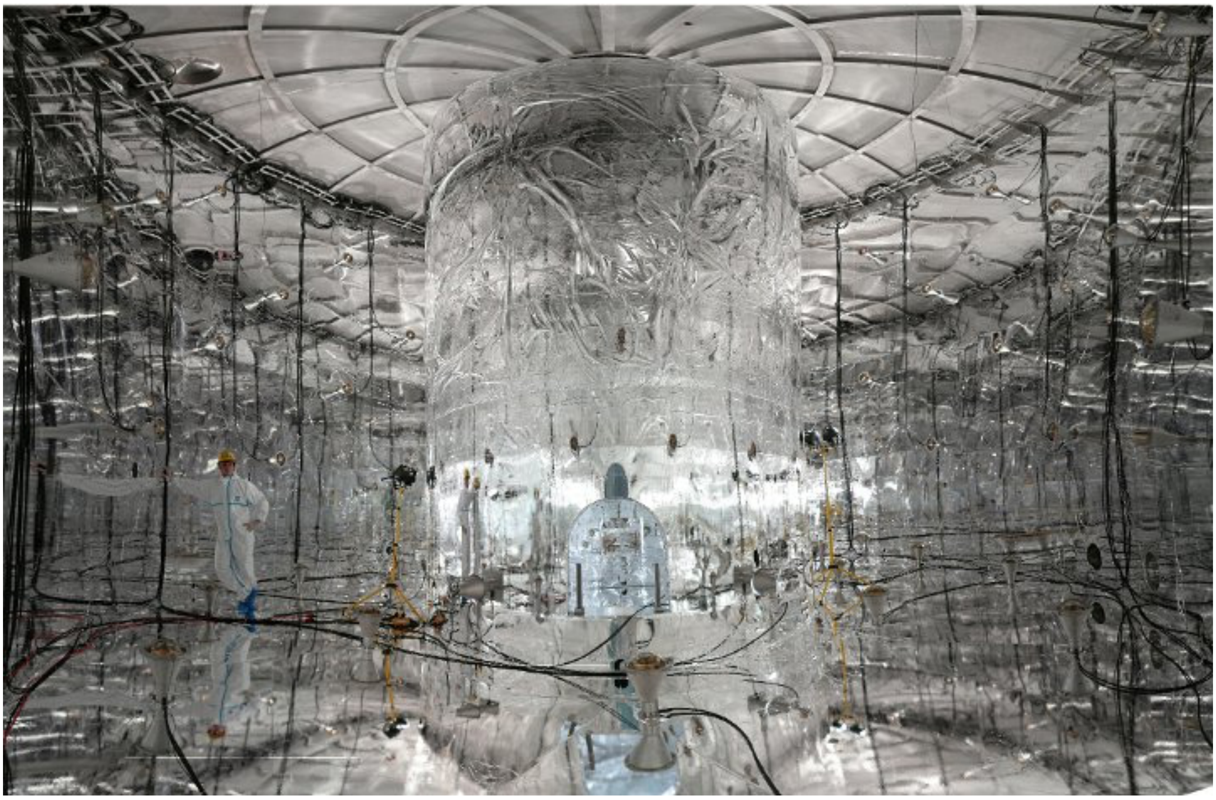
EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN



Module Handbook

Master of Science Astro and Particle Physics

Valid from: Winter Semester 2025
Valid until: Summer Semester 2026

Current as of: 31 July 2024

FACULTY OF SCIENCE
Department of Physics
Kepler Center for Astro and Particle Physics

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1 Objectives of the Programme

The Master of Science Programme in Astro and Particle Physics is an international research-oriented two years Master programme established by the Kepler-Center of the University of Tübingen.
The Kepler-Center is part of the Physics Department within the Faculty of Science of the University of Tübingen. It consists of scientists from three different institutes within the Physics Department: Institute for Astronomy & Astrophysics, Physical Institute and the Institute for Theoretical Physics. The Kepler-Center has a research focus in the areas of Astronomy & Astrophysics, Astroparticle Physics and Particle Physics, and it manages a coordinated PhD-programme with the topic: *Particles, Fields and Messengers of the Universe* with about 30 PhD students.

The Master programme connects science from the fields of particle physics, astrophysics and cosmology and combines different disciplines in experimental and theoretical physics, astronomy and astrophysics.
Scientists of the Kepler-Center use various methods to discover the origin, structure, and evolution of our universe and the properties of elementary particles under extreme conditions. This is one of the research foci of the University of Tübingen (Uni-Tübingen-Webpage).

The Southern German region concentrates industrial companies with a strong Hi-Tech component. These and other companies elsewhere have a high demand on well qualified young people with a strong background in natural sciences. Presently many physicists educated at the University Tübingen work in technology-oriented companies in this region, and the graduates from this Master programme will find an industrial environment with a strong demand on highly skilled people.

The graduates of the Master programme Astro and Particle Physics receive a comprehensive education in experimental as well as theoretical physics with a practical section and they are well prepared for the duties in industry and in other research oriented institutions.
The education will be in English throughout which prepares the students for the increasing internationalization in industry and modern society.
Due to the various research topics within the Kepler-Center students will obtain an education in a wide variety of topics ranging from experimental, numerical to theoretical.

The focus of the educational programme is put on a distinct quantitative approach as usual in physics, along with the acquisition of essential practical skills (primarily in the lab) with respect to problem sets in the field of Astro and Particle Physics.
The overall goal of the Master course is to impart solid knowledge and competences to qualify students to independently plan and carry out original scientific research in astro and particle physics and to critically evaluate their findings in comparison with published results.
The qualification goals in more detail:

- Our graduates have a sound standing in basic and advanced astro and particle physics covering various research fields including for example theoretical quantum field theory, general relativity, computational astrophysics, experimental neutrino physics, and many others.
- They are capable to critically scrutinize the suitability of specific scientific methods for studying various astro and particle physics related questions. In addition, they will be able to combine different techniques in a meaningful way to also make rather complex physical problems accessible.

- They can plan and undertake independently appropriate theoretical and laboratory investigations (collecting, recording and analyzing relevant data sets and combining these with theoretical studies).
- The graduates can present scientific findings of their research orally and in writing. Moreover, in discussions they are skilled to answer scientific questions in a proficient manner. At scientific meetings, they can communicate – in English – with experts in the field and contribute to discussions on current astro and particle physics related topics.

