Main Sequence Evolution
- core hydrogen burning phase

Post Main Sequence Evolution
- hydrogen shell burning
- helium burning
- red giant phases
- pulsation and mass loss

NEXT: Stellar Corpses; Supernovae

Evolution of Low and Intermediate-Mass Stars

Core H burning on MS
- PP v. CNO

Shell H burning -> RGB
- He core
  - flash (M < 1.8 M☉)
  - burn (M > 1.8 M☉)

He shell burning -> AGB
- C/O core - SN?
  - M < 1.44 M☉

• convection zone dips down to H burning shell; first "dredge up" (C enriched material)

• Carbon stars
  - S (C/O ~1) type
  - R, N (C/O > 1) type

• outer layer weakly bound -> strong stellar winds
  - spill carbon-rich dust into ISM
  - considerable mass loss (can affect evolution)

• becomes unstable against pulsation
  - He-shell flashes; instability strip (more about this later)

• outer shell puffs off into Planetary Nebula

• carbon-oxygen rich White Dwarf core remains

Evolution of Intermediate Mass Stars

• CNO cycle comparable or dominant to PP chain
• Evolution proceeds as in solar-mass stars
• If M ≥ 4 M☉ no Helium flash; instead...
  • core does not become degenerate; Triple-alpha starts (T > 10⁸ K) right away; still create C/O core
  • if hot enough, could ignite ¹²C core in runaway reaction
  • unlike He flash, this completely destroys star in a (type I and a half) Supernova explosion
Evolution of High-Mass Stars

Supergiants
Wolf-Rayet Stars
LBV’s
SN progenitors
NS & BH parents
nucleosynthesis
enrich and mix ISM
drive/stop star formation

Evolution of High-Mass Stars

• proceed as lower mass stars, but continue core-shell burning all the way up to Si, which produces an Iron core
• for 20 $M_\odot$ star...
  – H $10^7$ y
  – He $10^4$ y
  – C $300$ y
  – O $200$ d
  – Si $2$ d

no significant mass change during main sequence lifetime

significant mass can be lost during red giant phases

corpse type (and mass) related to main-sequence mass and to how much mass was lost in red giant phase

<table>
<thead>
<tr>
<th>Star/Loss Mass $10M_\odot$</th>
<th>MS Energy Production</th>
<th>Core Burning</th>
<th>Shell Burning</th>
<th>He Flash?</th>
<th>Final Core</th>
<th>Corpse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low Mass $10M_\odot$</td>
<td>PP chain</td>
<td>H, He</td>
<td>No</td>
<td>No</td>
<td>H, He</td>
<td>Black dwarf</td>
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<tr>
<td>Low Mass Stars $0.1M_\odot$</td>
<td>H, He, H, He</td>
<td>H, He</td>
<td>No</td>
<td>No</td>
<td>H, He</td>
<td>Black dwarf</td>
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<tr>
<td>Solar Mass Stars $0.4M_\odot$</td>
<td>CNO cycle (0.6 to 1.2 $M_\odot$)</td>
<td>H, He, H, He</td>
<td>No</td>
<td>No</td>
<td>H, He</td>
<td>Black dwarf</td>
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<tr>
<td>Intermediate Mass $4M_\odot$</td>
<td>CNO-dominated</td>
<td>H, He, H, He</td>
<td>No</td>
<td>No</td>
<td>C, O, Si</td>
<td>White dwarf or neutron star</td>
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<tr>
<td>High Mass Stars $50M_\odot$</td>
<td>CNO-dominated</td>
<td>H, He, H, He</td>
<td>No</td>
<td>No</td>
<td>C, O, Si, Si</td>
<td>Neutron star or black hole</td>
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</tbody>
</table>