Guidebook

Faculty of Physics University of Warsaw

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Erasmus

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A Word from the Dean

The high quality of its scientific research has always been one of the strengths of the University of Warsaw Faculty of Physics. A confirmation of this is provided by the large number of highly cited publications in prestigious international journals emanating from the Faculty and the research projects, both domestic and international, carried out there. Specialized laboratories in the Faculty of Physics are equipped with modern and, in many cases, unique, research devices. The huge research and teaching potential of the Faculty is demonstrated by: a track record of research recognized both nationally and internationally, modern curricula, a large number of titled professors (70) and doctoral faculty with Habilitation (51), the interdisciplinary character of our research and scientific collaboration with leading centers of research abroad. The Faculty of Physics is frequently visited by scientists from leading institutions of higher education and research from all over the world. Our highly qualified research staff share their knowledge and experience with graduate and undergraduate students, who have the opportunity to participate in research conducted at the Faculty from the beginning of their studies. We strive to equip graduates leaving our Faculty with the ability to apply the knowledge they obtain in the course of their studies, and to ensure that the capability to formulate and solve nonstandard problems, to reason logically, to use their imagination and work in a team will be among their basic attributes. Our graduates are our pride, as we see them succeed in their work in prestigious institutions of higher education, research institutes, hospitals, banks and businesses of all types around the world. Their brilliant careers are proof of the quality and usefulness of the knowledge they obtained during their studies at the University of Warsaw Faculty of Physics.

The Faculty of Physics benefits from the opportunities created by Poland's membership of the European Union. We are effective in obtaining funding from EU operative and framework programs dedicated to research and technological development. The quality of research and education is highly dependent on the conditions under which they are carried out. In the near future, new premises for the Faculty of Physics will be built at the Ochota Campus, providing better working and teaching conditions and enabling the creation of new, well equipped research laboratories.

While respecting the values that stem from the rich history and tradition of the Faculty of Physics, we must face the new challenges raised by changes in the surrounding world. Today's Faculty of Physics is resolutely forward-looking. We strive to adapt our teaching to the needs and expectations of the current generation. Interdisciplinary interests among the young, and the prospect of them finding interesting jobs in the future, have led us to open new specializations and study programs and to participate in multidisciplinary programs.

The Faculty of Physics is ready for the challenges of the 21st century. Our top aim remains the preservation of high standards of scientific research and education of the young.

Prof. dr hab. Teresa Rząca-Urban

Center of New Technologies II
– the future site of the University of Warsaw Faculty of Physics;
designed by Kuryłowicz & Associates Architects Studio, LLC →

History of the Faculty

Physics and astronomy in the University of Warsaw began in 1816 as parts of the then Faculty of Philosophy. The leading personalities of the period 1816-1831 were physicist Karol Skrodzki (1787-1832), the second rector of the university, and astronomer Franciszek Armiński (1789-1848), the founder of the Astronomical Observatory. During the first few years physics laboratory and lecture hall were situated in the Casimir Palace, which is now the site of Rector's office and administration in the main university campus at Krakowskie Przedmieście Street 26/28. Later physics was transferred to another building at the main campus. The Astronomical Observatory was formally inaugurated in 1825, after completion of the construction of its building at Aleje Ujazdowskie 4.

After the unsuccessful November Uprising against the Russian occupants in 1831, the University of Warsaw was closed down as part of the repression against the Polish population. Only the astronomical observatory continued to exist as a scientific institution, and provided meteorological observations and calendars. In 1862 the University of Warsaw was reopened under the name of Main School, but it existed only until 1869. In that year it was transformed into Russian Imperial Warsaw University with Russian as the language of instruction. It was generally boycotted by the Polish people.

The first World War brought the long-awaited change. In 1915 the Russians had to withdraw from Warsaw in view of the German offensive. The Imperial Warsaw University was evacuated to Rostov in Ukraine. The German military authorities in Warsaw gave the permission to form Polish university and polytechnic. The University of Warsaw was formally inaugurated on November 15, 1915, but its activities were quite limited because of the ongoing war.

The building at 69 Hoża st. in the 1930's

The first part of the new physics building at Hoża Street 69 was officially opened in January, 1921. Its founder, Stefan Pieńkowski (1883-1953), later also the rector of Warsaw University, launched an ambitious program of creating in Warsaw a strong and internationally recognized centre of physics. He started almost from nothing but in a short time succeeded to organize a world-renowned institute of experimental physics.

Theoretical physics at the Hoża centre was initiated by Czesław Białobrzeski (1878-1953), one of the best known Polish theorists. He was the first, in a paper published in 1913, to point out the importance of radiation pressure in the internal constitution of the stars.

Among several renowned Warsaw astronomers one should single out Michał Kamieński (1879-1973), one of the best world experts on cometary orbits, who was director of the Astronomical Observatory in the period 1923-1945. Observational activity was then focused on variable stars. In the 1930-ties the Institute of Experimental Physics of Warsaw University became the largest physics research centre in Poland. It was known as one of the best physics institutes in Europe because of its excellent equipment and research activity. The research concentrated on the then current problems of luminescence and spectroscopy, which was Pieńkowski's area of interest. However, he understood the need of expanding research to other fields. His pupils were sent to England and USA to be trained in nuclear physics, which after the discovery of the neutron in 1932 was gaining importance. Andrzej Sołtan (1897-1959) started to build a small cyclotron, but its construction was disrupted by the outbreak of the war in September, 1939.

Warsaw physicists became hosts of two important international conferences. Nowadays physics conferences are so numerous that every day one may find a meeting somewhere. However, eighty years ago such events were rather rare. On May 20-25, 1936, one hundred forty nine participants from eight countries (Belgium, France, Germany, Latvia, Poland, Rumania, USA, and Yugoslavia) convened in the large lecture hall at Hoża Street 69 for the First International Congress of Luminescence organized by Stefan Pieńkowski. Professor Peter Pringsheim from Brussels, who was elected the president of that Congress, stressed in the opening address that Warsaw, one of the main centres of luminescence studies, became a natural venue for such a meeting. The Proceedings of the Congress (29 papers plus a discussion) filled the whole 431 pages of volume V of Acta Physica Polonica. Czesław Białobrzeski was interested in the foundations of physics. He organized in Warsaw an important international conference "New Theories in Physics" (May 30 – June 3, 1938). The talks and debates concerned quantum mechanics, electrodynamics, theory of relativity and cosmology. Among the participants were Niels Bohr, Leon Brillouin, Louis de Broglie, Paul Dirac, Arthur Eddington, George Gamow, Samuel Goudsmit, Oskar Klein, Hendrik Kramers, Ralph de Laer Kronig, Paul Langevin, Edward Arthur Milne, John von Neumann, Francis Perrin, and Eugene Wigner.

The scale of physics research at the Hoża centre can be well illustrated by the fact that it provided almost forty percent of all papers published by the Polish physicists during the pre-war period.

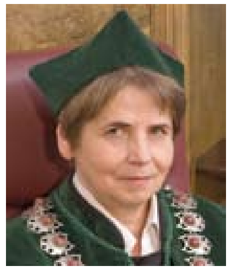
During World War II the astronomical observatory and the physics institute at Hoża were stripped of equipment and then completely destroyed. In 1945, Stefan Pieńkowski, elected the Rector of the University of Warsaw, had once more to start building physics centre at Hoża 69, while Włodzimierz Zonn (1905-1975) took himself to rebuild Warsaw astronomy. Zonn together with Stefan Piotrowski (1910-1985) soon transformed Warsaw Astronomical Observatory into a world-known centre of astrophysics. Its best known results are perhaps the recent discoveries of exosolar planets by the team led by Andrzej Udalski. The historic building of the observatory at Aleje Ujazdowskie 4 at present hosts only the library and offices of astronomers while the observations are done elsewhere, almost entirely at the Warsaw Observatory station Las Campanas in Chile.

The activity of the Institute of Experimental Physics at Hoża had soon expanded into several areas of physics. The building at Hoża 69 was reconstructed and considerably enlarged. Pieńkowski reestablished optical research while his pupils developed studies in other fields. Andrzej Sołtan formed a nuclear physics group. Leonard Sosnowski (1911-1986), one of the pioneers of the research on the *p-n* junction in semiconductors, organized solid state physics group. Marian Danysz (1909-1983) and Jerzy Pniewski (1913-1989) started elementary particle physics group and in 1952 discovered hypernuclei, which many regard as the most important discovery in post-war Polish physics. New research groups in biophysics, medical physics, and geophysics were organized. Among the recent successes one should mention experimental discovery, in 2002, of the two-proton radioactivity by the Polish-French team led by Marek Pfützner.

Theoretical physics at Hoża begun to be rebuilt by Białobrzeski, together with Wojciech Rubinowicz (1889-1974), known for his discovery, in 1918, of atomic selection rules has joined in rebuilding theoretical physics at Hoża. But the Institute of Theoretical Physics at Hoża had been formally founded and greatly expanded by Leopold Infeld (1898-1968), well known because of his collaboration with Albert Einstein. Infeld's own interest was mainly in the theory of relativity. However, he understood well that theoretical physics had to be developed along a broader front. Jerzy Pniewski recalled in his memoirs that Infeld once told him: "I am not an expert in your elementary particles, atomic nuclei or semiconductors, but I am able to recognize talented young people who will be send for training in the leading physics centres, so that after their return to Warsaw, all these branches of theoretical physics would be developed in our institute." Infeld's vision was indeed right. The Institute of Theoretical Physics soon greatly expanded. New groups have been formed of theorists engaged in research in atomic physics, nuclear physics, elementary particles, and condensed matter. It supplemented traditional topics such as classical and quantum field theory, mathematical physics, and statistical physics.

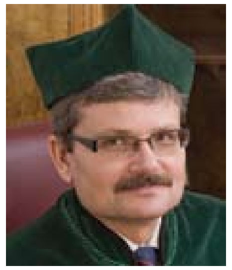
Structure of the Faculty

Faculty authorities



prof. dr hab. Teresa Rząca-Urban, Dean of the Faculty of Physics

dr hab. Andrzej Wysmołek, Deputy Dean, student affairs



dr hab. Dariusz Wasik, prof. UW, Deputy Dean, finance and faculty expansion

prof. dr hab. Marek Trippenbach, Deputy Dean, research and international collaboration

Institutes and other units

Institute of Experimental Physics

Director:
dr hab. Tomasz Matulewicz, prof. UW
Address: ul. Hoża 69, 00-681 Warszawa
http://ifd.fuw.edu.pl/

- Section of Biophysics
- Section of Particles and Fundamental Interactions
- Section of Physics Teaching Methodology
- Section of Biomedical Physics
- Section of Solid State Physics
- Section of Nuclear Physics
- Section of Optics
- Section of Condensed Matter Structure
- Section of Nuclear Spectroscopy
- Demonstration Laboratory
- Library

Institute of Theoretical Physics

Director:
prof. dr hab. Marek Napiórkowski
Address: ul. Hoża 69, 00-681 Warszawa

- Department of Condensed Matter Physics
- Department of Quantum Optics and Atomic Physics
- Department of the Theory of Particles and Elementary Interactions
- Department of the Theory of Strong and Electroweak Interactions
- Department of the Theory of Relativity and Gravitation
- Department of the Theory of the Structure of Atomic Nuclei
- Laboratory of Computer Physics
- Wojciech Rubinowicz Library

Institute of Geophysics

Director:
dr hab. Hanna Pawłowska, prof. UW
Address: ul. Pasteura 7, 02-093 Warszawa
http://www.igf.fuw.edu.pl/igf/

- Section of Atmospheric Physics
- Section of Litosphere Physics
- Section of Information Optics
- Library

Astronomical Observatory

Director:
prof. dr hab. Andrzej Udalski
Address: Al. Ujazdowskie 4, 00-478 Warszawa
http://www.astrouw.edu.pl/

- Section of Extragalactic Astronomy
- Section of Theoretical Astrophysics
- Department of Observational Astrophysics
- Ostrowik Observatory Station

Department of Mathematical Methods in Physics

Head:
dr hab. Jacek Jezierski, prof. UW
Address: ul. Hoża 74, 00-682 Warszawa
http://www.fuw.edu.pl/KMMF/

Directions of Research

Institute of Experimental Physics

Physics is an experimental science – the ultimate test of all theories devised amongst clouds of chalk dust and the glow of computer monitors is provided by observing the surrounding reality. Measurement. Experiment. Experience.

Our task at the Institute of Experimental Physics is to acquire knowledge about the Universe at all scales, from the observation of gamma-ray bursts originating in distant galaxies, through the study of signals emitted by the human brain, research on the structure and functions of living cells and the organic molecules they are built of, to studies on the most elementary components of matter. Much of this work is carried out with the aid of unique instruments which we design and build ourselves, as progress in science is often pushed forward by new, increasingly precise, subtle and swift methods of measurement and data analysis, which were not available to previous generations of scientists.

The Institute is composed of ten Sections, whose research jointly covers nearly all of modern physics: structural research, biophysics, biomedical physics, the physics of elementary particles and fundamental interactions, solid state physics, the physics of atomic nuclei and nuclear spectroscopy, optics, and teaching of physics.