The Master programme is a two years consecutive study with a modular structure. Students may join the programme twice a year, for the summer and winter semester. In the first year the students must attend lectures, seminars and labwork consisting of 60 ECTS credit points. All students must take two basic introductory modules Astronomy & Astrophysics and Particle Physics consisting of lectures and exercises in the first term, which lay the foundations for all students. These are augmented by an obligatory seminar and labwork. In the second term students can choose modules from a variety of different topics. In the second year the students will begin with the scientific work on a research topic of their choice in the areas of the Kepler-Center and finally write their Master Thesis, all together again 60 CP (30 for acquiring research oriented skills and 30 for the Thesis).

Requirements

To participate in the MSc programme a bachelor's degree in physics or a similar degree with a minimum grade of B (2.5 on the German scale) is required. In addition, proof must be provided of knowledge in areas relevant to astrophysics and particle physics (in particular theoretical physics, experimental physics, laboratory practicals).
The Exam Committee (Prüfungsausschuss) decides about the equivalence of the degree and possibly additional requirements such as additional lectures or lab classes that must be taken. In case of a too large number of participants a Selection Committee will decide about the acceptance. English is the language of instruction and examination in the Astro and Particle Physics Master's degree program. An adequate knowledge of English is required (level B2 of the Common European Framework of Reference for Languages).

2 Module Overview

To complete the programme, students must earn in total 120 credit points from a suite of compulsory and elective modules.

2.1 Overview by Modules

The following table contains the modules offered within the Master programme Astro and Particle Physics.

Module Code	Obligatory/Elective	Module Title	Recommended Semester	Credit Points
APP101	O	Astronomy & Astrophysics	1	9
APP102	O	Particle Physics	2	9
APP103	O	Laboratory Work	1-2	6
APP104	O	Modern Topics in Astro and Particle Physics	2+3	6
APP105	O	Nuclear and Particle Physics	1	6
APP201	E	Theoretical Astrophysics	1	6
APP202	E	Computational Methods in Physics/Astrophysics	1-2	6
APP203	E	Stellar Physics	1-2	6
APP204	E	General Relativity	1	6
APP205	E	Relativistic Astrophysics	2	6
APP206	E	Star and Planet Formation, Exoplanets	1-2	6
APP211	E	Neutrino Physics	1	6
APP212	E	High Energy Astrophysics	1	6
APP213	E	Cosmology	2	6

APP214	E	Extragalactic Astrophysics and Structure Formation	2	6
APP215	E	Space Physics and Astrophysics	2	6
APP216	E	Experimental Astro Particle Physics	2	6
APP221	E	Quantum Field Theory	1	6
APP222	E	Advanced Quantum Field Theory	2	6
APP301	O	Module of neighbouring field	2-3	6
APP401	O	Scientific Specialisation in Thesis Topic	3	12
APP402	O	Methods and Project Planning	3	12
APP403	O	Master Thesis	4	30

Notes:

The first section contains the required modules APP101-APP105 that consist of a total of 36 CP. The modules APP101, APP102 and APP105 are three basic modules laying the foundations for the Master study. Module APP103 requires practical (laboratory) work and module APP104 contains a Seminar and one Lecture that introduce the students to modern research in the field of astro and particle physics.
Modules APP201 to APP222 are elective. Students must select modules adding up to a total of 24 CP. These modules consist typically of lectures and exercises that cover topics from astro and particle physics. The students can select any modules from this which allows them to familiarize themselves with a broader range of scientific fields offered within this Master programme. At least two of the elective modules APP201-APP222 (a minimum of 12 CP) need to be graded

The module APP301 should be taken from neighbouring scientific fields - not astro and particle physics. This includes for example advanced modules from the 4-years Bachelor study of Physics (not listed explicitly in the table above), or other advanced modules from Mathematics. Choices from other fields are also possible but require a decision of the Exam Committee (Prüfungsausschuss) on an individual basis. Taking this additional module from a neighbouring field will allow the students to acquire knowledge, methods and skills in related scientific areas that will be helpful in their Master research in Astro and Particle Physics and will teach the students how to cooperate with other disciplines and find joint solutions.

The final part, modules APP401 - APP403, are obligatory and contain the Master Thesis itself (APP403) and two preparatory modules (APP401, APP402) introducing into scientific research.

The final grade of the MSc in Astro and Particle Physics is calculated as 2/3 times the grade of the Master Thesis plus 1/3 times the average grade of compulsory modules APP101 and APP102 (18 CP) and the graded modules from the elective area (12 CP).

2.2 Sample Study Plan

The following table shows exemplary a sample plan for a possible two years study within the Master Programme.

<table>
<tr><th>Semester</th><th>CP</th><th colspan="5">Modules</th></tr>
<tr><td>1.</td><td>30</td><td>Module APP101
Astronomy & Astro-physics
(9 CP)</td><td>Module APP105
Nuclear and Parti-cle Physics
(6 CP)</td><td>Module APP103
Laboratory Work
(6 CP)</td><td>Module
APP204
General Rela-tivity
(6 CP)</td><td rowspan="2">Module
APP104
Modern
Topics in
A&P
(6 CP)</td></tr>
<tr><td>2.</td><td>30</td><td>Module APP102
Particle Physics
(9 CP)</td><td>Module APP202
Computational
Methods
(6 CP)</td><td>Module APP212
High Energy As-trophysics
(6 CP)</td><td>Module
APP213
Cosmology
(6 CP)</td></tr>
<tr><td>3.</td><td>30</td><td>Module APP401
Scientific Specialisation in
Thesis Topic
(12 CP)</td><td>Module
APP301
Neighbouring
Field
(6 CP)</td><td colspan="3">Module APP402
Method and Project Planning
(12 CP)</td></tr>
<tr><td>4.</td><td>30</td><td colspan="5">Module APP403
Master Thesis
(30 CP)</td></tr>
</table>

Notes: Module APP104 contains a Seminar and a Lecture. Module APP103 (the labwork course) is usually offered during the term breaks between the lecture terms.
We encourage students to work and study abroad for some extended period during their studies in this Master programme. Convenient windows for such stays abroad are the 2nd or 3rd semester.

