Stars overview:
Aims of each lecture

Aims of lecture 1: observed properties

Key concept: black-body emission

Aims:

- Know what stellar properties can be measured
- Understand the connection between stellar colours and temperature
- Know and be able to use:

$$L = 4\pi R^2 \sigma T_e^4$$

Stefan-Boltzmann luminosity equation (for a black body)

$$\lambda_{\max} = \frac{2.9\times10^{-3}}{T}$$

Peak wavelength for black-body emission

Aims of lecture 2: observed properties

Key concept: formation of spectral lines

Aims:

- Understand the basis of stellar classification
- Understand the processes of excitation and ionisation
- Know and be able to use:

$$\frac{N_b}{N_a} = \frac{g_b}{g_a} e^{-(E_b - E_a)/kT}$$

Boltzmann equation: excitation states

$$\frac{N_{i+1}}{N_i} = \frac{2Z_{i+1}}{n_e Z_i} \left(\frac{2\pi m_e kT}{h^2} \right)^{\frac{3}{2}} e^{-\chi_i / kT}$$

Saha equation: ionisation states

Aims of lecture 3: observed properties

Key concept: mass measurements from binary system dynamics

Aims:

- Be able to define the various classes of binary system
- Know what properties can be measured from binary systems and how inclination angle effects the measured properties and masses

$$\frac{m_1}{m_2} = \frac{a_2}{a_1} = \frac{\alpha_2}{\alpha_1} = \frac{v_2}{v_1}$$

Mass ratio relationships

$$P^2 = \frac{4\pi^2 a^3}{G\left(m_1 + m_2\right)}$$

Keplers generalised 3rd law

Aims of lecture 4: stellar power source

Key concept: hydrostatic equilibrium

Aims:

- Understand hydrostatic equilibrium and why it applies to stars
- Understand the conditions in the cores of stars, the definition of mean molecular mass, and the forms of pressure in stars
- Know and be able to use:

$$\frac{dP}{dr} = -\frac{GM_r}{r^2}\rho$$

Hydrostatic equilibrium

$$P = \frac{\rho kT}{\mu m_H} + \frac{1}{3}aT^4$$

Internal pressure

Aims of lecture 5: stellar power source

Key concept: energy from gravitational collapse

Aims:

- Understand the virial theorem as it applies to stellar interiors
- Be able to calculate the energy available from gravitational collapse and to be able to calculate the Kelvin-Helmholtz time
- Know and be able to use:

$$K = \frac{1}{2}U$$

Virial theorem

$$E = \frac{3}{10}\frac{GM^2}{R}$$

Radiated energy from gravitational collapse

Aims of lecture 6: stellar power source

Key concept: nuclear fusion

Aims:

- Understand why energy is released by nuclear fusion processes and the factors behind the probability that a nuclear reaction will occur

- Know the difference between the classical and quantum temperature

- Know and be able to use:

$$T_{classical} = \frac{Z_1 Z_2 e_c^2}{6\pi\varepsilon_0 kr}$$

Classical temperature for nuclear reaction

$$\varepsilon_{ix} = \varepsilon_0' X_i X_x \rho^{\alpha} T^{\beta}$$

Energy release from nuclear reactions

Aims of lecture 7: stellar power source

Key concept: nucleosynthesis

Aims:

- Know and be able to apply the nuclear reaction rules
- Understand and be able to write down the PP I chain and to know the basic steps behind the other PP chains, CNO cycle, and 3α processes
- Have a basic understanding of the later nuclear fusion processes
- Understand how neutrinos can test our model of the solar core

Aims of lecture 8: stellar structure

Key concept: random walk of photons

Aims:

- Understand the basis behind energy transport in stars and be able to show:

$$\frac{dL}{dr} = 4\pi r^2 \rho \varepsilon$$

Energy conservation

- Understand the random walk of photons and be able to show:

$$\ell = \frac{1}{n\sigma}$$

Mean free path

$$N = \left(\frac{d}{\ell}\right)^2$$

Number of scattering events

Aims of lecture 9: stellar structure

Key concept: sources of opacity

<u>Aims:</u>

- Be able to describe the different sources of opacity and know when they are important in stars:

  bound free, bound bound, free free, and electron scattering

- Understand the definition of optical depth and the general form of opacity:

$$I_\lambda = I_{\lambda,0} e^{-\kappa_\lambda \rho s}$$

Optical depth: impact of opacity on intensity

$$\kappa = \kappa_0 \rho^\alpha T^\beta$$

General form of opacity

Aims of lecture 10: stellar structure

Key concept: convection

Aims:

