Content of Courses - University of Padova

Semester 2

Astronomical Spectroscopy

Content:
Radiation in the interstellar gas: definition of radiative terms; transfer equation; local thermodynamic equilibrium; equivalent thermodynamic equilibrium.
Emission and absorption lines in the interstellar environment: emission and absorption coefficients; statistic equilibrium; collisional processes and kinetic temperature; excitation in interstellar conditions; forbidden lines; recombination lines; intensity of lines as a function of density and temperature.
Continuum emission and absorption processes: free-free transitions; intensity of the thermal radio continuum; bound-free and free-bound transitions; synchrotron radiation.
Ionization: ionization equilibrium; ionization of hydrogen; HII regions; ionization of helium; dust extinction; HI regions; ionization of the heaviest elements.
Formation and dissociation of interstellar molecules: molecular hydrogen; CO, OH, H2O in diffuse nebulae; molecules in dense nebulae.
Thermal equilibrium and kinetic temperature of gas: Equation of thermal equilibrium; heating and cooling processes of gas; thermal equilibrium of HII regions; thermal state of HI regions.

Compulsory, 6 ECTS

Theoretical Astrophysics

Content:
1. Introduction and overview.
Observational constraints, the H-R diagram, mass-luminosity and mass-radius relations, stellar populations and abundances.
2. Hydrostatics, energetics and timescales.
Derivation of three of the structure equations (mass, momentum and energy conservation). Hydrostatic and thermal equilibrium. Derivation of the virial theorem and its consequences for stellar evolution. Derivation of the characteristic timescales of stellar evolution.
3. Equation of state (EoS).
Local Thermodynamical equilibrium. General derivation of n, U, P from statistical mechanics. Limiting cases: ideal gas, degeneracy. Mixture of gas and radiation. Adiabatic processes. Ionization (Saha equation, consequences for thermodynamic properties).
4. Energy transport in stellar interiors.
The 4th equation of stellar structure: the energy transport equation.
Diffusion approximation for radiation transport. The radiative temperature gradient . Opacity. Eddington luminosity. Convection: Derivation of stability criteria (Schwarzschild, Ledoux) .Convective energy transport: order-of-magnitude derivation. Mixing-length theory.
5.Nuclear reactions.
Nuclear energy generation (binding energy). Derivation of thermonuclear reaction rates (cross sections, tunnel effect, Gamow peak). Temperature dependence of reaction rates .Nuclear burning cycles: H-burning by pp-chain and CNO-cycle. He burning by 3-alpha and alpha+C reactions. Advanced burning reactions.
6. Stellar evolution equations.
Overview, time/space derivatives, limiting cases. Boundary conditions and their effect on stellar structure. How to obtain solutions.
7. Simple stellar models.
Polytropic models. Homology relations: principles, derivations, application to contraction and the main

sequence. Stability of stars: derivation of simplified criteria for dynamical and secular stability.
8. Schematic evolution from the virial theorem (VT).
Evolution of the stellar centre combining the VT and the EoS: evolution tracks in terms of (P,rho) and (T,rho). Evolution towards degeneracy or not. The Chandrasekhar mass, low-mass vs massive stars . Critical ignition masses, brown dwarfs, nuclear burning cycles.
9. Detailed evolution: towards and on the main sequence.
Simple derivation of Hayashi line, pre-MS evolution tracks properties of the ZAMS: M-L and M-R relations, occurrence of convection zones evolution across the MS band: structural changes, low-mass vs high-mass, effects of overshooting.
10. Post-MS evolution.
The Chandrasekhar limit, the mirror principle. H-shell burning: Hertzsprung-gap, red giant branch, first dredge-up. He-burning: horizontal branch, loops, Cepheids. RGB mass loss.
11. Late evolution of low- and intermediate-mass stars.
The Asymptotic Giant Branch: thermal pulses, 2nd/3rd dredge-up, mass loss, nucleosynthesis. White dwarfs: structure, non-ideal effects, derivation of simple cooling theory.
12. Pre-SN evolution of massive stars.
Importance of mass loss across the HRD (O stars, RSG, LBV and WR stars). Modern evolution tracks. Advanced evolution of the core: nuclear burning cycles and neutrino losses, acceleration of core evolution. Pre-SN structure
13. Explosions and remnants of massive stars.
Evolution of the core towards collapse: Fe-disintegration, electron captures, role of neutrinos supernovae. Observed properties and relation to massive star evolution. Limiting masses for neutron star and black hole formation, dependence on mass loss and metallicity.