The Cosmos

“Pi of the Sky” is a robotic telescope built to search the sky for optical bursts originating in outer space. The main objective of our search is to observe the most cataclysmic cosmic events known, the so-called Gamma-Ray Bursts (GRB). These mysterious explosions in outer space are brief, lasting between fractions of a second and a few dozen seconds, but their energies exceed that emitted by our Sun throughout its entire lifetime. We suspect these events to be a signal of the birth of black holes, originating from the collapse of massive stars or the fusion of two neutron stars.

The instruments making up “Pi of the Sky” were designed and built entirely in Poland by a team of scientists, graduate and undergraduate students from institutions of higher education and research in Warsaw, in collaboration with Polish firms. For the last five years the prototype and fully automatic “Pi of the Sky” device has been operating at the Las Campanas Observatory in Chile, alongside the Polish-made telescopes OGLE and ASAS.

On March 19, 2008 our telescope registered the brightest optical burst ever observed by Man, originating from a distant part of the Universe. The same event was simultaneously observed in the gamma-ray spectrum by the Swift satellite, which allowed it to be identified as a gamma-ray burst, designated as GRB 080319B. The burst was visible to the naked eye for 40 seconds, even though it originated 7.5 thousand million light years away, and it took more than half of the age of the Universe for the light we registered to reach us.

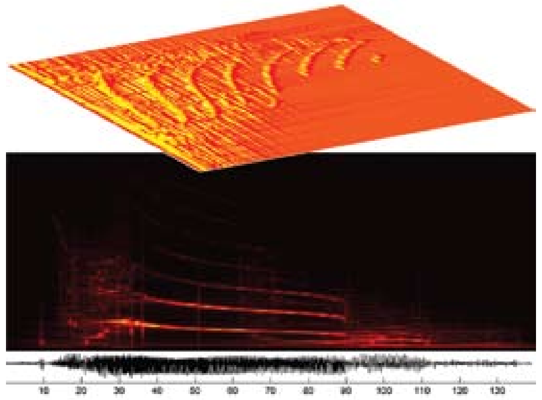
The detector in Chile is a prototype of a larger device which is currently under construction. To

Las Campanas Observatory in the Atacama Desert, Chile increase the odds of observing further bursts, we will use 24 cameras to continuously scan a quarter of the visible sky. We hope that observing a greater number of optical signals of GRBs will allow us to learn more about the mechanism of their origin.

Human – Brain – Computer

One of the greatest challenges of the 21st century is to learn about and understand the operation of the most important instrument of cognition, in use since the origins of science: the human brain. The significance of neuroinformatics as a new field which integrates all theneurosciences within the framework of the methodology of the physical sciences, was underlined by the establishment of the International Neuroinformatics Coordination Facility, with the active participation of our **Section of Biomedical Physics**.

A new area of study we have developed is that of brain-computer interfaces (BCI). Such systems are the only means of communication with the surrounding world for individuals with the so-called locked-in syndrome, such as was the case of the author of The Diving Bell and the Butterfly. A computer reads simple intentions from the brain voltages registered on the surface of the skull (EEG) and transforms them into commands to external devices, even making it possible to write texts without the use of a keyboard or any muscular movements – exclusively with the brain. Significant advances obtained in the analysis and modeling of the brain's electrical activity and other biosignals allowed us to join the forefront of research in BCI. We work together with the leading research centers in Poland and



An epileptic seizure, as registered by an intracranial electrode

abroad: the Medical University of Warsaw, the Johns Hopkins School of Medicine, the Harvard Medical School and the University of Amsterdam.

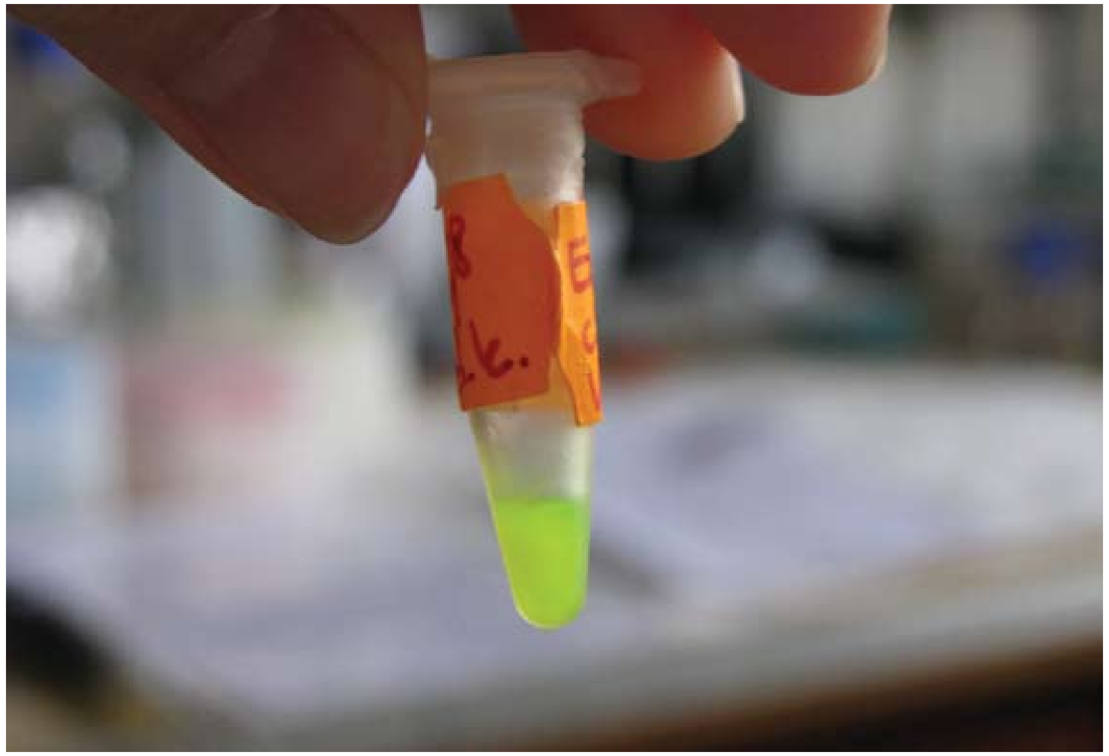
Projects currently under way include: work on the spatial localization of the origins of epileptic seizures based on surface EEG (joint work with the Children's Health Center in Warsaw and Fraunhofer FIRST); joint registration of EEG and fMRI signals for the study of states of minimal awareness (in collaboration with the Cyclotron Research Center at Liege); the analysis of magnetoencephalographic (MEG) signals (together with the Leibnitz Institute for Neurobiology); construction of automated systems of sleep analysis; the analysis of otoacoustical emissions (OAE); modeling of the brain's electrical activity; and finally, the development of mathematical methods of signal analysis. Other neuroinformatic projects include an XML-based metalanguage for the description of the structure of digital time series – SignalML; the first Polish neuroinformatics portal (http://eeg.pl); the world's first open project in brain-computer interfaces; and the world's first open system for markup, analysis

and registration of EEG – Svarog (Signal Viewer, Analyzer and Recorder on GPL).

The cell

Experimental and theoretical research on biomolecules, including proteins, nucleic acids and other compounds with potential chemotherapeutic properties is developed in the **Section of Biophysics**. Through an integrated and interdisciplinary approach to the problems being analyzed we attempt to understand the processes within living organisms at the molecular level. We analyze molecules and their interactions within functional complexes through the use of chemical and biological techniques (genetic engineering), methods of molecular spectroscopy, mass spectrometry, calorimetry and X-ray diffraction. To understand the mechanisms through which molecules affect the cell we employ quantum computation and computer methods of molecular dynamics, molecular design and bioinformatics. An important element of our research is collaboration with leading institutions both in Poland and abroad.

An important achievement by scientists at the Institute of Experimental Physics was the design, synthesis and patenting of analogs of mRNA 5' cap, including hydrolysis-resistant enzymes which degrade RNA inside the cell. The new analogs are a valuable instrument for the molecular mechanisms of action of proteic factors we have developed – such as the initiating factor eIF4E which is the key to the biosynthe-



The green fluorescent protein GFP

sis of proteins, and the multifunctional nucleic protein CBC, as well as in biotechnology, in the search for vaccines against cancer.

One of the key problems in molecular biophysics is that of the mechanisms of pH-dependent processes. The genomes of living organisms have developed in the course of evolution in such a way as to maintain, within the inner-cellular organelle, a value of pH suitable for the processes that take place there. One of our most recent achievements was the development of a theoretical method to compute the free energy in the processes of protein folding and unfolding, and protein-protein and protein-ligand association, taking into account protonation degrees of freedom of titrative groups. The search for mechanisms of enzymatic catalysis through proteins of the purine nucleoside phosphorylase (PNP) family is of utmost importance to the study of the immune system. The techniques of protein crystallization developed in the Section of Biophysics have allowed the X-ray diffractive structure of enzymes derived from various organisms in complexes with inhibitors to be determined.

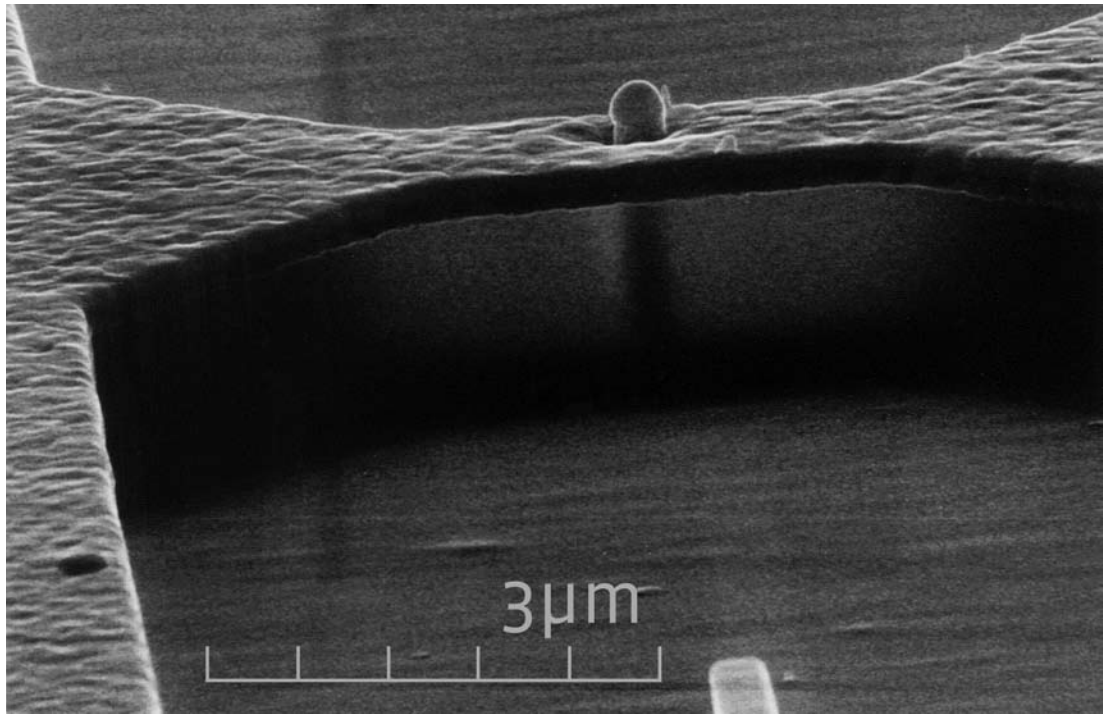
Biomolecular and subcellular systems are highly complex, and their description – which leads to an understanding of the logic according to which they function – is formulated with the aid of mathematical methods, computer modeling and bioinformatics. We develop models that employ methods of molecular quantum mechanics, statistical physics and systems theory, in particular, methods of analyzing the causality of phenomena based on the theory of signal analysis. We also carry out methodological research concerning the physical processes related to the interaction between particles and electromagnetic radiation – the basis of spectroscopy. We have developed a new model that describes the disactivation of excited electron states in molecules and complexes thereof. This model, an alternative to the multiexponential description of the decay of fluorescence, assumes a continuous distribution of lifetimes, described by the so-called power-like Tsalis q-exponential function.

Crystals

Two Sections, **Solid State Physics** and the **Structure of Condensed Matter**, carry out work on a wide range of problems in condensed matter physics, with particular attention to the properties of materials and semiconducting structures, suitably designed and produced often under extreme conditions.

One such material is graphene, a recently discovered crystalline variety of carbon. As a result of the ordering of atoms in a single layer, a material of highly unusual properties is obtained: excellent electrical and thermal conductivity, simple to produce at low cost. Currently the properties of graphene are being studied in the Section of Solid State Physics, from spectroscopic experiments to electrical characteristics. It may well be that a new generation of computer processors will mark the beginning of a new Age of Carbon in the history of civilization.

