Modern astrophysics

Chalmers, autumn 2020

Important concepts

Introduction (chapter 1)

- Typical sizes/distances and masses in the Universe.
- Distance measurements (only principles: parallax method, "standard candles").
- Magnitudes (apparent and absolute, calculations).
- Units used in astronomy (the astronomical unit, parsecs, arc seconds and other angular units).
- Celestial coordinates (right ascension, declination).
- When general relativity is needed.
- Sources of astronomical information (EM waves, neutrinos, …).
- Resolution of telescopes.
- Observations in different wavelength bands.

Calculations: Parallax, coordinates, magnitudes, resolution. Magnitude calculations are the most important in this section.

Exoplanets
(not in the book; use lecture notes and, e.g., Wikipedia)

- Principles and most important methods for planet detection.
- How to measure masses, sizes and orbits of exoplanets.
- General properties of other planetary systems, differences from the Solar system.
- Models for the formation of other planetary systems.

Calculations: Parameters of exoplanets
Useful links: http://exoplanet.eu/
http://en.wikipedia.org/wiki/Exoplanet

Interaction of radiation with matter (chapter 2)

You do not have to learn long derivations, but you should know the concepts below and be able to use the radiative transfer equation.
- Blackbody radiation, Stefan-Boltzmann's law, Wien's displacement law.
- Specific intensity.
- The radiative transfer equation, optical depth, the concepts optically thin and thick. See especially the equation between (2.20) and (2.21).
- Thermodynamic equilibrium.
- Approximations to Planck's law (*B* proportional to *T*), the radiative transfer equation written as $T_{\mathrm{b}}(\tau_\nu) = T_{\mathrm{bg}} e^{-\tau_\nu} + T_{\mathrm{ex}}(1 - e^{-\tau_\nu})$
- Formation of spectral lines in a stellar atmosphere: eq. (2.71) and the text below.
- Equivalent width of spectral lines.

Stellar astrophysics I (chapter 3)

- The five basic equations of stellar structure – to recognize, explain basic physics and use: the mass continuity equation, hydrostatic equilibrium, the energy equation, radiative transport of photons, energy equation for convection.
- Kelvin-Helmholz timescale.
- Important, basic relations amongst stellar quantities: Mass to luminosity relation, Hertzsprung-Russel diagram (HR-diagram), mass-lifetime relation.
- How can we observationally determine stellar masses and distances.
- Overview of the lifes of the stars found in the HR diagram.
- The specific use of HR diagrams for stellar clusters.
- Eddington luminosity limit.

Stellar astrophysics II (chapter 4)

- Energy production: fusion and fission.
- The problem with fusion (electrostatic forces), the solution (tunneling).
- The proton-proton chain, the CNO cycle: what are they (detailed reactions not needed), in which stars do they take place and what determines which process is dominating?
- Energy transport in stars of different masses: radiation and/or convection.
- Helioseismology: what is it?
- Solar neutrino experiments: why, results, explanation of results?
- Stellar evolution: basic principles and mechanisms, evolution in the HR diagram.
- Evolution of binary stars.
- Supernovae: what are they (two basic types)?

End states of stellar collapse (chapter 5)

- Why stellar collapse?
- Three end states: white dwarfs, neutron stars, black holes.
- Degenerate gas: what is it, and what is its importance for white dwarfs and neutron stars?
- Chandrasekhar's mass limit.
- Pulsars: what are they? Long-term change in pulse period, sudden "glitches".

Our Galaxy and its interstellar matter (chapter 6)

- Star count analysis.
- Malmquist bias.
- Shapley's model of the Milky Way.
- Interstellar extinction and reddening – how does it work, and what is the wavelength dependence?
- The circular approximation – be able to use it and understand its implications and limitations.
- The meaning of the epicycle theory for stars in orbits around the Galactic centre.
- Describe the two main stellar populations – pop I and pop II.
- Describe the main phases of the interstellar medium (ISM), Strömgren sphere, pressure and gravitational balance.
- How can we observe the various phases of the ISM?
- How can we study the magnetic fields of the Galaxy?

The solar system
(not in the book; use lecture notes and, e.g., Wikipedia)

You should be able to give an overview of the following:
- Planets (eight), dwarf planets (e.g., Pluto), small solar system bodies (meteoroids, asteroids, comets).
- How to measure (in principle) properties of planets: distance, size, mass, density, chemical composition, age (of surfaces, and of rocks, meteorites, etc.), surface temperature.
- Equilibrium surface temperature of a planet
- Atmospheres (why so different on Venus, Earth and Mars?)
- The current model for the formation of the solar system
- The current model for the formation of the Moon (collision with something big)

Calculations: Radioactive ages, temperatures
Useful links: http://en.wikipedia.org/wiki/Solar_system
https://en.wikipedia.org/wiki/Formation_and_evolution_of_the_Solar_System

Extragalactic astronomy (chapter 9)

- Morphological classification of normal galaxies – the tuning fork diagram.
- Describe and compare structures and features of elliptical and spiral galaxies – their surface luminosity distributions.
- Faber-Jackson relation – Tully-Fischer relation (recognize and use).
- Definition of redshift.
- Observational determination of the Hubble constant.
- Rough classification of AGNs – see table from lecture.
- Unification theory of AGNs – give examples of.
- General properties of galaxy clusters.

The spacetime dynamics of the Universe (chapter 10)

- Hubble's law: Newtonian interpretation, general relativity interpretation.
- Curvature: 2D analogs, metrics as description of the geometry of a surface or of the Universe.
- The Universe is (assumed to be) homogeneous and isotropic.
- The scale factor $a(t)$ and the co-moving coordinates (r, θ, φ).
- The Doppler effect: Newtonian and relativistic interpretation. The Hubble constant expressed using the scale factor.
- The Friedmann equation for the scale factor: Newtonian derivation using $E = -kc^2/2$.
- The critical density derived from the Friedmann equation. The density parameter Ω.
- The curvature of the Universe described by k (= 0, +1, –1). Properties of the different models (e.g., finite or infinite, density, evolution).
- The density as a function of a for matter and radiation (derivation not required).
- Solving the Friedmann equation in simple cases (e.g., the "flat" case for a matter dominated Universe) to get a as a function of t.

The thermal history of the Universe (chapter 11)

- The timetable of formation – very general.
- Concept of chemical and thermal equilibrium and the implication of primordial abundances.
- Baryon to photon ratio η – its cosmological significance.
- Importance of deuterium observations – why?
- Basic distinction between hot dark matter (HDM) and cold dark matter (CDM).
- The horizon problem – and its solution.
- Why is there a ”Last Scattering Surface”? Importance of the primary anisotropies.
- Sunyaev-Zeldovich effect.
- Evidence for evolution for 1. QSOs 2. Normal galaxies 3. Intergalactic medium (Gunn-Peterson test, Lyman-α forest)
- Reionization.
- Structure formation: Jeans length, perturbations can grow when Universe became matter dominated – note that timescales are different for CDM, consequences?

Relativistic cosmology (small parts of chapter 14)

- The cosmological constant and how it changes the solution of the Friedmann equation (i.e. the evolution of the Universe). Why was it introduced? Why was it abandoned?
- Cosmological tests: the Hubble test, the angular size test (no calculations).
- The surface brightness in relativistic cosmology, and its relation to Olber's paradox.
- Observations of distant supernovae and the re-introduction of the cosmological constant.
- Anisotropies in the CMBR and what can be learned from them.
- The present cosmological model: $\Omega_{M,0} \approx 0.3$, $\Omega_{\Lambda,0} \approx 0.7$