Content of Courses - University of Innsbruck

Semester 1

Concepts of Galactic Astrophysics
Content:
Interstellar matter: general overview; components of the ISM; heating and cooling processes; gravitational collapse processes; circuit of matter.
Prestellar and protostellar evolution: general overview; scales of star formation; evolutionary scheme; multiplicity.
From protostar(s) to star(s): general overview; pre-main-sequence evolution; young stellar objects; main sequence in the HRD.
Stellar nucleosynthesis: general principles; hydrogen burning; helium burning; fusion of heavier elements.
Late stellar evolution: red giant branch; asymptotic giant branch; planetary nebulae; supernovae.
Stellar remnants: white dwarfs (mass-radius relationship and mass limit, internal structure, cooling); neutron stars/pulsars; black holes (event horizon, rotating BHs, classes of BHs, gravitational waves from BHs); X-ray binaries.
The solar system: basic planetary data; Kepler's laws; dwarf planet; individual planets (some notions on properties and structure); Kuiper belt, Oort cloud, bow shock and heliopause.
Extrasolar planets: general overview; radial velocity method; transit method (and Kepler mission); other methods (pulsar timing, direct imaging, gravitational microlensing); multiple-planet systems.
The Galaxy: main structure; stellar streams; multiwavelength view of Milky Way; spiral arms and spiral arm tracers; dynamics; Solar neighborhood; Galactic bulge (multi-wavelength view); SMBH at the center of the Galaxy.
Compulsory, 6.5 ECTS

Concepts of Extragalactic Astrophysics
Content:
Part I. *Introductory notions:* 0. spherical coordinate systems (terrestrial and celestial sphere, equatorial and ecliptic system, horizontal system, Sidereal Time, Galactic system). Transformation equations between spherical coordinate systems. Concepts of flux, magnitude, luminosity, colour indices, distance modulus, bolometric correction.
Galaxies: 1. Brief historical introduction to galaxies and main historical steps of extragalactic astrophysics. Brief introduction to the cosmic distance ladder (in particular: trigonometric parallax, secular and statistical parallax, Baade-Wesselink method, Cepheids and RR Lyrae period-luminosity relations, Supernovae Ia, surface brightness fluctuations, Tully-Fisher and Faber-Jackson relations, non-relativistic and relativistic Doppler effect and Hubble law). The Milky Way as a galaxy: importance of astrometry to determine the structure of the Galaxy, Hipparcos and Gaia missions, radial velocities and proper motions of stars, main structural components of the Galaxy. Rotation of our Galaxy: differential rotation, Oort's constants, motions of population I and population II stars. Interstellar extinction, colour excess, the extinction law of the Galaxy.
2. Morphological classification of galaxies: Main structural components of various galaxy types and typical mass ranges. Morphological types (original and revised Hubble tuning fork, Simien & de Vaucouleurs classification). Inverse square law for fluxes, solid angle, specific intensity and surface brightness. Isophotes, triaxial ellipsoides, disky and boxy isophotes, isophotal diameter, Holmberg radius, typical ranges of galaxy sizes and lumonosities. Surface brightness profiles: de Vaucouleurs profile, exponential profile, Sérsic profile, "nuker" law and related quantitative structural parameters.
Integrated magnitudes, isophotal magnitudes, fix-aperture magnitudes.