Compulsory, 6 ECTS

Cosmology

Content:

1. The Large Scale Structure of the Universe. Local properties
    - General and structural properties of the universe.
    - Large scale distribution of galaxies. Angular and spatial correlation functions. Higher order correlations. Limber relation.
    - Power-spectrum of the cosmic structures. Relationship of the power-spectrum and $\xi(r)$. Observational data on the large scale structure. The initial power-spectrum of the perturbations. 3D mapping of galaxies, clusters, AGNs.
    - Counts-in-cells. Outline of fractal and topological analyses of the universe.
2. The Homogeneous and Isotropic Universe
    - Hubble law. The Cosmological Principle. Isotropic curved spaces. The Robertson-Walker metric. Geometrical properties of the space-time.
    - Cosmic dynamics, the Newtonian and general-relativistic approach. Cosmological models and parameters.
    - Fundamental observables. The redshift. Luminosity and angular diameter distances. Time-redshift relations. Hubble diagrams.
    - Generalized dynamical equations. The cosmological constant. Observational evidences
3. Deviations from homogeneity and isotropy. Gravitational lensing
    - Point-like lenses and isothermal spherical distributions. Lens potentials. Einstein radius. Lensing cross-sections. Lensing effects on time lags. Caustics.
    - Observations of the gravitational lensing and cosmological applications. Estimate of the total galaxy cluster mass. Estimates of H_0. Effects of a cosmological constant L in the lensing statistics.
4. Perturbations in an expanding universe. Peculiar motions of galaxies and structures.
    - Deviations from the Hubble flow, peculiar velocities in the cosmos. Observations of peculiar velocity fields.

- Origin of the large scale motions. Evolution of perturbations in the cosmic fluid in the linear regime. Hubble drag. Relationship of perturbations and the velocity fields.
- Constraints on the cosmological parameters from the large scale motions.

5. Brief thermal history of the Universe
   - The matter and radiation content of the Universe. Energy densities. Radiation-dominated universes. The epoch of recombination and equivalence. Time-scales of cosmic evolution.
   - Cosmic entropy per baryon.
   - Primordial nucleo-synthesis.
6. The Cosmic Microwave Background
   - Discovery of the CMB. Observations from ground and from space. COBE & WMAP. Origin of the CMB.
   - Spatial properties, isotropy of the CMB. Statistical description of the angular structure.
   - Origin of the CMB angular fluctuations. Physical processes in operation on the large scales. Fluctuations on intermediate angular scales. Contributions of sources to the anisotropies on small scales.
   - Constraints of CMB observations on the cosmological parameters.
   - The CMB spectrum. Spectral distortions. The Sunyaev-Zeldovich effect. Observational limits on the spectral distortions and their implications.
7. The Primordial Universe, Big Bang, phase transitions, cosmological inflation
   - The problem of the cosmological horizons. Propagation of the information and visibility of the universe.
   - Big Bang singularity. Planck time.
   - Overview of the standard model of elementary particles. Fundamental interactions. Cosmological phase transitions and their epochs.
   - Open questions about the standard Big Bang model. The horizon problem. The flatness problem. Cosmological inflation and solutions to the problems.
   - The Anthropic Principle.
8. The Post-Recombination Universe
   - Cosmological evolution of galaxies and active galactic nuclei.
   - Evolutionary history of star formation and production of heavy elements. Contributions to the background radiations.
   - Intergalactic diffuse gas. Absorption-lines in quasar spectra, Lyman-alpha clouds. The missing baryon problem.

Compulsory, 6.0 ECTS

Galaxy Dynamics

Content:

The cosmological framework: brief history of the shift sequence for Life site and the birth of modern cosmology. Cosmological Principles; Einstein's equations (by analogy), Robertson-Walker metric. Einstein's and de Sitter solutions.

Crucial phases of the cosmological evolution; formation of micro-structures in order to allow the macro ones and the macro-micro interplay; Jeans instability and role of dark matter; spherical collapse of a density perturbation. Structures on galaxy mass scales in the CDM scenario and their phases before virialization.

The thermodynamic perspective: entropy and information; violent relaxation mechanism in phase-space; statistic of Lynden-Bell, Shu, Kull-Treumann & Boeringer, Nakamura; Landau-damping and virialization.

Stress tensor and anisotropies of peculiar velocities in the dynamics of stellar systems. The tensor virial theorem for one and two-component system and its proof from Eulero equation and from Boltzmann equation. Application to v_rot/sigma diagram of elliptical galaxies. Dark virialized haloes: the general Zhao-density profiles.