Another area of great interest is the work being carried out on semiconducting nanostructures, such as quantum wells, wires and quantum dots. Due to dimensions on the scale of nanometers, these structures exhibit some unusual properties, not observed in bulk materials. Quantum



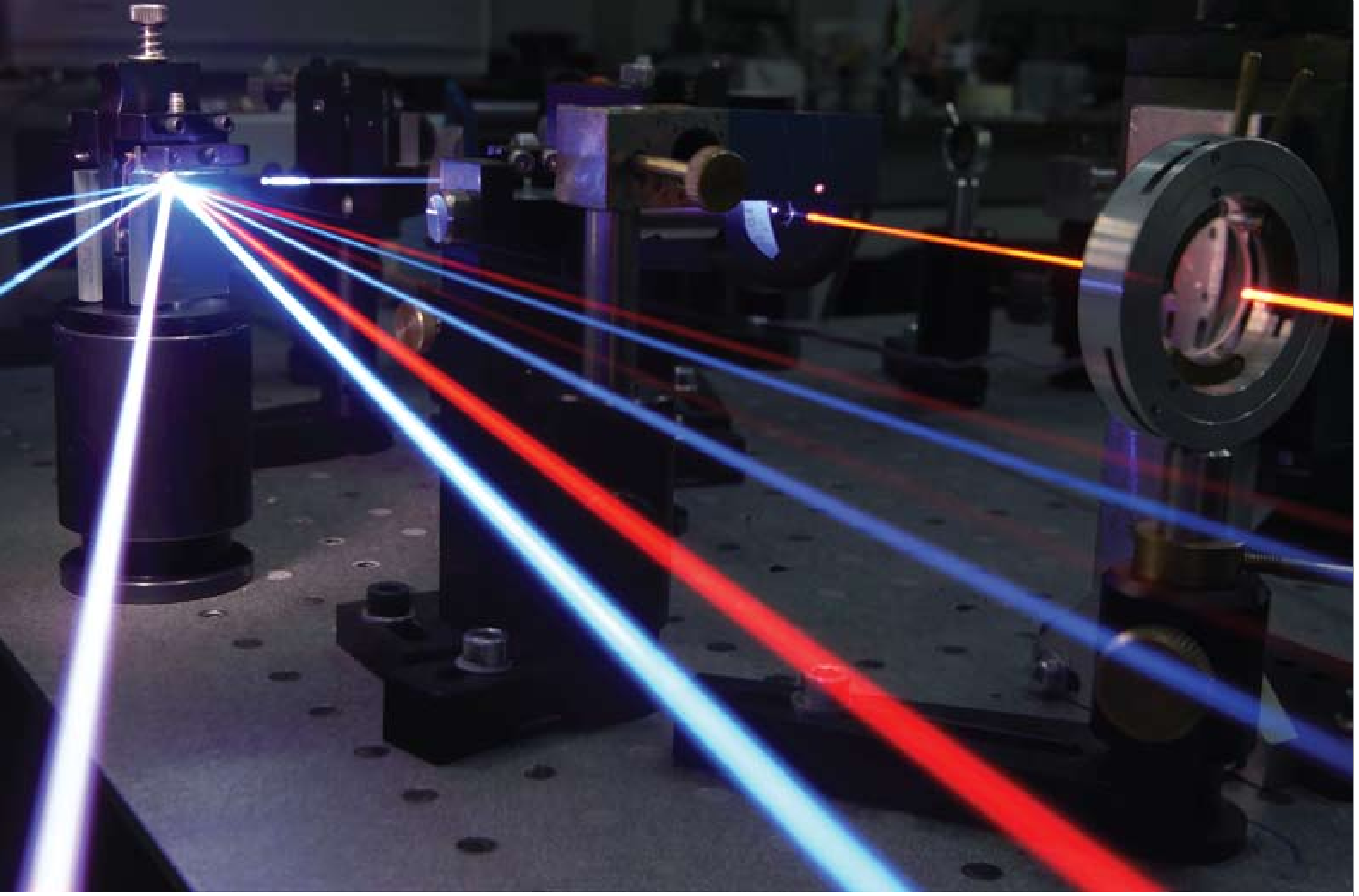
A nano-pole of 300 nm width, with a surrounding band serving as electrical contact

dots in particular open entirely new prospects in electronics and information technology: they allow for the storage, processing and retrieval of information in quantum form. Studies of such single dots under extreme conditions of low temperatures and strong magnetic fields, with femtosecond temporal resolution, are under way at the Laboratory of Ultrafast Magnetospectroscopy of Semiconducting Nanostructures. Quantum dots are a serious candidate for an efficient source of single photons, which is needed if we want to consider applications of the latter in the optical processing of information.

In the Laboratory of Quantum Physics of Transistors and the Far Infrared we are conducting research on the interaction between terahertz-frequency electromagnetic radiation and field transistors and other devices based on two-dimensional superconducting structures. Among the cases being studied are transistors of sizes of the order of a few dozen nanometers at very low temperatures and in strong magnetic fields; these may find application as sources and detectors of terahertz-frequency radiation, a spectral region which is currently under intense study.

Atoms and molecules

Light provides a perfect means to study atoms and the molecules they form. The radiation from highly stable lasers, and ultra-short laser pulses, are employed in the **Section of Optics** in the study of the structure and dynamics of simple



Generation of the second harmonic in a nonlinear crystal from a laser beam emitted by an amplifier of ultrashort laser pulses

molecules. Our tools are built and constantly developed by the Laboratory of Ultra-fast Processes: lasers that emit pulses of a duration of tens of femtoseconds, including new generation lasers based on crystals and optic fibers with ytterbium admixtures. With the aid of such brief pulses of light it is possible to study the details of chemical reactions, as well as to control such processes. The extremely high intensity light available in femtosecond laser pulses, such as those produced by the TW (terawatt) class amplifier designed and built in collaboration with the Center of Lasers at the Institute of Physical Chemistry of the Polish Academy of Sciences, opens up the fascinating area of nonlinear optics. The LUP group, in collaboration with researchers at the University of Oxford, has in addition made a significant contribution to the development of new techniques for measuring the briefest pulses of light.

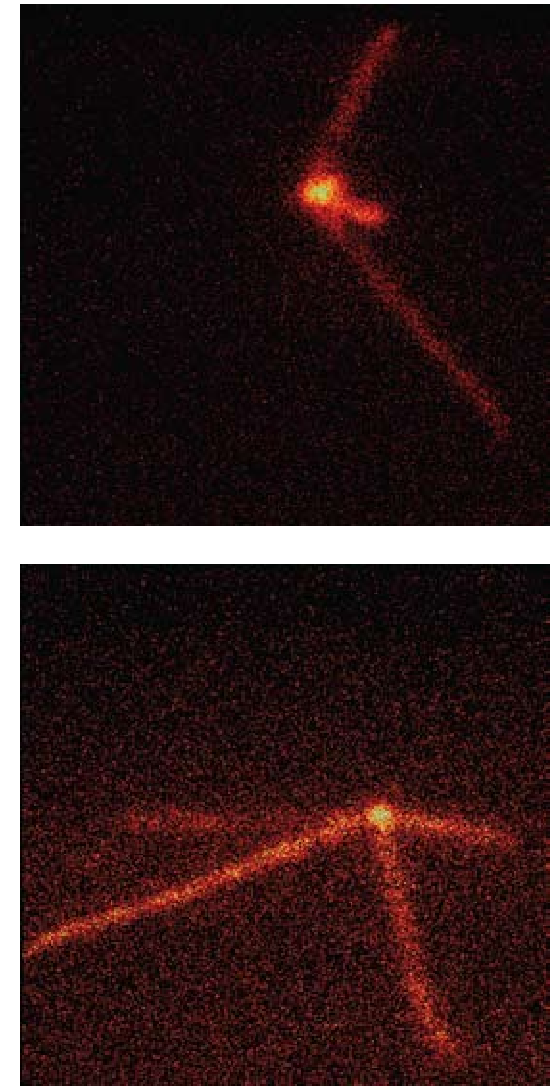
Laser pulses of lower intensity are employed in environmental research: by registering the scattering of light on clouds, we are able to follow processes taking place in the atmosphere and, after retuning our devices, to detect pollutants originating from factory chimneys. One laser lidar (optical radar), deployed on an automobile, enables field research to be carried out.

At the Laboratory of Spectroscopy of Intermolecular Interactions we study the optical spectra of diatomic molecules, gathering data needed to test advanced theories of quantum physics and chemistry. Work on the technology of ultra-cold molecules, including the development of a molecular condensate, creates a growing demand for precise spectroscopic data on molecules of

the alkalinemetals; our experiments provide such data.Recently, we have also been developing research in the field of experimental quantum optics. Here, rather than extreme light intensities it is single photons that are of interest. The ability to create, transform and measure subtle quantum states of electromagnetic radiation leads to a greater understanding of the nature and utility of light. Although optical computers remain within the domain of dreams, we are already able to build some of their elements (logic gates), quantum memories, and we are working on dedicated algorithms for such devices. Cryptographic systems, immune to eavesdropping, based on q-bits – photons that carry information encoded in their state of polarization – are already a reality.

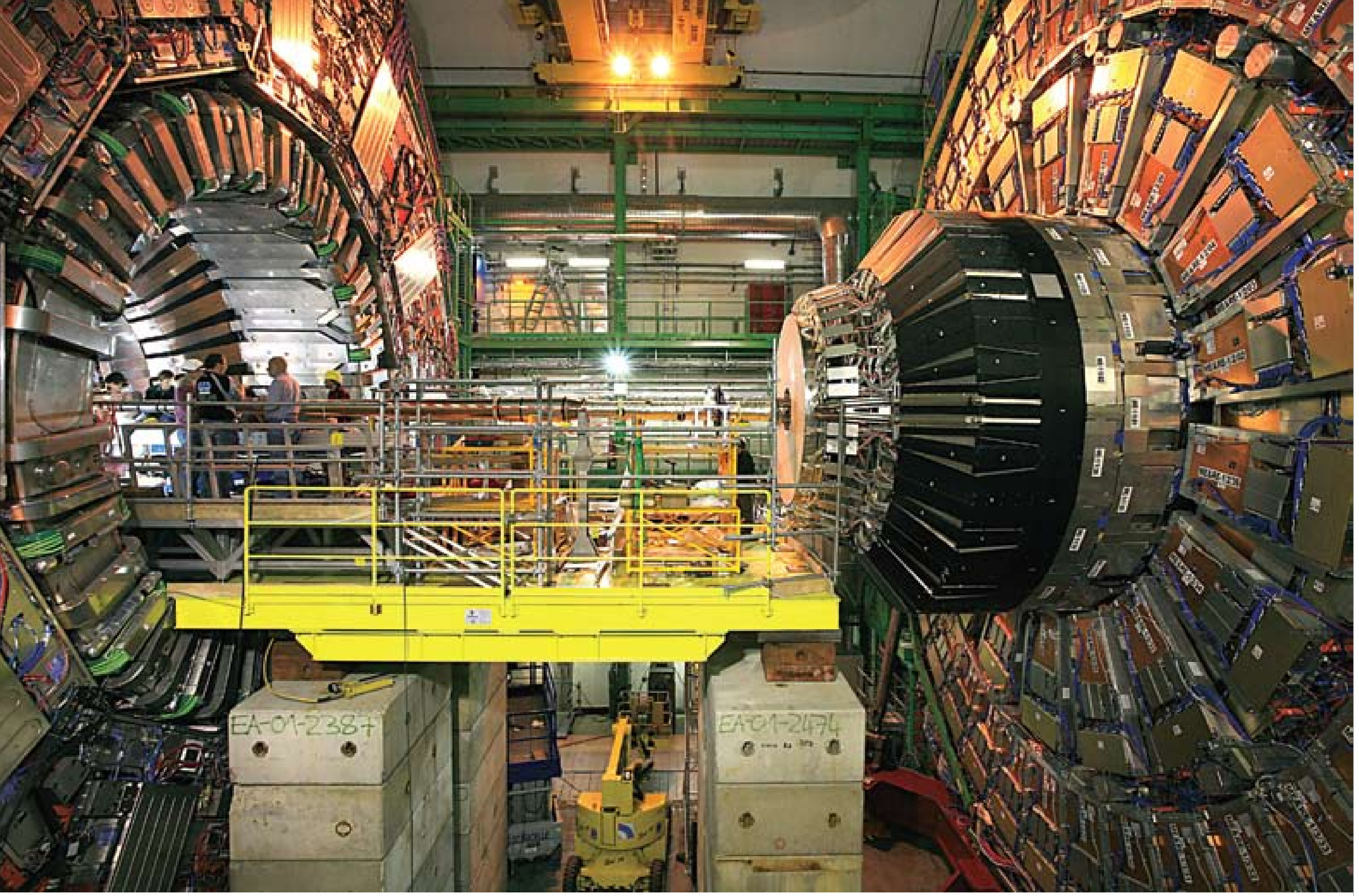
Atomic nuclei

Research in the Sections of **Physics of Atomic Nuclei** and of **Nuclear Spectroscopy** concerns experimental nuclear physics. We are working to understand the matter that surrounds us and striving to explain a number of fundamental questions, such as the age of the Universe, the origin of the elements that make up cosmic matter, the limits of the chart of the nuclides and whether it is possible for stable superheavy elements to exist. We produce and study atomic nuclei that are not found in nature. We study their structure and properties by observing transitions between their states and the nuclear radiation emitted during these transitions. Our experiments are carried out at the world's leading laboratories, such as CERN in Switzerland, GSI Darmstadt in Germany, or Oak Ridge and NSCL/MSU in the USA. We also employ the cyclotron at the University of Warsaw Heavy Ion Laboratory.



Exotic decays of the iron isotope ^{45}Fe

We are also interested in the properties of nuclear matter in states of various temperatures and densities. The objects of our research are produced in nuclear reactions induced by beams of heavy ions, accelerated up to relativistic energies. We also employ beams of radioactive ions, which allows us to produce nuclei that differ greatly from those already known to exist.



