DEPARTMENT OF PHYSICS
Astro & Particle Physics | Quantum Science | Bio & Nano Physics | Neuroscience
For centuries, researchers at the University of Tübingen have been pushing back the boundaries of fundamental science and technology. Today, some 28 research groups in the Department of Physics at our university continue to explore the frontiers. The focus of their work ranges from the tiniest subatomic particles to the largest structures in the universe, from the hottest stars to the coldest quantum objects, via the most intricate nanoscale physics and biotechnology.
Tübingen is a historic city of research and teaching, and with 25,000 students among 88,000 inhabitants, it remains forever young. The Eberhard Karls Universität Tübingen, founded in 1477, belongs to the renowned universities of Germany. Rich in tradition and culture, with a picturesque old town, punts on the Neckar River and a geographical location between the mountains of the Black Forest and the Swabian Alb, Tübingen offers a unique and inspiring environment for study and creativity. The Department of Physics offers Bachelor & Master courses in physics, in nano-science, and physics for teachers, as well as a large variety of PhD opportunities. The University of Tübingen has been selected for funding in the German government’s Excellence Initiative, making Tübingen one of Germany’s eleven universities distinguished with that title of excellence.

Studying at the Department of Physics

Bachelor Course
The Bachelor course (8 semesters) includes modules in higher mathematics, experimental and theoretical physics, laboratory courses, and specialized modules in

- Astronomy and Astrophysics
- Nuclear and Particle Physics
- Astroparticle Physics
- Condensed Matter Physics
- Quantum Optics, Cold Atom Physics, Superconductivity
- Nanostructures and Interfaces
- Biological and Medical Physics
- Scientific Computing

An overseas semester can be arranged, typically during the third year. The department has a large number of contacts with other leading universities worldwide and supports applicants. The Bachelor studies are completed by a major project and thesis.

For PhD opportunities please visit the Websites of the Research Centers!

Master Course
The Master course (2 semesters) is research oriented in one of the groups of the department. The aim is to develop skills for independent scientific work and research. The studies are completed by the Master Thesis. A Double Degree Program is offered where students of the universities of Tübingen and Trento (Italy) spend 2 semesters at the partner institution to broaden their education and experience.

Physics for Teachers
The Physics Department is strongly committed to a superior education of teachers, who have the vital mission of passing on modern physics ideas, and a basic understanding of our world, to the next generation of pupils and students. The study plan for the first three semesters, concentrating on basic classical physics, is the same as that for the Bachelor in Physics. After a 4th/5th/6th semester at a school, the prospective teachers attend lectures and seminars in which subjects of modern physics are taught, with special attention paid to didactical aspects. Additional seminars and laboratory courses are dedicated to the presentation and demonstration of experiments. The degree is completed within a 10-semester period by studies of a second subject, e.g. mathematics, and by studies of didactics and educational science.
Kepler Center for Astro and Particle Physics

The research area of the Kepler Center is at the intersection of particle physics, astrophysics, and cosmology. The Kepler Center comprises the groups of astrophysics, computational astrophysics, general relativity, and particle physics, and combines a rich experimental program with intense theoretical studies. The physics goals are multi-messenger observations of the universe, using the universe as a laboratory for elementary particles and extreme physical conditions, studying the properties of elementary particles and their influence on the evolution and the structure of the universe while constructing theoretical models to understand the processes within our universe.

Astronomy

One research topic of the Astronomy group is late stages of stellar evolution, i.e. white dwarfs and neutron stars. Quantitative analyses across the entire electromagnetic spectrum, performing radiation transfer calculations and stellar atmosphere modeling allow us to derive stellar parameters and to draw conclusions about the formation of these objects. In particular, the equation-of-state of matter at supra-nuclear densities can be constrained. In addition, the group is modeling and analyzing accretion disks around compact objects, which can be fed either by a stellar companion in close binary systems or by circumstellar material around solitary stars, such as disks formed from supernova-fallback material or planetary debris. Another experimental topic is the development of microchannel-plate detectors for UV radiation for use in space-based observatories. The World Space Observatory Ultraviolet (WSO/UV) is a 1.7-m telescope being built by Russia, launch planned for 2016. As the main instrument, it will carry a suite of spectrographs that were designed by the Astronomy Group together with other German partners. In particular, the spectrograph detectors are being developed and built by collaborations led by the Tubingen group.