3. Galaxy structure, kinematics, and dynamics. Scaling relations: Kormendy relation, Faber-Jackson relation, Fundamental Plane of elliptical galaxies, Tully-Fisher relation. Local galaxy luminosity function (Schechter function), cluster M* galaxies as standard candles, luminosity density of the local universe, luminosity function per galaxy type. Dynamically hot systems (elliptical galaxies and bulges): velocity dispersion, V/σ as a function of luminosity, virial theorem applied to elliptical galaxies, mass-to-light ratio. Dynamically cold system (galaxy discs): rotation curves and evidence for dark matter halos. Disc vertical structure (thin and thick disc), vertical structure of the Milky Way. Spiral arms and bars: structure of the arms (pitch angle), content of the arms, effect of differential rotation on spiral structure, formation of arms through density waves, stochastic self-propagating star formation in flocculent spirals, kinematics of bars (very briefly). Galaxy interactions and mergers.
4. Gas phases, dust, and their distribution in galaxies: molecular hydrogen and CO, neutral atomic hydrogen and 21cm line, extent of HI discs, distribution of molecular gas in the Milky Way and spiral galaxies in general (CO position-velocity diagrams), molecular gas in elliptical galaxies, hot gas in elliptical galaxies and evidences for dark matter, HII regions (Strömgren sphere, Hα emission).
5. Stellar populations, colours, and spectral classification of galaxies: Distribution of older and younger stellar populations, typical colour indices of galaxies of different types. Metallicity ([Fe/H], 12+log(O/H)), effect of metallicity on colours, age-metallicity degeneracy, colour-magnitude and luminosity-metallicity relations for elliptical galaxies, luminosity-metallicity relation for spiral galaxies. Spectral classification of galaxies (main optical spectral features), SEDs of various galaxy types. Star formation: stellar initial mass function, Schmidt-Kennicutt law, LIRGs and ULIRGs, star formation rate tracers. Evolutionary synthesis models. Stellar population synthesis models. Photometric redshifts.
6. Super-massive black holes at the center of galaxies: Evidence of SMBHs, methods of SMBH mass determination, the SMBH in our Galaxy. Scaling relations between SMBHs and global galaxy properties.
7. Galaxies at higher redshifts: Galaxy formation scenarios (monolithic collapse and hierarchical formation). Evolutionary correction, k-correction. Hubble Deep Field and Ultra Deep Field (morphological k-correction). Lyman Break galaxies, drop-out selection technique, colour-selection of high-z galaxies (EROs, DRGs). Star formation history of the universe (Madau-Lilly plot). Evolution of star formation rate density of the universe. Evolution of the galaxy luminosity function.
Part II. *Active Galactic Nuclei:* 1. AGN historical notes. General properties: typical luminosities, variability, central engine, Eddington luminosity, mass accretion rate, power law continuum. Thermal and non-thermal radiation processes in AGN (black-body, synchrotron radiation, Compton scattering, inverse Compton scattering. Spectral lines (recombination lines, forbidden lines). AGN classification, examples of optical spectra of various AGN types. AGN Unified Model. Super-Eddington luminosities in AGN. AGN lifetime (some estimation methods).
2. The Broad Line Region: BLR structure (spherical and non-spherical models), physical properties. Ionization parameter, column density, electron density, critical density of forbidden lines, covering and filling factors, mass of the BLR. Emission line profiles: thermal Doppler broadening, circular motions, random motions, radial motions. Reverberation mapping, determination of BLR size and SMBH mass
3. The Narrow Line Region: Main observational properties and spectral features. Diagnostic diagrams.
Determination of electronic density and temperature from forbidden emission lines. Physical conditions in the NLR, Partially Ionized Zone, collisional excitation of H lines. Ionization cones. Photoionization and shock ionization (with notes on the codes CLOUDY, SUMA, MAPPINGS). Dusty torus.
Part III. *Galaxy groups and clusters:* 1. Spatial distribution of galaxies: observed large scale structure of the universe, simulations of large scale structure. Galaxy clusters: size, mass, components, dynamics (galaxy velocity dispersion), physical properties of the Intra-Cluster Medium, X-ray emission from ICM, cooling function, dark matter, magnetic fields, relativistic particles, radio emission.
2. Determination of galaxy cluster mass through: X-ray method, gravitational lensing, glaxy velocity dispersion. X-ray emission: gas temperature, density gradient, β-profile. Theory of gravitational lenses (some notes): lens geometry, lens equation, multiple images, solution of the lens equation for a point mass (Einstein angle), magnification effect. Strong gravitational lensing in clusters, cluster mass from strong lensing. Weak

gravitational lensing in clusters, cluster mass distribution from weak lensing. Dynamical mass of clusters (virial theorem). Sunyaev-Zel'dovich effect.
3. Galaxy groups: X-ray emission of galaxy groups, comparison between cluster and group properties.
The Local Group.
4. Cosmological applications of galaxy cluster observations, evolution: Butcher-Oemler effect. Galaxy cluster observations and simulations to derive cosmological parameters. Advantages and drawbacks of simulations, N-body methods, Hydrodynamics (grid codes, particle codes), boundary and initial conditions, simulations on cluster scales, simulations on galaxy scales, magnetohydrodynamic simulations.
Cosmology: 1. Evidence for Big Bang: Expanding universe. Cosmic Microwave Background radiation, COBE, WMAP, PLANCK. Primordial nucleosynthesis. Structure formation.
2. Scale factor of the universe, expansion rate, curvature of the universe, density parameter, Friedmann-Lemaitre equations, dark energy, inflation.
3. SNe and CMBR as cosmological tools.
Compulsory, 6.5 ECTS

