1) Observed properties of stars.
(GK 1; Pr 1.1, 1.2; Po 1)

- What is a star?
- Why study stars?
- The sun
- Age of the sun
- Nearby stars and distribution in the galaxy
- Populations of stars
- Clusters of stars
- Distances and characterization of stars
  - Luminosity and flux
  - Magnitudes
  - Parallax
  - Standard candles
    - Cepheid variables
    - SN Ia

2) The HR diagram and stellar masses
(GK 2; Pr 1.4; Po 1)

- Colors of stars
  - B–V
  - Blackbody emission
  - HR Diagram
- Interpretation of HR diagram
  - stellar radii
  - kinds of stars
    - red giants
    - white dwarfs
    - planetary nebulae
    - AGB stars
    - Cepheids
    - Horizontal branch
  - evolutionary sequence
  - turn off mass and ages
- Masses from binaries
  - Circular orbits solution
  - General solution
  - Spectroscopic binaries
  - Eclipsing spectroscopic binaries
  - Empirical mass luminosity relation

3) Spectroscopy and abundances
(GK 1; Pr 2)

- Stellar spectra
  - OBFGKM
  - Atomic physics
    - H atom
    - others
  - Spectral types
  - Temperature and spectra
  - Boltzmann equation for levels
  - Saha equation for ionization
  - ionization stages
  - Rotation
- Stellar Abundances
  - More about ionization stages, e.g. Ca and H

Meteorite abundances
Standard solar set
Abundances in other stars and metallicity

4) Hydrostatic balance, Virial theorem, and time scales
(GK 3,4; Pr 1.3, 2; Po 2,8)

- Assumptions - most of the time
  - Fully ionized gas except very near surface
    - where partially ionized
  - Spherical symmetry
    - Broken by e.g., convection, rotation, magnetic fields, explosion, instabilities, etc
    - Makes equations a lot easier
  - Limits on rotation and magnetic fields
  - Homogeneous composition at birth
  - Isolation (drop this later in course)
  - Thermal and hydrostatic equilibrium (most of the time)

- Hydrostatic equilibrium
  - derive
  - central P and T estimates

- The free fall time scale
  - HE maintained to high accuracy

- Explosion time scale (see K&W)
  - applications - maintain HE
    - supernovae, explosive nucleosynthesis

- Lagrangian coordinate

- Virial theorem
  - From integrating HE
  - Mechanical and thermal equilibrium

- First law of thermodynamics

- Total energy of a star, negative heat capacity

- Other time scales
  - Nuclear
  - Thermal
  - Radiative

5) Stellar equation of state
(GK 5; Pr 2, 3; Po 3)

- Statistical mechanics

- Pressure integral

- Ideal gas pressure

- Definition of abundance variables

- Degenerate electrons

- Radiation

6) Radiation transport
(GK 6; Pr3.7; Po 5)

- Relation between pressure and energy

- Adiabatic processes

Derive temperature gradient equation
  define opacity
  optical depth
  boundary condition at photosphere

Sources of opacity
 Rosseland mean
 electron scattering
 bound free
 bound bound
 Kramers
 tables

Conduction

Eddington luminosity
Eddington lifetime and accretion rate

7) Polytropes
(GK 9, 10; Pr 5; Po 4)

Lane Emden equation

analytic solutions 0, 1, 5

mass, radius, pressure, temperature relations

Binding energies

Eddington standard model

Mass luminosity relation

8) Convection and other instabilities
(GK 11, 12; Pr 6; Po 5)

Condition for instability
 adiabatic gradient
 Schwarzschild criterion
 Ledoux criterion

Places where convection matters

Mixing length theory
  Estimate flux
  Get superadiabatic excess
  Get convective speed

Condition for nuclear stability

Degenerate instability

Thin shell instability

Global instability (gamma<4/3)

Examples

9) Nuclear physics
(Cla 4; GK 7; Pr 4.1; Po 6)

