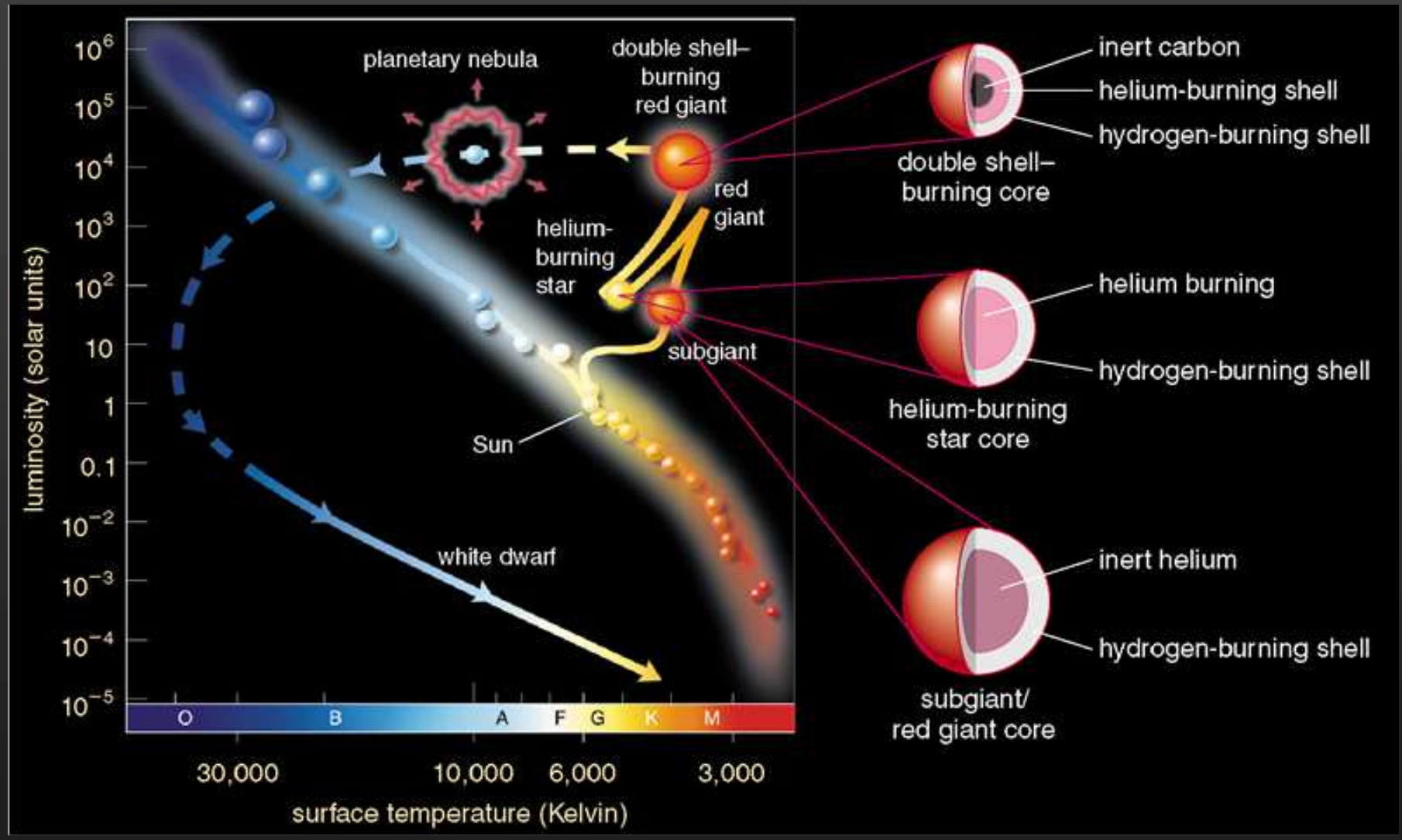
(R~const for MS stars)

