Astronomy 353

(Spring 2013)

ASTROPHYSICS: From Black Holes to the Firsts Stars

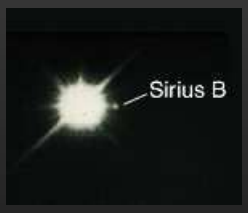
(Lecture 7: Stellar Structure and Evolution)

Instructor: Volker Bromm
TA: Aaron Smith

The University of Texas at Austin

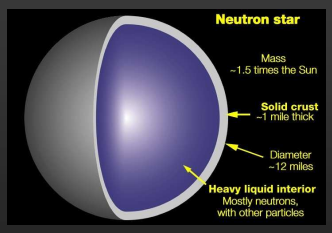
Stellar Remnants: How do they originate?

White Dwarfs



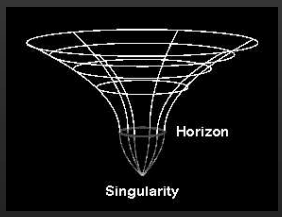
~ 10,000 km
(→ Earth)

Neutron Stars



~ 10 km

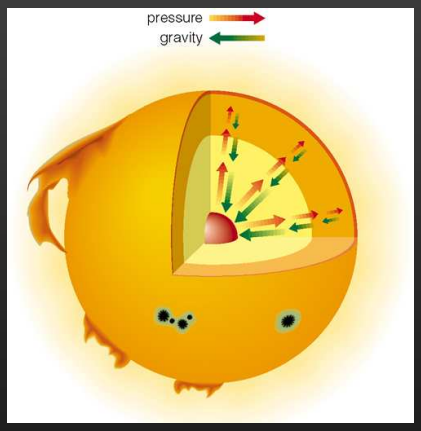
Black Holes



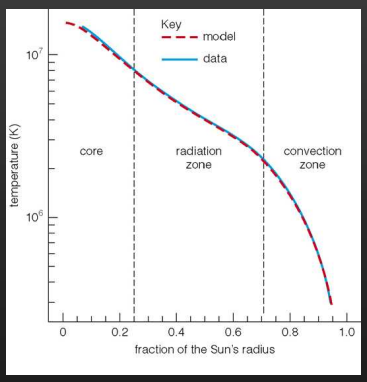
~ 3 km

Basic Structure of a Star

- in hydrostatic equilibrium (pressure = gravity)



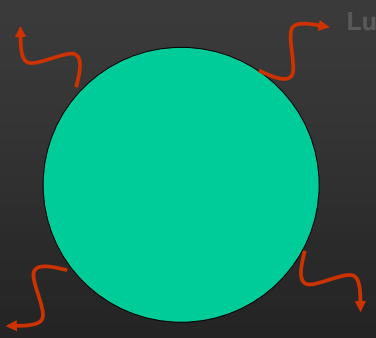
Temperature vs Radius



- High central pressure → high central temperature

Basic Structure of a Star

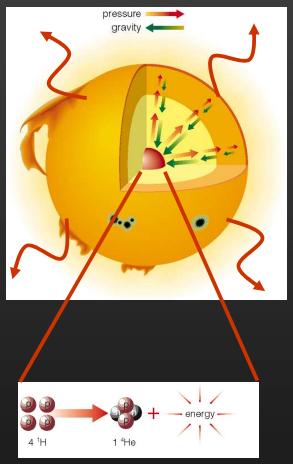
- Why does a star ***have*** to evolve?

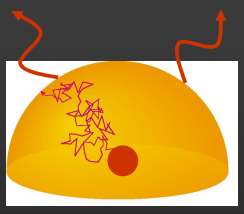


- A: Because it loses energy to radiation!

Basic Structure of a Star

• How does star replace lost energy?



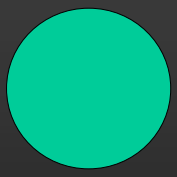


• Radiation (photons) random walk to the surface!

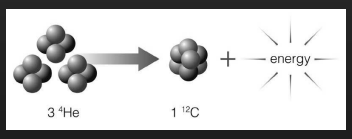
Nuclear fusion (hydrogen burning)

Basic Structure of a Star

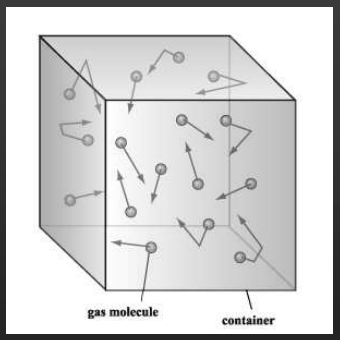
• What happens when nuclear fuel is exhausted?



A: Stellar core contracts!



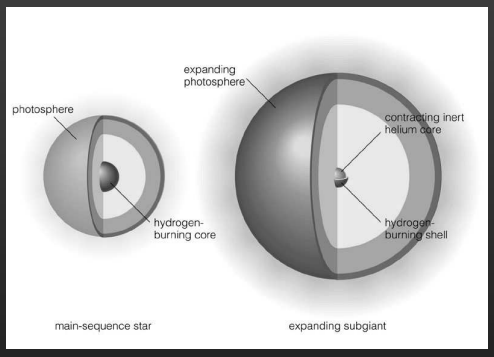
• further stages of nuclear burning! (e.g., Helium burning)

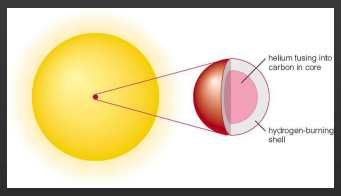


• Compressional heating!
→ central temperature goes up!