- Understand the Schwarzschild criterion for convection and have a basic understanding of the mixing length theory of convection in stars
- Know where convection occurs in stars and be able to assess whether convection occurs in the core of the Sun
- Know and be able to show:

$$\left|\frac{dT}{dr}\right|_{sur} > \left(\frac{\gamma_{ad}-1}{\gamma_{ad}}\right)\frac{T}{P}\left|\frac{dP}{dr}\right|_{sur}$$

Condition for convection to occur

$$\ell = \alpha H_P$$

Convection mixing length

Aims of lecture 11: stellar structure

Key concept: the structure of stars

Aims:

- Brief review of many of the concepts from the course
- Basic understanding of the conditions inside the Sun
- Understand what drives the minimum and maximum masses of stars and be able to show:

$$\frac{M_{max}}{M_{sun}} = \sqrt[\alpha-1]{\frac{4\pi c G M_{sun}}{\kappa L_{sun}}}$$

Maximum mass of stars

Aims of lecture 12: stellar structure

Key concept: physics of stellar pulsation

<u>Aims:</u>

- Understand how the period-luminosity relationship for Cepheid variables can be used to determine distances in the Universe
- Be able to define the term instability strip and understand why the instability strip has a narrow temperature range
- Understand how partial ionisation zones power stellar pulsation
- Know and be able to show:

$$\Pi \approx \sqrt{\frac{3\pi}{2\gamma G\rho}}$$

Stellar pulsation period

Aims of lecture 13: stellar evolution

Key concept: gravitational collapse of a gas cloud

Aims:

- Understand the basic physics behind cloud collapse and fragmentation
- Understand the paths that protostars take on the HR diagram ("Hayashi tracks") and be able to describe the basic properties of protostars
- Be able to define the term "Jeans mass" and show that it is given by:

$$M_J \cong \left(\frac{5kT}{G\mu m_H}\right)^{3/2}\left(\frac{3}{4\pi\rho_0}\right)^{1/2}$$

Condition required for gravitational collapse

Aims of lecture 14: stellar evolution

Key concept: the factors that drive the evolution of stars

Aims:

- Understand the factors that drive the evolution of stars both on and off the main sequence and why the evolution of stars is a function of mass

- Understand the evolution of low-intermediate mass stars from the main sequence to the horizontal branch, giant branch(es), and white dwarfs

- Know and be able to define and use:

$$t = \frac{X\xi Mc^2}{L}$$

Nuclear fusion lifetime

$$t = 10^{10}\left(\frac{M_{Sun}}{M}\right)^{\alpha-1} yrs$$

Mass-dependent main sequence lifetime

Aims of lecture 15: stellar evolution

Key concepts: endothermic processes and stellar core collapse

Aims:

- Understand how the evolution of massive stars differs from that of lower-mass stars

- Understand how endothermic processes doom the evolution of massive stars: photodisintegration, electron capture, and neutrino production

- Know how to calculate the amount of gravitational energy released in the collapse of the stellar core and how this drives a supernova

$$E = -\frac{3}{10}\frac{GM^2}{R}$$

Energy from gravitational collapse

- Be able to describe the basic properties of supernovae and their remnants

Aims of lecture 16: stellar evolution

Key concept: degeneracy pressure

Aims:

- Understand the basic properties of white dwarfs and neutron stars
- Have a basic understanding of cooling in white dwarfs
- Understand the principles behind degeneracy pressure and be able to show:

$$P = \frac{\hbar^2}{m_e}\left[\left(\frac{Z}{A}\right)\frac{\rho}{m_H}\right]^{5/3}$$

Electron-degeneracy pressure

Aims of lecture 17: stellar evolution

Key concept: conservation of angular momentum

Aims:

- Understand why pulsars are believed to be rotating neutron stars due to the collapse of the stellar core of massive stars

- Be able to show that the minimum rotation period is:

$$P_{\min} = \left(\frac{3\pi}{G\rho} \right)^{1/2}$$

Period-density relationship

- Know and be able to show:

$$R_S = \frac{2GM}{c^2} = 2.96 \left(\frac{M}{M_{Sun}} \right) km$$

Schwarzschild radius