2.3 Overview by Study Progress and Credit Requirements

The following table gives an overview on the study progress (the used abbreviations are explained on the next page)

		Assessment				Course				Semester			
The allocation of CPs to courses is for information only. Credits are only awarded upon completion of the module.		Grading	Type of Exam	Duration	Weight	Contact Hours	Status	Type of Course	Total CP	The allocation of exams to semesters is a recommendation only. Compulsory allocations are marked as such. 1. CP	2. CP	3. CP	4. CP
Basic Research in Astro and Particle Physics									36				
APP101	Astronomy & Astrophysics	g	W	180		6	o	L,E		9			
APP102	Particle Physics	g	W	180		6	o	L,E			9		
APP103	Laboratory Work	ng	fE			4	o	P			6		
APP104	Modern Topics in A&P	ng	fE			4	o	S,L				6	
APP105	Nuclear & Particle Physics	ne				6	o	L,E		6			
Specialisation Module									24				
APP201	Theoretical Astrophysics	ne/g	O	30		4	e	L,E		6			
APP202	Computational Methods	ne/g	O	30		4	e	L,E			6		
APP203	Stellar Physics	ne/g	O	30		4	e	L			6		
APP204	General Relativity	ne/g	W	60		4	e	L,E		6			
APP205	Relativistic Astrophysics	ne/g	O	30		4	e	L			6		
APP206	Star/Planet Formation, Exoplanets	ne/g	O	30		4	e	L			6		
APP211	Neutrino Physics	ne/g	O	30		4	e	L,E		6			
APP212	High Energy Astrophysics	ne/g	O	30		4	e	L,E		6			
APP213	Cosmology	ne/g	O	30		4	e	L,E			6		
APP214	Extragalactic Astrophysics	ne/g	O	30		4	e	L,E,S			6		
APP215	Space Physics and Astrophysics	ne/g	O	30		4	e	L,E,S			6		
APP216	Experimental Astroparticle Physics	ne/g	O	30		4	e	L,E,S			6		
APP221	Quantum Field Theory	ne/g	O	30		6	e	L,E		6			
APP222	Advanced Quantum Field Theory	ne/g	O	30		6	e	L,E			6		
Neighbouring Field									6				
APP301	Module of neighbouring field	ne/ng/g	fE/W/O			4	o	L/E/S			6		
Scientific Work									54				
APP401	Scientific Specialisation in Thesis Topic	ne				v.	o					12	
APP402	Methods and Project Planning	ne				v.	o					12	
APP403	Master Thesis	g	MT,C			v.							30
Total		-	0	-	-	-	-	-	120	30	30	30	30

The following abbreviations are used in overview above and in the individual module prescriptions below.

Key	
Grading:	g = graded; ng = ungraded (pass/fail); ne = no module examination
Type of Exam:	W = written exam; O = oral exam; fE = formative exam; MT = Master Thesis, C = Colloquium
Duration:	duration of the examination in minutes
Weight:	courses: weighting of the examination grade towards the module grade modules: weighting of the module grade towards the final grade
Contact Hours:	CH; hours spent in the classroom per week during the semester; v. = vari-able
Status:	o = obligatory; e = elective
Type of Course	L = lecture; S = seminar; E = exercise; P = practical
CP:	Credit Points (ECTS Credits)

3 Module Descriptions

The following module descriptions give a comprehensive overview of the Astro and Particle Physics Master course (APP). The information compiled reflects the module profiles as of July 2024. The lecturers as well as single lectures might be subject to changes. If in doubt about a specific course, please contact the course coordinator via ch.schaefer@uni-tuebingen.de and the module responsible person (see modules below).

Several of the modules described in the following consist of a lecture (L) in combination with exercises (E). This is the most common form of teaching and learning in the field of physics and astrophysics. Typically, it contains independent homework of the students as well as team-working through joint discussions of the (weekly) assignments sets. The results of their home-work will have to be presented and discussed by the students in the corresponding exercise classes.

Module Code: APP101	**Module Title:** Astronomy & Astrophysics		**Type of Module:** obligatory
CP (ECTS Credits)	9		
Workload - Time in Class - Self-Study	Total Workload: 270 h	Time in Class: 90 h / 6 SWS	Self-Study: 180 h
Duration	1 semester		
Frequency	Each term		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture with exercises		
Content	The module deals with the fundamentals of astronomy and astrophysics to be known by all students. This includes observational techniques, radiative transport, the Solar System, stars and planets, the Milky Way, galaxies, large scale structure of the universe, cosmology.		
Objectives	The students will obtain knowledge of the basic principles of astronomy and astrophysics. They can transfer and apply physical processes from other fields to astrophysical phenomena. Through solving a series of exercises and applying the methods presented in the lecture they acquire necessary skills for independent problem solving and deepen their understanding.		

Requirements for Obtaining Credit, Grading, Weight if appl.

	Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
Astronomy & Astrophysics	L	o	4	6	W	180	g	1.0
Astronomy & Astrophysics Exercises	E	o	2	3				

Transfer	BSc in Physics, MSc in Astro and Particle Physics
Prerequisites	Basic physical and mathematical knowledge is recommended.
Responsible	Andrea Santangelo, Beate Stelzer

<table>
<tr><td>Module Code:
APP102</td><td colspan="4">Module Title:
Particle Physics</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="8">9</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
270 h</td><td colspan="3">Time in Class:
90 h / 6 SWS</td><td colspan="4">Self-Study:
180 h</td></tr>
<tr><td>Duration</td><td colspan="8">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="8">Summer semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="8">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="8">Lecture with exercises</td></tr>
<tr><td>Content</td><td colspan="8">The module deals with the fundamentals of particle physics to be known by all students. This includes experimental as well as theoretical aspects.</td></tr>
<tr><td>Objectives</td><td colspan="8">The students will obtain knowledge of the basic principles of particle physics. They have acquired an understanding about the fundamental constituents of matter, energy and their interactions in the universe. The students will solve a series of exercises and apply the methods presented in the lecture to deepen their understanding.</td></tr>
<tr><td rowspan="3">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Particle Physics</td><td>L</td><td>o</td><td>4</td><td>6</td><td rowspan="2">W</td><td rowspan="2">180</td><td rowspan="2">g</td><td rowspan="2">1.0</td></tr>
<tr><td>Particle Physics Exercises</td><td>6</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="8">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="8">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="8">Josef Jochum, Werner Vogelsang</td></tr>
</table>

