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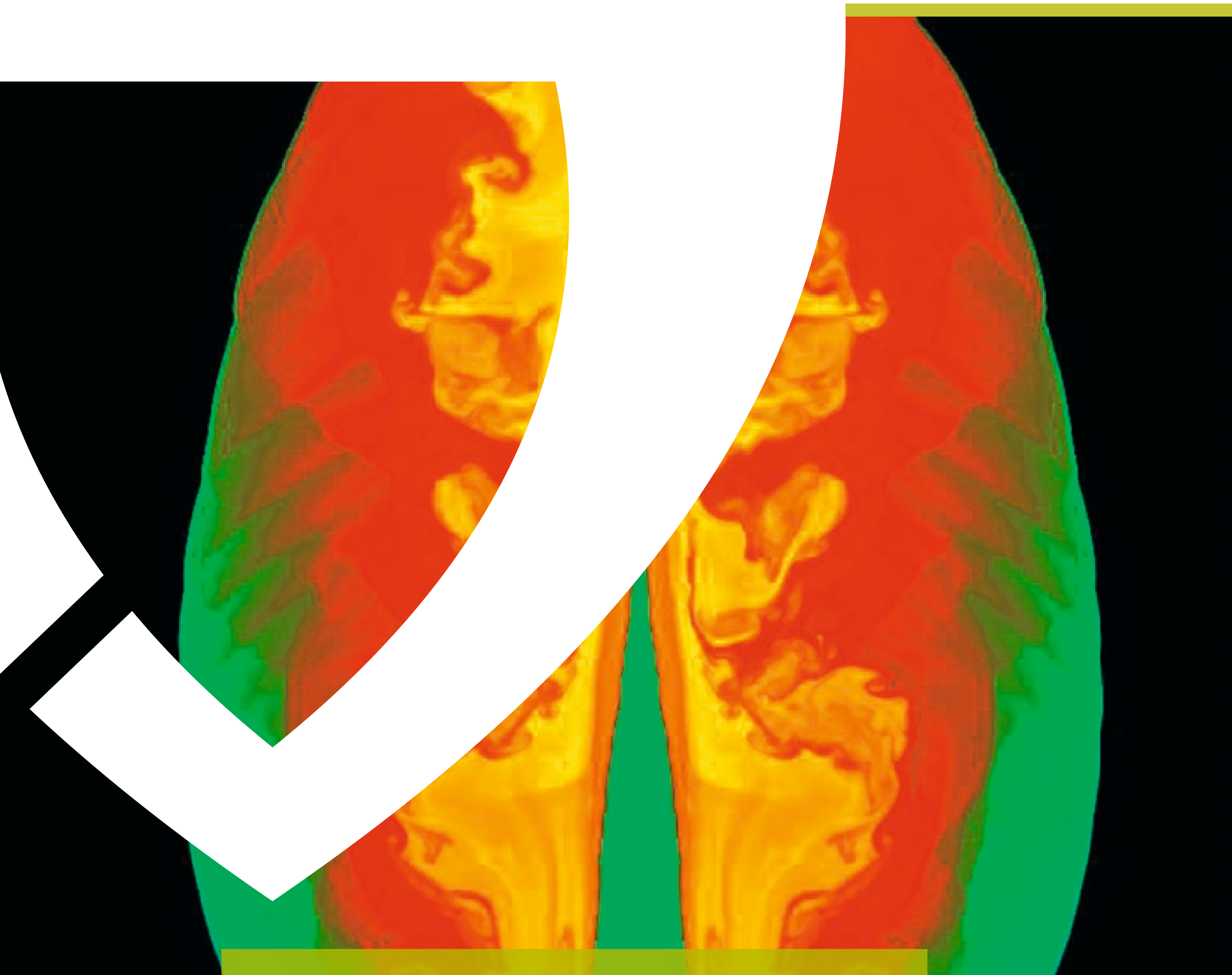


School of Engineering and Science

Astroparticle Physics

Graduate Program

Contents

1 Concept

1.1 Astroparticle Physics

Astroparticle Physics is one of the prime foci of modern science and addresses some of the most fundamental questions in nature, such as:

- What is the nature of Dark Matter and Dark Energy?
- Where and how do the chemical elements form?
- What powers large cosmic explosions?
- Where do the highest energy cosmic rays come from?

Since astronomical observations are becoming more and more accurate and particle physics laboratories on Earth are meeting their limitations, fundamental knowledge about the constituents of matter will come increasingly from outer space. One of the prime examples for this development is the discovery of neutrino masses from measurements of solar neutrinos.
In addition to astronomical observations, near-Earth space serves as a laboratory where fundamental plasma processes and energetic particles can be observed in-situ using magnetospheric and heliospheric spacecraft missions.