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High Energy Astrophysics

We like to say that the main scientific goal of the High Energy Astrophysics group is the exploration of the extremes of the Universe from space and from the ground. We are active in the experimental developments for future space missions that will observe the somewhat closer Milky Way and the far Universe using X-rays. We are members of the teams working on the eROSITA telescope onboard the Spectrum X-Gamma satellite, and on the future challenging missions of the European Space Agency: the Large Observatory For X-ray Timing (LOFT) and ATHENA, the Advanced Telescope for High Energy Astrophysics. For all these missions we develop digital electronic systems, while testing prototypes of the detectors in our laboratories. We also want to understand through simulations the background that these missions will experience and the response of the instruments. Today high energy astrophysics also means very high energy gamma rays. This is why we are active in the operation of the HESS Cherenkov Array Telescope, in Namibia, while taking part and the development of HESS II and in the future CTA. The control and alignment systems of the mirrors, the testing of the mirrors, the development of fast electronics are our main challenges.

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General Relativity

The Theoretical Astrophysics Group led by Kostas Kokkotas works on problems related mainly to sources of gravitational waves and also on the processes generating gamma rays and X-rays from neutron stars and black holes. Gravitational waves are expected to open a window for observing the universe and to provide unique information from astronomical objects and events that do not emit electromagnetic radiation. Neutron stars are among the primary sources and it is expected that via gravitational waves we may understand the details of their structure. The group studies the creation and the subsequent oscillations of neutron stars and the instabilities that may be induced via fast rotation. Moreover, the group is working on problems related to black-hole perturbations and their relation to gravitational waves as well as to thermodynamics and quantum processes near black holes.

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Nuclear Matter under Extreme Conditions and Exotic Hadronic States

Heavy-ion collisions at high energies provide the unique possibility to compress matter in the laboratory to densities as they prevail in the interior of neutron stars. The analysis of the data allows, among other things, the investigation of the equation-of-state of high-density baryonic matter. At the LHC accelerator matter densities and temperatures can be created which are comparable to the early universe of a few microseconds after the Big Bang. The data reveal the properties of a new state of matter – the Quark-Gluon Plasma – and its phase transition to hadronic matter, which itself may contain exotic states like hybrids and dibaryons. Whereas the latter are studied at the Research Center Jülich, the properties of a new state of matter – the Quark-Gluon Plasma – and its phase transition to hadronic matter, which itself may contain exotic states like hybrids and dibaryons. Whereas the latter are studied at the Research Center Jülich, plasma – and its phase transition to hadronic matter, which itself may contain exotic states like hybrids and dibaryons. Whereas the latter are studied at the Research Center Jülich, ultra-relativistic heavy-ion collisions are conducted at the ALICE experiment at the CERN-LHC in Geneva and in future also at the CBM experiment, which is presently under construction at the accelerator center FAIR in Darmstadt.

Particle Physics

We conduct experimental projects that search for physics beyond the standard model and study the role of elementary particles in cosmology. The projects CRESST and EURECA aim to directly detect the particles that form dark matter in the Universe, a hypothetical type of matter to account for a large part of the observed total mass in the Universe. Novel detection techniques for dark matter particles, based on superconducting thin films and crystals at very low temperatures, are developed in our lab. The GENDA experiment searches for the very rare process of neutrinoless double beta decay of nuclei. If detected it would provide unique information on the neutrino mass and prove that neutrinos are Majorana particles. The Double Chooz experiment measures neutrino oscillations with a nuclear power plant in France as an intense neutrino source and aims to complete our knowledge of the neutrino mixing matrix. Results obtained in Double Chooz and GENDA could provide the missing link between the neutrino and the matter-antimatter asymmetry in the Universe. In all projects, scientists from our group are member of international collaborations with many cooperations with institutes throughout the world. The group is directly involved in the data analysis of all the running experiments.

Theoretical Nuclear and Particle Physics, Quantum Field Theory

The activities in Theoretical Particle Physics are devoted to the low energy regime of quantum chromodynamics, QCD. We focus on the explanation of such non-perturbative effects of the strong interaction such as confinement of quarks and gluons and the spontaneous breaking of chiral symmetry. We also investigate the deconfinement phase transition and the restoration of chiral symmetry at finite temperature and baryon density.

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Research activities in theoretical particle physics also focus on the inner structure of the nucleus. We perform phenomenological studies of experimental data from lepton-nucleon and proton-proton scattering, with the goal of learning about the distributions of quarks and gluons inside a nucleon. Our work includes precision QCD calculations for observables at hadron colliders, among them the Large Hadron Collider LHC at CERN (Geneva) and machines in the US.

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We also carry out research on many-body theory and studies of quantum liquids in nuclear physics, particle physics and astrophysics. Theoretical as well as computational tools are developed to describe the properties of baryonic matter at densities, temperatures and decompositions that are typical for astrophysical objects.