Module Code: APP103	**Module Title:** Laboratory Work								**Type of Module:** obligatory	
CP (ECTS Credits)	6									
Workload - Time in Class - Self-Study	Total Workload: 180 h			Time in Class: 60 h / 4 SWS					Self-Study: 120 h	
Duration	1 semester									
Frequency	Each term in the lecture term break									
Language of Instruction	English									
Forms of Teaching and Learning	Practical course: conducting experiments, evaluation of data measurements, conducting of protocol, which is a formative exam.									
Content	The module introduces the students to modern laboratory work in the field of physics and astrophysics. This includes data acquisition and handling, detailed error analysis, and writing a report about the obtained results.									
Objectives	Through the laboratory work the students will obtain a hands-on expertise in performing and analyzing actual physical and astrophysical experiments. They will be able to prepare a meaningful and concise scientific report of their findings.									
Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade	
	Advanced Labwork in Astrophysics	P	o	4	6	fE		ng		
Transfer	BSc in Physics, MSc Astro and Particle Physics.									
Prerequisites	The module requires APP101 or APP102 or APP105. Basic physical and mathematical knowledge is recommended.									
Responsible	Sebastian Diebold									

<table>
<tr><td>Module Code:
APP104</td><td colspan="8">Module Title:
Modern Topics in Astro and Particle Physics</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="12">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td colspan="4">Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="12">1 or 2 semesters</td></tr>
<tr><td>Frequency</td><td colspan="12">Every term. A seminar is offered each semester. The lectures are distributed over two semesters, the student can start at any time. The student has to select one of the seminars below and one lecture from the APP2XX elective modules.</td></tr>
<tr><td>Language of Instruction</td><td colspan="12">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="12">Seminar and lecture</td></tr>
<tr><td>Content</td><td colspan="12">The module introduces the students to modern topics in the field of astro and particle physics.</td></tr>
<tr><td>Objectives</td><td colspan="12">The students are familiar with different theoretical approaches in astro and particle physics. They are able to analyze and contextualize research in the field and are able to critically evaluate positions in literature research, and to discuss and present them in an appropriate and accessible fashion. The accompanying lecture will deepen the knowledge in a specific research field within astro and particle physics.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Modern Topics in Astronomy and Astrophysics</td><td>S</td><td>e</td><td>2</td><td>3</td><td>fE</td><td></td><td>ng</td><td></td></tr>
<tr><td></td><td>Astro and Particle Physics (Kepler Seminar)</td><td>S</td><td>e</td><td>2</td><td>3</td><td>fE</td><td></td><td>ng</td><td></td></tr>
<tr><td></td><td>Lecture from APP2XX</td><td>L</td><td>o</td><td>2</td><td>3</td><td></td><td></td><td>ne</td><td></td></tr>
<tr><td>Transfer</td><td colspan="12">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="12">The module requires APP101 and APP102. Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="12">Head of examination committee</td></tr>
</table>

<table>
<tr><td>Module Code:
APP105</td><td colspan="4">Module Title:
Nuclear and Particle Physics</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="8">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
90 h / 6 SWS</td><td colspan="4">Self-Study:
90 h</td></tr>
<tr><td>Duration</td><td colspan="8">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="8">Winter semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="8">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="8">Lecture with exercises</td></tr>
<tr><td>Content</td><td colspan="8">Concept for subatomic investigations, basic quantities of the atomic nucleus and its building blocks, nucleon-nucleon interaction, structure of atomic nuclei (nuclear structure), nuclear reactions, radioactive decay, neutrinos and weak interaction, mesons and baryons, basic building blocks of matter and their interactions.</td></tr>
<tr><td>Objectives</td><td colspan="8">Students understand the experimental principles and their mathematical description in the field of nuclear and particle physics. Students know the prominent examples in this field and are able to solve selected examples with an appropriate degree of difficulty. They have acquired a clear idea of physical phenomena in the field and are able to communicate in a clear way about pnuclear and particle physics. Students are able to apply their acquired knowledge by independently working on physical problems in the field of nuclear and particle physics.</td></tr>
<tr><td rowspan="3">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Nuclear and Particle Physics</td><td>L</td><td>o</td><td>4</td><td>3</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">ne</td><td rowspan="2"></td></tr>
<tr><td>Nuclear and Particle Physics Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="8">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="8">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="8">Josef Jochum</td></tr>
</table>

<table>
<tr><td>Module Code:
APP201</td><td colspan="4">Module Title:
Theoretical Astrophysics</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="8">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="8">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="8">Winter semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="8">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="8">Lecture with exercises</td></tr>
<tr><td>Content</td><td colspan="8">The module deals with the fundamentals of theoretical research in astrophysics, and important applications. This includes: the equations of hydrodynamics, sound waves, shock waves, linearization, magnetohydrodynamics.</td></tr>
<tr><td>Objectives</td><td colspan="8">The students will obtain knowledge of important non-linear hydrodynamic processes. They will be able to solve the equations through linearization and make simple applications. The students will solve a series of exercises and apply the methods presented in the lecture to deepen their understanding.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Theoretical Astrophysics</td><td>L</td><td>o</td><td>2</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td></td><td>Theoretical Astrophysics Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="8">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="8">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="8">NN</td></tr>
</table>

Module Code: APP202	**Module Title:** Computational Methods in Physics and Astrophysics						**Type of Module:** elective			
CP (ECTS Credits)	6									
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS					Self-Study: 120 h			
Duration	1 semester									
Frequency	Winter or summer semester									
Language of Instruction	English									
Forms of Teaching and Learning	Lecture with exercises									
Content	The module deals with the fundamentals of numerical methods applicable to solving problems in Computational Astrophysics and Physics. This includes: Interpolation, integration, ordinary and partial differential equations, N-body problems, elliptic, heat and wave equations, or numerical hydrodynamics.									
Objectives	The students will obtain knowledge of important concepts in numerical analyses that occur in many physical and astrophysical applications. Through the lecture and accompanying exercises they will learn how to develop, implement and apply numerical algorithms using modern programming languages.									
Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade	
	Numerical Methods in Physics/Astrophysics	L	e	2	3	O	30	ne/g	1.0	
	Numerical Methods in Physics/Astrophysics Exercises	E	e	2	3					
	Computational Astrophysics	L	e	2	3	O	30	ne/g	1.0	
	Computational Astrophysics Exercises	E	e	2	3					
	Numerical Hydrodynamics	L	e	2	3	O	30	ne/g	1.0	
	Numerical Hydrodynamics Exercises	E	e	2	3					
Transfer	BSc in Physics, MSc Astro and Particle Physics.									
Prerequisites	Basic physical and mathematical knowledge is recommended. Programming experience is required.									
Responsible	Kostas Kokkotas									