1.2 Scope of the Program

Cross-disciplinary education and research in astrophysics, solar physics, space plasma physics, magnetohydrodynamics, theoretical particle physics, quantum field theory, quantum gravity/string theory, and cosmology, plus computational aspects of these fields. The primary aim is to achieve excellence both in research and teaching associated with the program. Distinguishing points:

- Strong focus on research and independent scientific work - starting in the first year
- Broad range of expertise and research interests, transdisciplinarity
- Substantial computational component
- Synergies with/supplemented by other existing programs at Jacobs University
- Associated graduate school (research training group, RTG) “Models of Gravity” (Bremen, Oldenburg; Bielefeld, Copenhagen, Hannover)
- Internationality, instruction in English
- Preliminary exam - to ensure a uniform and sufficient level of preparation

Faculty involved in the Astroparticle Physics Program at Jacobs University conduct active research in the fields of high-energy astrophysics, particle acceleration in the universe, cosmic explosions, theoretical and numerical cosmology, nucleosynthesis, solar physics, theoretical particle physics, and classical and quantum gravity.

1.3 Target Group

The program is intended for international students with an undergraduate education in physics or a closely related subject. The student is interested to do his doctorate studies in one of the fastest developing fields of current research and is looking for a broad and truly transdisciplinary education in the fundamental subdisciplines. A bachelor or equivalent degree is required to enter the graduate program. A strong analytical and quantitative background and an excellent scholastic record are expected. It is also possible to enter the program with an MSc or equivalent degree in a relevant field.

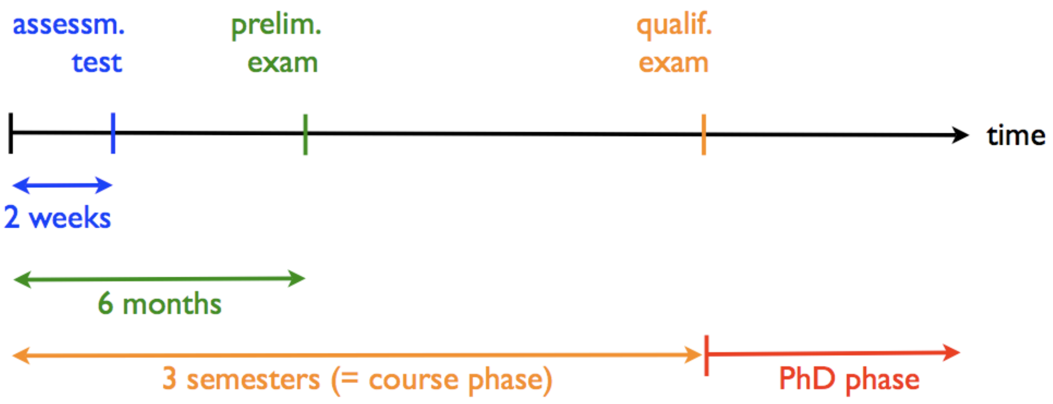
2 Structure of the Program

2.1 General Information

The program in Astroparticle Physics follows the general structure of graduate programs at Jacobs University. It is a research oriented integrated PhD program. It is, however, also possible to graduate with an MSc after four semesters of study.

The course phase of the program lasts three semesters. It begins with an *assessment test* to be conducted within the first two weeks of the first semester of study. The results are used to determine an appropriate individual course plan. Within the first six months, a *preliminary exam* is supposed to test the background knowledge in physics required for graduate study. After passing the *qualifying exam* at the end of the course phase, students can directly continue with their PhD studies. An MSc thesis is not required.

Students entering the PhD track directly (with an appropriate previous degree), need to pass a combined preliminary/qualifying exam within the first six months and register for independent research from the first semester.



2.2 Study Plan

For a graduate student entering with a bachelor (or equivalent) degree, the default study plan is as follows.

Semester 1:

- Core courses: 15 ECTS credits
- Supplementary courses: 10 ECTS credits
- Graduate Student Seminar: 5 ECTS credits

Assessment test within the first two weeks; preliminary exam within the first six months.

Semester 2:

- Core courses: 15 ECTS credits
- Supplementary courses: 5 ECTS credits
- Research methods / practical component: 5 ECTS credits
- Graduate Student Seminar: 5 ECTS credits

Semester 3:

- Core courses: 15 ECTS credits
- Graduate Student Seminar: 5 ECTS credits

- Independent Research: 10 ECTS credits
- Qualifying exam for graduate students wishing to pursue a PhD

Semester 4:

