

Module No.:  
Credit Points (CP):  
Category:  
Semester:

astro830  
  
Elective  
7.



## Module: Elective Advanced Lectures

### Module Elements:

Nr.	Course Title	Number	CP	Type	Workload	Sem.
<b>Observational Astronomy</b>						
1.	Selected 84* courses from catalogue	astro84*	3-6	see catalogue	90-180 hrs	WT/ST
<b>Modern Astrophysics</b>						
1.	Selected 85* courses from catalogue	astro85*	3-6	see catalogue	90-180 hrs	WT/ST
<b>Research Internship</b>						
1.	Internships in the Research Groups	astro831	4	internship		WT/ST
<b>Cologne Courses</b>						
1.	Astrophysics Courses from Cologne	see catalogue	3-8	see catalogue	90-240 hrs	WT/ST
1.	Also possible classes from M.Sc. in Physics					

### **Requirements:**

### **Preparation:**

### **Content:**

This module comprises a catalogue of special topics in theoretical and observational astrophysics, which supplements the compulsory courses such as to provide the students with a thorough understanding of modern astrophysics

### **Aims/Skills:**

The student has the opportunity to gain insight into specialized fields of modern theoretical and observational astrophysics, in addition to the compulsory courses, by selecting one such course out of the catalogue offered

### **Form of Testing and Examination:**

If the lecture is offered with exercises: requirements for the module examination (written or oral examination): successful work with exercises

**Length of Module:** 1 semester

**Maximum Number of Participants:** ca. 100

### **Registration Procedure:**

s. <https://basis.uni-bonn.de> u. <http://bamawww.physik.uni-bonn.de>

The students must obtain 18 CP in all out of the modules astro830, -840, -850.

# Module: Elective Advanced Lectures

Module No.: astro830

## Course: Internships in the Research Groups

Course No.: astro831

Category	Type	Language	Teaching hours	CP	Semester
Elective	Research Internship	English		4	WT/ST

### Requirements:

Students are asked to contact one of the BCGS lecturers prior to the start of their internship. Lecturers provide help if needed to find a suitable research group and topic. Not all groups may have internships available at all times, thus participation may be limited.

### Preparation:

A specialization lecture from the research field in question or equivalent preparation.

### Form of Testing and Examination:

A written report or, alternatively, a presentation in a meeting of the research group.

### Length of Course:

4-6 weeks

### Aims of the Course:

Students conduct their own small research project as a part-time member of one of the research groups in Bonn. The students learn methods of scientific research and apply them to their project.

### Contents of the Course:

One of the following possible items:

- setting up a small experiment,
- analyzing data from an existing experiment,
- simulating experimental situations,
- numerical or analytical calculations in a theory group.

### Recommended Literature:

provided by the supervisor within the research group.

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Radio Astronomy: Tools, Applications, Impacts

**Course No.:** astro841

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	WT

**Requirements:****Preparation:**

Good knowledge of electrodynamics, atomic physics, and astronomy

**Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

An introduction to modern radio astronomy, its history, methods, and research potentials is given. The goals are to equip the student with the background and know-how to analyze and interpret data from modern single-dish and interferometer radio telescopes, and to enable them to motivate and write radioastronomical observing proposals. Aperture synthesis techniques are explained at some depth. The lecture is furnished with numerous examples demonstrating the versatility and power of radioastronomical tools

**Contents of the Course:**

Radiation: processes, propagation; Signal detection; Radio telescopes: properties, types; Receivers: heterodyne, bolometers; Backends: continuum, spectroscopy, pulsars; Interferometers: Fourier optics, aperture synthesis; imaging; Future: APEX, ALMA, LOFAR.

**Recommended Literature:**

B. F. Burke; F. Graham-Smith, An Introduction to Radio Astronomy (Cambridge University Press 2002)  
 T. L. Wilson; C. Rohlfs; Tools of Radio Astronomy (Springer, Heidelberg 4. rev. und erw. Ed. 2006)  
 J. D. Kraus; Radio Astronomy (Cygnus-Quasar Books, Durham 2. Aufl. 1986)  
 R.A. Perley; F. R. Schwab, A.H. Bridle; Synthesis Imaging in Radio Astronomy, 3rd NRAO Summer School 1988 (Astronomical Society of the Pacific Conference Series, 1989)  
 A. R. Thompson, J. M. Moran, G.W. Swenson, Interferometry and Synthesis in Radio Astronomy (Wiley & Sons, Weinheim 2. Aufl. 2001)  
 Lecture Notes (U. Klein)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:****Submillimeter Astronomy**

Course No.: astro842

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:**

Basic astronomy knowledge

**Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

Students with B.Sc. in Physics will be introduced to astronomy in the submillimeter wavelength range, one of the last spectral regions to be explored with new high-altitude ground-based or airborne telescopes, and from space

