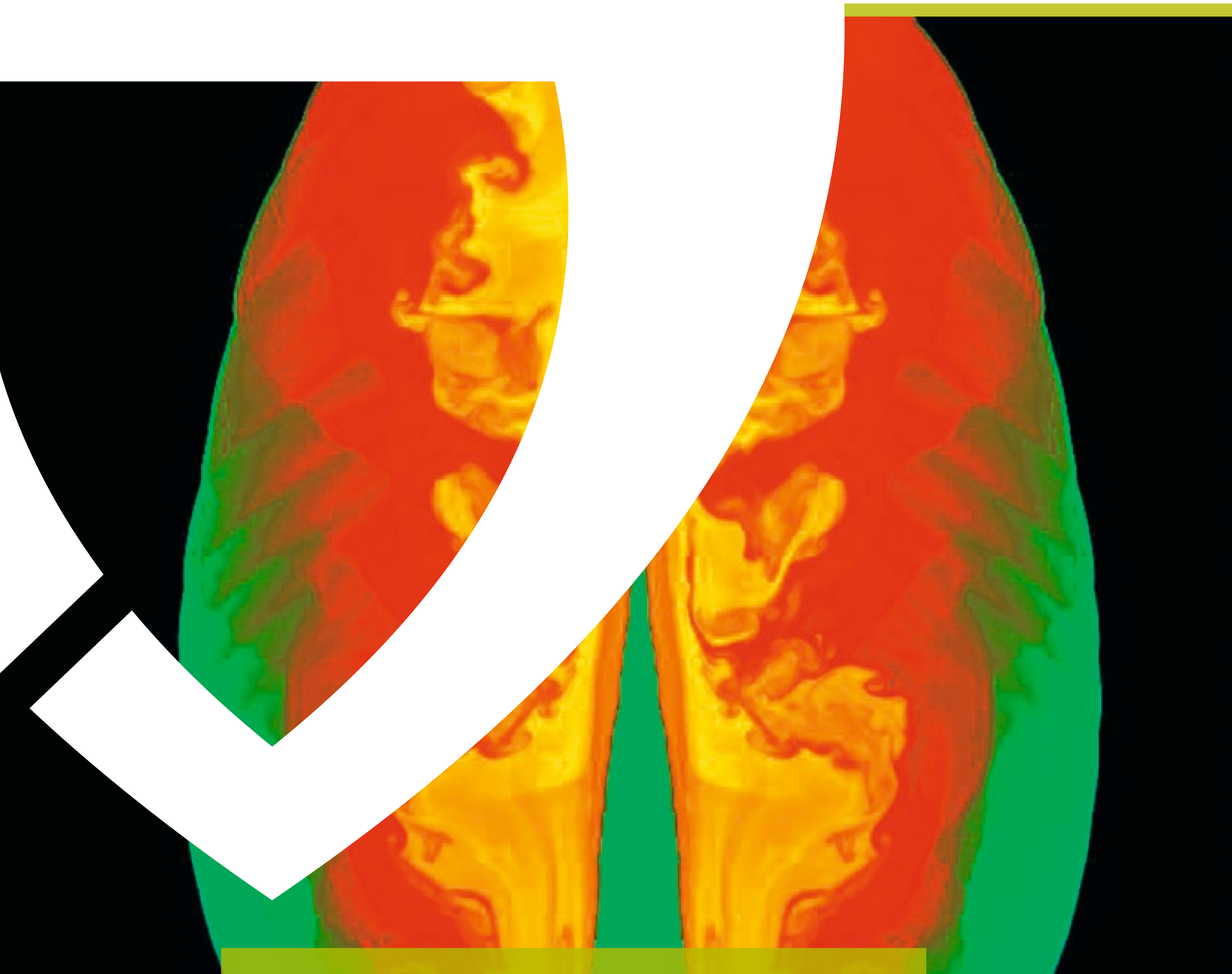
JACOBS UNIVERSITY



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?
- What is the nature of Dark Energy?
- Where are the chemical elements formed?
- 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 neutrinos from the Sun.

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:

- Preliminary exam - to ensure a uniform and sufficient level of preparation
- Strong focus on research and independent scientific work - starting in the first year
- Broad range of expertise and research interests, transdisciplinarity
- Synergies with/supplemented by other existing programs at Jacobs University
- Internationality, instruction in English
- Computational expertise

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, and theoretical particle physics.

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 (Germany: typically Vordiplom plus 2 semesters) 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 (Germany: Diplom) in a relevant field.