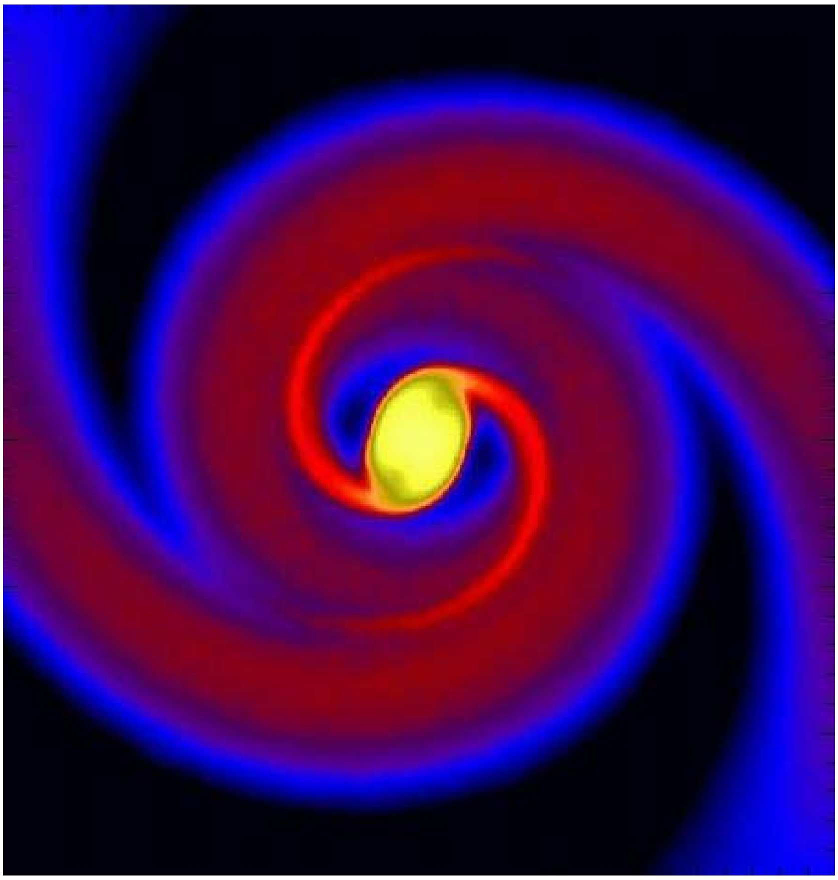
- MSc Thesis or PhD Research Proposal: 30 ECTS credits

It is possible to shift the number of lectures between the semesters. The total required ECTS credit points for course work are 60, balancing 60 ECTS credits for research and seminars.

Core courses are tailored to the requirements of the graduate program. See Section 3.1 for a list of core courses and detailed course descriptions. Please note that not all courses are offered each semester. ECTS credits per course are 5 or 7.5, depending on the course.

Supplementary courses can be courses from other graduate programs and suitable undergraduate courses, even language courses could be considered. The selection should be discussed with the Academic Advisor. The courses typically carry 5 ECTS credits.

Research methods / practical component will typically be a dedicated programming course but could also be an experimental or observational project, numerical work, etc.



3 Courses

3.1 Core Courses

210322 – High-Energy Astrophysics

Short Name: HighEnergyAstro
Instructors: S. Rosswog
Credit Points: Lecture, 7.5 ECTS
Semester: Spring

Course content This advanced course in astrophysics covers a broad range of topics from the field of high-energy astrophysics. This field has developed very rapidly in recent years owing to advances in radio, X-ray and gamma ray observations. We will discuss in detail the endpoints of stellar evolution and the formation of compact objects such as neutron stars and black holes. Topics on the stellar scale include gamma-ray bursts, supernovae, pulsars and X-ray binaries. On larger scales we will discuss active galactic nuclei, quasars and clusters of galaxies. The particlular emphasis of this course is on the underlying physics such as special relativistic dynamics, radiation processes and accretion. The course is aimed at students who major in Geosciences and Astrophysics as well as interested students from physics and mathematics. A good knowledge of physics and mathematics is required.

210323 – Modern Cosmology

Short Name: ModCosmology
Instructors: M. Camenzind
Credit Points: Lecture, 5.0 ECTS
Semester: Fall

Course content Cosmology refers to the study of the Universe in its totality as it can be observed by now, and by extension, the evolution of life in it. In recent times, physics and astrophysics have played a central role in shaping the understanding of the Universe through scientific observations and experiments. For most of human history, Cosmology was branch of metaphysics and religion. Cosmology as a science originated with the Copernican principle, which implies that celestial bodies obey identical physical laws to those on Earth, and Newtonian mechanics, which first allowed us to understand those laws. Even Einstein initially favoured a static Universe, before Edwin Hubble found evidence for the expansion of the Universe in 1929. In these lecture, I review the standard hot Big Bang Cosmology, emphasizing its successes, its shortcoming, and its major challenges, developing a detailed understanding of the formation of structure in the Universe and identifying the constituents of the ubiquitous Dark Matter and the nature of Dark Energy. I then discuss the success and failures of inflationary Cosmology, particularly emphasizing the quantum origin of metric (density and gravity-wave) perturbations.