**Contents of the Course:**

The basic concepts of emission/excitation mechanisms from interstellar dust and molecules are discussed as well as the properties of the observed objects: the dense interstellar medium, star forming regions, circumstellar environments. Star formation near and far is a central focus of submillimeter astronomy and will thus be introduced in depth. Telescopes, instrumentation, and observational techniques will be described in the course

**Recommended Literature:**

Contemporary review articles

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Astronomical Interferometry and Digital Image Processing

**Course No.:** astro843

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT

**Requirements:****Preparation:****Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Students learn the basics required to carry out research projects in the field of wave optics and astronomical infrared interferometry

**Contents of the Course:**

Statistical optics; Wave optics; image detectors; resolution enhancement by digital deconvolution; interferometric imaging methods in optical astronomy; Theory of photon noise; iterative image reconstruction methods; astronomical applications

**Recommended Literature:**

J. W. Goodman; Introduction to Fourier Optics (Roberts & Company Publishers 3. Aufl. 2004)  
 Lecture Notes

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:****Observational Cosmology**

Course No.: astro845

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:****Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

Students with B.Sc. in Physics will be introduced to past and current experiments in cosmology, with some bias toward radio- and submillimeter astronomy

**Contents of the Course:**

Brief history of cosmology and its initial discoveries: cosmic expansion, cosmic microwave background. Overview of modern cosmological experiments, their major aims and technology. Aims: constraints on Big Bang and dark energy, CMB power spectrum and polarization, Sunyaev-Zeldovich effect, Supernova Ia distance measures, structure /cluster /galaxy formation, epoch of reionization, high-redshift galaxies and quasars. Experiments: APEX, LOFAR, Planck, Herschel, ALMA, SKA. Techniques: bolometer, HEMT

**Recommended Literature:**

B. F. Burke; F. Graham-Smith, An Introduction to Radio Astronomy (Cambridge University Press 2002)  
 J. A. Peacock; Cosmological Physics (Cambridge University Press 1998)  
 Contemporary Review Articles

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Wave Optics and Astronomical Applications

**Course No.:** astro846

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	ST

**Requirements:****Preparation:****Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Acquire the fundamentals necessary to carry out research projects in the field of wave optics and astronomical infrared interferometry

**Contents of the Course:**

Fundamentals of wave optics; Fourier mathematics; digital image processing; Michelson interferometry; speckle interferometry; speckle holography; Knox-Thompson method; bispectrum-speckle interferometry; interferometric spectroscopy; infrared-long-baseline interferometry; optical phase-closure method; infrared interferometry of young stars and stars in late evolutionary stages and in nuclei of galaxies

**Recommended Literature:**

Lecture Notes

J. W. Goodman; Introduction to Fourier Optics (Roberts & Company Publishers 3rd edition, 2004)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:****Optical Observations**

Course No.: astro847

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Astronomy introduction classes

**Form of Testing and Examination:**

Requirements for the examination (written or oral exam): successful work with exercises

**Length of Course:**

1 semester

**Aims of the Course:**

The students should get familiar with major aspects of optical astronomical observations, data reduction, and image analysis.

**Contents of the Course:**

Optical CCD and near infrared imaging, data reduction, catalogue handling, astrometry, coordinate systems, photometry, spectroscopy, photometric redshifts, basic weak lensing data analysis, current surveys, how to write observing proposals.

Practical experience is gained by obtaining and analysing multi-filter CCD imaging observations using the 50cm telescope on the AlfA rooftop, as well as the analysis of professional data from the archive.

**Recommended Literature:**

Provided upon registration



**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Galactic and Intergalactic Magnetic Fields

**Course No.:** astro848

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Good knowledge of electrodynamics and astronomy

**Form of Testing and Examination:**

Requirements for examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

The students shall become familiar with relativistic plasmas in astrophysics. They shall comprehend the origin and significance of magnetic fields in diffuse astrophysical media. The potential role of magnetic fields in the evolution of the universe will be discussed. The detection and quantitative measurements of magnetic fields in the ISM and IGM shall be conveyed, along with a description of the current and future observational facilities.