Concepts of Physics for Astrophysicists
Content:
Fundamentals of Mechanics: universal gravitational attraction; central force; two-body problem with attractive force; equation of motion, conservation laws; determination of the gravitational constant; the concept of mass; inertial frames of reference - equivalence principle; measures of time; stellar drag; virial theorem; the relativity principle; relativistic terminology; relative motion; four-vectors; aberration of light; momentum, mass, energy; Doppler effect; particles at high energies; high-energy collisions; superluminal motions and tachyons.
Fundamentals of Thermodynamics and Statistical Mechanics: random events, random walk, phase space; distribution functions, probabilities, mean values, and fluctuations; the motion of molecules; radiation kinetics; the first lay of thermodynamics; isothermal and adiabatic processes; entropy and the second law of thermodynamics; thermal equilibrium, Boltzmann equation and Liouville's theorem; Bose-Einstein statistics; Fermi-Dirac statistics; Saha equation; elastic collisions; inelastic collisions; Einstein coefficients, oscillator strengths.
Fundamentals of radiation and radiative transfer: Coulomb's law and dielectric displacement; Ohm's law and dissipation; Ampere's law; Maxwell's equations; the wave equation, phase, and group velocity; energy density, pressure, and the Poynting vector; emitted power and received spectrum; radiation spectrum, blackbody; polarization, Stokes parameters; Faraday rotation; radiation from single moving charges, Larmor's formula, dipole approximation; radiation from unbound charges, Thomson scattering; scattering by bound charges; extinction by interstellar grains; thermal bremsstrahlung (free-free radiation and absorption); synchrotron radiation; the synchrotron radiation spectrum; synchrotron self-absorption; the Compton effect and inverse Compton effect; the Cherenkov effect.
Quantum Processes in Astrophysics: Absorption and emission of radiation by atomic systems; quantization of atomic systems (Spin, Pauli principle, the electrostatic interaction, LS coupling and terms, perturbations, level splittings, term diagrams, spin-orbit coupling, Zeeman effect); atomic hydrogen and hydrogen-like spectra; spectra of ionized hydrogen; hydrogen molecules; selection rules; transition rates; the information contained in spectral lines; absorption and emission line profile; line broadening mechanisms; quantum mechanical transition probabilities; stimulated emission and cosmic masers; stellar opacity; the radiative transfer problem; photoionisation; radiative recombination - Milne relations.
Compulsory, 6.0 ECTS

Advanced Mathematical Methods for Astrophysicists
Content:
Matrices and Vectors: Vector operations; Coordinate transforms; Orthogonal coordinates; Definition of matrices; Determinants; Eigenvalue problems; Differential operators; Gauss's / Stokes's theorem; Tensors.

Ordinary Differential Equations:
Linear & nonlinear differential equations; Separation of variables; Homogeneous & particular integral; Series solution; Numerical Methods; Runge-Kutta method
Partial Differential Equations:
Examples and physical application; General discussion; Separation of variables; Singular Points; Green's Function; Numerical solution; Special Functions; Dispersion relations
Fourier Transform:
Discrete and continuous transform; FFT; Laplace transform; Convolution; Solving differential equations
Statistical Methods:
Introduction; Distributions; The chi-squared test; Maximum likelihood method; Monte Carlo method; Stochastic differential equations.
Compulsory, 6.0 ECTS

Basic Concepts of Quantum Physics
Content:
Light - matter interaction, coherence effects, interferometry, folding, matter waves, quantum gasses, precision measuring, macroscopic quantum phenomena
Optional, 5.0 ECTS

Basic Concepts of Ion, Plasma, and Applied Physics
Content:
Electron / ions - matter interaction, plasmas in nature and technology, behaviours of plasmas, concepts the nuclear fusion and energy physics, molecule physics, mass spectrometry and analysis method, cluster physics and nanotechnology, nonlinear dynamics, bases the electrical engineering
Optional, 5.0 ECTS

Basic Concepts of Astro- and Particle Physics
Content:
Galactic and extragalactic dynamics, cosmology, structure formation and structure development, dark matter/energy, gamma and X-ray astrophysics, relativistic kinematics, electromagnetic, strong and weak elementary processes, Feynmann diagrams, hadron systematics, quark hypothesis and chromodynamics, electric weak union
Optional, 5.0 ECTS

(Theory of) Relativity
Content:
Introduction to the theory of special relativity and gravity. SR: Covariant formulation of electrodynamics. Minkowski space. Relativistic kinematics. "Paradoxes". GR: Principle of equivalence. Curved spacetime. Tensor fields and differential forms. Einstein's field equations. Geometry outside of spherical stars. Gravitational collaps and black holes. Gravitational waves. Cosmological models.
Optional, 5.0 ECTS

Galaxy Groups
Content:
Panoramic view of the main properties of groups of galaxies and overview of the use of spectrophotometric techniques for the investigation of physical phenomena that take place in the group environment: 1. General introduction on the Local Group and the galaxy systems in the local Universe; 2. Galaxy groups: Definitions and observational properties; 3. Physical phenomena within (mainly compact) galaxy groups investigated through photometry and spectroscopy: Tidal interactions, galaxy merging, star formation, nuclear activity, interaction

effects on galaxy kinematics, multiwavelength radiation emission; 4. Group dynamics: Velocity dispersion, mass determination, present views of group evolution; 5. Galaxy groups at higher redshifts: The role of galaxy surveys.
Optional, 5.0 ECTS