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Computational Astrophysics

The Computational Astrophysics Group deals with the numerical modelling of complex astrophysical phenomena. For that purpose we develop and apply complex numerical algorithms to solve the time-dependent equations of magnetohydrodynamics including radiative transport, and solid state physics. The group performs intense simulations using highly parallelised state-of-the-art particle and mesh-based codes. Major research topics include understanding the growth of planets in the Solar System and exoplanetary systems. We model the process of planet formation from micron-sized particles to the giant planets and study the evolution of whole planetary systems. We study the structure and evolution of accretion discs, for example, in close binary stars and around young protostars.

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The Computational Astrophysics Group deals with the numerical modelling of complex astrophysical phenomena. For that purpose we develop and apply complex numerical algorithms to solve the time-dependent equations of magnetohydrodynamics including radiative transport, and solid state physics. The group performs intense simulations using highly parallelised state-of-the-art particle and mesh-based codes. Major research topics include understanding the growth of planets in the Solar System and exoplanetary systems. We model the process of planet formation from micron-sized particles to the giant planets and study the evolution of whole planetary systems. We study the structure and evolution of accretion discs, for example, in close binary stars and around young protostars.
CQ Center for Collective Quantum Phenomena and their Applications

Superconductivity, cold atom physics and nanotechnology are the research areas of the Center involving six experimental groups and a theory group. Merging of these fields establishes a novel quantum technology with immense perspectives for fundamental research and applications.

Quantum Optics
The experimental group of Claus Zimmermann works on the fields of quantum optics, laser physics, and ultracold quantum gases. Degenerate Bose- and Fermi-gases, ultra-cold molecules, atoms in cavities, atom interferometry, and quantum optics at surfaces comprise the key expertise of the group.

Nano-Atomoptics
The experimental group of József Fortágh develops quantum instruments based on ultra-cold atoms and solid state nanostructures. Research is focused on quantum electronic systems based on atomic Bose-Einstein condensates and Rydberg atoms coupled to superconductors and carbon nanotubes. Techniques of cold atom scanning probe microscopy are investigated for ultrasensitive force measurements. The group collaborates with industrial partners on the development of optical measurement technologies.

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Bionanotechnology, soft-hard interfaces, along with scattering and microscopy, are the research areas of the Center for BioNanoPhysics. Applying state-of-the-art experimental techniques from physics to biological and other complex or hybrid matter offers fascinating new perspectives in this interdisciplinary research area. The experimental work is complemented by theoretical modelling.
Soft-Hard Interfaces

Frank Schreiber studies hybrid interfaces, i.e. soft /organic and biological matter in contact with conventional hard matter. Understanding this interface is crucial to many diverse areas of research and applications, from implants to biosensors and organic electronics. In addition, we are also working at the interfaces between different scientific disciplines, namely the physical sciences and the life sciences, where many future discoveries are expected.

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Biological and Medical Physics

The group of Tilman Schäffer addresses questions of biological and medical relevance using physical methods. Our main tools are various species of scanning probe microscopes. Seeking to descend deeper and deeper into the Nanoworld, we place the development of new instruments and methods with high-speed and low-noise characteristics at the foundation of our research. Our applications include elucidating the dynamic interactions of single biomolecules, revealing viscoelastic properties of living cells and tissues, exposing biominalization on the molecular scale, and illuminating transport processes in artificial and natural membranes.

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Scattering, Microscopy, and Spectroscopy

The properties of complex materials can only be understood if complementary tools for their characterization are applied. Tübingen has a longstanding tradition in the research of scattering and microscopy methods, which are continuously developed to improve resolution and sensitivity for the study of atomic and electronic structure as well as the chemical composition. In addition, Frank Schreiber’s group has strong links to large-scale research facilities, such as synchrotron and neutron sources, inter alia, in Grenoble. Oliver Eibl’s group applies quantitative electron microscopy and spectroscopy to devise relevant materials for energy technology, such as superconducting solar-cell materials, and thermoelastics to study structure-physical property correlations. Research is focused on materials with reduced dimensions (nanowires, thin films) and artificially designed nanostructures for optimizing their functional properties. Quantitative spectroscopic methods with x-rays and electrons yield the local chemical composition, plasmon energies and dispersions, and insight into the electronic structure of materials on the sub-nm scale. Innovations in electron optics such as energy filters, aberration-corrected lenses and monochromators are utilized in this research activity. Oliver Eibl is co-founder of the recently formed Network of Electron microscopy Tübingen (NET), which is a platform for interdisciplinary research covering materials science, nanotechnology and life sciences. Within this network the group has applied quantitative analytical Transmission electron microscopy to tissue and cells research for understanding age- and disease-induced changes of eye and skin tissue. This research allows for the simultaneous investigation of the chemical composition and ultrastructure on the sub-100-nm scale and is carried out together with colleagues from the university hospital.