The CMS detector at CERN

The products of these reactions are registered using the most modern detector systems – we are among the pioneers of the application of modern digital technology to nuclear measurements. One important and interesting result we have recently obtained was the discovery and measurement of two-proton radiation by the nuclide ^{45}Fe. Our field is also of considerable practical significance, finding applications in the energy industry, medicine, archaeology, geology and materials technology, among others.

Elementary particles

In the **Section of the Physics of Particles and Fundamental Interactions** we reach into known matter to the greatest possible depth. In order to answer questions concerning the elementary constituents of the Universe and the laws they obey, we employ research devices which are certainly not some of the smallest. Quite the contrary: huge detectors surround the areas where particles accelerated to nearly the speed of light collide in experiments conducted at international high energy laboratories: CERN in Geneva, and DESY in Hamburg.

The world of tiny objects evades our imagination: for many years we have striven to understand the origin of the spin of the proton – it turns out that the spins of its constituents, quarks and gluons, contribute only a tiny part of the known value, s=1/2. The so-called mystery of the proton's spin is one the most current questions in particle physics. This enigma was uncovered 20 years ago by chance, by physicists at CERN, and

has given rise to a torrent of experimental and theoretical studies. Our group at the Institute of Experimental Physics has been a part of this struggle since the beginning.

We played a significant part in building and putting into operation the CMS detector at one of the most complex research instruments ever built, the LHC accelerator (Large Hadron Collider). Physicists and engineers from Warsaw designed and built the element of the CMS detector that rapidly determines whether the interaction of two protons accelerated by the LHC registered at a given moment by the detector is interesting from the point of view of the current issues of particle physics. By such means we hope that from the extremely large number of collisions we will be able to register those that present evidence of the existence of the Higgs particle (by interaction with which other elementary particles obtain their mass), or of the existence in nature of a new kind of symmetry (supersymmetry).

We are also engaged in the study of neutrinos – along with photons the most common particles in nature, but difficult to observe. Traces of their interactions are registered in huge detectors placed hundreds or thousands of meters underground. In such laboratories we have already observed neutrinos from the Sun, from a supernova in the Large Magellanic Cloud, and from huge cosmic ray showers in the atmosphere. We also study the effect of neutrinos changing their identity after traveling hundreds of kilometers below the Earth's surface, in experiments that make use of neutrino beams from accelerators in the USA, Japan and Switzerland. Understanding the properties of these highly peculiar particles should bring us closer to knowing the origin of the asymmetry between matter and antimatter in the Universe.

As important as well-equipped laboratories are to the growth of science, of equal importance is the influx of young workers, whose enthusiasm and new ideas stimulate the activity of any research group. The **Section of Physics Teaching** specializes in issues related to the process of teaching of physics and the training of teachers; in particular, we emphasize that the learning of physics should not be confined to solving problems by rote, but instead should already become in schools a fascinating cognitive adventure.

Cathodoluminescence

Institute Of Theoretical Physics

The spectacular advances in physics which we have witnessed in the last century were due to the parallel development of experiment and theory. In many areas, such as the physics of elementary particles, it is hardly possible to carry out experiments at all without a theoretical description; on the other hand, experimental results are always the ultimate test of any theoretical hypothesis.

The Institute of Theoretical Physics of the University of Warsaw Faculty of Physics is the largest institute of theoretical physics in Poland. The scope of research carried out at the Institute includes all areas of modern physics: from the smallest scales of elementary particle physics, through nuclear physics, atomic physics, quantum optics, statistical physics and solid state physics, up to the largest scales described by the theory of gravitation, astrophysics and cosmology. In recent years we have witnessed an increasing unification of research methods and areas, with all fields exploiting quantum and statistical physics. For example, while astrophysics and cosmology are of course based on the theory of gravitation, they could no longer exist without the theory of elementary particles and nuclear physics; meanwhile, particle theory draws copiously from astrophysical and cosmological observations, etc. The division of the Institute into Departments has historical roots and in many cases does not fully reflect the actual mixing of research methods and problems studied, as these are often common to several Departments, an example being the violation of the fundamental symmetries. The exchange of Z0 bosons between a nucleus and electrons, described by the Standard Model of elementary particle physics, violates the symmetry of parity, leading to asymmetries in the interactions between light and atoms, a subject which is part of atomic physics. On the other hand, in view of the strong dependence of this asymmetry on the properties of nuclei, it is also a subject of study for nuclear physicists.

The elementary particles

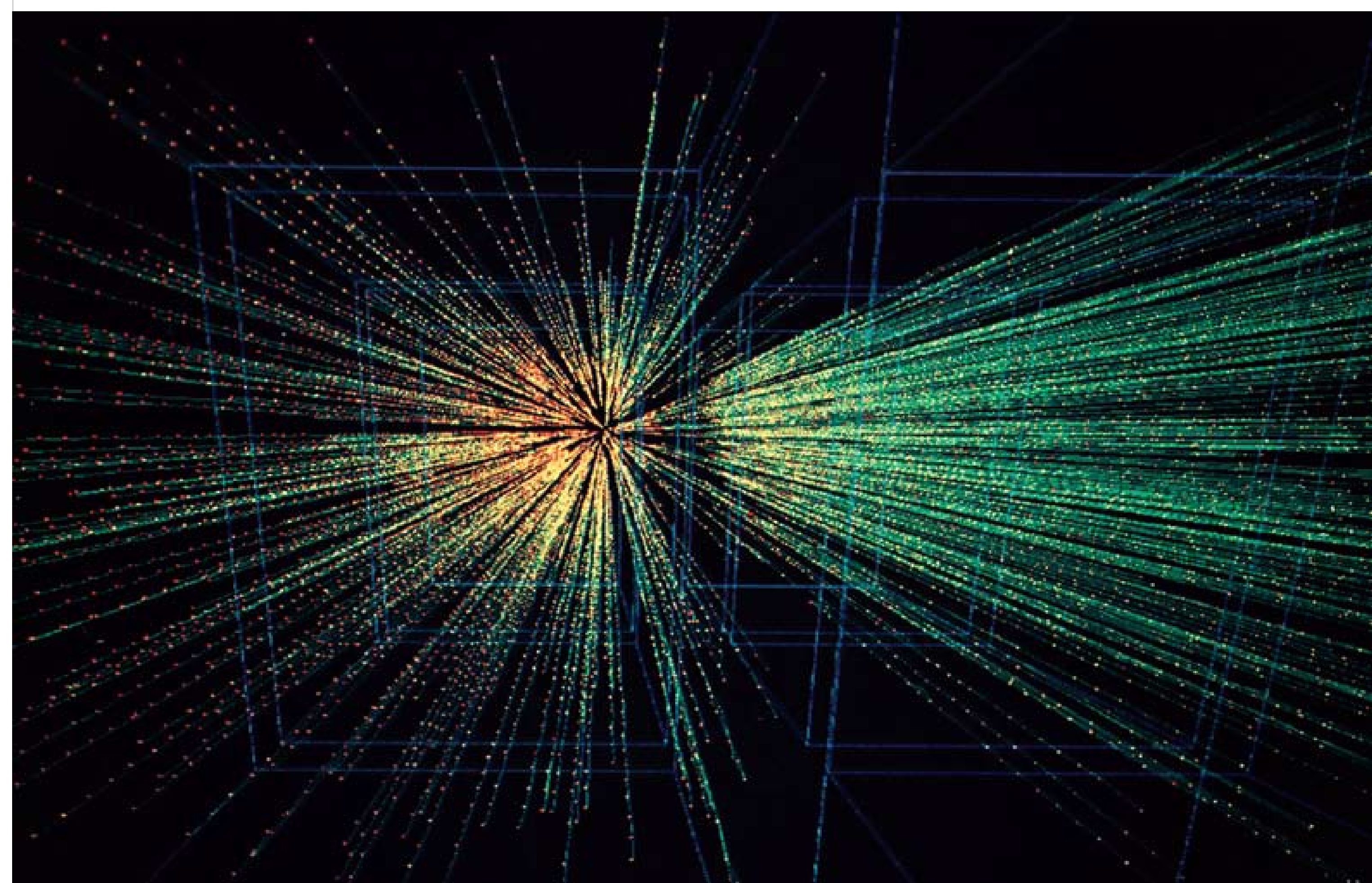
Research carried out at ever smaller scales: the discovery of atoms, photons, atomic nuclei and electrons, has led to the appearance of a field which describes the world on the deepest known level, namely, the theory of elementary particles. About forty years ago a theory known as the Standard Model was formulated, and it describes all known interactions (other than gravity) to a fantastic precision, providing a coherent description of them results of experiments carried out up to the present time, including accelerator experiments and observations of cosmic radiation. However, we already realize – interestingly, not from observation but on the basis of purely theoretical arguments – that this theory becomes inconsistent at higher energies, and on scales even smaller than those currently being studied (about 10^{18} m) it must be replaced by another, as yet unknown theory.

Research activity in the **Department of Particle Theory and Elementary Interactions**, and in the **Department of the Theory of Hadrons and Leptons**, is mainly devoted to searching for this new theory. For a long time research effort concentrated mainly on string theory, regarded as the most promising candidate for a theory that would unify the Standard Model with the

theory of gravitation. At present it seems that our mathematical methods do not yet suffice to confirm these expectations, although string theory continues to provide inspirations, such as the AdS/CFT conjecture, and it continues to be developed. However, most efforts are concentrated on quantum field theories that generalize the Standard Model and on obtaining predictions that would allow them to be verified experimentally, mainly at the LHC accelerator recently put into operation near Geneva.

The main directions of this search are the so-called supersymmetric theories, both those with global supersymmetry and local supersymmetry (supergravity), with the supersymmetry being invisible (broken) at low energies, but at high energies leading to the existence of supersymmetric partners of all known particles: selectrons, squarks, photinos, gluinos, etc. Scenarios for supersymmetry breaking at a scale achievable by the LHC have been studied for many years, and our Institute is well known for its activities in this field. Another proposal is the so-called conformal symmetry, which also provides a simple and consistent extension of the Standard Model, while predicting only a few new particles. An important field of activity is the physics of planned future accelerators. One further independent area is the study of the physics of heavy quarks via advanced calculations of decay rates, e.g. of the b quark.

Collision with a lead ion (LHC)



A highly important area of research at the Institute is the physics of elementary particles applied to cosmology. It is no longer possible to makeprogress in cosmology without involving the theory of elementary particles; at the same time, particle theory increasingly makes use of cosmological observations, as e.g. the history of the Universe is highly dependent on the particles it is composed of, and on their interactions. One highly sensitive indicator is given by the initial composition of the Universe, i.e. the abundances of light nuclei directly following primordial nucleosynthesis. A yet unsolved problem is that of baryogenesis: explaining the excess of matter over antimatter in the Universe. Known physical sources of such an asymmetry lead to an excess much smaller than that actually observed. Certainly, even more attention will be devoted to research in this area in the future.

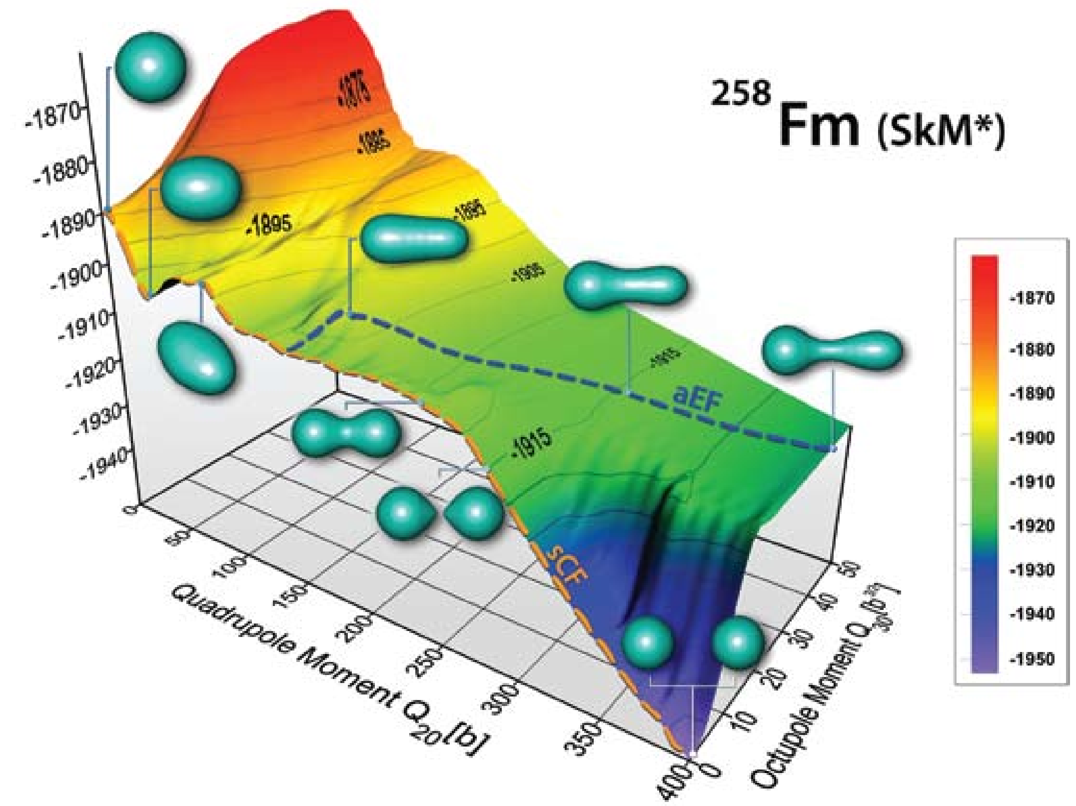
An important element of our research activity is provided by issues related to the Standard Model. Even though this theory has been known for over forty years, many problems still remain unsolved – an example being the description of the proton, or more generally of bound states in strongly interacting field theories. This is caused by the lack of mathematical methods needed for non-perturbative quantum field theory – one approach that has been proposed is known as quantum chromodynamics on the light cone.