Mass-Luminosity relation

L=f(M)
for MS stars

The Life-cycle of a Low-mass Star

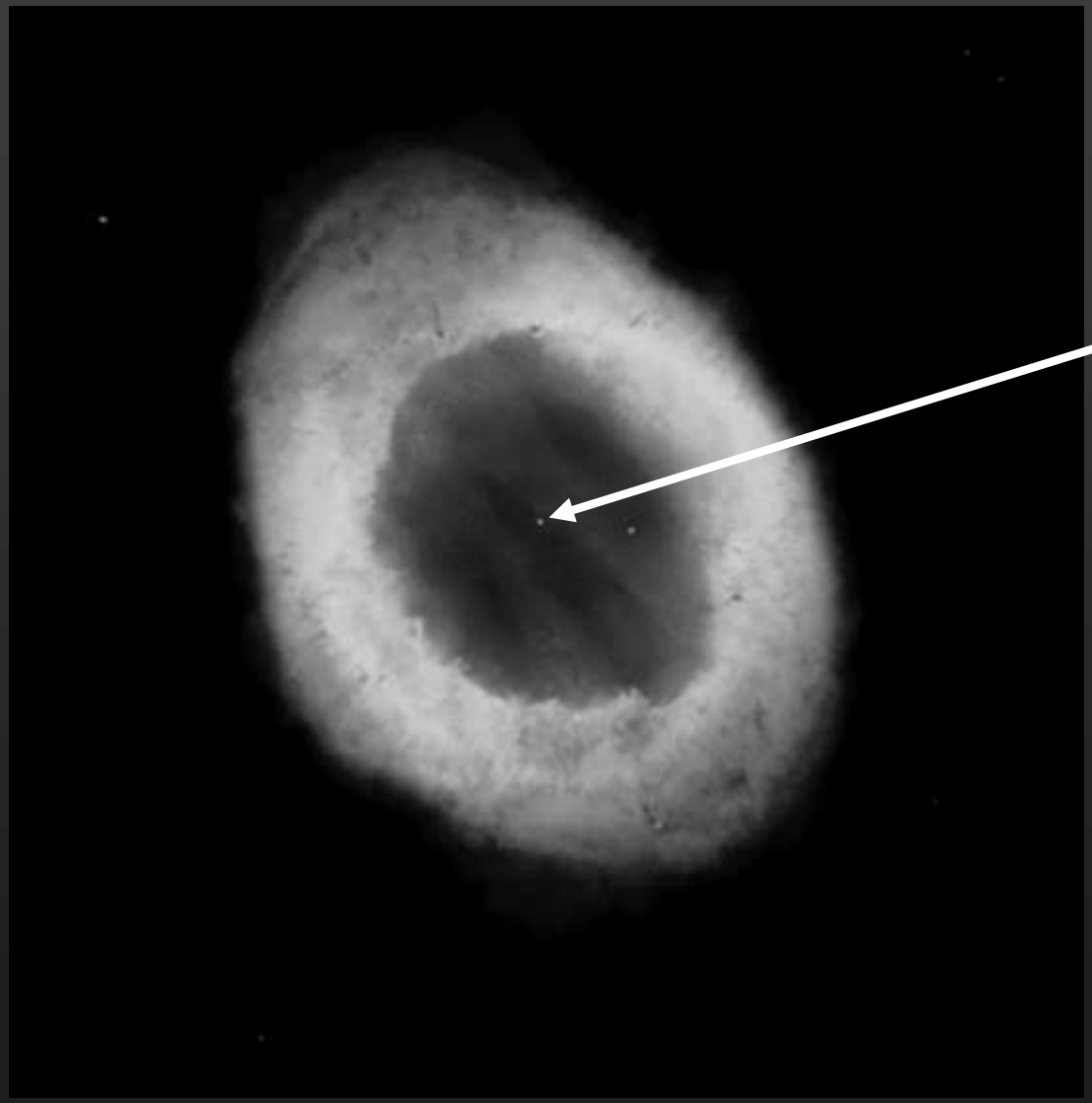