The Fundamental Plane of galaxies and related problems. The cosmic metaplane.

Compulsory, 6.0 ECTS

Astrophysics of Galaxies

Content:

1. Inside the luminosity distribution of galaxies.

Surface brightness laws in 2-D and 3-D. Freeman, De Vaucouleurs and Sersic laws. Theoretical relations between main luminosity parameters (effective radius, scale length, slope, effective and total magnitudes) . Deduction of the main parameters from the observations. Fit of a composite luminosity profiles with simple software (IRAF, Mathematica routines).

2. Galaxies in 3-D.

The tridimensional shape of galaxies. Statistical methods. Inclination of a galaxy: principal planes and methods to find inclination and line of the nodes. Polar ring and other reference planes. Twisting of the isophotes. 3D distribution: Exponential and Young density profiles.

3. Observing at other wavelengths.

HI and CO lines. Observing techniques in our and other galaxies. Forbidden lines, roto-vibrational bands. The molecular universe: detection of complex molecules. The role of Sub-millimetric telescopes and ALMA. Hot stars and the GALEX view of galaxies. Mining in astronomical archives. Web astronomy.

4. Motions in the milky Way.

Velocity ellipsoid near the Sun. Methods and applications: compute the orbit for a nearby star in the galactic potential. Tracers of spiral structure. Oort formulae.

5. The global dynamics of a galaxy: Stars and gas.

Asymmetric drift, anisotropy in the velocity dispersion ellipsoids. Observable effects of the anisotropy and of the influence of the velocity dispersion on galaxy spectra.

6. Non isotropic local and global dynamics.

Bars, rings, polar and inclined disks. Theories and stability of these galactic structures: epicyclic motions, tumbling and streaming motions in elongated potentials. Anomalous orbits. Observations of bars at different wavelengths.

7. Galaxy interactions.

Close encounters and mergers. Effects on the galaxy shapes, star formation, structure. Inclined and polar rings as effects of merging and capture. The gas-star counter-rotation. Mass in the rings. Optical, HI and CO observations. Origin of inclined rings.

Optional, 6 ECTS

Space Plasma Physics

Purpose and scope:

The course is aimed at providing the student with a basic knowledge of the physics of plasma with particular attention to the astrophysical plasmas.

Content:

1. Definition of plasma – Plasmas in astrophysics – Observational data – Different theoretical approaches.
2. Single particle motion – Trapped particles – Conservation relations.
3. Recalls of dynamics of fluids – Magnetohydrodynamics (MHD).
4. Waves in plasma fluids – Non linear steepening and shocks – Instabilities.
5. Collisions – Collisionless plasmas
6. Cosmic Rays – Fermi acceleration – Shock acceleration
7. Astrophysical dynamos
8. Magnetic reconnection
9. MHD flows in compact astrophysical objects

Optional, 6 ECTS

Celestial Mechanics

Content:

1. The equations of motion of a system of N bodies - Symmetries and first integrals - Reference frames
2. The Two-Body Problem - The conic section solutions and their representations - Regularization and formulation in universal variables
3. Computation of an ephemeris
4. Preliminary orbit determination - The method of Laplace - The method of Gauss.
5. Relative Keplerian motion - Rendez-vous - Orbital maneuvers
6. Lambert's theorem - Lambert targetting
7. The Three-Body Problem - Homographic solutions
8. The Circular Restricted Three-Body Problem - The Jacobi integral - Zero velocity surfaces - Periodic orbits
9. Navigation in the Solar System - The method of patched conics

Optional, 6 ECTS

Stellar Populations

Content:

The color magnitude diagrams: transformations luminosity-magnitude and temperature-color index. Effects of the interstellar reddening on the color-magnitude diagrams.
The concept of stellar populations: historical background.
Population II CM diagram. Measurement of age and metallicity.
Globular Clusters stellar populations
The helium content of the population II stars.
The Galactic model by Eggen, Lynden-Bell and Sandage.
The galactic halo model from Searle and Zinn.
The interstellar medium near to the Sun and the local bubble.
The population I and the galactic disk. Open clusters and field population.
Dwarf Galaxies.
The mass function.
Integrated properties of the stellar populations.
Star formation history in galaxies
Basic principles of the chemical evolution of the stellar populations.
The supernovae: classification, evolution, progenitors.
The use of the supernovae as indicator distances.

Optional, 6 ECTS

Italian as a Foreign Language

Optional, 3 ECTS

Semester 4

Master Thesis and Presentation

Compulsory, 30 ECTS

Italian as a Foreign Language

Optional, 3 ECTS