Reminders

1. Online Quiz Chapter 12 Due Today
2. Online Quiz Chapter 13 Due Next Week
3. Read Chapters 12-13
Lecture 23 — Helium Flash, Low Mass Evolution, Close Binary Evolution, Type Ia Supernovae, Massive Star Evolution
Turnoff In HR Diagram Determines Age
Helium Burning
Result of Helium Burning is both Carbon and Oxygen
Pressure-Temperature Thermostat

- Ordinary Pressure $P \propto \rho T$
- If $T$ rises, $P$ rises, star expands, $T$ falls
- With Quantum Mechanical Pressure $P \propto \rho^\gamma$
- If $T$ rises, $P$ stays constant, nuclear reaction rates get bigger, $T$ rises more, nuclear reaction rates get bigger, BOOM!!!!!
Quantum Mechanical Pressure: The Helium Flash

- Low-density gas (nondegenerate)
- High-density gas (degenerate)
Clicker Question

The property of a star that determines its destiny is its:

(a) density
(b) radius
(c) luminosity
(d) mass
Stellar Evolution of Low and Intermediate Mass Stars I

- Exhaust Hydrogen in Core
- Leave the MS
- Ignite Hydrogen in Shell
- Form Red Giant
- Begin Helium Burning in Core (low mass stars have helium flash)
Stellar Evolution of Low and Intermediate Mass Stars II

- Now on Horizontal Branch or Helium Main Sequence
- Exhaust Helium in Core, leaving Carbon + Oxygen Core
- Ignite Helium in Shell
- Ascend the Asymptotic Giant Branch (AGB)
- Lose Most of their Mass as Planetary Nebula
- End up as C+O White Dwarf
Globulars Old: Few Metals

Theory
- Evolution of a globular cluster star
- Helium-shell fusion
- Helium core fusion
- Globular cluster main sequence

Observation
- Globular cluster M3
- Horizontal Branch
- Giant stars
- Main-sequence stars
- Faintest stars not observed
Evolution of a 3 M☉ Star
Evolution of the Sun

A diagram illustrating the stages of the Sun's evolution, including its transition from the main sequence to a red giant, yellow giant, planetary nebula, and finally a white dwarf. The timeline and key events are highlighted, such as the Sun's age and the stages it will undergo over time.
Evolution in HR Diagram

The diagram illustrates the evolution of stars on the Hertzsprung-Russell (HR) diagram, showing different stages of stellar evolution. The x-axis represents temperature in Kelvin (K), while the y-axis shows the relative luminosity ($L/L_\odot$). The HR diagram is divided into various zones:

- **Nuclei of planetary nebulae**
- **Supergiants**
- **Main sequence**
- **Giants**
- **White dwarfs**

A mathematical model of a 0.8 solar mass stellar remnant is shown contracting to become a white dwarf.
Ring Nebula
Energy Transport is Different in Massive Stars
Carbon burning
Only in Massive Stars $M \gtrsim 8 \, M_\odot$
Clicker Question

On the main sequence the Sun uses:
(a) CNO cycle
(b) p-p cycle
(c) triple alpha process
(d) gravitational contraction
Clicker Question

On the main sequence a 3 M☉ star uses:

(a) CNO cycle
(b) p-p cycle
(c) triple alpha process
(d) gravitational contraction
Close Binary Evolution: Roche Lobes
Close Binary Evolution: Mass Transfer

The Evolution of a Binary System

Star B is more massive than Star A.

Star B becomes a giant and loses mass to Star A.

Star B loses mass, and Star A gains mass.

Star A is a massive main-sequence star with a lower-mass giant companion—a Wolf-Rayet system.

Star A has now become a giant and loses mass back to the white dwarf that remains of Star B.