2 Structure of the Program

2.1 General Information

The Program in Astroparticle Physics has grown as an independent track out of the Graduate Program in Geosciences and Astrophysics. It 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. For a graduate student entering with a bachelor (or equivalent) degree, the default study plan is:

Semester 1:

- Lectures: 22.5 ECTS credits (3 graduate courses)
- Graduate Student Seminar: 5 ECTS credits
- Theory seminar

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

Semester 2:

- Lectures: 22.5 ECTS credits (3 graduate courses)
- Graduate Student Seminar: 5 ECTS credits
- Theory Seminar

Semester 3:

- Lectures: 15 ECTS credits (2 graduate courses)
- Graduate Student Seminar: 5 ECTS credits
- Theory Seminar
- Independent Research: 10 ECTS credits
- Qualifying exam for graduate students wishing to pursue a PhD

Semester 4:

- Graduate Student Seminar: 5 ECTS credits
- Theory Seminar
- MSc Thesis: 30 ECTS credits / start of PhD research program

The result of the assessment test is used to determine an appropriate individual course plan. The preliminary exam tests the background knowledge in physics required for graduate study. It is possible to shift the number of lectures between the semesters. The total required ECTS credits for course work are 60, balancing 60 ECTS credits for research and seminars. Lectures are graduate courses (400-level, 7.5 ECTS credits) including typically two Foundations in Astroparticle Physics courses that are tailored to the individual needs of the student and may include (advanced) undergraduate components.

After passing the qualifying exam 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 Course Plan

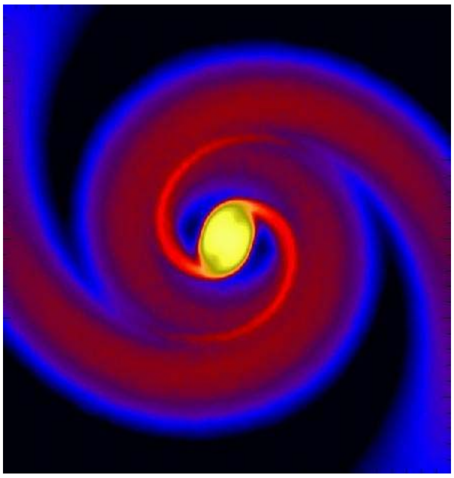
The curriculum comprises a choice of courses listed in section 0 (Main Courses), supplemented by courses from sections 2.5 and 2.6. The number of courses is constrained by the IUB-wide graduation requirements. The following table lists a typical choice of courses for the qualifying/masters phase of the graduate program. As indicated in the table, some courses can be taken either in the 1^{st} or 3^{rd} semester of graduate study - they are listed twice in the table.

1st Semester (Fall)	2nd Semester (Spring)	3rd Semester (Fall)	4th Semester (Spring)
Galaxies and Cosmology	High-Energy Astrophysics	Galaxies and Cosmology	
Physics of the Early Universe	Space Plasma Physics	Relativistic Astrophysics	
General Relativity and Black Holes	Solar Physics	Topics in Astroparticle Physics	
Lie Groups and Lie Algebras	QFT and Particles I	QFT and Particles II	
Computational Physics	Computational Fluid Dynamics	Computational Physics	
Graduate Student Seminar	Graduate Student Seminar	Graduate Student Seminar	Graduate Student Seminar
Theory Seminar	Theory Seminar	Theory Seminar	Theory Seminar
		Independent Research	MSc Thesis / PhD Research
Preliminary Exam		Qualifying Exam	

2.3 Main Courses

Please note that not all courses are offered each semester. For detailed course description please see Section 3.

- Galaxies and Cosmology
- Space Plasma Physics
- Solar Physics
- High-Energy Astrophysics
- Physics of the Early Universe
- Relativistic Astrophysics
- Quantum Field Theory and Particle Physics I, II
- General Relativity and Black Holes
- Lie Groups and Lie Algebras
- Strings, Branes, and Matrices
- Foundations of Astroparticle Physics
- Advanced Topics in Astroparticle Physics
- Computational Fluid Dynamics
- Graduate Student Seminar
- Theory Seminar
- Independent Research



3 Courses

3.1 Main Courses

210421 – Galaxies and Cosmology

Short Name: AstroII
Instructors: M. Brüggen, M. Hoeft
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content In this course we explore the structure of the Milky Way and other galaxies out to the youngest galaxies in the far distant universe. Galaxies consist of stars, gas and a halo of dark matter. On the basis of observations from across the entire electromagnetic spectrum we will try to form a picture of the composition of galaxies, their evolution and formation. We further study the distribution of galaxies in the universe and their environments at different epochs. This will be accompanied by a discussion of the basics of cosmology and the formation of structure in the universe.