210331 – Solar Physics

Short Name: SolarPhys
Instructors: G. Haerendel
Credit Points: Lecture, 5.0 ECTS
Semester: Fall

Course content This course discusses selected aspects of the physics of the Sun. The first half deals with the internal structure of the Sun, the nuclear energy source, the energy transport by radiation and convection, and finally leads to an understanding of the solar spectrum and the photosphere. Solar oscillations and the tools for solar observations conclude this part. The second half of the course deals with the solar magnetism, starting with the photospheric activity, the internal dynamo and then turns to the outer atmosphere, the chromosphere and corona, with their various magnetic structures, the heating problem and the explosive events like solar flares and coronal mass ejections. Specific particle acceleration processes and radio emissions will be discussed. Finally, the origin of the solar wind is being addressed.

210332 – Space Plasma Physics

Short Name: SpacePhys
Instructors: J. Vogt
Credit Points: Lecture, 5.0 ECTS
Semester: Spring

Course content The Earth's environment in space is controlled by the interaction of the magnetised solar wind plasma with the geomagnetic field generated in the Earth's core. A geomagnetic cavity is formed in the interplanetary medium (namely, the magnetosphere) where a rich variety of dynamic phenomena can be observed. The dynamics of the magnetosphere gives rise to beautiful auroral displays but is also associated with failures of communication satellites. Furthermore, near-Earth space is a huge natural plasma laboratory accessible by spacecraft which helps to develop a consistent picture of fundamental plasma physical processes. This course addresses both space plasma physics theory and observations. Spacecraft measurements and ground-based observations are presented to introduce prominent plasma phenomena in near-Earth space. The theoretical models discussed in class include the single-particle picture, single-fluid and multi-fluid magnetohydrodynamics (MHD), and plasma kinetic theory. Emphasis will be on the plasma fluid concept that allows to study flows, waves, and discontinuities in the magnetosphere and in the solar wind.

210392 – Earth and Planetary Physics

Short Name: EarthPlanetPhys
Instructors: J. Vogt
Credit Points: Lecture, 5.0 ECTS
Semester: Spring

Course content The course addresses global aspects of geophysics, and also the physics of other planets. Seismology is a most powerful approach to study the Earth's interior. Geophysical potential fields such as the Earth's gravity field and the geomagnetic field can be measured from the ground and also from spacecraft, and can be modeled using the same theoretical approach. Global aspects of the Earth's heat flow are addressed in the context of geodynamics and plate tectonics. Our understanding of global Earth processes guides us in the studies of other planets and their satellites. Of particular interest are the Earth's Moon and the planet Mars as prime targets of ongoing and future exploration programs, but also the gas giants Jupiter and Saturn with their systems of satellites.

210461 – The Physics of Compact Objects

Short Name: PhysCompObj
Instructors: S. Rosswog
Credit Points: Lecture, 5.0 ECTS
Semester:

Course content It is the ultimate fate of every star ti end up as compact stellar object, depending on the initial stellar mass as either a white dwarf, a neutron star or a black hole. These objects are governed by a wealth of interesting physical processes. They involve strong, sometimes relativistic gravity, matter in a highly degenerate state, and - in the case of neutron stars - beyond nuclear density. As accreting sources they are prime targets of space-based X-ray observatories. This course will give a systematic introduction to the physics of these objects.

210462 – Space Physics Data Analysis Techniques

Short Name: 210462
Instructors: J. Vogt
Credit Points: Lecture, 5.0 ECTS
Semester:

Course content Since the beginning of space age in the late 1950's, satellite measurements have significantly advanced our understanding of the Earth's magnetosphere and the solar wind. The data from in-situ observations typically come in the form of time series. Single-spacecraft missions suffer from spatiotemporal ambiguity that multi-spacecraft missions such as Cluster (ESA) ot Themis (NASA) can partially resolve. This course introduces important approaches to time series analysis, we discuss the minimum variance of principle and its application in boundary analysis and gradient estimation. In multi-point data analysis, reciprocal vectors offer a convenient means to address diverse analysis tasks. The techniques are applied to data from the Cluster mission through the Cluster Active Archive. The course will be offered in the form of a reading course combined with computer assignments.

210472 – Physics of the Interstellar Medium

Short Name: ISM
Instructors: M. Brüggen, E. Rödiger
Credit Points: Lecture, 5.0 ECTS
Semester: Spring

Course content The space between the stars inside a galaxy is filled with gas of various conditions, ranging from cold molecular gas to hot and ionised plasma. This interstellar medium is coupled tightly to the stars: on the one hand, new stars form out of the cold gas phases; on the other hand, radiation and mass loss heat the interstellar medium and enrich it with heavy elements. The characteristics of the ISM and the star formation activity of the host galaxy are governed by a number of physical processes: gravity, radiation, turbulence, chemical processes and magnetic fields. This course gives an introduction to the current theoretical and observational understanding of the interstellar medium. Topics include: current galactic structure, gas dynamics, shocks, gravitational collapse, star formation, supernovae remnants. The course is offered as a reading course.