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BioNanoTechnology

Dieter Kern and Frank Schreiber characterise the structure and interactions of biological molecules and materials on the molecular scale, and manipulate and detect them. To this end, artificial nanomaterials are prepared to construct, for example microfluidic devices or metal nanoparticles with specific optical properties to facilitate detection of biomolecules. Charge transfer and biocompatibility issues at bio-electric interfaces in neuroscience are addressed by specifically structured electrode surfaces and directed material growth (as part of the cluster of excellence Integrative Neurosciences). This area of research is literally at the interface between different traditional disciplines, and the opportunities to use unconventional (hard-matter) nanotechnology for bio-driven applications are virtually endless.

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Physics in the Center for Integrative Neuroscience (CIN)

The Werner Reichardt Centre for Integrative Neuroscience (CIN) is an interdisciplinary institution at the Eberhard Karls Universität Tübingen that aims at understanding the neural mechanisms and algorithms in the brain that underlie perception, cognition, and behaviour. Several faculties of the university, two Max Planck Institutes (MPI for Biological Cybernetics and MPI for Intelligent Systems), the Hertie Institute for Clinical Brain Research and the Fraunhofer Institute for Manufacturing, Engineering and Automation are part of the CIN. Its interdisciplinary concept is further supported by numerous internal and external partners.

Computational Vision & Neurosciences

Brains have developed to generate autonomous behaviour in a highly variable world. Unraveling this striking ability of living organisms is a major challenge of systems neuroscience. Most fundamentally, we are missing a theory that can explain what kind of knowledge about the world makes such autonomous behavior possible. Furthermore, we do not know how this knowledge is encoded in the activities of neural populations in the brain. Many aspects of these basic questions about brain function and neural information processing can be addressed in the more specific context of biological vision. Humans, for instance, rarely encounter serious problems in recognizing objects under different circumstances, whereas this is still an unsolved challenge in computer vision.

The research agenda of Matthias Bethge’s group can be summarized by two basic questions originally posed by Hermann von Helmholtz:

- What are the principles that govern how the visual pathways make inferences from the visual image? How do we use image information to compute these perceptual inferences?

A principal difficulty in the understanding of biological vision is the complexity of the inference problems we encounter at the level of behaviour as well as at the level of neuronal responses. This complexity mostly results from the large number of degrees of freedom in both the sensory input and the neuronal responses.

Natural Image Statistics

Development of mathematical generative models of natural images and image transformations using unsupervised learning methods. Particular emphasis is placed on quantitative comparisons of the performance of these models.

Neural Population Coding

Development of new efficient methods to predict the spike trains of neurons in response to natural stimuli with the goal of inferring the contribution of these neurons to the image processing performed in the visual system. In particular, construction of population response models for multi-cell recordings.

Psychophysics with Natural Images

Evaluation of the relationship between natural image models and perception based on psychophysical studies.

Using methods of statistical inference and learning theory, as well as signal processing, non-linear dynamics and optimization theory, Bethge’s research addresses the problem of perceptual inference from natural images and its neural basis at three different levels: Natural image statistics, Neural population coding, and Psychophysics.

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Plasmonic Nanostructures

The junior group Plasmonic Nanostructures addresses the design, fabrication, characterization and integration of metallic nanostructures acting as optical antennas. They are utilized for focusing light beyond the diffraction limit and creating strong electric near-fields. The plasmon resonance is tailored via geometry, metal and substrate. Processes for rings, corals, sharp-tipped cones and more are developed. They are used for researching light-matter interactions and for applications in near-field microscopy, spectroscopy, biosensing and photovoltaics.

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Biomedical Physics – Radiation Oncology

Modern cancer therapy concepts aim for treatment individualization according to patient-specific factors. Our research section develops technical and methodological concepts for improving state-of-the-art high-precision radiotherapy (RT). A main research focus is the integration of molecular imaging (MI) using positron emission tomography or functional magnetic resonance imaging into individualized RT treatment. We investigate technical aspects of MI-based RT planning, including the design of theoretical models on image formation and biomarker distribution in tumors, treatment response models and MI-based-dose prescription functions.