210331 – Space Plasma Physics

Short Name: SpacePhys
Instructors: J. Vogt
Credit Points: Lecture, 7.5 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.
Plasma kinetic theory serves as a starting point where particle distribution functions and the governing dynamic equations are discussed. Integration of kinetic equations yields multi-fluid theory and, finally, the equations of magnetohydro-dynamics (MHD). The plasma fluid picture allows to study flows, waves, and discontinuities in the magnetosphere and the solar wind.

210332 – Solar Physics

Short Name: SpacePhysIII
Instructors: W. Daeppen, G. Haerendel
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content The first half of the course 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.

210322 – High-Energy Astrophysics

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

Course content This 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. Further topics include gamma-ray bursts, supernovae, pulsars, planetary nebulae and X-ray binaries. On larger scales we will discuss active galactic nuclei, quasars and clusters of galaxies. Particular emphasis is put on physical processes such as accretion, radiation processes and nuclear burning.

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.

210xxx – Relativistic Astrophysics

Short Name:
Instructors: S. Rosswog, M. Brüggen
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content This course covers a broad range of phenomena in high-energy astrophysics that warrant a relativistic description. These phenomena include black holes, neutron stars, supernovae, gamma-ray bursts, astrophysical jets and gravitational radiation. Moreover, we will study the kinematics of relativistic plasmas that are of great importance in gamma-ray and radio astronomy. The course will give a brief introduction to relativity and will focus on applications of relativity. The format of the course will be a combination of lectures, problem solving classes and computational labs. This course will be complimentary to the courses on general relativity, the early universe and high-energy astrophysics.

200xxx – Quantum Field Theory and Particle Physics I

Short Name:
Instructors: P. Schupp
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content First part of a thorough introduction to classical and quantum field theory with applications to particle physics. Syllabus: Classical field theory (space-time and internal symmetries, covariant field equations: Klein-Gordon, Dirac, Maxwell, Yang-Mills and Einstein equations), introductory quantum field theory (free fields, quantization, bosonic and fermionic simple harmonic oscillator, Fock space), Feynman rules (practical introduction to Feynman diagrams, bosonic and fermionic path integrals, elementary perturbation theory), elementary processes (calculation of scattering cross sections, decay rates, magnetic moments). (*This course could be based on the course "Particles and Fields"*)

200xxx – Quantum Field Theory and Particle Physics II

Short Name:
Instructors: P. Schupp
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content Second part of a thorough introduction to classical and quantum field theory with applications to particle physics. Syllabus: Nonabelian gauge theories (Lie algebras: classification, Killing form, examples), covariant quantization (BRST, ghosts, Ward identities), renormalization (beta function, asymptotic freedom), choice of advanced topics (BV, supersymmetry, non-perturbative topological effects: instantons, solitons, monopoles).

200471/200472 – General Relativity and Black Holes

Short Name: GenRel
Instructors: P. Solodukhin
Credit Points: Lecture, 7.5 ECTS
Semester: Spring/Fall

Course content This course is an introduction to Einstein's theory of gravity and the exciting (and still mysterious) physics of black holes. The focus is put on the geometrical nature of General Relativity. The course starts with a brief introduction to basic elements of differential geometry. No prior knowledge of differential geometry is assumed. In the part devoted to black holes we are going to explain why black holes do not have "hair" and how the event horizon is fatal for the loss of information. Syllabus: Elements of the Differential Geometry; Covariant description of the matter fields; Einstein's equations; Exact solutions; Weak field approximation (gravitational waves); Space-time singularities; Euclidean General Relativity (topological invariants, characteristic classes and gravitational instantons); Black holes (Gravitational collapse, uniqueness and "No-hair" theorem, Cosmic Censorship Conjecture, Killing and Event horizons, observational predictions; black holes in dimensions other than four); Hawking radiation (Quantum fields in curved spacetime, Particle production, black holes and thermodynamics, black hole entropy, the Information Problem).