200372 – Computational Fluid Dynamics

Short Name: CFD
Instructors: A. Khalili
Credit Points: Physics Specialization Course, 5 ECTS
Semester: Spring

Course content Computational fluid dynamics (CFD) has become one of the most sophisticated tools, beside the analytical and experimental methods, for solving problems in fluid dynamics, heat and mass transfer. This course will introduce the physical and mathematical foundations of CFD for incompressible viscous flows, and to provide students with a working knowledge of CFD. By the end of the course, the successful student will be able to develop, debug, and analyze a finite difference code that solves the Navier-Stokes equations. The course will start by an introduction to numerical methods and explain what is CFD. Next, basic equations of fluid mechanics are reviewed. The partial differential equations are, then classified. Finite difference methods are explained, and different solution techniques for systems of linear algebraic equations are explained. Finally, important issues such as the stability and convergence criteria are explained, when dealing with CFD.

200391 – Physics of the Early Universe

Short Name: PhysEarlyUniverse
Instructors: B. Hartmann
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content While particle physics deals with physics on the smallest scales, cosmology is mainly concerned with physics on the largest scales. To understand the structure we see in the universe today, it is vital to have knowledge about the early universe. Due to the extreme conditions in the early universe, especially the high energies, which (up to now) cannot be simulated in terrestrial accelerators, it is a very good testing ground for theories beyond the standard model such as Grand Unified Theories (GUTs) or even String Theory. In this sense, the early universe is the main ground to understand the interplay between cosmology and astrophysics on the one hand and particle physics on the other hand. In this lecture, we will start with a brief overview of what is known about the universe today. Topics include the cosmic microwave background, the large-scale structure of the universe as well as the abundance of different elements. In what follows, we will illustrate how these observations can be explained in the so-called ”Hot Big Bang” model of the universe. Topics here are nucleosynthesis, baryogenesis as well as phase transitions and the inflationary epoch.

200472 – General Relativity

Short Name: GenRel
Instructors: B. Hartmann
Credit Points: Lecture, 5.0 ECTS
Semester: Spring

Course content General Relativity describes Gravitation in terms of the curvature of space-time. While in Special Relativity, space-time is rigid, it becomes dynamical in General Relativity and interacts with matter/energy. The interaction between matter and space-time is governed by the famous Einstein equations. The first part of the course is concerned with the mathematical and geometrical aspects of General Relativity, while the second part will contain consequences of the theory such as black holes and cosmological models.

210431 – Foundations of Astroparticle Physics

Short Name: FoundationsAstroPhy
Instructors: M. Brüggen, S. Rosswog, P. Schupp, J. Vogt
Credit Points: 7.5 ECTS
Semester:

Course content Tailored to each student’s individual needs, this course comprises a set of modules in which the basics of mathematics, physics and astrophysics are refreshed. This course usually contains (advanced) undergraduate components.

3.2 Supplementary Courses

The following courses provide supplementary material for the main courses of the graduate program. Some of these courses may help to fill in gaps in the required background knowledge that is expected to arise due to differences in the educational background.

200201 – Analytical Mechanics

Short Name: AdvPhys A I
Instructors: P. Schupp
Credit Points: Lecture, 5 ECTS
Semester: Fall

Course content Classical mechanics provides the foundation for many fields of modern physics; it is indispensable for physics in general. Topics of the course include single particle dynamics, energy and potential, planetary orbits, systems of particles, statics, rigid body dynamics, analytical mechanics (variational principle, Lagrange's and Hamilton's equations), small oscillations, an introduction to relativistic mechanics, and a selection of more advanced topics. Mathematical concepts that we will encounter include vector calculus, ordinary and partial differential equations, linear algebra (vectors, tensors, eigenvalue problems) and elementary group theory.

200211 – Electrodynamics, Relativity

Short Name: AdvPhys B I
Instructors: B. Hartmann
Credit Points: Lecture, 5 ECTS
Semester: Fall

Course content The course provides an introduction to the classical theory of one of the four fundamental forces in nature: the electromagnetic force. Well understood and very apparent in everyday life, the electromagnetic field is described by the Maxwell equations. We will discuss these equations in detail, use it to describe diverse phenomena and show that Special Relativity is one of the fundamental ingredients to describe the electromagnetic field. Topics include: electromagnetic fields in free space, metals, dielectrics, wave guides, Laplace and Poisson equation, the response of solid state material to electromagnetic fields, electromagnetic radiation, dipole radiation, Green's function, multipoles. The relativistic formulation of electrodynamics includes an introduction to special relativity covering: Einstein's postulates, time dilation, length contraction, simultaneity, Lorentz transformation, relativistic effects and paradoxes.