Stellar Evolution

• core contraction ↔ envelope expansion ("mirror principle")



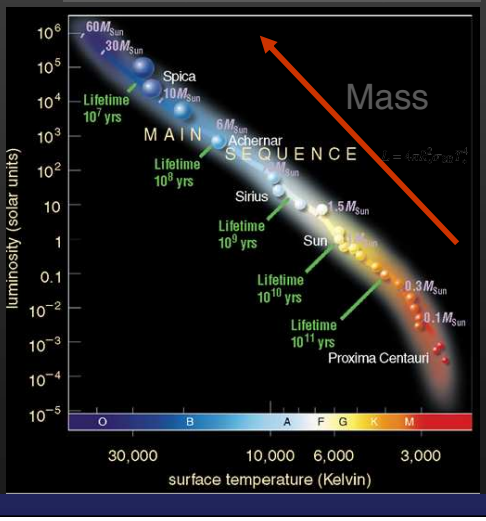


• stars evolve to become giants!

The Hertzsprung-Russell Diagram (HRD)

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

Luminosity vs Surface temperature



Stars are ~ black-body radiators

$$L = 4\pi R_*^2 \sigma_{SB} T_*^4$$

Stars obey virial theorem

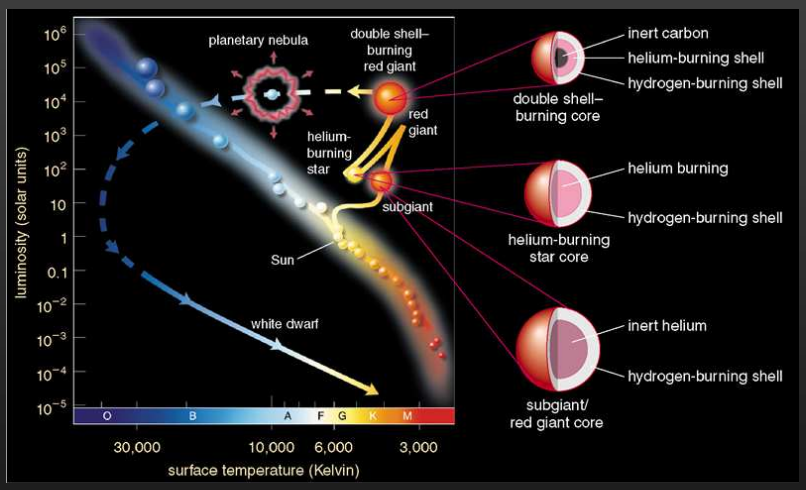
$k_B T \sim G M m_H / R$
(R~const for MS stars)

Mass-Luminosity relation

L=f(M)
for MS stars

The Life-cycle of a Low-mass Star

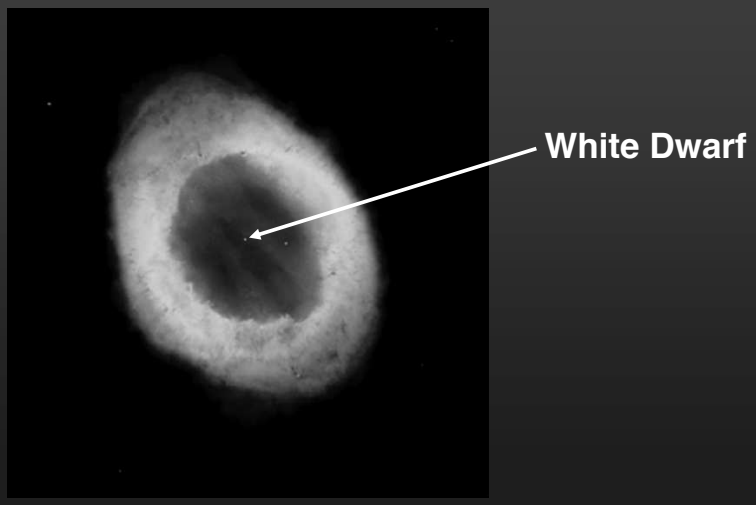
• Prototype: Our Sun



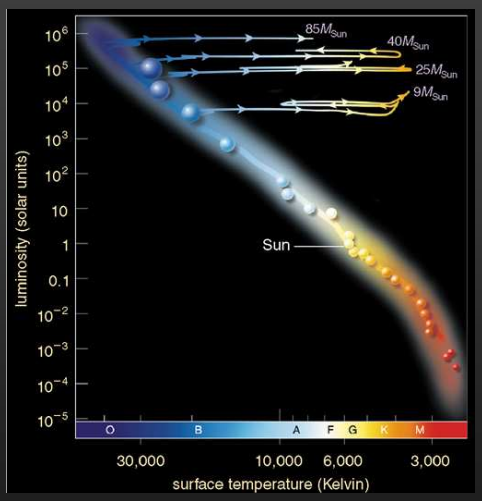
• Final outcome (Stellar grave): White Dwarf (WD)

The Life-cycle of a Low-mass Star

• Final Death Throe: Planetary Nebula



The Life-cycle of a High-mass Star

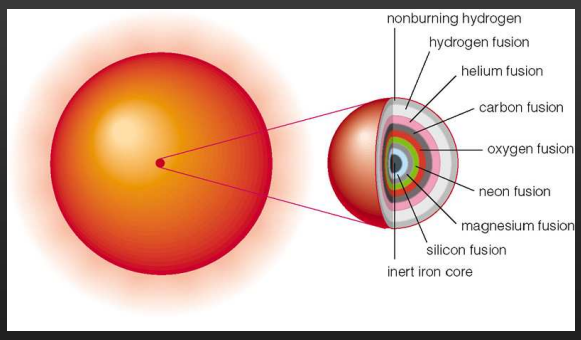


Supernova (SN)
(stellar masses
> 8 M_o)

- 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 → triggers SN explosion

Summary:

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

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