**Contents of the Course:**

Introduction: magnetism, physical quantities, history, observational evidence; radiation processes: radiation transport, free-free radiation, synchrotron radiation, inverse-Compton radiation, propagation effects; diagnostics: optical polarisation, synchrotron radiation, Faraday rotation, Zeeman effect; radio continuum observations: total and polarised intensity, rotation measure, RM synthesis, telescopes; Milky Way: diffuse ISM, molecular clouds and star-forming regions, supernova remnants, diffusive shock acceleration, cosmic rays, origin and maintenance of magnetic fields, galactic dynamo; external galaxies: spiral galaxies, dwarf irregular galaxies, elliptical galaxies, origin of magnetic fields; active galactic nuclei: radio galaxies, quasars, Seyfert galaxies, origin of magnetic fields; intergalactic magnetic fields: clusters of galaxies, radio halos, radio relics, mini-halos, magnetisation of the IGM, cosmological shocks; cosmological magnetic fields

**Recommended Literature:**

M.S. Longair: High Energy Astrophysics, Vol. 1+2 (Cambridge University Press, 2008)  
 S. Rosswog, M. Brüggen: Introduction to High-Energy Astrophysics (Cambr. Univ. Press 2009)  
 L. Spitzer: Physics of Fully Ionized Gases (Dover Publications, 2006)  
 Lecture Notes (U. Klein)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Multiwavelength Observations of Galaxy Clusters

**Course No.:** astro849

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Introductory Astronomy lectures

**Form of Testing and Examination:**

Written or oral examination, successful exercise work

**Length of Course:**

1 semester

**Aims of the Course:**

To introduce the students into the largest clearly defined structures in the Universe, clusters of galaxies. In modern astronomy, it has been realized that a full understanding of objects cannot be achieved by looking at just one waveband. Different phenomena become apparent only in certain wavebands, e.g., the most massive visible component of galaxy clusters - the intracluster gas - cannot be detected with optical telescopes. Moreover, some phenomena, e.g., radio outbursts from supermassive black holes, influence others like the X-ray emission from the intracluster gas. In this course, the students will acquire a synoptic, multiwavelength view of galaxy groups and galaxy clusters.

**Contents of the Course:**

The lecture covers galaxy cluster observations from all wavebands, radio through gamma-ray, and provides a comprehensive overview of the physical mechanisms at work. Specifically, the following topics will be covered: galaxies and their evolution, physics and chemistry of the hot intracluster gas, relativistic gas, and active supermassive black holes; cluster weighing methods, Sunyaev-Zeldovich effect, gravitational lensing, radio halos and relics, and the most energetic events in the Universe since the big bang: cluster mergers.

**Recommended Literature:**

Lecture script and references therein

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

# Introduction to Hydro- and Magnetohydrodynamics

**Course No.:** astro8401

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	ST

**Requirements:****Preparation:**

Revision of vectors and vector calculus, electromagnetism, basic thermodynamics

**Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

The students will become familiar with the basic laws of hydrodynamics and magnetohydrodynamics and will understand their universal applicability and importance in many varied contexts. As well as learning about the basic phenomena such as waves and compressible flow, several particular contexts (mainly in astrophysics and atmospheric physics) will be examined in detail using analytical tools which the students will then learn to apply in other, new situations and contexts. By doing this the students will develop abilities to tackle and interpret any hydrodynamical phenomenon they encounter.

**Contents of the Course:**

The fluid approximation, Euler equations, ideal fluids, viscous fluids, diffusion of heat, sound waves, hydrostatics, flow around an object, the Bernoulli equation, the Reynolds number and other dimensionless parameters used to describe a flow, compressible and incompressible flow, supersonic and subsonic flow, shock waves (with example: supernovae), surface gravity waves, internal gravity waves, waves in a rotating body of fluid (example: earth's atmosphere), stability analysis (examples: convection, salt fingers in ocean), the magnetohydrodynamics equations, Alfvén waves, flux conservation, flux freezing, magnetic pressure and tension, force-free fields, reconnection (with example: solar corona), angular momentum transport and the magneto-rotational instability (example: astrophysical discs).

**Recommended Literature:**

E.Landau & E.Lifshitz, Fluid mechanics (Pergamon Press 1987)

S.Shore; Astrophysical hydrodynamics: an introduction (Wiley-VCH, 2007)

Lecture notes at <http://www.astro.uni-bonn.de/~jonathan/misc/astroMHDnotes.pdf>

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:****X-Ray Astronomy**

**Course No.:** astro8402

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Introductory astronomy lectures

**Form of Testing and Examination:**

Written or oral examination, successful exercise work

**Length of Course:**

1 semester

**Aims of the Course:**

The student shall be familiarized with X-ray observations as a powerful tool to study almost all astrophysical objects in ways not possible in other wavebands.

**Contents of the Course:**

History, space-based instruments, radiation processes, solar system objects, isolated compact objects, binaries with compact objects, supernova remnants, interstellar medium, Galactic center, normal galaxies, galaxy clusters, superclusters, intergalactic medium, active galactic nuclei.