200202 – Quantum Mechanics

Short Name: AdvPhys A II
Instructors: P. Schupp
Credit Points: Lecture, 5 ECTS
Semester: Spring

Course content Thorough introduction to quantum mechanics. The following topics are covered: Foundation and postulates of quantum mechanics, Schrödinger Equation; one-dimensional problems (harmonic oscillator; potential steps, barrier, and wells); uncertainty relation; angular momentum; central potential (hydrogen atom); operators, matrices, states (Dirac notation, representations); spin and addition of angular momentum; stationary approximation methods (time-independent perturbation theory, variational principle).

200302 – Elementary Particles and Fields

Short Name: ExpTheoPhys A II
Instructors: B. Hartmann
Credit Points: Lecture, 5 ECTS
Semester: Spring

Course content This course provides an introductory overview about theoretical and experimental aspects of elementary particle physics, quantum field theory and nuclear physics. The Standard Model of particle physics is introduced and experimental and phenomenological aspects of particle physics are discussed. Theoretical topics include gauge theories of the fundamental forces of nature, an introduction to quantum field theory and Feynman diagrams.

200331 – Computational Physics

Short Name: CompPhys
Instructors: U. Kleinekathöfer
Credit Points: Lecture, 5 ECTS
Semester:

Course content Computational physics discusses a number of practical, numerical solutions for typical problems in physics. While the very nature of physics is to express relationships between physical quantities in mathematical terms, an analytic solution of the resulting formulas is often not available. Instead, numerical solutions based on computer programs are required to obtain useful results for real-life physics problems. The first part introduces basic numerical techniques such as for integration, interpolation, root finding, function optimization, and solving differential equations which are important tools in any numerical approach not only in physics. In the second half of the course, modern applications like molecular dynamics and Monte-Carlo techniques are discussed, including analysis of data resulting from such approaches.
Since the course includes numerous examples and exercises for programming codes, some programming skills in Fortran or C are strongly recommended as prerequisites.

200371 – Fundamentals of Hydrodynamics

Short Name: Hydro
Instructors: A. Khalili
Credit Points: Physics Specialization Course, 5 ECTS
Semester: Fall

Course content The Fluid Dynamics course addresses fundamental equations, which govern many flow problems occurring in science and engineering. We start with the concept of continuum and Lagrangian versus Eulerian approach. Based on conservation laws of physics, we derive continuity, momentum and energy equations. As special cases of general flow equations, irrotational flows and hydrostatics will be considered. Further, hydrodynamic instability, turbulence, waves, rotation, geostrophic flows, and flow through porous medium will be treated as special topics. The course will be accompanied with performing experiments at IUB and Max-Planck Institute for Marine Microbiology in Bremen. All mathematical tools that are needed will be treated prior to lectures.

210202 – Astrophysical Processes

Short Name: AdvGeoAstroAII
Instructors: M. Brüggen
Credit Points: ESS program
Semester: Spring

Course content This course lays the physical groundwork for a basic understanding of astrophysical processes. Starting from the fundamental principles that govern the behaviour of matter and radiation, we will study the nature of stars and galaxies. The focus of this course lies in the application of basic physical laws to astronomical objects. This course will combine lectures and interactive example classes with a special emphasis on problem-solving.

3.3 Seminars and Independent Research

200441 – Graduate Student Seminar

Short Name:
Instructors: Graduate Students in Astroparticle Physics, Astroparticle Physics Faculty
Credit Points: Seminar, 5 ECTS, mandatory
Semester:

Course content Research Seminar/Journal Club organized by the graduate students. The students give talks about their own field of research and about interesting research papers. Students attending this course should also attend the talks in the Theory Seminar.