Module Code: APP203	**Module Title:** Stellar Physics		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 or 2 semesters		
Frequency	Every semester. The 3 lectures are distributed over two semesters, the student can start at any semester. The student selects any two of these lectures.		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture		
Content	The module consists of three independent lectures which cover the basic principles of stellar physics. 1) Stellar structure and evolution: Interior structure equations and properties of stellar matter. 2) Stellar oscillations: Theory of self-excited stellar pulsations and stellar seismology. 3) Stellar atmospheres: Structure and radiation transfer equations as a basis of quantitative stellar spectroscopy.		
Objectives	The students will obtain knowledge of modern concepts and numerical techniques to describe processes in stars and the time evolution of stars. They will learn how theoretical modeling and observations are combined to advance our knowledge of stars and to uncover their role as engines that drive the chemical evolution of the Universe.		

Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
	Stellar Structure and Evolution	L	e	2	3	O	30	ne/g	1.0
	Stellar Oscillations	L	e	2	3				
	Stellar Atmospheres	L	e	2	3				
	Endpoints of Stellar Evolution: Supernovae, White Dwarfs, Neutron Stars, Black Holes	L	e	2	3				
	Neutron Stars	L	e	2	3				

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Basic astronomical, physical and mathematical knowledge is recommended.
Responsible	Andrea Santangelo

Module Code: APP204	**Module Title:** General Relativity		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 semester		
Frequency	Winter semester		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture with exercises		
Content	The module includes an introduction to the General Theory of Relativity. It will include a short introduction to tensor analysis, derivation, interpretation and solution of Einstein's equations, orbits in curved spacetimes, the theory and properties of black holes and elements of relativistic cosmology.		
Objectives	The students will obtain knowledge of the basics of the prevailing theory of gravity. They will be trained in tensor calculus and in relativistic mechanics. They will gain knowledge of the structure and dynamics of relativistic objects such as black holes. They will also obtain elementary knowledge of the neutron star's theory, gravitational waves and relativistic cosmology.		

Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
	Introduction to GR	L	e	2	3	W	60	ne/g	1.0
	Introduction to GR Exercises	E	e	2	3				
	Advanced Topics in GR	L	e	2	3	O	30	ne/g	1.0
	Relativistic Astrophysics	L	e	2	3	O	30	ne/g	1.0
	Black Hole Astrophysics	L	e	2	3			ne	
	Black Hole Physics	L	e	2	3			ne	
	Mathematical Relativity	L	e	2	3			ne	
	Mathematical Relativity Exercises	E	e	2	3				

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Basic physical and mathematical knowledge, electrodynamics and mechanics are recommended. For Mathematical Relativity (lecture from the department of Mathematics), Geometry in Physics/Differential Geometry is required.
Responsible	Kostas Kokkotas

Module Code: APP205	**Module Title:** Relativistic Astrophysics		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 semester		
Frequency	Summer semester		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture with exercises, Seminar		
Content	The module includes two parallel series of lectures which can be selected in- dependently. The first sub-module (Gravitational Waves & Neutron Stars) will include the theory of gravitational waves and their applications in astrophysics and cosmology. In the same sub-module a series of lectures on neutron star physics and astrophysics will be offered. The second sub-module (Theoretical and Experimental Tests of Gravity) will include an introduction to post-Newtonian and perturbation approaches to general relativity. This knowledge will be used to study the basic experiments in gravitational physics and the potential extensions of the theory (alternative theories of gravity).		
Objectives	In the first sub-course (Gravitational Waves & Neutron Stars), the students will be trained in combining observational data with theory. The recent discovery of gravitational waves opened a new window into the universe and together with X- and gamma ray observation will provide information for the densest objects in the universe. In parallel, they will get training in the physics, dynamics and astrophysics of the most complicated material objects in the universe, the neutron stars. In the second sub-course (Theoretical and Experimental Tests of Gravity), the students will obtain knowledge of the post-Newtonian and perturbative approximations to gravity, they will learn also the potential alternative's to Einstein's theory and the experiments designed to validate them. The theoretical skills that they will acquire may be used in modern space technology and design.		

Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
	Introduction to GR	L	e	2	3	O/W	30	ne/g	1.0
	Introduction to GR Exercises	E	e	2	3				
	Relativistic Astrophysics	L	e	2	3	O/W	30	ne/g	1.0
	Advanced Topics in GR	L	e	2	3			ne	
	Black Hole Astrophysics	L	e	2	3			ne	
	Black Hole Physics	L	e	2	3			ne	

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Knowledge of electrodynamics, mechanics and general relativity is recommended.
Responsible	Kostas Kokkotas

Module Code: APP206	**Module Title:** Star and Planet Formation, Exoplanets		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 or 2 semesters		
Frequency	The individual lectures will be offered on a regular basis, they can be distributed over two semesters, the student can start at any semester. The student selects any two of these courses.		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture		
Content	The module consists of independent lectures which cover the observational aspects of extrasolar planets and theories about the formation of stars and their planetary systems in general, including our Solar System. It consists of the following lectures: 1) (In)habitable Worlds. 2) Architecture of Exoplanet Systems. 3) Star Formation.		
Objectives	The students obtain knowledge about the observational techniques required to detect extrasolar planets, and learn about the present status of the architecture and physical nature of the observed planets. They will learn about our current view on the formation of stars and planets both from an observational and theoretical standpoint. This includes modern concepts and theoretical techniques in order to understand the formation of planets in our Solar System and in extrasolar planetary systems.		

Requirements for Obtaining Credit, Grading, Weight if appl.

	Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
(In)habitable Worlds	L	e	2	3	O	30	ne/g	1.0
Architecture of Exoplanet Systems	L	e	2	3				
Star Formation	L	e	2	3				

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Basic astronomical, physical and mathematical knowledge is recommended.
Responsible	Beate Stelzer

Module Code: APP211	**Module Title:** Neutrinophysics		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 semester		
Frequency	Winter semester		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture with exercises		
Content	The module deals with the properties and the role of neutrinos. The experimental techniques to study neutrinos as well as the basic theoretical concepts are presented and discussed. This includes the basic particle properties: mass and spin, neutrino flavors, neutrino oscillations, Majorana- and Dirac-type neutrinos, See-Saw mechanism, and the role of neutrinos in cosmology.		
Objectives	The students will obtain knowledge on the properties of neutrinos and on their role in particle physics and in cosmology. The students will learn about the experimental techniques to study neutrinos and about the theoretical concepts to understand the fundamental role of neutrinos. With neutrinos as an example, they will gain an understanding on the connection between particle properties and the structure of the universe.		

Requirements for Obtaining Credit, Grading, Weight if appl.

	Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
Neutrinophysics	L	o	2	3	O	30	ne/g	1.0
Neutrinophysics Exercises	E	o	2	3				

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Basic knowledge in particle physics and in quantum mechanics is recommended.
Responsible	Tobias Lachenmaier

Module Code: APP212	**Module Title:** High Energy Astrophysics		**Type of Module:** elective
CP (ECTS Credits)	6		
Workload - Time in Class - Self-Study	Total Workload: 180 h	Time in Class: 60 h / 4 SWS	Self-Study: 120 h
Duration	1 semester		
Frequency	Winter semester		
Language of Instruction	English		
Forms of Teaching and Learning	Lecture with exercises		
Content	The module deals with the physics processes of the high energy universe, from X-rays to Ultra High Energies. It includes a review of the basic concepts of radiation interaction and transport; all major radiative processes, from bremssstrahlung to synchrotron radiation and Compton effect; particle acceleration in the non-thermal universe; production of cosmic neutrinos and cosmic rays. It also deals with the peculiar astro- physical environments in which high energy radiation is formed such as ionized plasmas, accretion disks, jets and shocks.		
Objectives	The students will obtain knowledge on the physics of the high energy processes, on the relativistic approach to astrophysical processes, on the mechanisms of the non thermal Universe. They will learn how to describe and understand astrophysical situations in which high energy radiation and particles are produced. The students will solve a series of exercises and apply the methods presented in the lectures to deepen their understanding, and to treat new astrophysical problems with the same formalism.		

Requirements for Obtaining Credit, Grading, Weight if appl.

	Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade
High Energy Astrophysics	L	e	2	3	O	30	ne/g	1.0
High Energy Astrophysics Exercises	E	e	2	3				
Endpoints of Stellar Evolution: Supernovae, White Dwarfs, Neutron Stars, Black Holes	L	e	2	3	O	30	ne/g	1.0
Observational X-ray Astronomy	L	e	2	3				

Transfer	BSc in Physics, MSc Astro and Particle Physics.
Prerequisites	Knowledge of physics and mathematics at the level normally obtained at the end of the 4th semester of undergraduate studies in physics, mathematics, or engineering is recommended.
Responsible	Andrea Santangelo

<table>
<tr><td colspan="1">Module Code:
APP213</td><td colspan="5">Module Title:
Cosmology</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Summer semester</td></tr>
<tr><td>Language of In-struction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Lecture with exercises</td></tr>
<tr><td>Content</td><td colspan="9">The module deals with the structure and the evolution of the universe. This includes the basic concepts and equations of cosmology, different types of the universe, the evolution of the universe, the connection between particle physics and cosmology, observational cosmology and structure formation.</td></tr>
<tr><td>Objectives</td><td colspan="9">The students will obtain knowledge on the mathematical description of the universe and learn about modern observational techniques of precision cosmology. They will learn how to calculate the influence of different types of matter on the evolution of the Universe. The students will solve a series of exercises and apply the methods presented in the lecture to deepen their understanding.</td></tr>
<tr><td rowspan="3">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evalua-tion</td><td>Calculation of Module Grade</td></tr>
<tr><td>Cosmology</td><td>L</td><td>o</td><td>2</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td>Cosmology Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="9">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="9">Josef Jochum, Andrea Santangelo</td></tr>
</table>

Module Code: APP214	**Module Title:** Extragalactic Astrophysics and Structure Formation								**Type of Module:** elective			
CP (ECTS Credits)	6											
Workload - Time in Class - Self-Study	Total Workload: 180 h			Time in Class: 60 h / 4 SWS					Self-Study: 120 h			
Duration	1 semester											
Frequency	Summer semester											
Language of Instruction	English											
Forms of Teaching and Learning	Lecture with seminars											
Content	The module deals with the physics, the astrophysics, and the objects of the extragalactic universe. Starting from the Milky way, galaxies, active galactic nuclei, cluster of galaxies, gamma ray-bursts will be presented. In addition we will present the astrophysics of structures formation and the objects of the high-z universe. The cosmological implications of the observation of the extragalactic universe will be also discussed.											
Objectives	The students will obtain knowledge on the astrophysics and cosmology of the extragalactic universe. They will learn about modern observational techniques of extragalactic astronomy and will be able to define an observational program to investigate specific classes of extragalactic sources. The students will participate in a seminar to deepen their understanding of key topics of extragalactic astrophysics, while improving their communication capabilities in astrophysics, and science in general. The students will be also able to individually elaborate the cosmological implication of extragalactic astrophysics.											
Requirements for Obtaining Credit, Grading, Weight if appl.		Type of Course	Status	CH	CP	Type of Exam	Length of Exam	Type of Evaluation	Calculation of Module Grade			
	Extragalactic Astrophysics and Structure Formation	L	o	2	3	O	30	ne/g	1.0			
	High Energy Astrophysics	S	o	2	3							
Transfer	BSc in Physics, MSc Astro and Particle Physics.											
Prerequisites	Basic physical and mathematical knowledge is recommended.											
Responsible	Andrea Santangelo											