**Recommended Literature:**

Lecture notes will be provided

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

# Hydrodynamics and astrophysical magnetohydrodynamics

**Course No.:** astro8403

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Revision of elementary thermodynamics, vector calculus and electromagnetism. Please note that although this course is designed mainly with astrophysics in mind, no knowledge of astrophysics is assumed. Students of other branches of physics are welcome.

**Form of Testing and Examination:**

Exercises throughout the semester, and an oral examination at the end of the course.

**Length of Course:**

1 semester

**Aims of the Course:**

Almost the entire universe is fluid and so an understanding of many phenomena is impossible without a proper grasp of fluid dynamics. This course introduces the field, drawing on examples from astrophysics as well as atmospheric physics to illustrate the principles. The aim is for the students to develop an intuitive understanding of underlying principles. Roughly the last quarter of the course is an introduction to magnetohydrodynamics; here the emphasis is on astrophysical applications (rather than laboratory/plasma physics).

**Contents of the Course:**

The fluid approximation, Euler equations, ideal fluids, viscous fluids, diffusion of heat, sound waves, hydrostatics, flow around a solid body, the Bernoulli equation, the Reynolds number and other dimensionless parameters used to describe a flow, compressible and incompressible flow, supersonic and subsonic flow, shocks (with example: supernovae), surface & internal gravity waves, vortices and vorticity, waves in a rotating body of fluid (example: earth's atmosphere), stability analysis (examples: convection, shear instability), the magnetohydrodynamics equations, Alfvén waves, flux conservation, flux freezing, magnetic pressure and tension, force-free fields, reconnection (with example: solar corona), angular momentum transport and the magneto-rotational instability (example: astrophysical discs).

**Recommended Literature:**

E. Landau & E. Lifshitz, "Fluid mechanics" Pergamon Press 1987

S. Shore, "Astrophysical hydrodynamics: an introduction", Wiley-VCH 2007

A. Choudhuri, "The physics of fluids and plasmas", Cambridge 1998

Lecture notes at [http://www.astro.uni-bonn.de/~jonathan/misc/Hydro\\_astroMHD.pdf](http://www.astro.uni-bonn.de/~jonathan/misc/Hydro_astroMHD.pdf)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## Radiointerferometry: Methods and Science

**Course No.:** astro8404

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+2	4	ST

**Requirements:****Preparation:**

Einführung in die Radioastronomie (astro123), Radio Astronomy (astro841)

**Form of Testing and Examination:**

Requirements for the examination (written or oral): Successful participation in the exercise sessions

**Length of Course:**

1 semester

**Aims of the Course:**

Basics of radiointerferometric observations and techniques; review of science highlights; use of common data analysis packages.

**Contents of the Course:**

Principles of interferometry, aperture synthesis, calibration, continuum and spectral line imaging, zero spacing, VLBI, use of AIPS and CASA, ALMA and VLA proposal writing, LOFAR and SKA, science highlights.

**Recommended Literature:**

"Synthesis Imaging in Radio Astronomy II" (ASP Conference Series, V. 180, 1998), Editors: Taylor, Carilli, Perley

Interferometry and Synthesis in Radio Astronomy (Wiley 2001), by Thompson, Moran, Swenson

On-line material

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Stellar and Solar Coronae**

Course No.: astro851

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:****Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

The student shall gain thorough knowledge of activity phenomena exhibited by the sun and other stars

**Contents of the Course:**

Sunspots and solar corona; Solar cycle; The Dynamo theory; Emission mechanism; Coronal loops;  
 Magnetic reconnection; Flares; Magnetic stellar activity; Mapping star-spots: Doppler imaging; Radio  
 corone

**Recommended Literature:**

Literature references will be provided during the course

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Gravitational Lensing**

Course No.: astro852

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:****Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

After learning the basics of gravitational lensing followed by the main applications of strong and weak lensing, the students will acquire knowledge about the theoretical and observational tools and methods, as well as about the current state of the art in lensing research. Strong emphasis lies on weak lensing as a primary tool to study the properties of the dark-matter distribution and the equation of state of dark energy

**Contents of the Course:**

The detection of the deflection of light in a gravitational field was not only one of the crucial tests of Einstein's Theory of General Relativity, but has become in the past two decades a highly valuable tool for astronomers and cosmologists. It is ideally suited for studying the mass distribution of distant objects, search for compact objects as a potential constituent of the Galactic dark matter, provide powerful (and cheap) 'natural telescopes' to take a deeper look into the distant Universe, to measure the mass distribution in clusters and on larger spatial scales, and to study the relation between luminous and dark matter in the Universe. Principles and methods are described in detail and the applications will be presented

