



The University of Sydney

Senior Physics Semester 2, 2007

Astrophysics

(PHYS 3x71, 3x79, 3x81, 3x82)

MODULE OUTLINE

This module introduces one of the most important concepts in astrophysics – radiative processes – and its application to stellar atmospheres and beyond. This leads into the study of physical processes in the interstellar medium and galaxies, including quasars and other active galactic nuclei.

Lectures

Lecturer: Dr Zdenka Kuncic, rm. 464, ext. 13162, z.kuncic@physics.usyd.edu.au

Please note: as I shall be away during week 9 (beginning Mon. 17 Sept.), I have scheduled the following replacement lecturers:

Prof. Don Melrose - Lecs. 5 & 6 (Tue. 18/09 & Thur. 20/09)

Prof. Bryan Gaensler - Lec. 7 (Fri. 21/09)

The module consists of a total of 19 lectures in Semester 2, 2007. A week-by-week timetable can be found at the Senior Physics website (www.physics.usyd.edu.au/current/sphys/timetable_weekly_2.shtml). Most lectures will be held in LT5. Two lectures will be split between ADV (39xx) and REG (30xx) classes, with ADV remaining in LT5 and REG moving to LT4. In addition to the ADV/REG split lectures, some lecture material will be marked as ADV only and will be thus non-examinable for those in the REG stream.

Proposed ADV/REG split lectures: Fri. 5 Oct. (Lec. 10) & Fri. 19 Oct. (Lec. 16). TBC.

Assessment

There will be 2 assignments contributing a maximum of 25% to the total assessment for this module. Assignments should be completed individually and handed into the Student Support Office by 5pm on the due date. You may discuss the questions with your peers and the course lecturer. Ensure your script is marked with your name, SID, and unit code. The final exam constitutes 75% of the total assessment for this module. The learning outcomes provide a guideline for examinable material.

Assignment due dates:

Assignment 1: Tuesday 2 Oct. (Wk. 10)
Assignment 2: Tuesday 23 Oct. (Wk. 13)

Text and Reference Books

There is no set text book for this unit. Lecture notes will be available via WebCT and will also be placed on the lecturer's webpage (www.physics.usyd.edu.au/kuncic). The following reference books may also be useful. They are available on closed reserve from the Library.

- Bowers, R. and Deeming, T., 1984, *Astrophysics, Vols. I and II*
- Shu, F. H., 1982, *The Physical Universe*
- Osterbrock, D. E., 1989, *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei*

The following are recommended books for further reading and reference:

- Harwit, M., 2006, *Astrophysical Concepts*
- Lang, K. R., 1999, *Astrophysical Formulae*
- Padmanabhan, T., 2006, *An Invitation to Astrophysics*
- Maoz, D., 2007, *Astrophysics in a Nutshell*
- Rybicki, G. & Lightman, A., 2004, *Radiative Processes in Astrophysics*
- Binney, J. & Merrifield, M., 1998, *Galactic Astronomy*

Course Content:

Lec. 1: Radiation

- 1.1 Basic definitions – the radiation field, specific intensity, flux.
- 1.2 Blackbody radiation – derivation of Planck function (ADV only), Stefan-Boltzmann law, Rayleigh-Jeans law, Wien limit.

APEC HOLIDAY Friday 7 Sept.

Lec. 2: Radiative Energy Transport

- 2.1 Emission and extinction coefficients – concept of optical depth
- 2.2 Radiative transfer equation – definition of source function
- 2.3 Simple solutions to the RTE – Kirchoff's law for thermodynamic equilibrium
- 2.4 Formal solution to the RTE – local vs. strict thermodynamic equilibrium

Lec. 3: Stellar Atmospheres

- 3.1 Introduction – the Sun
- 3.2 Model stellar atmospheres – plane-parallel geometry, LTE, hydrostatic and radiative equilibrium
- 3.3 The grey atmosphere – frequency independent absorption coefficient, limb darkening
- 3.4 Construction of a model stellar atmosphere – outline

Lec. 4: Radiative Processes I

- 4.1 Radiative processes – bound vs. free transitions
- 4.2 The Einstein coefficients – spontaneous & stimulated emission, true absorption, radiative equilibrium, detailed balance emission/absorption coefficients and RTE in terms of Einstein coefficients
- 4.3 Thermodynamic and statistical equilibrium – Maxwell, Boltzmann & Saha relations, LTE source function, non-LTE (ADV only)

Lec. 5: Radiative Processes II

- 5.1 LTE line transition rates – emission & absorption coefficients in terms of oscillator strengths, hydrogen transitions, absorption cross-section
- 5.2 Spectroscopic notation – quantum numbers, electronic configurations, selection rules
- 5.3 Fine structure – spin-orbit interactions, Zeeman effect
- 5.4 Hyperfine structure – hydrogen 21 cm line transition