100xxx – Lie Groups and Lie Algebras

Short Name:
Instructors: C. Blohmann
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content The course presents fundamental concepts, methods and results of Lie theory and representation theory. It covers symmetries as matrix groups, the relation between Lie groups and Lie algebras, structure theory of Lie algebras, classification of semisimple Lie algebras, representations of Lie algebras, and tensor representations and their irreducible decompositions. A Lie group is a group with a differentiable structure, the derivations at the identity form its Lie algebra. Lie groups and Lie algebras are indispensable in many areas of mathematics and physics. As a mathematical subject on its own, Lie theory has led to many beautiful results, such as the famous classification of semisimple Lie algebras. In physics, Lie groups and their representations are essential to the theory of elementary particles and its current developments. Due to the close correspondence of physical phenomena and abstract mathematical structures, the theory of Lie groups has become a showcase of mathematical physics. A solid background in multivariable real analysis and linear algebra is presumed. Familiarity with some basic algebra and group theory would be helpful. No prior knowledge of differential geometry is assumed.

200492 – Strings, Branes and Matrices

Short Name: Strings
Instructors: P. Schupp, R. Helling
Credit Points: Lecture, 7.5 ECTS
Semester: Spring

Course content A contemporary introduction to string theory: Strings and Branes - the building blocks of the theory, perturbative string theory (bosonic & supersymmetric strings, CFT, 4 types of fundamental string theories), dualities, compactifications, choice of advanced topics (M-theory, matrix theory, non-commutative geometry).

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.

210xxx – Advanced Topics in Astroparticle Physics

Short Name:
Instructors: Astroparticle Physics Faculty
Credit Points: Lecture, 7.5 ECTS
Semester:

Course content Advanced graduate courses on selected topics of expertise of the astroparticle physics faculty.

200372 – Computational Fluid Dynamics

Short Name: ComputationalFluidDyn
Instructors: A. Khalili
Credit Points:
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.

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: PhysTheSem
Instructors: P. Schupp, M. Brüggen, H. Meyer-Ortmanns
Credit Points:
Semester: Fall/Spring

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

3.2 Independent Research

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.

3.3 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.

Courses at the Undergraduate Level

200371 – Fundamentals of Hydrodynamics

Short Name: FundHydro
Instructors: A. Khalili
Credit Points: Physics Specialization Course
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, J. Vogt
Credit Points: GeoAstro Course
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 behavior 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.

210212 – Space Physics and Global Geophysics

Short Name: AdvGeoAstroBII
Instructors: J. Vogt
Credit Points: GeoAstro Course
Semester: Fall

Course content This course addresses basic aspects of near-Earth space plasma physics and the geophysical fields that reach out into space, namely, the Earth's gravity field and the geomagnetic field. The lecture consists of three parts. The first part starts with a short review of principles from classical mechanics before we study the motion of charged particles in electric and magnetic fields. Drift approximation and adiabatic theory allow to understand the formation of the Earth's radiation belts and the ring current. Collisions between electrons, ions, and neutral particles in the ionosphere give rise to anisotropic conductivities. The second part deals with gravity and magnetism of the planet Earth. In particular, we discuss the representation of geophysical potential fields in terms of spherical harmonics. The third part begins with a review of concepts from electrodynamics and fluid dynamics. Transport processes and wave phenomena are addressed. We conclude with useful concepts from magnetohydrodynamics and a short discussion of dynamo theory.

200302 – Fields and Particles

Short Name: ExpTheoPhysAII
Instructors: P. Schupp, V. Wagner
Credit Points: Physics Course
Semester: Spring

Course content Three introductory modules on Classical and Quantum Field Theory and Particle Physics: Relativity and Classical Field Theory (5 weeks): Relativistic formulation of electrodynamics, gauge field theories, introduction to general relativity (geodesics, Einstein equations, Schwarzschild solution); Quantum Field Theory (5 weeks): Introduction to quantum field theory: second quantization, scalar quantum field theory, parallels to statistical physics; Particle Physics (4 weeks): Introduction to phenomenological and experimental aspects of elementary particle physics; topics include the Standard Model and Feynman diagrams.

200202/200301 – Quantum Mechanics I/II

Short Name: AdvPhysAII/ExpTheoPhysAI
Instructors: P. Schupp, S. Tautz, V. Wagner, A. Materny
Credit Points: Lecture Module, 5 ECTS total
Semester: Spring/Fall

Course content Quantum Mechanics I (Advanced Physics A II, $1 * st$ Module): Physical basis and postulates of quantum mechanics, Schrödinger Equation, Simple quantum mechanical systems, Matrix/operator formulation of quantum mechanics, Introduction to perturbation theory, Angular momentum and spin, Hydrogen atom.
Quantum Mechanics II (Experimental and Theoretical Physics A I, $1 * st$ Module): Symmetry in quantum mechanics, addition of angular momentum, approximation methods, multi-particle quantum mechanics, scattering theory.