**Recommended Literature:**

P. Schneider, C. Kochanek, J. Wambsganss; Gravitational Lensing: Strong, Weak and Micro: Saas-Fee Advanced Course 33. Swiss Society of Astrophysics and Astronomy (Springer, Heidelberg 2006)  
 P. Schneider, J. Ehlers, E. F. Falco; Gravitational Lenses (Springer, Heidelberg 1992)



**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:**

# The Physics of Dense Stellar Systems as the Building Blocks of Galaxies

**Course No.:** astro8531

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+2	6	WT

**Requirements:****Preparation:**

Participation in the lecture course and in the exercise classes and reading

**Form of Testing and Examination:**

A final two hour written exam on the contents of the course

**Length of Course:**

1 semester

**Aims of the Course:**

The students are taught the fundamentals of collisional stellar dynamics and of the emergence of stellar populations from galactic building blocks

**Contents of the Course:**

Fundamentals of stellar dynamics: distribution functions, generating functions, collisionless Boltzmann equation, Jeans equations, Fokker-Planck equation, dynamical states, collisional dynamics and relaxation, formal differentiation between star clusters and galaxies, mass segregation, evaporation, ejection, star-cluster evolution, the form, variation and origin of the stellar initial mass function, stellar populations, their evolution and their properties, binary stars as energy sinks and sources, the distribution functions of binary stars and the evolution of these distribution functions, star-cluster birth, violent relaxation, birth of dwarf galaxies.

The lecture course covers a broad range of topics related to the emergence of stellar populations from their molecular cloud cores. It provides a Bonn-unique synthesis on the one hand side between observationally and theoretically derived distribution functions, which describe stellar populations, and on the other hand side the temporal evolution of these distribution functions, such that a comprehensive mathematical formulation of stellar populations in galaxies becomes possible with this knowledge.

**Recommended Literature:**

Lecture notes

Galactic Dynamics by J.Binney and S.Tremaine (1987, Princeton University Press)

Dynamics and Evolution of Galactic Nuclei by D.Merritt (2013, Princeton University Press)

Dynamical Evolution of Globular Clusters by Lyman Spitzer, Jr. (1987, Princeton University Press)

The Gravitational Million-Body Problem by Douglas Heggie and Piet Hut (2003, Cambridge University Press)

Gravitational N-body Simulations: Tools and Algorithms by Sverre Aarseth (2003, Cambridge University Press)

Initial Conditions for Star Clusters by Pavel Kroupa (2008, Lecture Notes in Physics, Springer)

The stellar and sub-stellar IMF of simple and composite populations by Pavel Kroupa (2013, Stars and Stellar Systems Vol.5, Springer)

The universality hypothesis: binary and stellar populations in star clusters and galaxies by Pavel Kroupa



**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Numerical Dynamics**

Course No.: astro854

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:****Form of Testing and Examination:**

Requirements for the examination (written): successful work with exercises and programming tasks

**Length of Course:**

1 semester

**Aims of the Course:**

The students will have to familiarize themselves with the various numerical recipes to solve the coupled 2nd-order differential equations as well as with the limitations of these methods

**Contents of the Course:**

The two-body problem and its analytical solution. Ordered dynamics: integration of planetary motion, solar system, extra-solar planets. Collisional dynamics: integration of stellar orbits in star clusters, star-cluster evolution. Collisionless dynamics: integration of stellar orbits in galaxies, cosmological aspects

**Recommended Literature:**

Write-up of the class;

S. J. Aarseth; Gravitational N-body simulations: Tools and Algorithms (Cambridge University Press, 2003)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Quasars and Microquasars**

Course No.: astro856

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture	English	2	3	WT

**Requirements:****Preparation:****Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

The phenomenon of quasars and their energy production shall be studied from the smallest (stellar binaries) to the largest (active galactic nuclei) scales

**Contents of the Course:**

Microquasars and Quasars; X-ray binaries; Accretion; Neutron stars; Black holes; X-ray observations; Spectral states; Radio observations; Doppler boosting; Energy losses; Magneto-hydrodynamic production of jets; Gamma-ray observations; Review of Microquasars; Quasi periodic oscillations (QPO)

**Recommended Literature:**

Literature references will be provided during the course

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Star Formation**

Course No.: astro857

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:****Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

An introduction to basic concepts, modern theories, and the current observational basis of star formation.

**Contents of the Course:**

The structure and evolution of the interstellar medium in relation to Star Formation: molecular excitation, interstellar chemistry; the star formation process: conditions, cloud collapse, protostellar evolution; low mass vs. massive star formation; related phenomena: jets and outflows, protostellar disks, shocks, photodissociation regions; the initial mass function, global star formation, starbursts, the star formation history of the Universe, the very first stars.

