Radiation Processes in Astrophysics

Most of what we know about the Universe comes from detection of electromagnetic radiation emitted by individual sources or by diffuse media. Once we understand the processes by which the radiation was created and the processes by which the radiation is scattered or modified as it passes through matter, we can address the physical nature of the sources and infer the thermal and non-thermal properties of astrophysical plasmas.
The physics of radiation processes includes electromagnetism and special relativity, with introductory statistical mechanics, quantum mechanics, and atomic structure.

The course will go through the basic properties of radiation production and transport in astrophysical plasmas, including black-body, synchrotron, inverse-Compton, bremsstrahlung, and atomic and molecular line emission. The course is mostly based on the book by Rybicki & Lightman, *Radiative Processes in Astrophysics*, complemented with examples taken from actual astrophysical objects. By the end of the course, students will be able to read and interpret a variety of multi-wavelength (from radio to high-energy gamma rays) photon spectra, recognizing the relevant emission mechanisms and eventually the main properties of the emitting source.

Student performance will be evaluated through a final quiz/exam on the basic concepts illustrated in the course and their applications to astrophysical objects. Homeworks will allow students to practice/learn such concepts in preparation for the final exam.

SYLLABUS (POST-COURSE)

FUNDAMENTALS OF RADIATIVE TRANSFER
The electromagnetic spectrum
Definition of flux, brightness, luminosity, pressure, energy density
Emission and absorption coefficients; Einstein coefficients
Radiative transfer equation; optical depth; mean free path
Lasers/masers; scattering; random walk; extinction

BLACK BODY RADIATION
Black body emission; Kirchhoff’s law; Planck function
Rayleigh-Jeans and Wien approximation; Brightness temperature; color temperature,

THEORY OF RADIATION FIELDS
Maxwell's equations; Poynting flux; electromagnetic waves in vacuum
Electromagnetic potentials; retarded potentials
Velocity and radiation fields; Larmor's formula; dipole approximation;
Thomson scattering

RELATIVISTIC COVARIANCE AND KINEMATICS
Special relativity; Lorentz transformations; Covariant electro-magnetism
Four-momentum; covariant dynamics
Emission from relativistic particles; beaming

THERMAL BREMSSTRAHLUNG
Emission and absorption coefficients;
Spectrum and relation with black body

SYNCHROTRON
Total power emitted by single particle; characteristic frequency and spectrum
Emission from a power-law distribution of particles
Absorption and source function

INVERSE COMPTON SCATTERING
Compton scattering: Thomson and Klein-Nishina cross sections
Power and spectrum emitted by a single particle and by a particle distribution
Method of virtual quanta

PLASMA EFFECTS
Wave propagation in plasmas; plasma frequency; Phase and group velocity;
Dispersion measure; Faraday rotation; Rayleigh diffusion; Cherenkov radiation

HIGH-ENERGY EMISSION PROCESSES
Relativistic bremsstrahlung
Nuclear reactions: threshold, pion production; hadronic gamma-rays

LINE EMISSION
Atomic structure: configurations, terms; fine and hyperfine structure; 21cm line
Optical and X-ray lines; Molecular lines;
Allowed/forbidden transitions; Line width: Doppler broadening; Red/blue shift

ASTROPHYSICAL SPECTRA
Typical spectra: stars, supernova remnants, active galactic nuclei, pulsar wind nebulae
Cosmic backgrounds