<table>
<tr><td colspan="2">Module Code:
APP215</td><td colspan="6">Module Title:
Space Physics and Astrophysics</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td colspan="2">CP
(ECTS Credits)</td><td colspan="10">6</td></tr>
<tr><td colspan="2">Workload
- Time in Class
- Self-Study</td><td colspan="2">Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td colspan="2">Duration</td><td colspan="10">1 semester</td></tr>
<tr><td colspan="2">Frequency</td><td colspan="10">Summer semester</td></tr>
<tr><td colspan="2">Language of Instruction</td><td colspan="10">English</td></tr>
<tr><td colspan="2">Forms of Teaching and Learning</td><td colspan="10">Lecture with seminars</td></tr>
<tr><td colspan="2">Content</td><td colspan="10">The module deals with physics and astrophysics at the core of space-based research. The scientific objectives of space-based research, from fundamental physics to astrophysics and Solar System exploration, will be presented and discussed. In addition, experimental techniques used in space science missions, and all related technologies (detectors, electronics), will be introduced and discussed. A relevant part of the course will also focus on the system components of a space missions, trying to answer the question: what are the key elements of a space mission?</td></tr>
<tr><td colspan="2">Objectives</td><td colspan="10">The students will obtain knowledge on the scientific, experimental, and technological aspects of space-based exploration. Within a seminar, organized by the students with the support of senior supervisors, key aspects of specific space-based investigations will be addressed and deepened. Students will confront in a creative way on the question: how can we design and operate a space mission? They will learn how to contextualize science exploration in space, from the definition of the science objectives, to the choices of technology and mission operations.</td></tr>
<tr><td colspan="2" rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td colspan="2"></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td colspan="2">Observational Techniques in Astrophysics</td><td>L</td><td>e</td><td>2</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td colspan="2"></td><td colspan="2">High Energy Astrophysics</td><td>S</td><td>e</td><td>2</td><td>3</td></tr>
<tr><td colspan="2">Transfer</td><td colspan="10">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td colspan="2">Prerequisites</td><td colspan="10">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td colspan="2">Responsible</td><td colspan="10">Andrea Santangelo</td></tr>
</table>

<table>
<tr><td>Module Code:
APP216</td><td colspan="4">Module Title:
Experimental Astroparticle Physics</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="8">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="8">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="8">Summer semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="8">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="8">Lecture with exercises</td></tr>
<tr><td>Content</td><td colspan="8">The module deals with fundamental methods in astroparticle physics and their application in recent experiments. This includes neutrino physics and neutrino astronomy, dark matter, cosmic rays, X-ray and gamma astronomy, and the link between particle physics and astronomy.</td></tr>
<tr><td>Objectives</td><td colspan="8">The students will obtain knowledge on the cosmological and astronomical observations of the largest structures in the universe and the cosmic microwave background and learn more about particle properties in the early universe. They will learn about the extension of the standard model of particle physics in the context of astrophysical processes as particle accelerators using the universe as a laboratory for elementary particles. The students will solve a series of exercises and apply the methods presented in the lecture to deepen their understanding.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Experimental Astroparticle Physics</td><td>L</td><td>o</td><td>2</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td></td><td>Experimental Astroparticle Physics Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="8">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="8">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="8">Tobias Lachenmaier</td></tr>
</table>

<table>
<tr><td>Module Code:
APP221</td><td colspan="5">Module Title:
Quantum Field Theory</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Winter semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Lecture and exercises</td></tr>
<tr><td>Content</td><td colspan="9">The module gives an introduction into relativistic quantum field theory, describing its foundations and applications. It addresses the quantization of free fields, symmetries, causality, interactions, perturbation theory and Feynman rules, renormalization, gauge fields.</td></tr>
<tr><td>Objectives</td><td colspan="9">Upon completion of the course, the students will be familiar with the concepts and essential techniques of quantum field theory. They will be able to derive and use the ingredients for basic and advanced quantum field theory computations.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Quantum Field Theory</td><td>L</td><td>o</td><td>4</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td></td><td>Quantum Field Theory Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="9">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9">Basic physical and mathematical knowledge is recommended.</td></tr>
<tr><td>Responsible</td><td colspan="9">Werner Vogelsang</td></tr>
</table>

<table>
<tr><td>Module Code:
APP222</td><td colspan="4">Module Title:
Advanced Quantum Field Theory</td><td colspan="4">Type of Module:
elective</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="8">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
270 h</td><td colspan="3">Time in Class:
90 h / 6 SWS</td><td colspan="4">Self-Study:
180 h</td></tr>
<tr><td>Duration</td><td colspan="8">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="8">Every 2nd year</td></tr>
<tr><td>Language of Instruction</td><td colspan="8">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="8">Lecture and exercises</td></tr>
<tr><td>Content</td><td colspan="8">One-loop renormalization of quantum electrodynamics, non-Abelian gauge theories, standard model of particle physics.</td></tr>
<tr><td>Objectives</td><td colspan="8">Applications of quantum field theory in particle physics, perturbation-theoretical calculation of scattering processes.</td></tr>
<tr><td rowspan="3">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Advanced Quantum Field Theory</td><td>L</td><td>o</td><td>4</td><td>3</td><td rowspan="2">O</td><td rowspan="2">30</td><td rowspan="2">ne/g</td><td rowspan="2">1.0</td></tr>
<tr><td>Advanced Quantum Field Theory Exercises</td><td>E</td><td>o</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="8">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="8">The module requires APP221.</td></tr>
<tr><td>Responsible</td><td colspan="8">Werner Vogelsang</td></tr>
</table>

<table>
<tr><td>Module Code:
APP301</td><td colspan="5">Module Title:
Neighbouring Field</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">6</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
180 h</td><td colspan="4">Time in Class:
60 h / 4 SWS</td><td colspan="4">Self-Study:
120 h</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Each semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Lecture, possibly with exercises</td></tr>
<tr><td>Content</td><td colspan="9">The module needs to be taken from a neighbouring field, e.g., advanced courses from mathematics or other fields of physics that are not covered by the modules of this Master Programme. Examples from mathematics are: Algebraic Topology, Numerics of instationary Differential Equations or any other courses.</td></tr>
<tr><td>Objectives</td><td colspan="9">The students will acquire knowledge, methods and skills in related scientific areas. They are able to cooperate with other disciplines and find joint solutions, and to apply scientific expertise from other fields to Astro and Particle physics.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Lecture</td><td>L</td><td>e</td><td>2/4</td><td>3/6</td><td rowspan="2">fE/
W/
O</td><td rowspan="2">30</td><td rowspan="2">ne/n
g/g</td><td rowspan="2">1.0</td></tr>
<tr><td></td><td>Exercise</td><td>E</td><td>e</td><td>2</td><td>3</td></tr>
<tr><td>Transfer</td><td colspan="9">BSc in Physics, MSc Astro and Particle Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9"></td></tr>
<tr><td>Responsible</td><td colspan="9">Head of examination committee</td></tr>
</table>