**Recommended Literature:**

Stahler, Palla: The Formation of Stars (Wiley-VCH, 2004)

Additional literature will be given during the course

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Nucleosynthesis**

Course No.: astro858

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	3+1	6	ST

**Requirements:****Preparation:**

Introduction to Astronomy, Stars and Stellar Evolution

**Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Obtain an overview of the different nucleosynthesis processes in the universe, an understanding of how they work, and where they work.

**Contents of the Course:**

Basic: Thermonuclear reactions  
 Big Bang nucleosynthesis  
 Overview of stellar evolution  
 Hydrostatic Nucleosynthesis I: Hydrogen burning  
 Hydrostatic Nucleosynthesis II: Helium burning and beyond  
 Hydrostatic Nucleosynthesis III: The s-process  
 Hydrostatic Nucleosynthesis IV: s-process components  
 Explosive Nucleosynthesis I: Core-collapse supernovae  
 Explosive Nucleosynthesis II: r-process and p-process  
 Explosive Nucleosynthesis III: Thermonuclear supernovae  
 Cosmic ray nucleosynthesis  
 Chemical Evolution of galaxies

**Recommended Literature:**

Lecture script

C.E. Rolfs, W.S. Rodney: Cauldrons in the Cosmos (ISBN 0-226-45033-3), not compulsory

D.D. Clayton: Physics of Stellar Evolution and Nucleosynthesis (ISBN 0-226-10953-4), not compulsory

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:**

## The cosmic history of the intergalactic medium

**Course No.:** astro859

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:**

Basic atomic physics (hydrogen atom) and basic thermodynamics. No previous knowledge of astrophysics is required.

**Form of Testing and Examination:**

Written or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

The aim of this course is to familiarize students with the physics of the intergalactic medium (the material that pervades the vast regions between galaxies) and with its significance for cosmology and the astrophysics of galaxies. Thanks to progress in observations, theoretical modeling, and computational power, our knowledge in this field is growing rapidly. The main questions driving current research will be discussed and new results introduced as they occur.

**Contents of the Course:**

Basic: Transport of continuum and line radiation, photo-ionizations and radiative recombinations, the cooling function, the expanding universe.

Advanced: Cosmic recombination, the dark ages, hydrogen and helium reionization, 21cm-probes of the dark ages and reionization, quasar absorption systems, the UV background, the warm-hot intergalactic medium, intracluster gas, Lyman-alpha fluorescence.

**Recommended Literature:**

The study of the intergalactic medium is a young subject. No textbook exists for this topic. Lecture notes will be distributed.

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Binary Stars**

Course No.: astro8501

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Introductory astronomy and cosmology lectures, stars and stellar evolution

**Form of Testing and Examination:**

Written or oral examination, successful exercise work

**Length of Course:**

1 semester

**Aims of the Course:**

The course will provide the necessary understanding of the basic physics of binary stars, in particular orbits, mass-transfer, chemistry and the importance of binary stars and populations of binaries to modern astrophysics.

**Contents of the Course:**

Most stars are not alone, they orbit a companion in a binary star system. This course will address the evolution of such binary stars and their impact on the Universe. It will start by considering orbital dynamics and observations of binaries, followed by stellar interaction in the form of mass transfer by Roche-lobe overflow and wind mass transfer. The effect of duplicity on chemistry, rotation rates and orbital parameters will be studied with the emphasis on uniquely binary-star phenomena such as type Ia supernovae, thermonuclear novae and gamma-ray bursts. It will conclude with quantitative studies of populations of binary stars.

**Recommended Literature:**

An Introduction to Close Binary Stars - Hilditch - Cambridge University Press ISBN 0-421-79800-0  
 Interacting Binary Stars - Pringle and Wade - CUP (Out of print but you can find cheap second-hand copies on [www.amazon.com](http://www.amazon.com)) ISBN 0-521-26608-4  
 Evolutionary Processes in Binary and Multiple Stars - Eggleton - CUP ISBN 0-521-85557-8



**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:**

# Physics of Supernovae and Gamma-Ray Bursts

**Course No.:** astro8502

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:**

Introductory astronomy and cosmology lectures

**Form of Testing and Examination:**

Written or oral examination, successful exercise work

**Length of Course:**

1 semester

**Aims of the Course:**

The student will learn basic physics on supernova and gamma-ray burst, and will have an overview on their applications to various fields of astrophysics.

**Contents of the Course:**

Basic physics on stellar hydrodynamics, radiation processes, and stellar death.  
 Type Ia supernova: observations and theory. Application to cosmology  
 Core collapse supernova: observations and theory  
 Gamma-ray bursts: observations and theory.  
 Implications for massive star population and star-formation history  
 Supernova nucleosynthesis and chemical evolution of galaxies  
 Explosions of the first generations of stars  
 Some related issues: supernova remnants, neutrinos, shock break-out, etc.