200411/200412 – Theory Seminar

Short Name: PhysTheoSem
Instructors:
Credit Points:
Semester: Fall/Spring

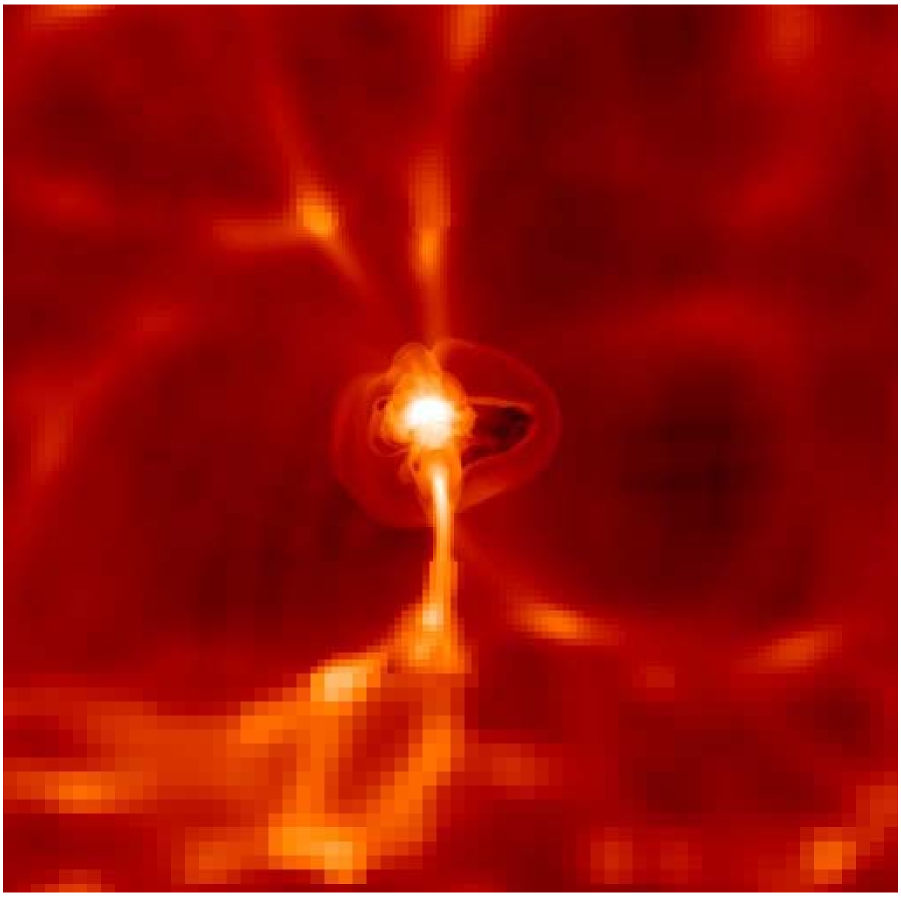
Course content Biweekly seminar, focus on high-quality external speakers.

210411 – Independent Research

Short Name: AstoPhysRes
Instructors: Astroparticle Physics Research
Credit Points: Research, 10 ECTS, mandatory
Semester:

Course content Within this course the students conduct small research projects. At the end of the course a brief report on the research topic needs to be compiled. For students planning to obtain a MSc degree, a more extended research project culminates in an MSc thesis in the last semester of study.

4 Research



4.1 Faculty

4.1.1 Core Faculty

- Prof. Dr. Marcus Brüggen
- PD Dr. Betti Hartmann, University Lecturer Physics
- Prof. Dr. Stephan Rosswog
- Prof. Dr. Peter Schupp
- Prof. Dr. Joachim Vogt

4.1.2 Extended Faculty, Associated Scientists

- Prof. Dr. Gerhard Haerendel
- Prof. Dr. Arzhang Khalili
- Dr. Elke Rödiger, Research Associate

4.2 Fields of Expertise and Research Interests

4.2.1 Faculty

Marcus Brüggen Expertise in astrophysics, solar physics, numerical and computational astrophysics. Research interests revolve around topical issues in computational and astrophysical fluid dynamics. Recent works dealt with the physics of the Intra-Cluster Medium, Radio Galaxies, Active Galactic Nuclei, Winds from Galaxies, Numerical Cosmology and Supernovae. Using state-of-the-art computational techniques and hardware, our group is involved in the most ambitious simulations of astrophysical phenomena. Further research interests lie in the field of solar and neutrino physics.

Betti Hartmann Expertise in classical field theory, non-abelian gauge theory, general relativity, computational physics. Recent research interests include gravitating solitons in space-times including a cosmological constant and/or in more than 4 space-time dimensions; soliton dynamics with applications to biophysical questions as e.g. polymers or fullerenes; quasi-exactly solvable quantum systems.

Stephan Rosswog Expertise in theoretical astrophysics and computational physics. Research interests mostly centered on the physics and astrophysics of compact stellar objects like white dwarfs, neutron stars and black holes. Related astrophysical questions are: What causes the cosmological explosions known as gamma-ray bursts? What is the gravitational wave signal of a collapsing neutron star binary? What happens in a tidal disruption of a neutron star by a black hole? What are the progenitors of type Ia supernova? In which event(s) do the heaviest elements form?

Peter Schupp Expertise in quantum field theory and gravity, mathematical physics, and non-commutative geometry. Current research includes projects on non-commutative quantum field theory and gravity, deformation quantization, non-commutative geometry, coherent states, and spin systems. The primary motivation for this research is the development of a microscopic description of space-time geometry including gravitational and quantum effects that is valid down to ultra-short distances. I am always interested in challenging problems in mathematical physics and have for instance worked on quantum spin systems, strongly correlated electrons, and coherent states. In the context of string theory I am particularly interested in the (non-commutative) geometry and physics of branes. PhD projects in the framework of the graduate program can be in any of the aforementioned fields and can more generally be related to contemporary problems of cosmology and astrophysics and fundamental physics.

