Goals of the course:

i. Understand the global characteristics of stars
ii. Relate relevant microphysics to the global stellar characteristics
iii. Link stellar structure to evolution and vice versa
iv. Link the “stellar zoo” to stellar evolutionary phases and understand their interrelationship
v. Understand how the virial theorem controls the mechanical structure of stars and be able to back this up with simple models
vi. Understand how opacity controls energy flow and how this factors into the thermal – and mechanical – structure of stars and be able to back this up with simple models
vii. Understand how these control the observational properties of stars
viii. Understand stellar evolution and the physical factors driving it
ix. Link the various instabilities to the microphysical properties of gases in a qualitative way

Structure of the course

i. Derive the equations governing stellar structure
ii. Study the microphysics of the processes involved: equation of state, opacity, nuclear reactions, energy transport
iii. Study simplified models of stellar structure based among others on polytropes
iv. Compare and contrast the evolution of stars of different initial mass

Chapter 1: Overview

i. Know typical values for stellar properties such as radius, mass, temperature, luminosity, age, and their observed relations
ii. Describe the Hertzsprung-Russell diagram and name/locate the various stages of stellar evolution
iii. Describe the stellar "zoo" and locate them on the HR diagram
Chapter 2: The equations of stellar structure

i. You should know the equations of stellar structure in their various forms
ii. Derive/discuss the various timescales involved
iii. Derive the virial theorem and apply it to relate internal energy (temperature, pressure, density) and stellar mass and radius

Chapter 3: Energy transport, the equation of state, & opacities

i. Describe radiative/conductive energy transport as a diffusion process
ii. Describe qualitatively why mass is the key to stellar structure
iii. Derive a simple relationship between stellar luminosity and mass
iv. Understand the relationships between pressure, density and temperature for an ideal gas, a photon gas, a (partially) degenerate electron gas – from non-relativistic to extreme relativistic – and locate the regions in the density-temperature plane where these different laws are applicable (and describe this)
v. You should know for which stars degeneracy becomes important
vi. You should know the different adiabatic exponents and their relationship to stellar (in)stability and be able to derive their values for different equations of state
vii. Describe convective energy transport, derive the (in)stability criteria, and apply these criteria to locate stellar zones that are convectively unstable
viii. Understand the basics of mixing length theory
ix. Derive an equation for the Rosseland mean opacity
x. Understand the sources of opacity in stars and be able to link them to the physical process involved and you should know which process dominates at what temperature/densities
xi. You should know Kramers opacity law and the H⁻ opacity law
xii. Understand the importance of the Eddington luminosity for stellar stability and its relationship (if any) to the maximum stellar mass

Chapter 4: Energy transport, the equation of state, & opacities

i. Link nuclear properties to nuclear energy sources
ii. Describe the nuclear potential well and derive approximate values for the energies involved
iii. Describe nuclear reactions and understand the importance of tunneling
iv. Describe expressions for thermonuclear reaction rates – resonant and non-resonant – for protons and neutrons
v. Describe the origin of the Gamow peak and derive approximate values for relevant reactions
vi. Describe the different stellar nuclear burning stages, the energies involved, and their relevant density and temperature ranges
Chapter 5: Stellar structure equations

i. You should have a general understanding of the equations of stellar structure and the constitutive relations
ii. You should have a general understanding of the method of solution and of the role of the boundary conditions
iii. You should understand the polytrope solutions of the stellar structure equations and examples of their applicability
iv. You should be able to work (quantitatively) with polytropes to understand stellar structure (if relevant values are provided)
v. Understand Eddington's standard model and its application to stars
vi. Describe fully convective stars as polytropes, and relate them to the Hayashi track
vii. Describe the evolution of protostars and describe this in terms of polytropes
viii. Describe white dwarfs as polytropes and describe qualitatively the origin of the Chandrasekhar mass

Note that solution methods is not part of the course

Chapter 6: Stellar evolution

i. Describe qualitatively the different stages of stellar evolution and relate them to the properties of the core
ii. Derive mass-luminosity and mass-radius relationships for main sequence and stars and red giants
iii. Compare and contrast the structure of stars of different mass
iv. Derive simple expressions describing the luminosity evolution on the main sequence and red giant branch
v. Understand the role of electron degeneracy in the evolution of stars
vi. Describe the interplay of H- and He-shell burning on the AGB
vii. Describe the various dredge up events that can drive the surface composition of giants

Chapter 7: Stellar pulsations and instabilities

i. Understand the physical origin of dynamical and thermal instabilities
ii. Describe the thermal instabilities of degenerate gasses and of then shell burning zones
iii. Understand the destabilizing effects of radiation pressure
iv. Understand the physics of stellar pulsations and be able to describe the $\kappa$-mechanism
v. Locate the pulsational unstable zones in a star and derive a simple expression for the location of pulsating stars in the HR diagram

Chapter 8: Asteroseismology
i. Describe stellar seismic spectra in terms of the large and small separations and relate those to stellar characteristics

ii. You should qualitatively understand the frequency spectrum of stars and their asymptotic behavior

iii. Describe the applications of asteroseismology in stellar evolution studies

**Assignments**

You can prepare yourself by working on the exercises handed out as well as those in the Pols textbook on the web.