**Recommended Literature:**

Lecture notes with key references for each topic will be provided.

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:**

# Radio and X-Ray Observations of Dark Matter and Dark Energy

**Course No.:** astro8503

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:**

Introductory astronomy and cosmology lectures

**Form of Testing and Examination:**

Written or oral examination, successful exercise work

**Length of Course:**

1 semester

**Aims of the Course:**

The student will learn how the phenomena of dark matter and dark energy are explored using radio and X-ray observations, from the largest down to galaxy scales.

**Contents of the Course:**

Introduction into the evolution of the Universe and the theoretical background of dark matter and dark energy tests, dark matter associated with galaxies, dark matter associated with galaxy clusters and superclusters, the cosmic microwave background (CMB), epoch of re-ionization, low-frequency radio astronomy, high- $z$  supernovae, cosmic infrared background (CIB), precise distance measurements at cosmological distances, observational evidence for hierarchical structure formation, MOND vs. dark matter cosmology.

**Recommended Literature:**

Lecture notes will be provided

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:**

## Lecture on Advanced Topics in Modern Astrophysics

**Course No.:** astro8504

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT/ST

**Requirements:****Preparation:**

Theoretical courses at the Bachelor degree level

**Form of Testing and Examination:**

Requirements for the examination (written or oral): successful work with the exercises

**Length of Course:**

1 semester

**Aims of the Course:**

This course is to allow the students to have deeper insight into a specialised subject of astrophysics that is not covered in the astrophysics curriculum otherwise. The content of the course depends on the lecturer's expertise and may vary from time to time.

**Contents of the Course:**

See detailed announcements ("kommentiertes Vorlesungsverzeichnis")

**Recommended Literature:**

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Astrophysics II (MA)**

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	4+1	8	WT

**Requirements:****Preparation:**

Astrophysics I

**Form of Testing and Examination:**

written test

**Length of Course:**

1 semester

**Aims of the Course:**

The student will gain the ability to apply fundamental concepts of physics to describe astrophysical phenomena and will obtain an overview of the experimental foundations of our knowledge about the cosmos. The courses will enable him to understand the fundamental principles of the universe and its history. The courses also give an introduction to topics of active research in astrophysics and thus prepares the students towards their own research activity within the master thesis.

**Contents of the Course:**

Based on the introductory course 'Astrophysics I' in the Bachelor program this course deepens the understanding in selected topical areas of relevance. These are:

Interstellar medium: molecular clouds, HII regions, photon dominated regions, shock waves, radiation processes, radiative transfer, astrochemistry

Star formation (low mass and high mass), planetary system formation

Galaxies: galactic structure, morphology, dynamics, chemical evolution, nuclei of active galaxies

Large scale structure of the universe: intergalactic distance ladder, galaxy clusters, dark matter, gravitational lenses, experimental cosmology

**Recommended Literature:**

Binney and Merrifield, Galactic Astronomy (Princeton University Press)

Binney and Tremaine, Galactic Dynamics (Princeton University Press)

Carroll and Ostlie, An Introduction to Modern Astrophysics (Addison-Wesley)

Schneider, Einführung in die extragalaktische Astronomie & Kosmologie (Springer, Berlin)

Shu, The Physics of Astrophysics I & II (University Science Books, Mill Valley)

Tielens, The Physics and Chemistry of the Interstellar Medium (Cambridge University Press)

Unsöld and Baschek, Der neue Kosmos (Springer, Berlin)

Weigert and Wendker, Astronomie und Astrophysik (VCH Verlag)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Star Formation (MA)**

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2	3	WT

**Requirements:****Preparation:**

Astrophysics I (Astrophysics II recommended)

**Form of Testing and Examination:**

Oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Understanding of fundamental concepts of star formation in a variety of environments.

**Contents of the Course:**

The lecture introduces the basic aspects of Star Formation:

Physical Processes in the ISM, Interstellar Chemistry, ISM and Molecular Clouds, Equilibrium Configurations and Collapse, Protostars, Formation of High Mass Stars, Jets, Outflows, Disks, Pre-main sequence stars, Initial Mass Function, Structure of the Galaxy, Starburst Galaxies, Star Formation in the early Universe

**Recommended Literature:**

Palla and Stahler, Formation of Stars (Wiley)

Carroll and Ostlie, An Introduction to Modern Astrophysics (Addison-Wesley)

Shu, The Physics of Astrophysics I & II (University Science Books, Mill Valley)

Tielens, The Physics and Chemistry of the Interstellar Medium (Cambridge University Press)

Spitzer, Physical Processes in the Interstellar Medium (Wiley)

Unsöld and Baschek, Der neue Kosmos (Springer, Berlin)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro850 **Modern Astrophysics**

**Course:****Galaxy Dynamics (MA)**

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	WT

**Requirements:****Preparation:**

Astrophysics I ( Astrophysics II recommended)

**Form of Testing and Examination:**

Oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Understanding of fundamental concepts of stellar and galaxy dynamics.