Joachim Vogt Expertise in space plasma physics, magnetohydrodynamic (MHD) simulations and modeling, and data analysis in space physics. Ongoing research projects deal with paleomagnetospheric phenomena and the analysis of data from multi-spacecraft missions. MHD simulations and plasma theory are used to study paleomagnetospheric processes and to evaluate their effects on high-energetic particle trajectories of solar and cosmic origin. The project involves close collaboration with research groups using nuclear particle physics codes and atmospheric chemistry models to evaluate the effect of geomagnetic variations on the Earth's atmosphere. In the area of satellite data analysis I currently concentrate on the four-spacecraft mission Cluster-II and the forthcoming Chinese-European mission Double Star.

4.2.2 Associated Scientists

Gerhard Haerendel More than 30 years of experience in space research, including the function of P.I. of several international rocket and satellite projects such as PORCUPINE, Colored Bubbles, AMPTE, CRRES, FREJA, and EQUATOR-S. The sounding rocket work pioneered the application of the barium plasma cloud technique to various aspects of plasma and magnetospheric physics, culminating in the creation of artificial comets in 1984 and 1985. Interpretations of satellite data led to the discovery of dayside boundary layers, small-scale reconnection events, high-beta plasma blobs in the magnetosphere and the in-situ confirmation of reconnection. Theoretical work includes motion of plasma clouds, formation of ionospheric irregularities, equatorial spread-F, ambipolar diffusion, diffusion of trapped particles, wave-particle interactions, reconnection, boundary layers, auroral arcs, cometary interactions, origin of spicules, solar flares and gamma-ray production in neutron stars.

5 Facility and Resources

5.1 Computational Laboratory for Analysis, Modeling, and Visualization

The Computational Laboratory for Analysis, Modeling and Visualization (CLAMV) is the center for scientific computing at Jacobs University. This includes participation in scientific research projects as well as graduate teaching. CLAMV provides and maintains hardware and software facilities and gives support for running projects. In addition to the on-campus facilities CLAMV provides access to high-performance computing centers. CLAMV / Jacobs University cooperates with BremHLR (Competence Center of High Performance Computing Bremen) and HLRN (High Performance Computer North) and other centers for high-performance computing.

5.2 Graduate Program in Mathematical Sciences

In addition to interesting mathematics courses, one of the foci of the Mathematical Sciences Graduate Program could be of particular interest for Astroparticle graduate students: Mathematical Physics. Traditionally there has been a strong cross-fertilization between mathematics and physics. Mathematics provides the language and forms the foundation of modern physics. Physics has inspired many important developments in mathematics. More then ever this is true today. Graduate students who want to do research in modern theoretical physics need a strong mathematical background like it is provided in the graduate program in mathematical sciences. There are two main directions of specialization for graduate students interested in Mathematical Physics: Classical Mathematical Physics (rigorous approaches to problems from various fields of physics): Core courses are Real Analysis and Quantum Field Theory. Modern Mathematical Physics (development of models and theories of fundamental physics and study of their implications): Core courses are Quantum Field Theory, Differential Geometry and Lie Groups and Lie Algebras.

5.3 Graduate School (RTG) Models of Gravity

Research Training Group in collaboration involving gravity research groups at Jacobs University and the universities of Bremen, Oldenburg, Bielefeld, Copenhagen (NBI), Hannover with expertise ranging from string theory, over effective theories of gravity all the way to observations and applications. Starting date: April 2012; 30 PhD students and postdocs expeced.
The main theme of the RTG is the study of models of gravity which, e.g., emerge as effective theories in the low energy limit of string theory or other approaches to quantum gravity. Beside the purely theoretical study of properties of these generalized models we also intend to discuss issues related to Dark Matter, Dark Energy, and the Pioneer anomaly. The studies mainly consist of first finding analytically or numerically solutions of the generalized Einstein equations in four and higher dimensions under various conditions, and then characterizing the properties of these solutions, in particular, by studying the motion of test particles. The test particles may be classical point particles, particles with structure, or quantum fields. The obtained results will also be of importance for various experimental projects carried out at the participating institutes. The structure of the research program demonstrates the synergies obtainable from the complementary expertises of the participating groups. Four main features characterize this RTG: (i) An active and internationally well recognized research topic. (ii) The increase of the

already existing synergetic cooperation between the members. (iii) A unique offer of courses and a well balanced educational scheme. (iv) The enhancement of the role of women in this area of physics.

5.4 MAMOC Research Center

The MAMOC (Mathematics, Modeling, and Computing) Research Center hosts research at the interface between mathematics, theoretical natural sciences, modeling, and high-performance computing with applications in engineering and science. It is a place for research within and between these areas, and strives to contribute to the modeling of complex systems. The main goals of the center are to foster (a) fundamental research in mathematics and theoretical natural sciences, (b) modeling of complex systems in engineering and science, (c) development of computational methods, algorithmic design and scientific computing.