Lec. 6: Radiative Processes III

- 6.1 LTE continuum transition rates – photoionisation and recombination, derivation of free-bound emissivity (ADV only), bremsstrahlung radiation
- 6.2 Scattering effects – modifications to RTE
- 6.3 Collisional processes – critical density

Lec. 7: The Interstellar Medium

- 7.1 Overview – dust, nebulae, gas
- 7.2 Molecular clouds – radiative transitions, star formation

MID-SEMESTER BREAK

Lec. 8: Radiative Processes in the ISM I

- 8.1 Atomic neutral gas – H I 21 cm in emission and absorption, interstellar absorption lines

Lec. 9: Radiative Processes in the ISM II

- 9.1 Diffuse warm gas – emission measure, dispersion measure
- 9.2 H II regions – photoionisation equilibrium, Strömgren sphere, derivation of ionising flux (ADV only)
- 9.3 Dust extinction – definition of extinction, reddening
- 9.4 Dust emission – the Orion nebula

Lec. 10: ADV/REG Split I

- 10.1 ADV – numerical radiative transfer I
- 10.2 REG – worked problems on radiative transfer in stellar atmospheres and H II regions

Lec. 11: The Milky Way

- 11.1 The Milky Way as a galaxy – historical overview, disk/bulge/halo components, stellar populations, spiral structure and star formation, rotation curve and dark matter
- 11.2 The Galactic centre – Sgr A*, evidence for a supermassive black hole

Lec. 12: Galaxies I

- 12.1 The morphological classification system – Hubble types, properties of ellipticals vs. spirals, interacting galaxies, groups and clusters
- 12.2 Distance scales – distance modulus, distance measurement methods for nearby vs. distant galaxies, Hubble's law, cosmological redshift

Lec. 13: Galaxies II

- 13.1 Surface brightness and luminosity – de Vaucouleurs law
- 13.2 Colour distribution – stellar types in ellipticals vs. spirals

Lec. 14: Galaxies III

- 14.1 Mass and luminosity functions – Salpeter mass function, Schechter function (ADV only)
- 14.2 Star counts – Malmquist bias
- 14.3 Mass-to-light ratios – spirals vs. ellipticals
- 14.4 Galactic dynamics – the virial theorem, velocity dispersions, rotation curves

Lec. 15: Active Galaxies I

- 15.1 Introduction to AGN – observational properties
- 15.2 AGN classification – Seyferts, radio galaxies, quasars, blazars

Lec. 16: ADV/REG Split II

- 16.1 ADV – numerical radiative transfer II
- 16.2 REG – worked problems on galaxies

Lec. 17: Active Galaxies II

- 17.1 The black hole paradigm for AGN – energy requirement, Eddington luminosity, accretion power
- 17.2 The unification model for AGN

Lec. 18: Quasars

- 18.1 Introduction – spectra with cosmological redshift, supermassive black holes, quasar evolution
- 18.2 Quasar absorption lines – damped Lyman α systems, the Lyman α forest, broad absorption line quasars

Lec. 19: Revision

Learning outcomes:

- Radiative Energy Transport:
 - ◇ recognise the blackbody spectrum and Stefan-Boltzmann law
 - ◇ write down and explain the radiative transfer equation (RTE) and know how to apply it quantitatively to derive simple stellar atmosphere models
 - ◇ understand the concepts of optical depth and local/strict thermodynamic equilibrium
 - ◇ understand how emission and absorption processes are related to the statistical relations of Maxwell, Boltzmann and Saha.

- Astrophysics of the Interstellar Medium:
 - ◇ explain the processes of collisional, photo- and shock ionisation and give astrophysical examples of where they are important
 - ◇ understand how these processes are incorporated into the RTE and why numerical methods are useful for solving these problems
 - ◇ recognise and explain the observational properties of the different components of interstellar gas (e.g. HI, HII regions, molecular clouds) and interstellar dust

- Astrophysics of Galaxies:
 - ◇ understand the basic physical properties of the Milky Way galaxy, as deduced from measurements of stellar motions, mass-to-light ratio, and observations in different wavebands
 - ◇ recognise the morphological classification of other galaxies
 - ◇ have a basic understanding of the the internal dynamics of galaxies
 - ◇ know what velocity dispersion is and the role of dark matter
 - ◇ know how active galaxies differ observationally from normal galaxies and understand qualitatively the standard accreting black hole paradigm for active galactic nuclei (AGN)
 - ◇ understand the radiative transfer problem in the context of AGN line-emitting regions and quasar absorption lines.