**Contents of the Course:**

The lecture introduces to basic aspects of stellar and galaxy dynamics: Multiple stellar systems, dynamics of open and compact stellar clusters, elliptical, disk and barred spiral galaxies, gas kinematics, galaxy evolution in galaxy clusters, gravitational friction, violent relaxation, the Hubble fork, galaxy collisions and mergers, cosmological evolution of stellar systems.

**Recommended Literature:**

Binney and Merryfield, Galactic Astronomy (Princeton University Press)

Binney and Tremaine, Galactic Dynamics (Princeton University Press)

Carroll and Ostlie, An Introduction to Modern Astrophysics (Addison-Wesley)

Schneider, Einführung in die extragalaktische Astronomie & Kosmologie (Springer, Berlin)

Weigert and Wendker, Astronomie und Astrophysik (VCH Verlag)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:****Active Galactic Nuclei (OA)**

Course No.:

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Astrophysics I (Astrophysics II recommended)

**Form of Testing and Examination:**

Oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Understanding of fundamental concepts and physical radiation mechanisms for active galactic nuclei  
 Like Seyfert-galaxies, QSOs, quasars, and violently variable objects.

**Contents of the Course:**

The lecture introduces to basic aspects of active galactic nuclei:

Types of sources HII-galaxies, LINERs, Seyfert I, Seyfert II, QSO I, QSO II, BLLac /OVV-sources

Structure of an active nucleus: Broad line region (BLR), Narrow line region (NLR) and extended narrow line region (ionization cone).

Forbidden and permitted line transitions as density and temperature probes

Continuum emission processes: free-free and synchrotron radiation

Radio galaxies, jets and lobes as well as super luminal motion in jets.

**Recommended Literature:**

Binney and Merryfield, Galactic Astronomy (Princeton University Press)

Binney and Tremaine, Galactic Dynamics (Princeton University Press)

Carroll and Ostlie, An Introduction to Modern Astrophysics (Addison-Wesley)

Schneider, Einführung in die extragalaktische Astronomie & Kosmologie (Springer, Berlin)

Shu, The Physics of Astrophysics I & II (University Science Books, Mill Valley)

Tielens, The Physics and Chemistry of the Interstellar Medium (Cambridge University Press)

Unsöld and Baschek, Der neue Kosmos (Springer, Berlin)

Weigert and Wendker, Astronomie und Astrophysik (VCH Verlag)

**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## **Methods of Experimental Astrophysics (OA)**

**Course No.:**

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Elementary Physics (Bachelor level); Astrophysics I (and II)

**Form of Testing and Examination:**

Exercise and written test; or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Gain insight into which type of instrumentation, based on which principles, is employed for particular astronomical and astrophysical applications; and learn about their practical and fundamental limitations in resolution and sensitivity

**Contents of the Course:**

- detection of radiation: direct and coherent detection
- Signal/Noise ratio: fundamental and practical limits
- principles of optical instruments: imaging
- principles of optical instruments: spectroscopy
- radio receivers: Local Oscillator, Mixer and Backend-Spectrometers
- calibration: theory and measurement strategies

**Recommended Literature:**

Rieke: Detection of Light

Kraus: Radioastronomy

Bracewell: The Fourier Transform and its Applications



**Modules:**

astro830 **Elective Advanced Lectures**  
 astro840 **Observational Astronomy**

**Course:**

## The Fourier-Transform and its Applications (OA)

**Course No.:**

Category	Type	Language	Teaching hours	CP	Semester
Elective	Lecture with exercises	English	2+1	4	ST

**Requirements:****Preparation:**

Elementary Physics (Bachelor level); Elementary QM

**Form of Testing and Examination:**

Exercise and written test; or oral examination

**Length of Course:**

1 semester

**Aims of the Course:**

Strengthen insight into how the mathematical principles of Fourier Theory as a common principle affect many areas of physics (optics: diffraction/interference; QM: Heisenberg principle; statistics of noise and drifts; data acquisition: sampling) and other applications (data compression, signal processing).

**Contents of the Course:**

- introduction to the principles of Fourier Transform mathematics
- Delta-function and more general distributions
- diffraction optics and interferometry
- uncertainty principle in QM as application of FT
- theory of noise, drifts and their statistics
- intro to wavelet analysis and data compression

**Recommended Literature:**

Bracewell: The Fourier Transform and its Applications