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Quantum-Ion-Interferometry
(Emmy Noether group)

The objective of our research group is the construction and application of the first stable ion-interferometer. Compared to neutral atomic or molecular interferometers, the additional parameter charge opens the door to fundamental quantum-mechanical experiments, such as the magnetic and electric Aharonov-Bohm effect and the construction of highly sensitive, compact sensors for rotation and acceleration. We also study matter-wave decoherence above a superconducting surface and develop novel superconducting metal tips for extremely monochromatic and coherent electron emission.

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Evolution of Galaxies (Emmy Noether group)

The evolution of galaxies is studied by using the x-ray sources as observational probes: e.g. x-ray binaries, which contain a neutron star or a black hole, or supernova remnants, which are responsible for the chemical enrichment, the energy budget, and the dynamics in the interstellar medium. Physical phenomena in these systems like gravitation, nuclear fusion, radiation, or shock waves also played a major role in the formation of the first cosmological structures.

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Surface Quantum Optics

The junior research group Surface Quantum Optics investigates the physics of hybrid systems which are composed of ultracold atoms (Bose-Einstein condensates) and solid state surfaces. Particular interest is devoted to the interaction with optical near-fields above plasmonic nanostructures like metallic nanowires and nanotips. The goals are (i) to address fundamental physical problems of quantum electrodynamics (QED) by measuring Casimir-Polder forces and (ii) to implement strong coupling between single atoms and single plasmonic excitations for applications in quantum information and optical computing.

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Junior Research Groups

Computational Quantum Physics

The work within CQ receives theoretical support from the Computational Physics Group of Thomas Judd. The group specializes in high performance simulations and focuses on the interactions between cold atoms and solid structures including nanotubes, graphene, superconductors and microchips.

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Research and teaching at the Department of Physics greatly benefit from high-tech laboratories and an extensive array of unique research facilities. The infrastructure continues to grow at an accelerating rate with national and international funding of the individual groups and investments from the University.

**Key Facilities of the Physics Department**

**Core Facility LISA: Light-Matter Interaction, Sensors and Analytics**
The Department of Physics participates in the University’s core facility LISA: a joint research and service facility created around the Nanostructure Laboratory. Clean room and dark room facilities; thin-film deposition (pulsed laser deposition, sputtering, thermal & e-beam evaporation), organic layers, LPCVD, PECVD carbon nanotube growth; micro- and nanostructuring (e-beam & photo/nanoimprint lithography, dual beam focused ion beam, argon ion milling, plasma & reactive ion etching, ashing); thin film/surface analysis (Microscopy: UHV-scanning tunneling, Auger, atomic force and scanning electron. Spectroscopy: photo-electron, transmission and Fourier transform infrared. X-ray diffractometry; Rutherford backscattering; UV/vis fluorescence; ellipsometry, mass spectrometry, gas chromatography, profilometry, 4-point measurements); laser scanning microscopy/spectroscopy (confocal/near-field, parabolic mirror based, UHV low temperature, single molecule); He/He dilution fridges.

**Cold Atom and Quantum Optics Laboratories**
Ultracold rubidium and lithium experiments, atom-cavity systems, Rydberg setups, cold atom/solid state interface, 4K and 25mK cryostats, Bose-Einstein condensates at superconductors, cold atom scanning probe microscopes. Frequency comb technology, laser, optical, interferometric, spectroscopic measurement technologies.

**Supercomputer**
BFNgrid supercomputing facilities with several thousand processors; local high-performance cluster (Magny-Cours) with several hundred processors. Both suited for serial and parallel jobs.

**Astrophysics**
Clean room and dark room facilities; thin-film deposition; 1-m vacuum chamber with UV monochromator; climatic chamber; UHV system; 100-m optical bench; 80-cm telescope.

**Particle Physics**
Rosenau Accelerator: 3MV Van de Graaf, beams from H to C; neutron beams; RBS analysis. Underground Laboratory: Shrinking – 16 mwe, ultra pure Ge Spectrometer, Dilution Refrigerator (5 mK Base Temp), SQUID read out array. Dark Room Facility: PMT single-photon testing; scintillator testing; cryostate for optical charactization (scintillation, reflectivity, etc.) at low temperatures (down to 1.7 K); large-volume (1qm) liquid scintillator/or water cerenkov detector, 11 PMTs 8 inch. UHV deposition system for tungsten superconducting thin films. Barbecue facilities.

**Bio-Nano Laboratories**
Clean room; optical & e-beam lithography; thin-film deposition; microscopy (optical, SEM, TEM, AFM, SCMs, dark field, fluorescence, Raman); spectroscopy (Raman, Auger, photo electron, mass, UV/vis, FTIR); surface analysis; wet and dry etching; ovens; cryostats (variable, 4 K, 100 mK, 8 T); UHV station for field-emitter characterization; cell culture equipment.