Nuclear physics

Research in the **Department of the Theory of the Structure of Atomic Nuclei** is concentrated on two main subjects: the physics of exotic nuclei and the physics of rapidly rotating nuclei. This research is mainly based on the density functional method, which allows one to describe the global properties of nuclei irrespective of their atomic number or mass number.

Atomic nuclei display features characteristic of complex multi-fermion systems. They are bound by internal interactions and display features typical of both single-particle dynamics and collective motion, plus a wide spectrum of intermediate effects. Atomic nuclei exist due to the strong interaction, but are in fact rather weakly-bound systems and therefore often display some of the features of open quantum systems. This is in particular apparent for weakly-bound exotic nuclei, far from the valley of stability. Such nuclei carry a large excess of neutrons over protons, or vice versa, leading to interesting effects related to the continuous spectrum of particles. In the case of neutron-rich nuclei inhomogeneous neutron clusters far from the center appear, altering the shell structure of such nuclei. Among proton-rich nuclei, we observe spontaneous single-proton and two-proton emission, and predict fascinating effects related to proton-neutron pairing. Through beta decays, exotic nuclei of this type create an opportunity to study the parameters of the fundamental interactions within the Standard Model (the Cabibbo-Kobayashi-Maskawa angles of the quark mixing matrix).

Rotation of the atomic nucleus is an obvious case of collective motion of a bound state of many particles. The interaction between the centrifugal force and the internal structure of the nucleus enables us to study in detail even effects of small magnitude. The rotation may, for instance, induce octupole deformation of the nucleus, which then assumes a pear-like shape. It is also possible to observe so-called chiral rotational bands, where spin states within the nucleus may occur in a left- or right-chiral configuration. Nuclear rotation plays a role similar to that of magnetic fields in crystals, allowing one to study unusual configurations with respect to the breaking of time-reflection symmetry.

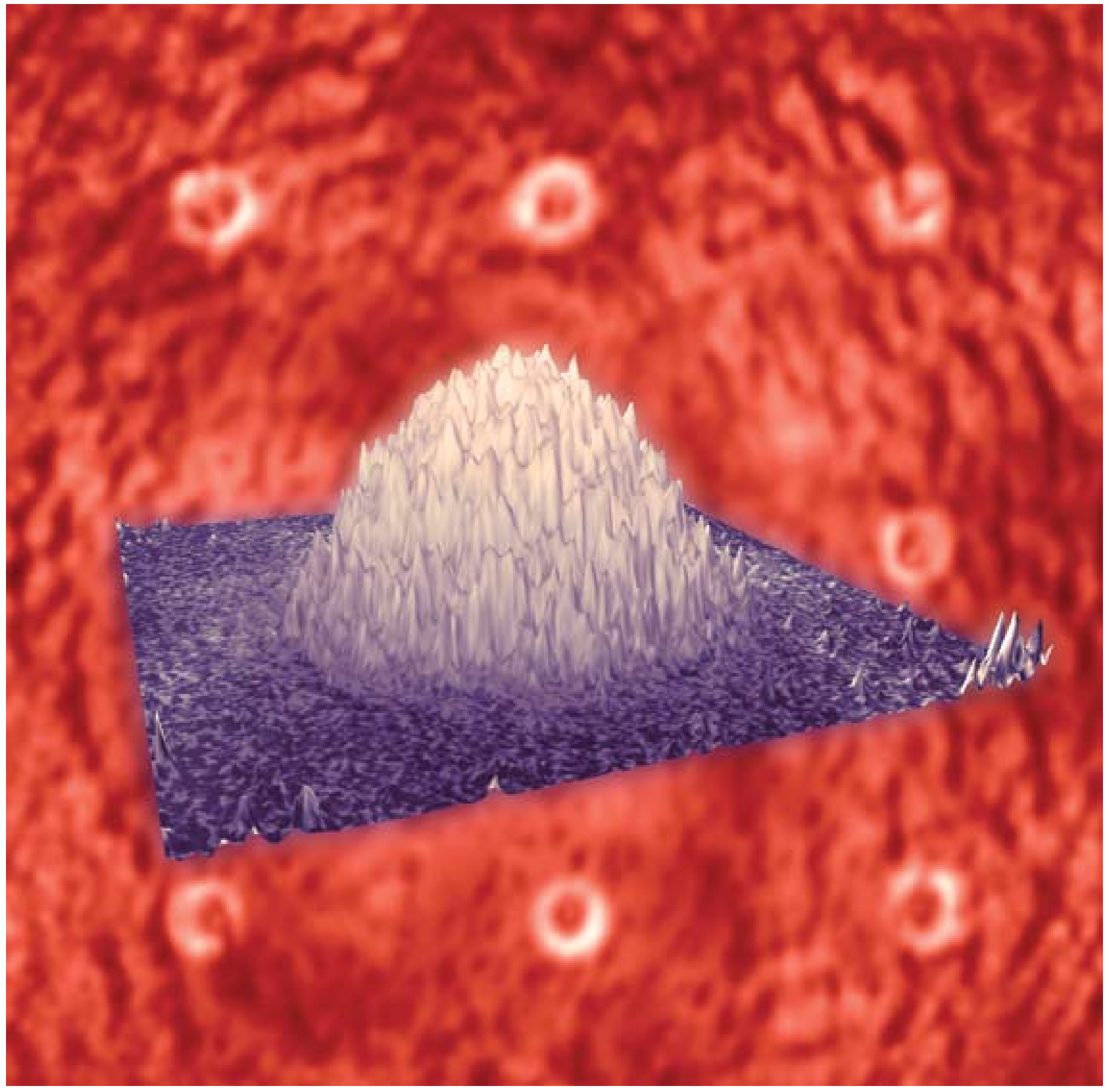


Fission of a fermium nucleus

A new method of theoretical study of atomic nuclei consists of employing multiprocessor computer systems, which allow for parallel calculations of many nuclei at once. By solving self-consistent equations we may obtain in a short time an entire map of the nuclides. This makes it possible to search for improved density functionals, with better fitted coupling constants. Currently, we are seeking functionals accurate enough to reproduce the known spectroscopic data to high precision, while also predicting the properties of nuclei that have not yet been studied experimentally.

Atoms and light

Research in this area carried out in the **Department of Quantum Optics and Atomic Physics** encompasses three fields: quantum optics, the theory of ultracold atoms (Bose-Einstein condensates) and coherent matter waves, the theory of interactions between very high intensity laser


Artist's depiction of matter waves – illustration made at Immanuel Bloch's group in Mainz

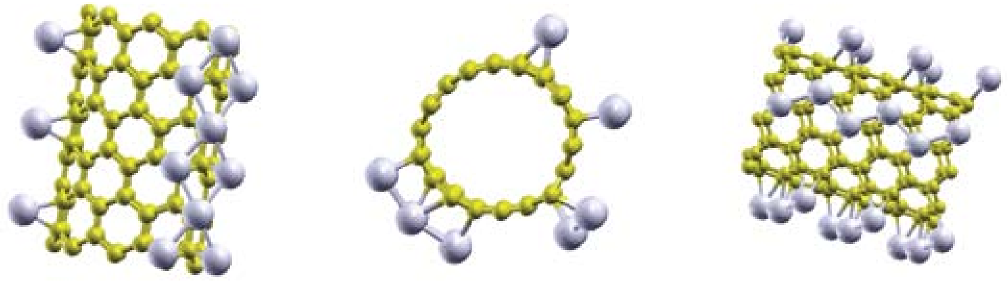
beams and atoms, and high precision calculations of the structure and properties of atoms in order to verify the predictions of the quantum theory of electromagnetic interactions and to determine the values of the fundamental constants.

Quantum optics deals with effects in optical and atomic systems that result from the coexistence of wavelike and corpuscular properties in the micro-world. The continuous advance of experimental techniques has led to previously unimaginable possibilities of isolating and controlling single atoms and photons, which allow us to study the quantum world in a direct manner. Such research, both experimental and theoretical, has highly important consequences for the technologies employed in computing and telecommunications. The standard approach to encoding information makes use of distinguishable (classical) states of physical systems. Meanwhile, quantum mechanics indicates that there exist states with no classical equivalent – superpositions of quantum states – which open entirely new possibilities. By making use of quantum correlations, we may for instance increase the throughput and security of optical telecommunication lines, or create entirely new and radically faster computational algorithms.

One of the media where these ideas may potentially be realized is provided by ultracold atomic gases. At microkelvin temperatures atoms display collective behavior, forming coherent matter waves reminiscent of a laser beam. This research has led to the appearence of a new area of physics, called atom optics.

Another direction of research is the description of physical effects in high intensity laser beams. This subject is being developed in Europe, where plans have been drawn up for the construction of new sources of such beams: ELI (Extreme Light Infrastructure), HiPER (High Power Laser Energy Research Facility), and FLASH (Free-electron LASer in Hamburg). Research in the Institute of Theoretical Physics concentrates on fundamental processes in strong laser beams, where nonlinear effects play an important role (eg. the ponderomotoric force which causes a drift of the oscillating particles towards an area of weaker field), Compton and Moeller scattering, photoionization, or the generation of higher harmonics. An independent area of study concerns the possibility of controlling and driving classical and quantum processes by external electromagnetic fields, an important issue for astronomy, quantum information, spintronics, nanophotonics and other fields. Also of importance is the possibility of enhancing or suppressing the decay rates of quantum states (in atoms, molecules or semiconductor heterostructures) by applying strong electric, magnetic or laser fields.

In the Department of Quantum Optics and Atomic Physics precise calculations of the quantum properties of atomic systems, such as their energy levels, coupling to magnetic fields, or the influence of weak interactions (Z0 bosons) on the violation of parity invariance in atoms are performed. This requires a variety of subtle interactions between electrons and the nucleus, relativistic corrections, electron self-interactions, and vacuum polarization to be taken into account, and our Institute is a world leader in this area. Even for atoms with a small number of electrons, the mere statement of the problem (determining the Hamiltonian) and the numerical calculations are highly advanced and often require nontrivial computational methods, often jointly with symbolic computations. The final comparison between calculations and experimental data – interestingly enough, theoretical calculations are often ahead of experimental results or display a higher precision – allows us to determine the values of the physical constants, and to study and verify the quantum theory of electromagnetic interactions. Work done at our Institute in this field has been recently rewarded by a "Precision Measurement Grant" from the National Institute of Standards and Technology, USA.



Carbon nanotubes functionalized by palladium atoms

The physics of condensed matter

Research in the **Department of Condensed Matter Physics** concerns problems related to the solution of exact statistical mechanical models of solid state matter and fluids, the description of strongly correlated systems, and modeling of the properties of nanostructures and macroparticles.

The laws of classical or quantum physics, applied to systems consisting of a huge number of interacting particles, should in principle fully describe all the properties of such systems. It turns out, however, that even the description of the approach of such a system to a stationary or equilibrium state is beyond the capability of the methods of modern theoretical physics, and is regarded as one of the most difficult problems in statistical physics. This is why work done at the Institute, proving the existence of stationary solutions to the Boltzmann equation (an equation that describes how the macroscopic properties of a system change under the influence of microscopic interactions), was an important step towards the understanding of such a process. Other research is conducted in the direction of describing the properties of soft matter, such as hard-sphere suspensions, composite molecules, or polymers in liquids. We study the Stokes dynamics of particles that interact through long-range hydrodynamical forces, in the aspect of the self-organization of matter and the properties of systems far from equilibrium. Another direction of research on such systems is that of processes of growth, which display a huge variety and complexity – apparent in such examples as snowflakes, river webs and biological structures. One such example is given by the flow within porous rocks and the consequent dissolving of carbonates, which leads to the formation of calcite caves. The description of this process involves both convective and diffusive transport and the kinetics of chemical reactions, leading to a highly complex web of flows. Another typical application is to biological systems; although it has recently become possible to measure quantities such as the elasticity of individual biomolecules (via atomic force microscopes), in the organism such molecules are usually subject to cyclic deformations, little studied until now. At the Institute we have recently proposed a model of the action of such forces on proteins, and we have studied their complex dynamical response.

Research is conducted on phase transitions in the presence of a phase boundary surface, which is significant in view of applications to nanotechnology, medicine and biology. By applying the effective Hamiltonian method and including the effects of the curvature of the boundary surface, important results have been obtained, for instance in the description of Casimir forces in critical fluctuations of the boundary surface.

A separate direction of research concerns the properties of solid state matter, semiconductors in particular. Ab initio calculations which reproduce the properties of crystalline structures on the basis of the electron structure of atoms are of great importance for applications to electronics and the so-called spintronics, which involves the interaction between the spin of the electron and the local electrical and magnetic properties of the medium. In these calculations we study the properties of charge and spin transport in layered structures, nanostructures and macromolecules. In turn, the optical properties of semiconductors play a basic role in optoelectronics – here research has shown that Coulomb interactions in a highly excited and spin-polarized electron-hole plasma are well described by the time-dependent Hartree-Fock approximation.