200201 – Classical Mechanics

Short Name: AdvPhysAI
Instructors: H. Meyer-Ortmanns
Credit Points: Physics Course
Semester: Fall

Course content Three modules: Classical Mechanics I (5 weeks), Classical Mechanics II (5 weeks), and Special Relativity (4 weeks). Classical mechanics provides the foundation for many fields of modern physics and it is indispensable for physics in general. Topics covered in the first two modules include planetary motion, systems of particles, statics, rigid body dynamics, introduction to analytical mechanics (variational principle, Lagrange's and Hamilton's equations), and small oscillations. The third module provides an introduction to special relativity: Einstein's postulates, time dilation, length contraction, simultaneity, Lorentz transformation, relativistic effects and paradoxes, relativistic momentum, energy and mass. (There is also the possibility of a brief module on non-linear dynamics.)

200331 – Computational Physics

Short Name: CompPhys
Instructors:
Credit Points: Physics Course
Semester: Fall

Course content Computer simulations play an increasingly important role in physics, ranging from simulations of collision-experiments, large-scale Monte-Carlo simulations in theoretical elementary particle physics, over quantum Monte Carlo, molecular dynamics, density functional methods in condensed matter physics and physical chemistry, to genetic algorithms with applications to biophysics. The course gives an overview of the variety of numerical methods, and a detailed introduction to errors and uncertainties in computations, data fitting, Monte-Carlo simulations, and molecular dynamics techniques. The lecture and the corresponding tutorial will present numerous examples for programming codes. Therefore some programming skills in Fortran or C are strongly recommended as prerequisites.

Courses at the Graduate Level

100451 – Differential Geometry

Short Name: DiffGeom
Instructors: V. Kaimanovich, D. Schleicher
Credit Points: Lecture, 7.5 ECTS, Mathematics
Semester: Spring

Course content Differential geometry is the study of differentiable manifolds. Assuming basic concepts from 100 311 (Analysis III) and 100 351 (Introductory Geometry), such as manifolds, differential forms, and Stokes' theorem, the focus in this course is on Riemannian geometry: the study of curved spaces which is at the heart of much current mathematics as well as mathematical physics (for example, General Relativity).

3.4 Tentative Courses

200xxx – Particle Physics and Cosmology

Short Name:
Instructors:
Credit Points: Physics Specialization Course
Semester:

Course content The great diversity of the universe stems from a limited number of elementary particles acting under the influence of a few fundamental forces. The building blocks of the universe, the quarks and leptons, interact by the exchange of mediating bosons. This course provides a description of the Standard Model of particle physics and explores the astrophysical and cosmological implications. Topics in cosmology include: Hubbles law and the expanding universe, cosmological models, Friedmann equation, cosmic microwave radiation: the hot Big Bang, radiation and matter eras, nucleosynthesis in the Big Bang, baryon-antibaryon asymmetry, dark matter and dark energy, inflation.

200xxx – Relativity

Short Name:
Instructors:
Credit Points: Physics Specialization Course
Semester:

Course content Special relativity (mechanics and electrodynamics), general relativity, classical field theory and gravity with selected applications to astrophysics and cosmology.

