Unit 1 Energy Generation

1. Basics
   (a) Energy equilibrium
   (b) Nuclear interactions
   (c) Nuclear reaction rates
   (d) Energy release in nuclear reactions
   (e) Binding energy
2. Hydrogen burning
   (a) PP-I chain
   (b) PP-II and PP-III chain
   (c) CNO cycle
3. Things not discussed

Unit 2 Hydrostatics

1. Are stars approximately a one-fluid plasma?
2. Time scales of stars
   (a) Dynamical timescale
   (b) Thermal timescale
   (c) Nuclear timescale
3. Equation of state
   (a) Preliminaries
   (b) Mean molecular weight (μ)
   (c) Ideal monatomic gas
   (d) Completely degenerate gas
   (e) Partially degenerate gas
   (f) —
   (g) Radiation Pressure
   (h) Density-temperature equation of state landscape
   (i) Thermodynamics of an ideal gas
   (j) Mixture of ideal gas and radiation: pressure effects
   (k) Mixture of ideal gas and radiation: ionization effects
4. Hydrostatic equilibrium
   (a) Derivation
5. The Virial Theorem
6. Polytropes
   (a) Motivation and derivation
   (b) Lane-Emden equation
   (c) Polytrope solutions

Unit 3 Energy Transport

1. Radiation

   (a) Basics

   - Efficiency of energy transfer depends on:
     1. Temperature gradient of the solar interior
     2. Mean free path for photons: $\ell = \frac{1}{\kappa\rho}$

   (b) Diffusion

   - Fick's Law: $F = -D\nabla_r n$; $D = \frac{1}{3}\overline{v}\ell =$ diffusion coefficient
   - Temperature gradient: $\frac{\mathrm{d}T}{\mathrm{d}r} = -\frac{3}{16\pi ac}\frac{\kappa\rho}{r^2}\frac{L}{T^3}$

   (c) Frequency dependence of radiation

   - Rosseland mean opacity, κ_R

   (d) Opacity sources

   - $\kappa = \kappa_0\rho^n T^{-s}$ [cm^2 g^{-1}]
   - *Kramer's opacities* scale as $\kappa \sim \rho T^{-3.5}$ $(n = 1, s = 3.5)$
   - Four main sources:
     i. Compton/Thomson scattering (photon-electron)
     ii. Free-free absorption (Kramer's, core)
     iii. Bound-free absorption (Kramer's, surface)
        – H^-: Sensitive to metallicity, needs free electrons, $\nu =$ IR and up
     iv. Bound-bound absorption

   (e) Consequences (See figures)

   (f) Eddington Luminosity

   - Maximum luminosity a star can have and still balance gravity

   (g) Final tools:

   - $\nabla \equiv \frac{dlnT}{dlnP} =$ True driving gradient:
   - $\nabla_{rad} =$ Radiation gradient, slope required if all luminosity was carried by radiation through diffusion
   - $\nabla_{ad} =$ Adiabatic gradient, rate that temperature of a parcel of gas changes with height

2. Conduction: $\frac{1}{\kappa_{tot}} = \frac{1}{\kappa_R} + \frac{1}{\kappa_{cond}}$

3. Convection

   (a) The convective instability: Schwarzschild criterion, Brunt-Vaisala frequency

   (b) Another useful formulation:

   $$TdS = dU + PdV$$
   $$\frac{dS}{dr} = c_P(\nabla - \nabla_{ad})\frac{dlnP}{dr}$$

   Entropy is constant for adiabatic processes

   (c) Semiconvection

   $$N^2 = \frac{g^2\rho}{P}\left(\nabla_{ad} - \nabla + \nabla_\mu\right)$$

   Ledoux criterion: Schwarzschild criterion is satisfied, but the medium is still stable due to a positive composition gradient

   (d) One more useful formulation

   (e) Physical conditions for convection onset

- L/m is large
- κ is large
- ρ/T^3 is large
- $\nabla_{ad} = 1 - 1/\gamma$ is small

(f) Mixing length theory

(g) Convective overshoot: momentum carries convection beyond the layer where parcels become stable, possibly depositing mixed material in stable regions.

(h) Depth of outer convection zones

- T_{eff}
- chemical abundances

Higher metallicity $\longrightarrow$ higher opacity and deeper convection zones

Unit 4 The Main Sequence

1. Summary of stellar structure
2. Homology relations for stars in **radiative equilibrium**
   (a) Basic idea
   (b) Dependence on mass
   (c) Dependence on T_{eff}
   (d) Dependence on mean molecular weight (μ)
   (e) Dependence on heavy metal abundances
   (f) Contracting stars in radiative equilibrium
   (g) Convective stars
3. Evolution on the main sequence
   (a) Low-mass stars
   (b) High-mass stars
   (c) A note about *very* low mass stars
4. Summary of Main-Sequence properties

Unit 5 The Post Main Sequence

1. General considerations
   (a) Schònberg-Chandrasekhar Limit
   (b) The subgiant branch
2. Toward and up the RGB
   (a) High-mass stars
   (b) Low-mass stars
   (c) RGB properties
   (d) Summary
3. Helium burning
   (a) Quick tour of non-hydrogen nuclear reactions
   (b) Horizontal Branch
   (c) Location of the ZAHB
   (d) Horizontal branch evolution
   (e) Asymtotic giant branch
   (f) Thermal pulses
4. Last stages of evolution: low-mass stars
   (a) Production of s elements
   (b) Planetary nebula
   (c) White dwarfs
   (d) Further WD properties
   (e) Type Ia supernovae
5. Last stages of evolution: high-mass stars
   (a) Nuclear burning
   (b) Type II supernova – core collapse
   (c) Neutron star
   (d) Black hole