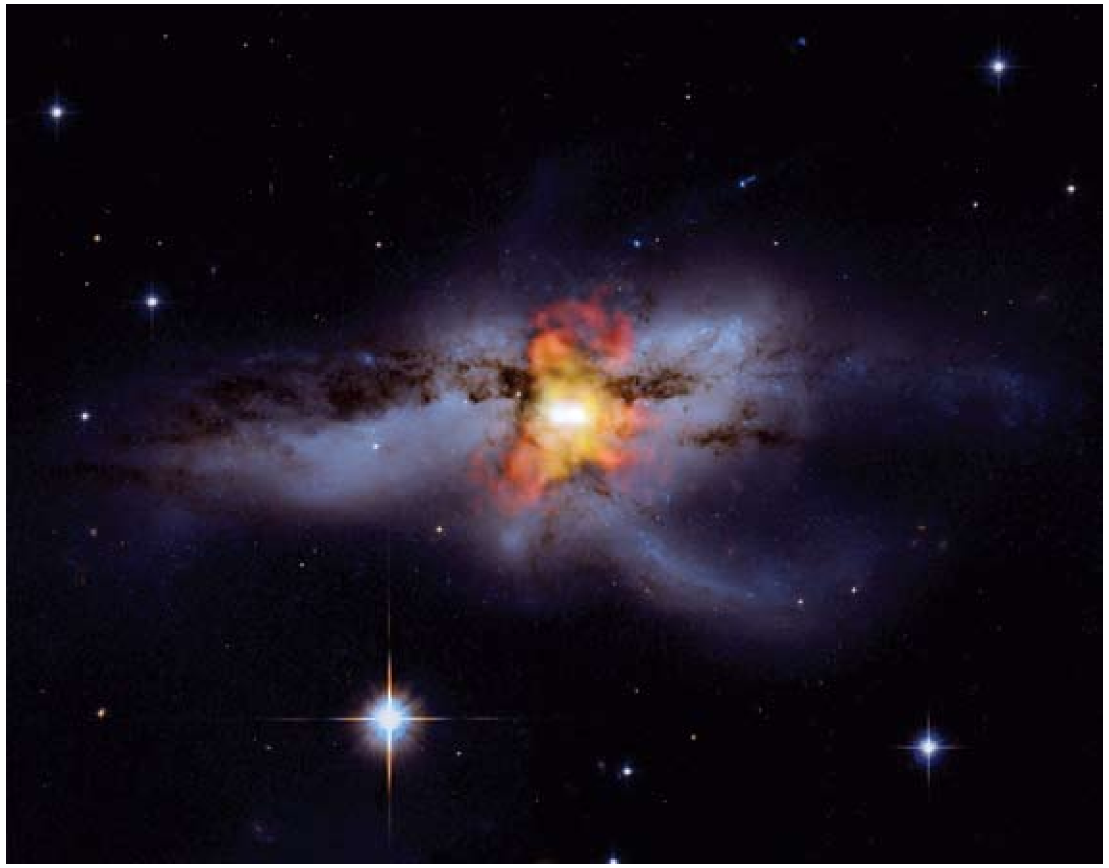
Small atomic-scale systems are strongly correlated electron systems – this can be seen from the example of charge transfer in small structures such as carbon nanotubes and graphene. Such effects are studied employing the dynamical mean field method, recently used to describe a system of cold bosons on the so-called optical lattice. This method has also proved useful in the description of correlated bosons on a lattice – both as a boson condensate and uncondensed – and their interactions. An independent direction of research in this group is the analysis of single-particle and collective excitations in solid state systems, characterized by a dispersion relation. Coupling between them may lead to a sudden change of the slope of the dispersion curve, and measured by emission photospectroscopy this may yield significant information about strongly correlated electron systems.

The theory of gravity

The theory of gravity known as general relativity, created by Einstein in 1915, had until recently remained an area of classical physics totally divorced from particle theory, solid state physics and quantum physics. Currently this theory is becoming increasingly mixed with other theories – primarily particle theory – mainly through attempts to describe interactions at very high energies (and therefore at very small lengths), where the gravitational interaction is strongly coupled to the remaining interactions and requires quantum effects to be taken into account. The scope of current research in the Department of Relativity Theory and Gravitation includes both classical and quantum problems. For decades the Institute has been a world-renowned place of research in classical gravity theory. In the last decade it has also become one of the leading centers of research on the so-called loop approach to the quantum theory of gravity. Research in this area is proceeding in several independent directions.

Data from recent cosmological observations, principally on background radiation and on very distant supernovae explosions, indicate that barely 4 percent of the energy of the Universe is in the form of known particles, while the rest comes in forms still unknown: dark matter and dark energy (about 23 percent and 73 percent, respectively). The conjecture that invisible forms of matter may exist has been around for a long time, due to the rotation curves of galaxies which disagree with the mass of luminous stars observed in those galaxies. An attempt to explain the existence of dark matter originates from particle theory. Theoretical models beyond the Standard Model propose several candidates for dark matter. Such particles must be extremely weakly interacting, and either very massive (in supersymmetric theories) or, on the contrary, of very small mass (axions). Meanwhile, dark energy is much more mysterious, and its very small observed value lacks any theoretical explanation to date. The existence of both forms leads to dramatic consequences for the large-scale Universe. These are a subject of research at the Institute, in the context of the process of the formation of large-scale structures, based on the so-called deep galactic surveys and the redshifts of light emitted by quasars. Another topic is the anisotropy of the microwave background radiation; before long the Planck satellite is due to provide the first high-precision data.

Another direction, which has long been a specialty of the Institute, is the study of metrics with torsion in the framework of the so-called Einstein-Cartan theory. This theory seems to be more natural than Einstein's theory, as it accounts for



The galaxy NGC6240

separate couplings of gravity to energy-momentum and to spin. Within this theory, and assuming the existence of macroscopic spin in the Universe, solutions exist that do not display an initial singularity (and they have been found at the Institute). Such solutions provide a cosmological perspective totally different from that present in the standard cosmology, based on isotropic solutions of Einstein's theory. Theories with torsion have recently been intensively developed in relation with string theory and supergravity, as these theories also display a torsion independent of the energy-momentum tensor. At the Institute we have been developing a theory with totally skew-symmetric torsion, related to higher dimensional supergravity.

A different kind of metrics, also a subject of study at the Institute, are the asymptotically flat metrics. They describe gravitational radiation emitted by compact (spatially bounded) sources, and can be studied within the Bondi-Sachs approach, or with Penrose's conformal formalism. At the Institute, we study the physical quantities that characterize these metrics, such as the total energy, momentum or angular momentum.

Special attention is given to the so-called Robinson-Trautman metrics, for which the Einstein equations assume a particularly simple form. An independent direction, motivated by string theory, is the search for asymptotically flat solutions to Einstein's equations in higher-dimensional spacetimes. A recent discovery was a solution of this type in the form of a generalized Gross-Perry metric.

A well-known solution in the theory of gravity is the black hole, an area that cannot be classically accessed from the outside. In the Department of Relativity Theory and Gravitation active research is under way on the so-called quasi-local description of black holes, and on the existence of solutions with a horizon in higher-dimensional spacetimes. A study of Robinson-Trautman metrics is also being conducted in the context of black holes.

Beyond doubt the greatest challenge facing modern physics is that of joining the theory of gravitation and quantum theory into one consistent whole, in other words, the development of a quantum theory of gravity. One such proposed theory is the already mentioned string theory (which was developed from elementary particle theory), while another totally independent proposal, developed from gravitational theory, is known as the loop theory of gravity. Here the Einstein equations and the principle of invariance under coordinate transformations (diffeomorphism invariance) are the starting point. The Institute has played a key role in the development of this theory since its beginnings, for example the breakthrough work on the existence and uniqueness of the measure, or the calculation of black hole entropy within this theory. A recently proposed project is the application of loop gravity to the description of the early moments of the Universe (loop quantum cosmology), where the Institute also has a leading role. Other current research concerns the application of quantum gravitational models of "spin foam" and relational Dirac observables, closely related to loop quantum gravity.

Institute of Geophysics

The Institute consists of three sections. The research carried out within these sections spans a wide range of problems including: processes in the Earth's atmosphere, theoretical hydrodynamics, the structure of the Earth's interior, the structure of other planets and photonics and plasmonics.

Clouds, precipitation and aerosols

Clouds are present throughout the atmosphere, on average they cover 60 percent of the globe. A cloud is an aggregate of water droplets or ice crystals resulting from the condensation of water vapor. For such droplets or crystals to appear, centers of condensation must be present. These are usually microscopic dust particles, originating from natural or man-made sources, known as atmospheric aerosols. The concentration and type of these aerosols are the factors that determine the concentration and size of the cloud droplets, impacting precipitation and the lifetime of clouds. The droplets and crystals that form clouds interact with solar and infrared radiation, reflecting or absorbing it. By their role in the origin and life cycle of clouds, aerosols have a significant impact on the climate and weather.

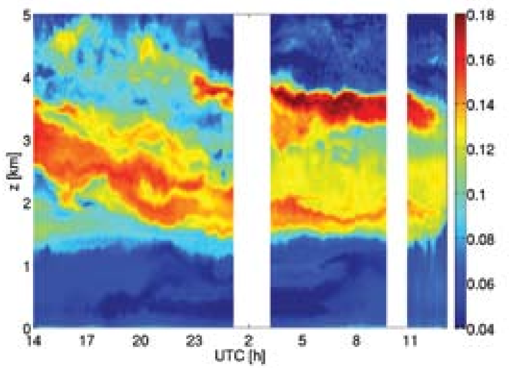
In the **Atmospheric Physics Section** we conduct measurements in the interior of clouds from onboard airplanes. We take part in major international research projects and measure-

A research airplane carrying a UFT thermometer (red, below the tip of the fuselage) during the POST (Physics of Stratocumulus Top) experiment, California, summer of 2008

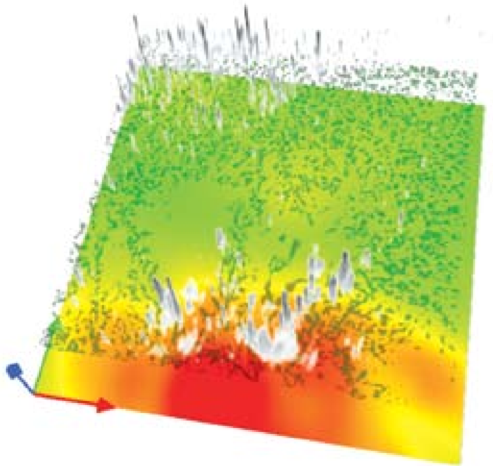
ment campaigns. Based on the data gathered we analyze the microphysical and thermodynamical processes that govern the evolution and radiative properties of clouds and the origin of precipitation. We are able to measure various properties of clouds, such as droplet sizes or the temperature of the air between them, as well as to determine the average properties of individual clouds or entire cloud fields. The results of these studies allow us to understand the physical processes taking place inside clouds, and to make use of this understanding in numerical climate and weather modeling. We also run a laboratory where we build and develop measuring devices. The ultrafast thermometer (UFT) built in this laboratory is the only device in the world capable of measuring temperature fluctuations inside clouds on centimeter and millimeter scales during flight.

As part of an international collaboration we are contributing to the development of numerical cloud models at various spatial and temporal scales. We model and study cloud processes taking place at scales that range from the order of centimeters up to tens of kilometers. By comparing results from models and measurements we create new descriptions of effects that were previously not taken into account by the models. We have workstations, fast storage arrays, and a multiprocessor computer for calculations, and we also make use of supercomputing resources at top centers in Poland and around the world.