Introduction to Radioastronomy
Content:
An overview of 1. principles of radio observations and 2. galactic and extra-galactic radio sources. Fundamentals of radio interferometry , physical mechanisms responsible for emission at radio frequencies, radio sources in the milky way, extra-galactic radio sources.
Optional, 2.5 ECTS

The Physics and Effects of Mergers in Clusters of Galaxies
Optional, 2.5 ECTS

Interstellar Matter
Content:
Introduction to the physics of the interstellar gas, excitation and cooling processes of thin gas, interaction with dust.
Optional, 2.5 ECTS

Formation of Planets and Planetary Systems
Content:
The course will give a short overview on the formation of planets and planetary systmems in the planetesimal and the core accretion hypothesis. The main topics are:
- observational evidences, the diversity of planetary systems;
- a special case: the Solar System;
- observation, characterization, and physics of protoplanetary accretion disks;
- formation of planetesimals by coagulation of dust particles, the meter size barrier;
- the growth of planetesimals (runaway and oligarchic growth);
- formation of terrestrial planets;
- formation of giant planets;
- disk-planet and planet-planet interactions, migration of planets in gas and planetesimal disks;
- formation of planetary systems, the Nice model.

Optional, 2.5 ECTS

Astrophysics Seminar
Content:
Acquirement of an own lecture on a technical or scientific problem. Its contents go beyond the substance treated in the previous studies towards new scientific results.
Optional, 2.5 ECTS

Recent Results of Galactic Research **NOT OFFERED IN WINTER TERM 2011**
Content:
Environment of the Galaxy (e.g. Local Group), evolution of the Galaxy (e.g. past and present interactions with dwarf galaxies), Structure of the Galaxy's halo (e.g. stellar streams), spiral arm structure, physics and morphology of interstellar matter, object classes of circum- and interstellar matter, Galactic bulge, Galactic centre (including the central black hole)
Optional, 2.5 ECTS

Theory of Gravitational Lenses NOT OFFERED IN WINTER TERM 2011
Content:
Lensing equation, strong and weak lensing, micro lensing, gravitational shear, applications
Optional, 2.0 ECTS

Variable Stars NOT OFFERED IN WINTER TERM 2011
Content:
Observation technology, classes and divisions of the variable stars and their physical background, Kappa mechanism, cataclysmic processes, nuclear reactions, additionally to "frontal lessons" the analysis of data at a computer project is worked out (particularly in the reference to periodicity)
Optional, 2.5 ECTS

German as a Foreign Language
Optional: 5.0 ECTS

Additional optional courses are available from the curriculum of the local Master of Physics

Semester 4

Master Thesis
Compulsory: 27.5 ECTS

Thesis Presentation
Compulsory: 2.5 ECTS

Astrophysics Seminar
Content:
Acquirement of an own lecture on a technical or scientific problem. Its contents go beyond the substance treated in the previous studies towards new scientific results.
Optional, 2.5 ECTS

High Performance Computing Seminar
Content:
Recent developments in high performance computing, applications, interdisciplinary discussion, developing of presentation skills
Optional, 1.0 ECTS

Seminar on Galaxy Clusters
Content:
Observations and simulations of galaxy clusters, multiwavelength studies, developing of discussion and presentation skills
Optional, 2.5 ECTS

Computational Methods in Physics and Astrophysics
Content:
Various techniques to simulate fluids, plasmas and N-body systems, applications
in several examples of cosmic objects, investigating numerical stability
Optional, 5 ECTS

Statistics and Detectors
Content:
Basic statistical tests, mathematical background and requirements, small event number statistics, ideal and real detectors, physics of important detectors and their capabilities, data reduction techniques, analysis and interpretation, faulty and nonlinear qualities of detectors and correction possibilities, analysis of time series data.
Optional, 2.5 ECTS

Solar and Stellar Physics NOT OFFERED IN SUMMER TERM 2012
Content:
Stability and convection, a view inside the sun, magnetism, atmosphere and line formation, corona and solar & stellar wind
Optional, 2.5 ECTS

Astroparticle Physics
Content:
astrophysical nucleosynthesis, extensive structures, interstellar medium;
standard model of the non gravitational forces as a calibrating theory, radiation corrections, experimental tests;

cosmic radiation, neutrinos
Optional, 2.5 ECTS

Physics of Galaxy Clusters
Content:
Constituents, formation and evolution, interaction, scaling relations, multi-wavelength observations, tools for cosmology
Optional, 2.0 ECTS

German as a Foreign Language
Optional: 5.0 ECTS

German as a Foreign Language – Conversation
Optional, 2.0 ECTS