- Prototype: Our Sun



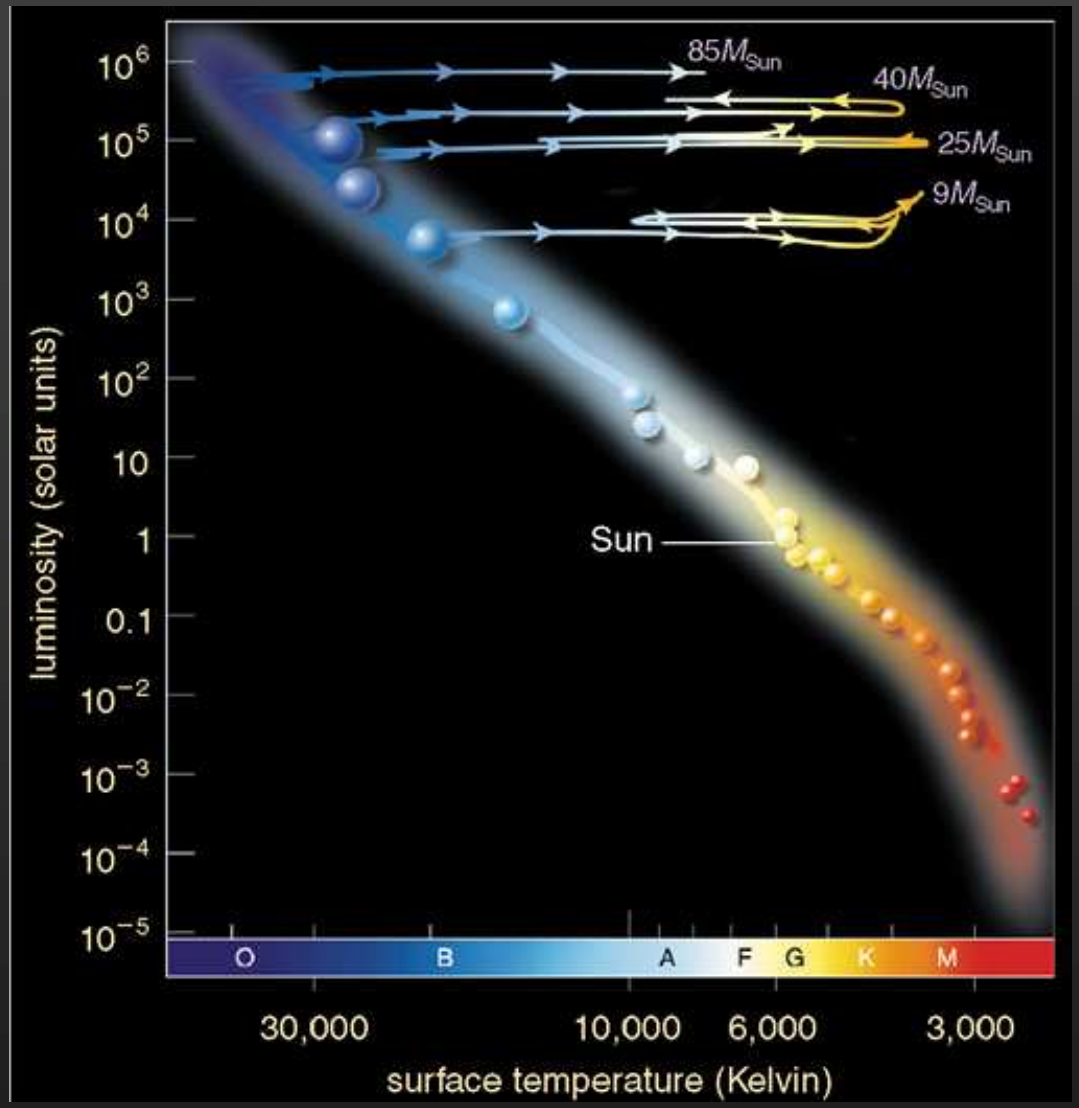
- Final outcome (Stellar grave): White Dwarf (WD)