Aerosol concentrations influence the climate and weather not just through their relations with clouds. Dust, both natural and man-made, interacts with solar radiation, impacting the Earth's radiation balance. The spatial distribution of dust is highly inhomogeneous and strongly time-dependent, making it very difficult to describe its impact on the radiation balance. The optical properties of aerosol particles, their shape and size, which we study in various places throughout the world – both on-site and through teledetection methods – are of great importance with respect to climate. We operate a rooftop measurement platform, a receiver of satellite meteoro-



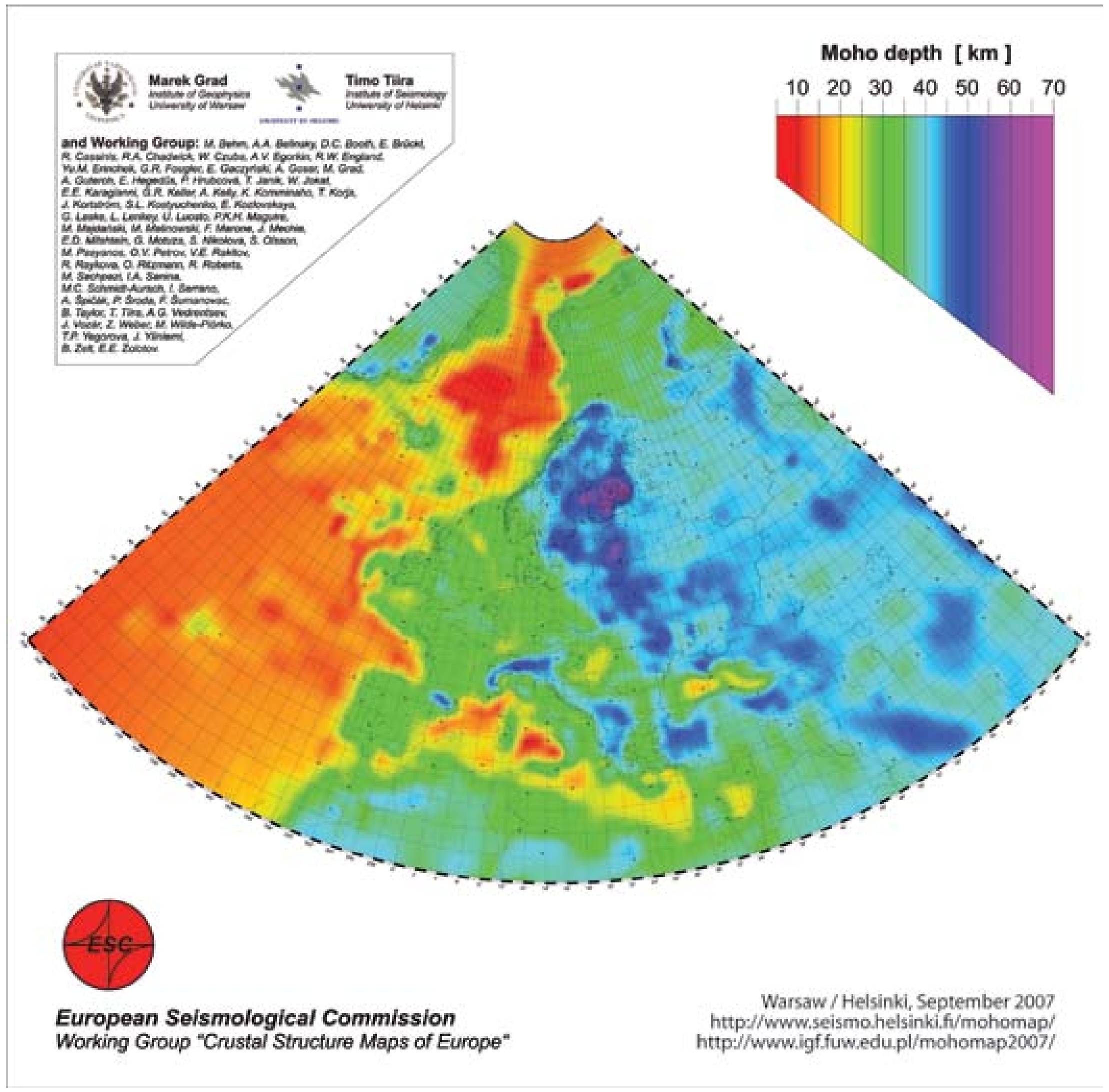
Desert dust from the Sahara above the site of the Section of Atmosphere Physics – lidar image at wavelength of 532 nm (depolarization of signal scattered on nonspherical grains of sand, in yellow and orange)



Convective clouds over southern Poland: result of numerical simulations using the EULAG model, performed on the Blue Gene computere logical images, an automated weather station and modern lidars and devices for photometric and radiometric measurements. We perform calculations on how the presence of aerosols of different types affects radiation transfer through the atmosphere, and how atmospheric circulation transports aerosols over large distances.

Theoretical hydrodynamics

In the Section of Atmospheric Physics we also conduct basic research on the mechanics of fluids and on geophysical fluid dynamics. We work on vortex dynamics and turbulence, chaotic and nonlinear processes. Theoretical studies assist the development and improvement of numerical



Depth of the Mohorovičicia boundary (Moho) between the Earth's mantle and the crust of the European plate

models, leading toward a better understanding of the dynamical processes that take place in the atmosphere and the oceans.

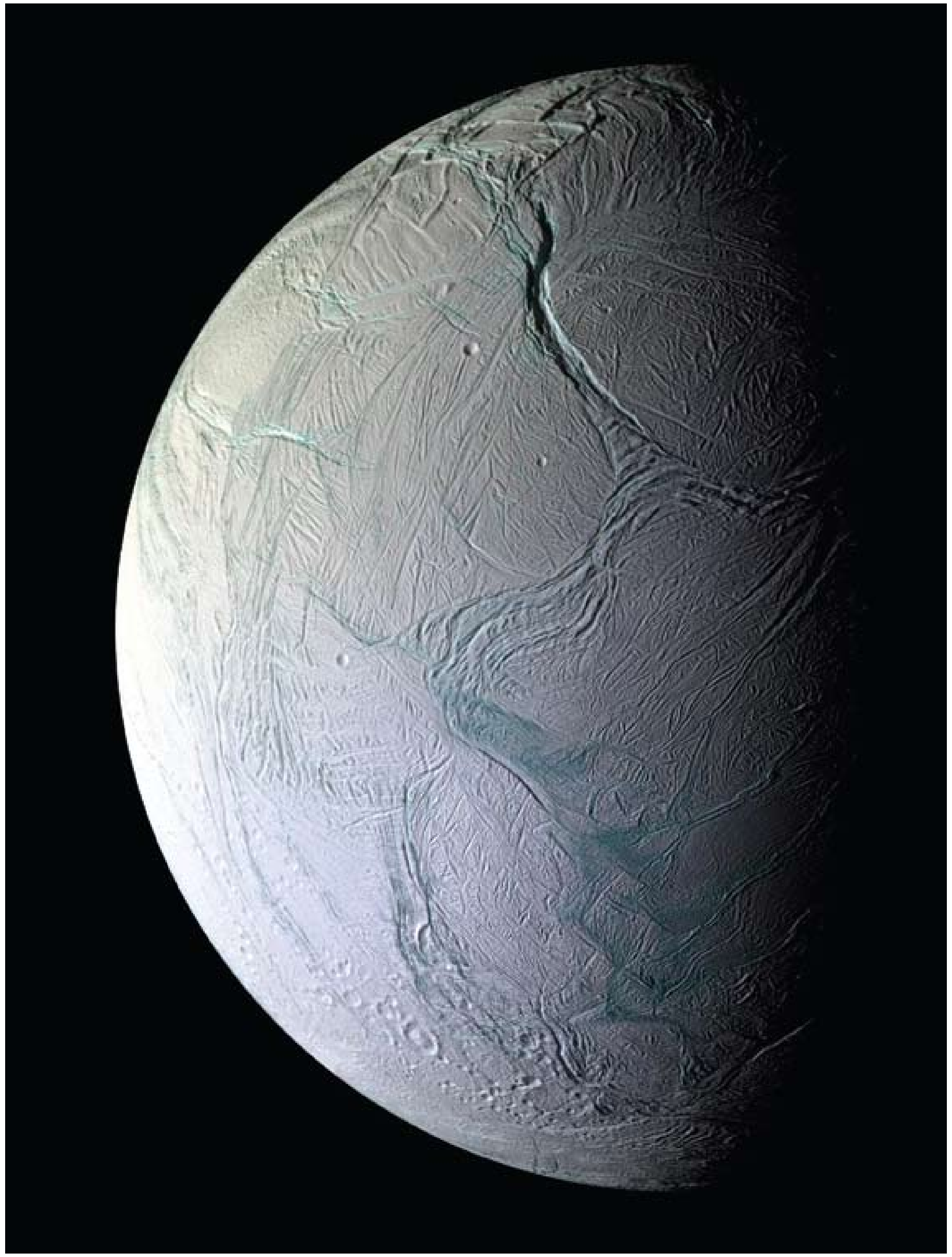
Studies of the Earth's interior

A variety of methods are used to study the interior of the Earth. The most precise are seismic methods, based on the observation of elastic (seismic) waves that pass through the Earth's interior; these waves may either originate from earthquakes or be artificially generated. Additional methods are based on the observation of other physical fields: the gravitational field (gravitational anomalies), the magnetic field, and the geothermal flux. Other important data are those concerning the motion of the plates of the lithosphere and smaller blocks of the Earth's crust. One of Europe's main tectonic structures, the Trans-European Suture Zone (TESZ), which separates the Precambrian East and North European Craton from the older formations of the Paleozoic Platform of Western Europe, runs through Poland. The TESZ is one of the major subjects of study in the **Section for Physics of the Lithosphere**. The structure of the Earth's crust over Poland's territory was studied with the participation of members of the Institute of Geophysics in the course of international seismic experiments carried out from 1997-2003. Based on data obtained by deep seismic sounding it was possible to determine the structure up to a depth of several tens of kilometers. We also took part in similar studies carried out in the polar regions (e.g. within the framework of the 4th International Polar Year in 2007-2008). Other research conducted at the Institute of Geophysics concerns the investigation of deeper structures (of the lower lithosphere and the upper mantle). We were one of the main participants in the international seismic experiment PASSEQ 2006-2008, involving simultaneously two hundred seismic stations. We strive for an integrated interpretation of seismic, gravitational and thermal data, in other words we are working towards explaining the current makeup of the Earth, its gravitational field and thermal flow by modeling the motion of lithospheric plates and of matter within the mantle. This research concerns both global and regional problems (such as the raising of sedimental basins).

Studies of other celestial bodies

Research in the Section of Physics of the Lithosphere is concerned with a variety of celestial bodies, both their surfaces and their interiors. Data are obtained from space probes and through telescopic observations. We also carry out laboratory studies on the properties of the matter forming these bodies, and numerical simulations.

As a result of studies on the evolution and spatial distribution of water and ground ice on Mars, we have determined a formula for correcting the agreement with measurements of the calculated rates of sublimation and condensation of ice under low-pressure conditions. Research on flows in porous media was applied to regolith on Titan (a satellite of Saturn): based on numerical simulations, the possibility of convection in liquid methane/ethane present in porous regolith was proposed. Another subject of our research is the tectonics and volcanism of planets and selected satellites, in particular the activity of Saturn's satellites: Enceladus, Dione and Iapetus; for instance, we have been able to explain the cryo-



Enceladus: one of Saturn's satellites, the smallest body in the Solar System that displays volcanic and tectonic activity

-volcanic activity on Enceladus, and the lack of such activity on Mimas (known as the Mimas-Enceladus paradox). We have also taken an interest in the evolution of the surfaces and interiors of the nuclei of short-period comets, with attention to the transformation of the microcrystalline structure and changes in the microstructure of porous ice.

A numerical simulation has shown the possibility of rapid changes in the brightness of the 17P/Holmes comet, as a result of changing spatial orientation of the comet.

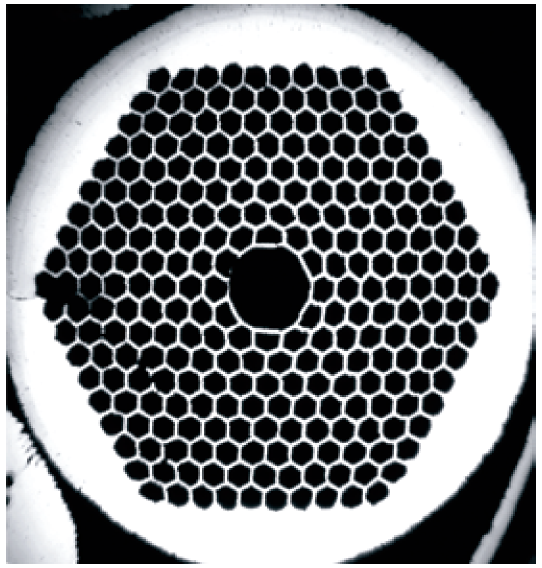
We study the origins and characteristics of impact craters, and the possibility of conditions necessary for the development of life forms.

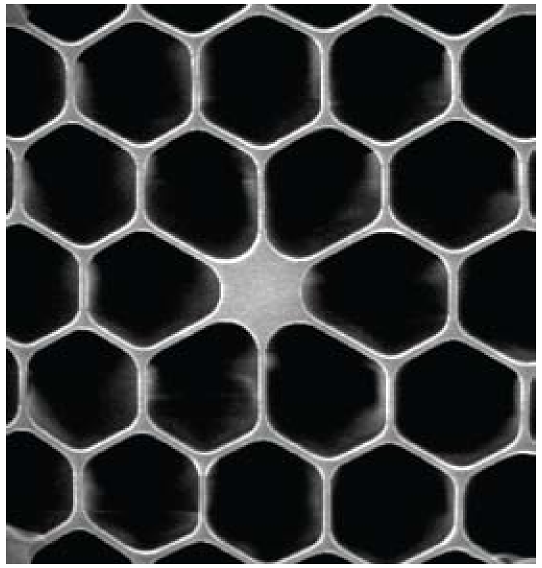
Photonics

One of the leading research subjects in the **Section of Information Optics** is that of metamaterials – this term applies to man-made materials which display electromagnetic properties not found in natural materials. An example is metamaterials with a negative refractive index, which can hopefully be applied to build new devices for information transmission or the cloaking of objects. The first metamaterials were demonstrated in 2001 for the microwave range. The search continues for a good metamaterial for visible light.

A new scientific field, which joins computational electrodynamics based on Maxwell's equations with materials physics, is that of plasmonics. The propagation of light in plasmonic nanosystems, built from dielectrics and noble metals, is determined by limiting conditions: the concentration and transport of energy is performed by localized plasmons and plasmon-polariton surface waves.

