Radiative processes in astrophysical plasma(L16)

Non-Examinable (Part-III Level)

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The main aim of this non-examinable 16-lecture Part-III course is to provide a broad overview of the physics underlying the main radiative processes occurring in astrophysical plasma. We will focus first on emission line diagnostics, which mostly covers the lower-energies, then discuss the continuum emission. We provide general background theory but devote a good fraction of the lectures to applications, to provide an insight on current research in astrophysics based on high-resolution spectroscopy

The course will cover the following topics:

- Introduction to Radiation quantities and examples of spectra of astrophysical plasma, from the X-rays to the near infrared. An introduction to the background theory and the plasma diagnostics using line and continuum emission.
- Radiation and matter in thermodynamical equilibrium: black-body radiation, thermal plasma, Maxwell, Boltzmann, Saha distributions.
- Basics of radiative transfer. The interaction between atoms and radiation: spontaneous emission and absorption, stimulated emission, Einstein's coefficients and their relation with the absorption and emission coefficients. Spectral line profiles and line broadening effects. Optical depth and opacity of a spectral line.
- Basics of atomic structure for complex atoms. Non-relativistic Breit-Pauli vs. relativistic (Dirac) approach. Central field approximation, coupling schemes, good quantum numbers. Transition probabilities, dipole approximation, selection rules, forbidden lines. The formation of the periodic table.
- Atomic data (wavelengths, A-values, identifications) and their uncertainties. Examples.
- Fundamental processes affecting the level populations within an ion. Collisional excitation due to impact by electrons and protons and reverse processes. Cross-sections and rates.
- Statistical equilibrium equations. LTE vs. NLTE. Level population within an atom. Two-level atom. Metastable levels and the principle of measuring electron densities from line ratios.
- Photoexcitation, resonant scattering, Doppler dimming in moving plasma.
- Fundamental processes affecting the ion charge state distributions in plasmas. Collisional ionization by electrons and protons, photoionization. Dielectronic and radiative recombination. Cross-sections and reverse processes. Rates. Ion charge state distributions.
- Density-dependent effects on the ion charge state distributions. Non-equilibrium effects: ionising and recombining plasma, non-Maxwellian electron distributions.
- Measuring electron densities and temperatures in low-density plasma using emission lines e.g. in planetary nebulae, galaxy cluster hot plasma, stellar coronae.
- Techniques for measuring temperature distributions and chemical abundances using emission lines. Examples of solar/stellar spectra.

- Theory of the X-ray satellite lines for He-like ions, formed by inner-shell excitation and dielectronic recombination. Diagnostic applications: how to directly measure electron temperatures, the ionization state of the plasma and non-thermal electrons. The Perseus cluster observed by Hitomi.
- Continuum radiation. Free-free, free-bound. Measuring electron temperatures from continuum emission.
- Cyclotron and synchrotron emission and absorption. Examples of synchrotron emission in astrophysical plasma. Thompson scattering, Compton scattering, inverse Compton scattering.
- Active Galactic Nuclei: accretion disks, broad and narrow emission line spectra, Compton reflection, X-ray emission and the 6 keV iron feature.

Prerequisites

This course assumes you are familiar with Principles of Quantum Mechanics. It would be useful to have knowledge of Atomic structure (at least the Hydrogen atom), and of Elements of quantum field theory.

Literature

1. Del Zanna, G. and Mason, H.E., *Solar UV and X-Ray Spectral Diagnostics*, Living Reviews in Solar Physics, 2018, 15,5, DOI: 10.1007/s41116-018-0015-3
   https://link.springer.com/article/10.1007/s41116-018-0015-3
2. Landi Degl' Innocenti, E., *Atomic Spectroscopy and Radiative Processes*, Springer, 2014.
3. Rybicki, G. B. and Lightman, A. P., *Radiative processes in astrophysics.*, New York, Wiley-Interscience, 1979.
4. Ghisellini, G., *Radiative processes in high energy astrophysics*, 2013.
   http://adsabs.harvard.edu/abs/2013LNP...873.....G