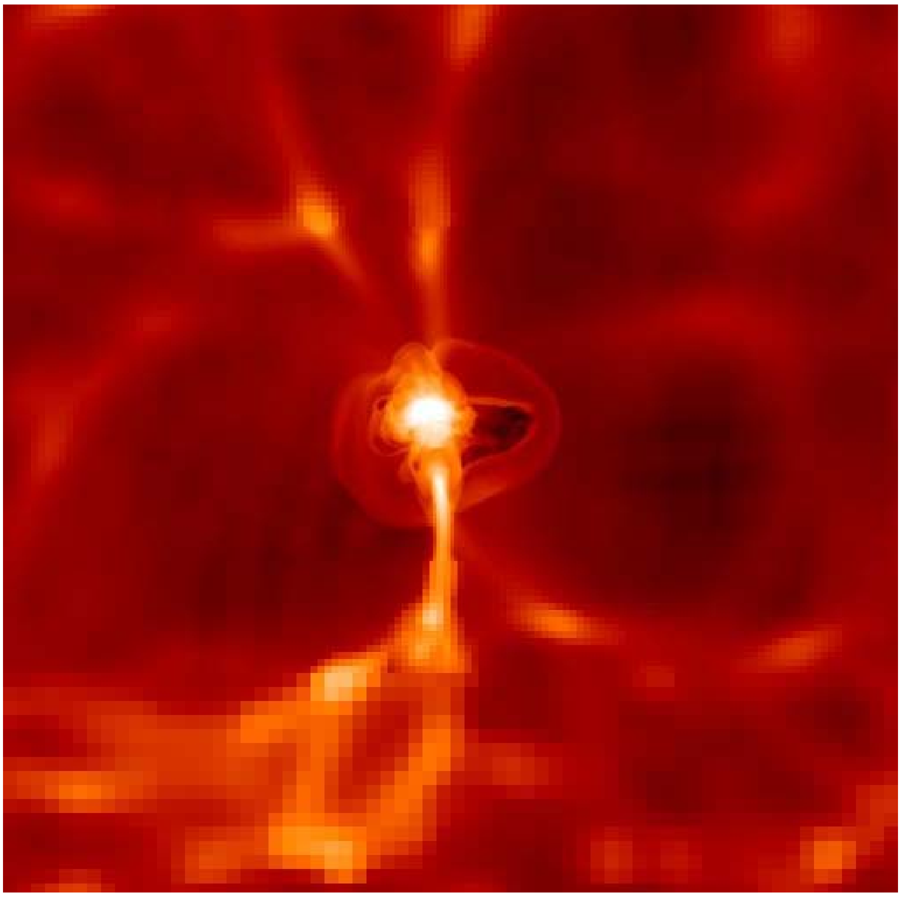
201322 – Topics in Mathematical Physics

Short Name: MathPhys
Instructors: P. Schupp, V. Wagner
Credit Points: Physics Specialization Course
Semester: Spring

Course content Selected topics in classical and modern mathematical physics, e.g.:

- Tools and tricks of mathematical physics with an introduction to groundbreaking mathematically rigorous works in various fields of physics ranging from solid state theory, over statistical mechanics to elementary particles.
- Current topics in quantum field theory, particle physics and gravity.
- Strings, branes and matrices - a contempory introduction to string theory.

4 Research



4.1 Faculty

4.1.1 Core Faculty

- Prof. Dr. Marcus Brüggen
- 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. Betti Hartmann, Research Instructor Physics
- Dr. Sergey Solodukhin, Senior Research Associate Physics
- Dr. Robert Helling, Research Associate Physics
- Dr. Matthias Hoeft, Postdoctoral Fellow Astrophysics
- Dr. Bertalan Zieger, Postdoctoral Fellow Physics
- Dr. Joachim Schmidt, Research Associate
- Dr. Christian Blohmann, Postdoctoral Fellow Physics (on leave)

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.

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 theoretical particle physics, quantum field theory, and mathematical physics. Current research includes projects on non-commutative quantum field theory, deformation quantization, and non-commutative geometry. 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 Matrix Theory and 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

Sergey Solodukhin Expertise in quantum gravity, general relativity, black holes. Research interests in AdS/CFT correspondence, Gauge/Gravity duality, holographic principle, black holes.

Matthias Hoeft Expertise in computational astrophysics and experimental nuclear astrophysics. Current research interests focus on the physics of the Intra-cluster medium, the evolution of its thermal and non-thermal components and the structure formation in the universe.

Robert C. Helling Expertise in superstring theory, D-brane constructions, quantum field theory, non-commutative geometry, foundations of spacetime physics, and protein folding. Research interests especially in gravity-gauge theory dualities and quantum field theory descriptions of geometry.

Bertalan Zieger Expertise in geomagnetism, atmospheric physics, and space physics. Current research focus on studies of paleomagnetospheric processes using global magnetohydrodynamic simulations.

Joachim Schmidt Expertise in theoretical physics, solar physics, and heliospheric physics. Research interests include solar wind turbulence studies using simulations and spacecraft observations, interaction of energetic particles and cosmic rays with magnetohydrodynamic waves, and the dynamics of coronal mass ejections in the solar wind.

Christian Blohmann Expertise in mathematical physics, differential geometry, operator algebras. Research interests include non-commutative geometry, quantum groups and quantum spaces, generalized space-time symmetries, gravity induced vacuum dispersion.

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.

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.

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). Cooperations with other centers for high-performance computing are in planning. CLAMV offers its own seminar. Topics come from all areas of applied 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.