Nuclei
 Nomenclature
 Nuclear force - short range
 Binding energy goes as A not A**2
 Repulsive at small distances

Liquid drop model
 A Fermi gas
 Why Z = N
 Systematics of BE/A
 Fission vs fusion
 Most tightly bound nuclei in iron group
 Odd-even and closed shell effects
 Shell model

Stability
  strong
   neutron and proton drip
   A = 4 very bound, no mass 5 or 8
   alpha decay
   fission
  weak
   beta decay
   electron capture
   positron emission

10) Nuclear reactions
(Cla 4; GK 7,8; Pr 4; Po 6)

Non-resonant reactions
  S factor
  Gamow peak
  T dependence
  common cases in stars

Resonant reactions
  conserve spin and parity
  proceed through exited states
  examples

Key reactions for H and He burning
 C burning etc deferred
 pp1, 2, 3   CNO
 3a and 12C(ag)

r- and s-process and post helium burning deferred

11) Star formation and early evolution
(GK 15; Pr 9,12; Po 9)

ISM
 multiphase
 where star formation happens

Jeans mass

Hayashi track
 H- opacity

12) Overview of evolution of stellar cores
(GK 13; Pr 7; 12; Po 8)

Map out log rho - log T plane by EOS

By nuclear reactions

By instability and degeneracy

Map out by rho propto T**3 evolution for different masses

Critical masses

Initial mass function?

Nucleosynthesis

13) Main sequence stars
(GK 14; Pr 7, 9; Po 7, 10)

pp1, 2, 3, CNO tricycle if not already covered in 10

Homology on the main sequence
- Mass luminosity relations
- Teff-luminosity relations
- General characteristics as function of mass

Evolution on the main sequence

Massive vs low mass stars

The sun and solar neutrinos

Schonberg Chandrasekhar mass

Hydrogen shell burning

14) Post main sequence through helium burning
(GK 16; Pr 4,7, 9; Po 11)

Hydrogen shell burning
Red giant formation

mass loss

Degenerate instabilities

Helium core flash

Cepheid variables

Horizontal branch

AGB stars

Thin shell instability

The s-process

Planetary nebulae

White dwarfs

15) Post-helium burning in massive stars
(Po 12; GK 8; Pr 4, 7)

advanced burning stages in massive stars
- carbon
- neon
- oxygen
- silicon
- s-process

Effects of rotation
PreSN stars
- systematics
- generalized Chandrasekhar mass

16) Core-collapse supernovae
(GK 17; Pr 10; Po 13)

Iron core instability and collapse

Neutrino transport model

Rotation and B fields

Shock wave propagation

Explosive nucleosynthesis

The r-process

Mixing

Light curves and spectra
- Ib, c
- IIp

17) Novae and Type Ia supernovae
(Po 13; Pr 10; 11)

- Binary evolution in general
  - Interacting binaries
  - Common envelope

- Classical novae
  - Observations
  - Model

- Type Ia supernovae
  - Observations
  - Models
    - Chandra
    - sub-Chandra
    - Merging WDs
  - Nucleosynthesis
  - Light curves
  - Spectra

18) Neutron stars and binary x-ray sources
(GK 18; Pr 10, 11;

- Properties of neutron stars
  - structure
  - pulsars
    - dipole formula
    - neutron star quakes
    - planets
  - magnetars
    - soft gamma-ray repeaters
    - anomalous x-ray pulsars

- Nuclear physics and observations of XRBs

- Binary x-ray sources
  - Observational characteristics
  - Masses

- Black holes

19) Pair instability supernovae and Other exotica

- Gamma-ray bursts
  - Observational history
  - Beaming
  - Models

collapsar
ms magnetar

r–process and merging neutron stars

Pair instability supernovae
Pop III stars – reionization
Pulsational pair instability

Ultraluminous supernovae
Magnetar powered supernovae