Stellar Evolution

90% of its lifetime: star converts Hydrogen to Helium

- p-p cycle Main Sequence
  Helium builds up in the core, but not yet burning
- gravity compresses which increases temperature
- helium starts burning, more energy produced
  Different equilibrium, less stable
- NOT on main sequence
- where on HR diagram is complicated
- simplistically Red Giants=He burning
Stellar Evolution

• test out model of stellar evolution using Star Clusters

• HR diagram of a cluster gives “snapshot” of stars with the same age but different masses

• Birth \( \rightarrow \) Main Sequence \( \rightarrow \) Red Giant \( \rightarrow \) “live+die” faster if higher mass

• tell age of cluster by most massive star still on Main Sequence. Young clusters still have massive bright stars on main sequence
Star Clusters

stars are usually near other stars - CLUSTER

• formed at the same time from same “gas cloud”
• similar chemical composition
• about the same distance from us

Can classify by appearance and use to:
• study stellar lifetimes
• measure distances (earlier: spectroscopic parallax)
Open Star Clusters

can see individual stars by eye or with modest telescope

- usually some bright, hot stars
- 100-1000 stars in region of about 50 LY with few LY separating stars
- have significant amount of heavy elements like Carbon and Oxygen

Understood as group of recently formed stars
Open Star Clusters - Pleiades

“Seven Sisters” being chased by Orion the hunter (Greek), Orion also chasing Taurus the bull. Called Subaru star cluster in Japan

Subaru Car insignia

Subaru Telescope Hawaii
Open Star Clusters - Pleiades

Also have emission nebula around some stars. 6 brightest stars can be seen by unaided eye if in dark locale and you have good eyesight.

7 daughters of Atlas and Pleineo: Alcyone, Merope, Electra, Caleano, Taygeta, Maia (mother of Hermes), Sterope.
Globular Star Clusters

“fuzzy cotton ball” by eye or with modest telescope

- usually dim red stars
- dense with 100,000 stars in 50-300 LY region with less than one light year separating stars
- no heavy elements. Just Hydrogen and Helium
- often outside plane of galaxy

Understood as group of old stars formed in early history of the galaxy 3-12 billion years old
Very Young (few million years) Star Cluster

“moving” to main sequence

Note many more low mass stars

Some with high surface temp (25,000) have made it to the main sequence

Stars in nebula region, typical of young stars
Six brightest stars can be seen by unaided eye.

PLEIADES
largest stars “moving” off main sequence to become giants
Modest highest temp (10,000). Larger and hotter stars have “disappeared” mostly as supernovas
5 billion year old Star Cluster

largest stars are gone
stars little more massive the Sun have become giants

Highest temp on main sequence now 6200

Many small stars with low surface temperature remain on main sequence
## Fate of Stars

<table>
<thead>
<tr>
<th>INITIAL MASS relative to Sun’s mass</th>
<th>Final State</th>
</tr>
</thead>
<tbody>
<tr>
<td>M &lt; 0.01</td>
<td>Planet, Never a star</td>
</tr>
<tr>
<td>0.01 &lt; M &lt; 0.08</td>
<td>Brown dwarf (not true star)</td>
</tr>
<tr>
<td>0.08 &lt; M &lt; 0.25</td>
<td>not Red Giant → White Dwarf</td>
</tr>
<tr>
<td>0.25 &lt; M &lt; 12</td>
<td>Red Giant → White Dwarf</td>
</tr>
<tr>
<td>12 &lt; M &lt; 40</td>
<td>Supernova: neutron star</td>
</tr>
<tr>
<td>M &gt; 40</td>
<td>Supernova: black hole</td>
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</tbody>
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2017: Some very massive stars go directly to a Black Hole without a supernova. Postulated for a while as the number of massive stars seems greater that the number of SN remnants. A BH has been detected without a SN remnant, which seems to confirm this. Some WD can become SN by acquiring mass from companion star.
Red Giants ➔ White Dwarves

- for “light” stars (less than 10 times the mass of the Sun) burning of He to Carbon creates Oxygen (whose mass is slightly less than He+C mass) is final fusion stage and an inert C-O core (no fusion) is built up inside the Red Giant.
Red Giants → White Dwarves II

• “oscillate” and loss of over 1/2 star’s mass during Red Giant phase

Mass being lost

At some point all that is left is the hot, dense, inert (no fusion) C/O core about size of Earth: WHITE DWARF

Will slowly cool down over time
Planetary Nebula

• NOT planets (historic term) the material ejected by “pulsating” Red Giant can emit light as heated up by star at center

• Can lose over half the star’s mass. Red Giant moving towards WD

Blinking eye nebula. In Cygnus. 2000 LY away
Planetary Nebula – Hourglass and Helix Nebula

Hourglass nebula in constellation Musca. 8,000 LY away. Helium, oxygen, nitrogen, carbon shells give different colors

Helix nebula. In Aquarius, 700 LY away

Sometimes called “Eye of God” or “Eye of Sauron”
Red Giant $\rightarrow$ White Dwarves

Evolution of star changes its position on HR diagram over time

Star becomes smaller but hotter as inner layers being exposed. Note very high surface temperatures which cool down very rapidly from about 200,000 degrees to 40,000 degrees.
Sun: Main Sequence → Red Giant → White Dwarves

white dwarf
Extra Slides
Planetary Nebula – Ring Nebula

Ring nebula in Lyra M57. 2,300 LY away. Can only see with a telescope. Emission lines of Hydrogen and Oxygen are prominent
Hertzsprung-Russell Diagram Reminder

Plot Luminosity versus surface temperature. Star size is diagonal line large stars in upper right hand corner. White Dwarf radius 0.01 Sun = size of Earth