Master's Degree in Physics : Astrophysics
Courses open to students from Freiburg University (M2[1])
2018 / 2022

NB: the ECTS accreditations below are designed specifically for EUCOR students or other exchange students from outside Strasbourg, who wish to follow only a small subset of lectures. For students of Strasbourg University, please refer to the internal documents of the Master's programme in Astrophysics.

M2-S3 :

UE1 / Module 1 : Astrophysics [stars, galaxies, the Universe, ..]

Galaxies (C. Boily, O. Bienaymé) [20 hours in class, 3 ECTS]
- Observational properties, scaling relations and their interpretation
- The Milky Way
- Boltzmann and Jeans equations, integrals of motion, gravitational "fluids", stability
- Waves in gravitational systems, dispersion relations, the WKB limit, BBGKY approach
- Dark matter in galaxies
- Galaxy formation and evolution in the cosmological context

Cosmology (D. Aubert) [~16 hours in class, 3 ECTS]
- Evolution of the universe, basic concepts of general relativity, standard model
- The hot universe, the acoustic phase, recombination
- The cosmic background, correlation functions, current missions
- Large scale structure, observational constraints on the evolution of structure, theory

Stellar Physics (J. Pétri, A. Lançon) [~20 hours in class, 3 ECTS]
- Stellar interiors
- Stellar evolution
- An introduction to multiple stars and to extra-solar planets

Interstellar medium (L. Cambrésy) [10 hours in class, complement to lectures on galaxies and on stars]
- Constituents and their properties. Spatial distribution
- Stability, fragmentation.
- Emission, extinction. Spectral line diagnostics.
- Cooling/heating mechanisms

Introcuction to Astrophysics & Astronomy (15h – A. Siebert)
For students who joined M2 without adequate backgrounds, the following courses are offered. They take place as soon as technically possible in the semester, always starting early in September.
Astronomical objects, scales and orders of magnitudes, distance measurements

1 Year 2 of the Master's programme (M2) corresponds to Year 5 of the full university curriculum. The year has 2 semesters, labelled M2-S3 and M2-S4. M2-S3, the "Winter semester", starts in the first half of September and ends at the beginning of February ; M2-S4, the "Spring semester" offers no lectures: the students work on research projects.

The 2-body problem and applications; tides, Roche lobes and Lagrange points
Units used in professional astronomy
Photometry, modern photometric systems, stellar color-magnitude diagrams
Basics on stars, their structure, their evolution
The expansion of the universe and the standard cosmological parameters

UE2 / Module 2 : Data Analysis

Databases and Virtual Observatories (S. Derrière) [20 hours in class, 3 ECTS]
Lectures and practical sessions.
Data in astronomy : acquisition, storage, data preservation; formats for catalogs, images, spectra

- Acquisition, storage, data preservation
- Formats for catalogs, images, spectra, etc.

Databases :

- relational algebra
- the SQL language

Standards and practical tools of the astronomical Virtual Observatory
Efficient usage of astronomical databases in science projects.
Projects based on actual astronomical databases. Written report and oral defense.

Probabilities and statistics in astronomy (A. Siebert, O. Bienaymé, B. Wandelt) [20 hours in class, 3 ECTS]
Probabilities (reminders):

- classical probability laws
- changing variables
- variance, covariance, correlation

Inference :

- parameter estimation, biases, efficiency; examples, caveats
- confidence intervals

Simulating variables (Monte-Carlo techniques)
Multi-variate analysis, principal components

UE3 / Module 3 : Numerical Physics & the modeling of astrophysical media

Plasmas, astrophysical fluids & MHD (H. Baty) [20 hours in class, 3 ECTS]
The diversity of plasmas and astrophysical fluids in the universe

- the fluid model
- kinetic theory

Magneto-hydrodynamics

- stationary flows (solar wind)
- wave propagation (coronal heating, stellar vibration modes)
- the growth of instabilities (solar eruptions, astrophysical jets, turbulence, magnetic reconnexion,etc.)

An introduction to the numerical approach, and to existing numerical tools.

Numerical simulations in astrophysics (P. Ocvirk, A. Siebert, J. Pétri) [14 contact hours + personal project work, 3ECTS]
Lectures : classical algorithms of major astronomical simulations
Personal project : numerical study of one astrophysical problem; coding, debugging, testing, exploiting the code, presenting results and discussing the results are important aspects of these projects.

Computer sciences (26h – G. Landais)
The Unix environment
A scripting language : python
Java programming :

- Object-oriented programming
- The basics of the Java language

Personal project : students work individually or in pairs, on a group project in which all contributions are connected. Results are presented in writing and if needed orally.

<u>Elective subjects</u> : Modules 4, 5 & 6

1. Optional course : High Energy Astrophysics (20h, 3 ECTS – J. Pétri)
High energy photon acquisition, past, current and future observatories.
Cosmic rays
Astrophysical sources of high energy photons (compact objects, binaries, explosions)
Propagation of high energy photons
Analysis and interpretation of high energy data
NB: the focus in this lecture is on X-rays rather than on gamma-rays

2. Optional course : The Evolution of Galaxies (20h, 3 ECTS – C. Boily, A. Lançon)
Aspects of stellar astrophysics : the stellar IMF, isochrones, chemical yields
Evolutionary population synthesis :
- single stellar populations; colors, spectral indices, spectra
- complex stellar populations

Chemical evolution of galaxies
- measuring metallicity, alpha elements and what they tell us, other useful elements, observed trends
- the closed boxed model, the solar neighborhood, the G-dwarf problem, open models
- a glimpse at chemo-dynamical models; 3D spectroscopy

Resolved galaxies; galactic archeology; the history of the Local Group
Case studies (individual objects, large surveys, fundamental scaling relations)
Active galactic nuclei in the history of galaxies
- Galaxy clusters: gas and galaxies, cooling flow, Abell's classification, morphological evolution of galaxies, ram pressure stripping ;
- Galactic satellites: dynamical friction, starburst, LSBs ;
- Galaxy mergers: evolution with redshift, the Toomre sequence, boxy- and discy-ellipticals, star formation rate, simulation techniques ;
- Spiral galaxies: thin and thick discs, coupled resonances bar/spirals, models with one- and two-pattern speeds ;
- Active galaxies: observational properties, types (Seifert I, II, BL Lac, ..), central black hole, jets, ..

3. Optional course : Inversion methods in astrophysics (20h, 3 ECTS – E. Thiébaut, M. Louys)
Inverse problems
- linear / non linear
- well behaved / ill-conditioned (linear case : conditioning number, singular values, etc.)

Examples (deconvolution, etc.)
Maximum likelihood
The Bayesian approach
Imposing regularity constraints on the solutions

4. Optional course : Disques circum-stellaires, exoplanètes [see Grenoble]

M2-S4

Strasbourg Observatory hosts Master's students for research projects of various durations (including Master's thesis projects). This is discussed on the case-by-case basis.

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