<table>
<tr><td>Module Code:
APP401</td><td colspan="5">Module Title:
Scientific Specialisation in Thesis Topic</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">12</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
360 h</td><td colspan="4">Contact time:
variable, depending on the activity</td><td colspan="4">Self-Study:
variable, depending on the activity</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Every semester, the student must apply to start this module[1].</td></tr>
<tr><td>Language of Instruction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Advising the students to perform independent scientific research.</td></tr>
<tr><td>Content</td><td colspan="9">The module serves to define a specific scientific project in theoretical or experimental astro and particle physics. To prepare the Master Thesis the student will specialize in a research group of the Kepler Center in which she/he will prepare the thesis.</td></tr>
<tr><td>Objectives</td><td colspan="9">The students are able to formulate independently an own research project and situate it within current scholarly debates. They are capable of developing own solution methods and present them in an appropriate manner. They can react appropriately to the feedback of peers and faculty, and they are also able to understand and provide feedback on other students' projects.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Project related work</td><td>PR</td><td>o</td><td>v.</td><td>12</td><td></td><td></td><td>ne</td><td></td></tr>
<tr><td>Transfer</td><td colspan="9">The module prepares for the research in the subject of the Master Thesis. Can be used for the MSc in Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9">Completion of required modules APP101, APP102, APP103, APP105, and 18 ETCS from elective part APP201-APP222.</td></tr>
<tr><td>Responsible</td><td colspan="9">Supervisor of Master Thesis, head of examination committee.</td></tr>
</table>

[1] see https://uni-tuebingen.de/fakultaeten/mathematisch-naturwissenschaftliche-fakultaet/fachbereiche/physik/studium/studiengaenge/msc-astro-and-particle-physics/#c1284816

<table>
<tr><td>Module Code:
APP402</td><td colspan="5">Module Title:
Methods and Project Planning</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">12</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
360 h</td><td colspan="4">Contact time:
variable, depending on the activity</td><td colspan="4">Self-Study:
variable, depending on the activity</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Every semester, together with APP401.</td></tr>
<tr><td>Language of Instruction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Advising the student to scientific methods and project planning.</td></tr>
<tr><td>Content</td><td colspan="9">The module serves to teach the student methods of project management. The formulation, presentation and discussion of the project plan for the own research project will be done together with the supervisor. The project will be done in the research group in which the Master Thesis will be prepared. At the beginning of the module the supervisor will present the topic of the thesis.</td></tr>
<tr><td>Objectives</td><td colspan="9">The students are able to prepare independently (albeit under the supervision of an adviser) a larger research project and to present it in an appropriate fashion. They critically evaluate secondary sources and situate their project within current scholarly discourses. They are able to demonstrate that they have acquired general knowledge and can critically discuss special topics of their choice against this background.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Project related work</td><td>PR</td><td>o</td><td>v.</td><td>12</td><td></td><td></td><td>ne</td><td></td></tr>
<tr><td>Transfer</td><td colspan="9">The module prepares for the research in the subject of the Master Thesis. Can be used for the MSc in Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9">Completion of required modules APP101, APP102, APP103, APP105, and 18 ETCS from elective part APP201-APP222.</td></tr>
<tr><td>Responsible</td><td colspan="9">Supervisor of Master Thesis, head of examination committee.</td></tr>
</table>

<table>
<tr><td>Module Code:
APP403</td><td colspan="5">Module Title:
Master Thesis</td><td colspan="4">Type of Module:
obligatory</td></tr>
<tr><td>CP
(ECTS Credits)</td><td colspan="9">30</td></tr>
<tr><td>Workload
- Time in Class
- Self-Study</td><td>Total Workload:
900 h</td><td colspan="4">Contact time:
variable, depending on the activity</td><td colspan="4">Self-Study:
variable, depending on the activity</td></tr>
<tr><td>Duration</td><td colspan="9">1 semester</td></tr>
<tr><td>Frequency</td><td colspan="9">Every semester</td></tr>
<tr><td>Language of Instruction</td><td colspan="9">English</td></tr>
<tr><td>Forms of Teaching and Learning</td><td colspan="9">Independent research project under supervision (100%).</td></tr>
<tr><td>Content</td><td colspan="9">Scientific research, method developments, and/or laboratory tasks, preparation of a scientific essay.</td></tr>
<tr><td>Objectives</td><td colspan="9">After successful completion of the Master Thesis, students have acquired profound skills in state-of-the art methods in astro and particle physics. They are acquainted with the current scientific questions and recent publications in their research field. They are trained in compiling and analyzing scientific data and writing a scientific report. In addition to scientific expertise, students will acquire soft skills, such as time and project management, working in international, interdisciplinary teams, English communication and writing skills, and rules of responsible conduct of research. Overall, with successful completion of the Master Thesis, students proof their scientific competence and demonstrate that they are well prepared to tackle demanding research projects such as, for example, a doctoral thesis.</td></tr>
<tr><td rowspan="2">Requirements for Obtaining Credit, Grading, Weight if appl.</td><td></td><td>Type of Course</td><td>Status</td><td>CH</td><td>CP</td><td>Type of Exam</td><td>Length of Exam</td><td>Type of Evaluation</td><td>Calculation of Module Grade</td></tr>
<tr><td>Module Component</td><td>MT</td><td>o</td><td>v.</td><td>27</td><td>MT</td><td rowspan="2"></td><td rowspan="2">g</td><td rowspan="2">1.0</td></tr>
<tr><td></td><td>Defence of thesis</td><td>C</td><td>o</td><td></td><td>3</td><td>O</td></tr>
<tr><td>Transfer</td><td colspan="9">The module is the final one of the Master programme. Can be used for the MSc in Physics.</td></tr>
<tr><td>Prerequisites</td><td colspan="9">Completion of required modules APP101, APP102, APP103, APP105, and 18 ETCS from elective part APP201-APP222.</td></tr>
<tr><td>Responsible</td><td colspan="9">Supervisor of Master Thesis, head of examination committee.</td></tr>
</table>