# 31 — Main-Sequence Stars [$Revision : 1.1$]

- Massive vs. Low-Mass Stars
  - Number of definitions exist for what constitutes a massive star
  - Structural: below $\sim 1.3\,M_\odot$, convective envelope; above, radiative
  - Energetic: below $\sim 1.2\,M_\odot$, PP chain dominates; above, CNO cycle
  - Terminal: above $\sim 9\,M_\odot$, supernova; below, white dwarf
  - Spectroscopic: above $\sim 1.5\,M_\odot$, early spectral type (OBA); below, late
- Structural differences
  - Most significant structural difference is distribution of **convective** & **radiative zones**
  - In cores of low-mass stars like Sun
    * Lower luminostiy means **PP chain** can generate sufficient energy to match star's needs
    * Small temperature sensitivity ($\sim T^4$) means spread-out energy generation
    * So, luminosity $L_r$ grows slowly throughout core, and $F = L_r/4\pi r^2$ is moderate
    * Radiation capable of transporting all this flux
    * So, radiative core
  - But in cores of massive stars
    * Higher luminosity means that **CNO cycle** must be used to match star's energy generation needs
    * High temperature sensitivity ($\sim T^{19}$) means centrally-concentrated energy generation
    * So, luminosity $L_r$ grows raidly in core, and $F = L_r/4\pi r^2$ is large
    * To transport all energy by radiation, temperature gradient very steep; convection sets in
    * So, convective core
    * Convection is very efficient, so $\nabla = \nabla_{\rm ad}$ to high degree of accuracy
    * Convection mixes composition changes due to nuclear burning; so, flat composition profile in core
  - In envelopes of low-mass stars like Sun
    * Large opacity due to bound-free transitions of hydrogen and helium
    * To drive radiative flux through this opacity, need steep temperature gradient; convection sets in
    * So, convective envelope
    * Depth of convection increases towards lower masses; below $\sim 0.3\,M_\odot$, whole star is convective
  - But in envelopes of high-mass stars
    * Hydrogen and helium already ionized; opacity generally low
    * To drive radiative flux, temperature gradient can be moderate; no need for convection
    * So, radiative envelope
    * In the more-massive stars ($M \gtrsim 10\,M_\odot$), iron and nickel cause opacity peak at $\sim 200,000\,$K; this 'iron bump' can cause thin, weak convection zone
- Evolutionary differences
  - Massive-star lifetimes (ZAMS to TAMS) are much shorter due to much-higher luminosity

  - Tracks in HR diagram are different — low-mass tracks are vertical, high-mass are diagonal
  - In both cases, luminosity increases due to increase in molecular weight in core
    * Higher $\mu$ requires higher $T$ or $\rho$ to support overlying layers
    * Core contracts somewhat to make these changes
    * Faster nuclear burning occurs
    * Luminosity increases
  - Difference due to differing abundance/molecular weight distribution in cores
    * Low-mass stars have smoothly varying abundance change
    * High-mass stars have discontinuous abundance chage (although discontinuity smeared out by core shrinkage), due to convective mixing
    * Very-low-mass stars ($\lesssim 0.3\,M_\odot$) are completely mixed by convection; this gives very long ages

- End of main sequence evolution
  - At end of main sequence, general configuration is same:
    * Nearly-isothermal core with zero luminosity
    * Core is hot due to high $\mu$
    * At core boundary, temperature high enough for nuclear burning
    * This burning in shell around core
  - High temperatures, large burning volume leads to high shell luminosity
  - However, star is no longer in thermal equilibrium; envelope expands