The Life-cycle of a Low-mass Star

- Final Death Throe: Planetary Nebula



The Life-cycle of a High-mass Star



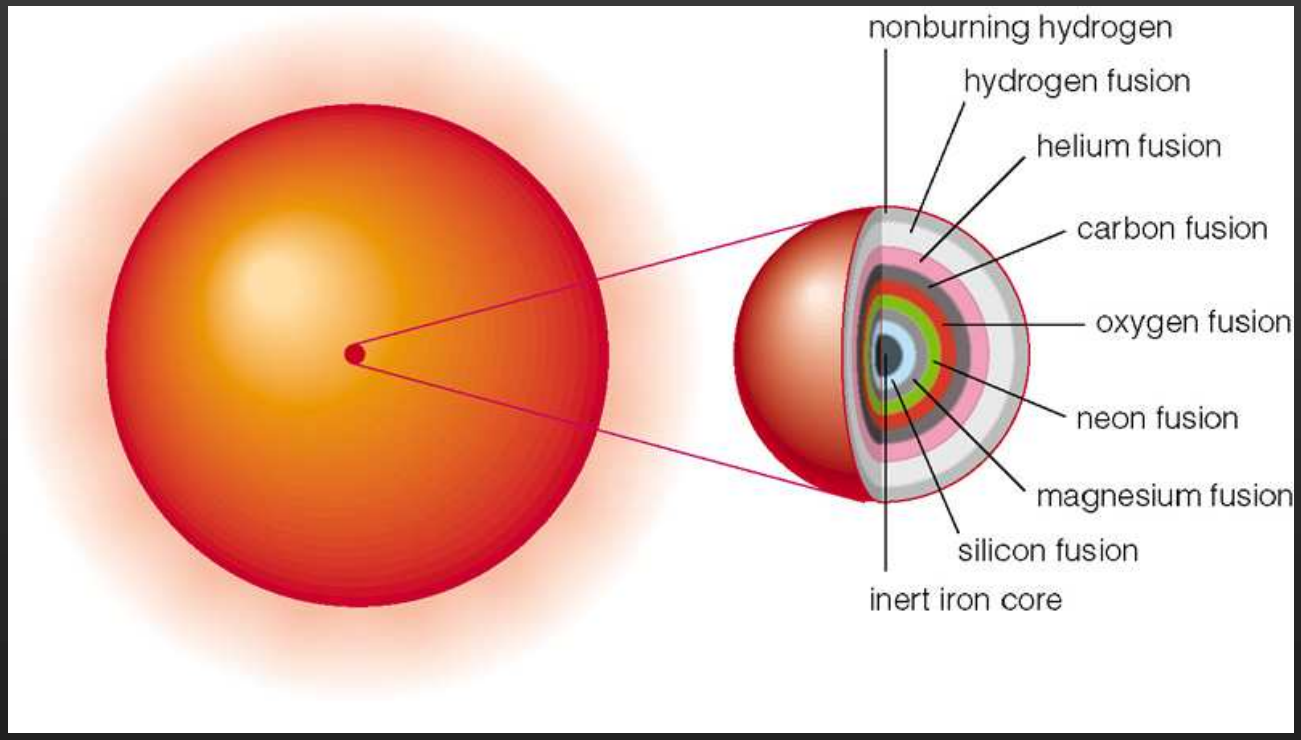
Supernova (SN)

(stellar masses > 8 M_o)

- Final outcome (Stellar grave):
  Neutron Star (NS) or Black Hole (BH)

The Life-cycle of a High-mass Star

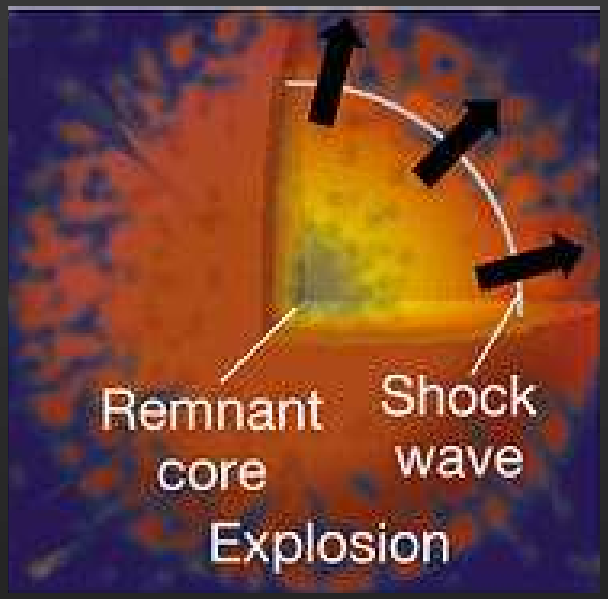
- High-mass stars burn nuclear fuel all the way to iron ("onion structure of chemical composition")



- iron core has to collapse à triggers SN explosion

Supernova (SN) Explosions

- extremely energetic and violent events



SN Remnants (e.g., Crab Nebula)

Summary:

- Evolution of Low-mass stars:
  - **Main-sequence à Red Giant à Planetary Nebula à White Dwarf (WD)**

- Evolution of High-mass stars ($M > 8\ M_{\odot}$):
  - **Main-sequence à Red Supergiant à SN explosion à Neutron Star (NS) or Black Hole (BH)**