In the Section we have developed a nanolens, able to focus light in an area smaller than the classical diffractive limit, by employing a radially polarized light beam. Near-field microscopy is a research technique where the surface of a material and its physical properties, including optical properties, are studied by means of a probe

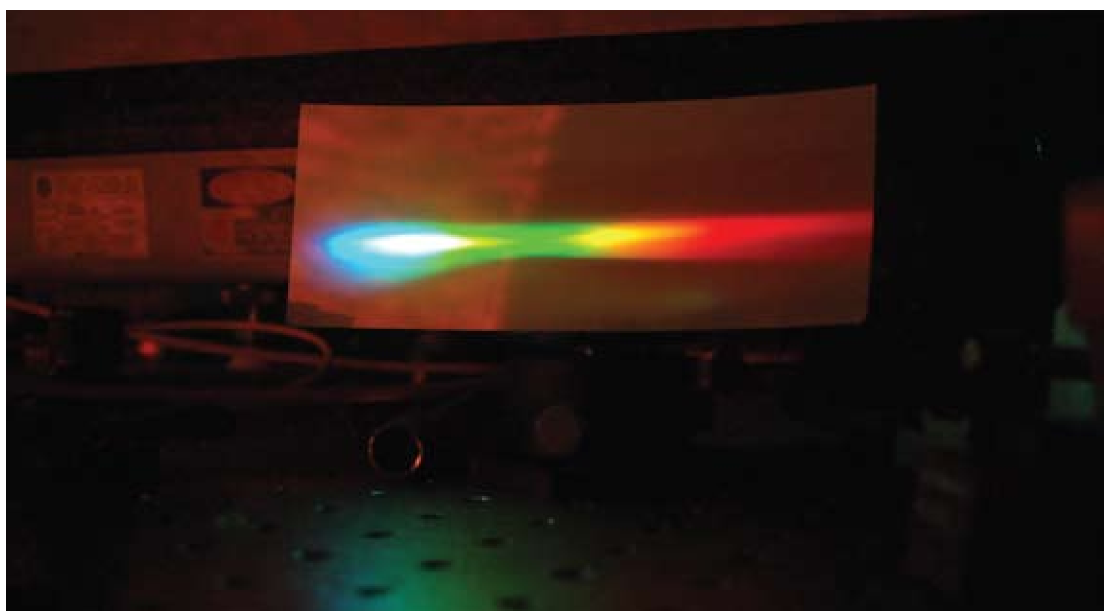




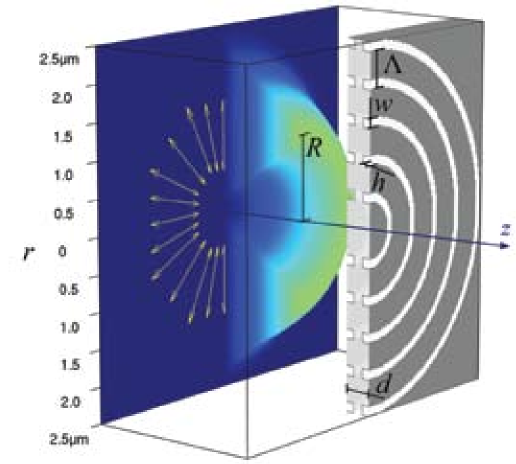
Cross-section of an example of a photonic optical fiber that scans the surface point by point; the probe is moved with very high precision, of the order of nanometers or better. By studying the intensity distribution of the emitted light it becomes possible to determine the optical properties to a very high resolution, due to the detection of radiation including evanescent waves that are present only at distances up to a few tens of nanometers from the sample's surface. This technology is highly dependent on the construction of the optical probe; in the Section of Information Optics we have devised a new design for such probes. Photonic crystals are periodic structures which act similarly to a Bragg reflector – which may itself be regarded as a one-dimensional photonic crystal. In the Section we conduct theoretical research on and computer simulations of photonic crystals, which are employed for instance as light guides in micro-and nanosystems. Photonic optical fibers, whose cross-sections form photonic crystals, make it possible to guide light by using either of two effects: the effective refractive index, when a glass core is surrounded by holes of air, or the forbidden gap, when light injected into a core of air is unable to leave it, because propagation in a direction perpendicular to the axis of the fiber is forbidden. Photonic fibers may display nonlinear properties, leading to supercontinuum generation, i.e. the conversion of a very brief laser pulse (such as 1 femtosecond) inside a segment of the fiber into wide-spectrum light.

Our traditional subject matter which we have been developing for many years is image processing and recognition. Image processing algorithms are often based on concepts from Fourier optics, extending image analysis into the space (or plane) of spatial frequencies. This concept of image processing is present, for instance, in all modern methods of compression of images and video sequences.

Other research is conducted in the field of diffractive (wave) optics: currently this encompasses, for instance, studies of the methods of imaging phase objects – objects that distort the wave front without altering the intensity of the light. This makes it difficult to determine the shape of the distorting surface, as it is not directly visible.



Spectrum of light obtained by the conversion of a femtosecond pulse inside a photonic optical fiber



Operating diagram of a photonic nanolens

The Section of Information Optics operates its own optical laboratory, equipped with a variety of sources of radiation, a near-field optical scanning microscope (SNOM) and an atomic force microscope (AFM), a Wyko interference profile meter for white light, optical spectrum analyzers and others. We have at our disposal a wide range of computing equipment, including blade computers. We collaborate with numerous research centers, both in Poland and abroad. Many prototype devices (in particular, photonic optical fibers) are made for us at the Institute of Electronic Materials Technology in Warsaw.

Department of Mathematical Methods in Physics

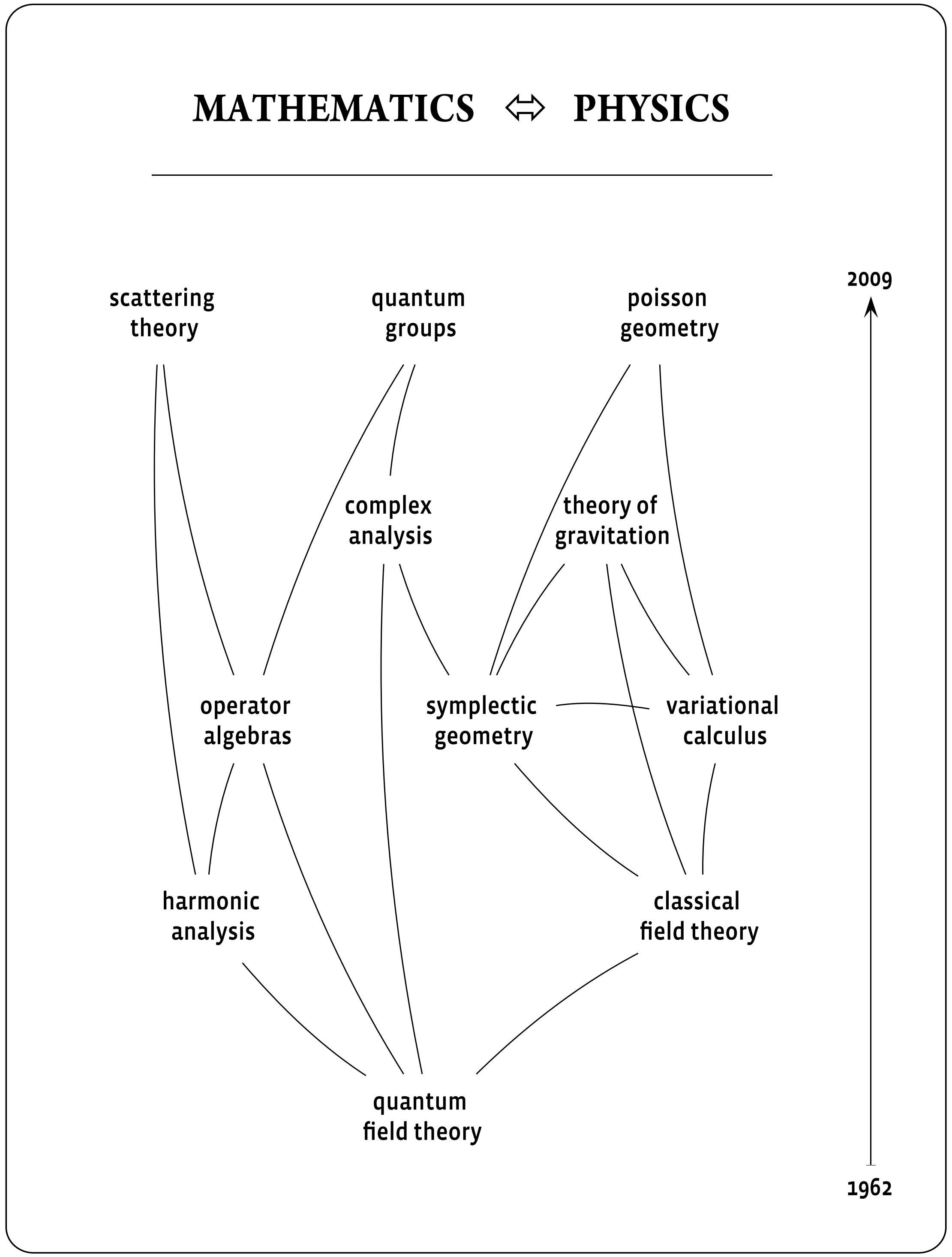
In the Department of Mathematical Methods in Physics, we work in mathematical physics and other areas of mathematics originating in physical problems. The main lines of the research we conduct, together with their inter-relationships and timeline, are visualized on the accompanying diagram.

Research conducted in the Department is concerned with the geometrical foundations of physical theories, including classical and quantum field theory, the mechanics of charged matter and control theory of static systems. A related field is the geometrical-variational description of physical systems; such a description is motivated by the need to understand the relationship between classical and quantum physics. Another area of interest to us is the theory of gravitation. One of our achievements in this field is an improved understanding of the issues related to gravitational radiation. An extensive analysis of the so-called Bondi mass has demonstrated it to be the only concept that allows for a meaningful definition of energy within the theory of gravitation. Other important results we have obtained concern nonlinear geometrical problems, in particular in soliton theory.

We also carry out research on the theory of operator algebras and their application to quantum statistical physics. One contribution to the understanding of the foundations of quantum statistical physics was the introduction of the concept of passive states. Another topic within the scope of our interests is the rigorous analysis of the operators and methods of quantum mechanics. Members of the Department have been quite successful in the solution of a number of difficult problems, some of which had remained open for a long time. These include the proof of asymptotic completeness for long-range many-body scattering, which was the highlight of a wide-ranging program of research in scattering theory.

Another area of work in the Department is the theory of classical groups (especially its geometrical aspects) and of quantum groups (on the topological level); in particular, we have performed an in-depth study of the case of compact quantum groups, while examples of non-compact groups have influenced significantly the shape of the general theory. We take pride in the fact that a good part of the major concepts and achievements in the field of quantum groups has resulted from research conducted in our Department.

The subject area of the Department's research is one of the fastest growing fields. Our members take an active part in various forms of international collaboration, such as European Union programs, visiting scientist programs, conferences, etc. In the period 2004-2008, the Department was part of the EU project "Noncommutative geometry and quantum groups". Within the framework of this project eight courses conducted by world-class experts were held in the Department. Another example of involvement in international activities was the Department's participation in the scientific network "Analysis and Quantum" in 2002-2006 (the Polish section's headquarters were in the Department). This coordinated activity by eight European institutions was aimed at developing mathematical tools for the study of quantum systems.



Studies at the Faculty

We are now in the 21st century, a time when it is no longer possible to function without advanced science and technology. There is a growing demand for personnel well versed in the exact sciences – people able to take advantage of the most recent advances of our civilization and prepared to participate in the search for the new solutions required for its further growth.

The Faculty of Physics offers courses of study that guarantee a high level of education to our graduates. We take care to provide our students with a solid theoretical foundation in physics, mathematics and programming, as well as the specialized knowledge required for a career in the fastest growing areas of science, technology and business. At the same time, we strive to stimulate in our students the desire to acquire new knowledge and a constant readiness to face new challenges. Graduates with such preparation are eagerly sought after at institutions of higher education in Poland and abroad, other educational institutions, hi-tech businesses, IT and consulting firms, insurance companies, banks, medical institutions, publishers and the media.

Following current world tendencies, we have opened a new study program: **Applications of Physics in Biology and Medicine**, and jointly with the Faculty of Chemistry, another major: **Nanostructure Engineering**. Also jointly with the Faculty of Chemistry, we will introduce in the academic year 2011/2012 another new major: **Nuclear energy and chemistry**. Its graduates will enhance the supply of personnel in the growing jobs market associated with the nuclear energy industry.

In view of the growing demand for specialists in the exact sciences, the Ministry of Science and Higher Education has included Physics on its list of preferred majors. The additional funding this entails provides a new source of scholarships for those who undertake second-degree studies.

The excellent teaching and research staff at the Faculty of Physics is a guarantee of a high level of instruction. Among over 200 teachers we have 70 full professors, 51 PhDs with Habilitation and 81 PhDs. We currently have nearly 650 undergraduate students and over 100 PhD students.

The research achievements of our staff, many of whom are recognized world authorities in their fields, contribute to the University of Warsaw's strong international position. Our Faculty is one of those that assure our University a position at the top of nationwide rankings.

The Faculty of Physics boasts a number of well-equipped specialized research laboratories. Part of our research is conducted in collaboration with top foreign institutions, such as: CERN (Switzerland), DESY and GSI (Germany), Oxford and Cambridge (UK), CNRS Laboratories (France), Fermilab (USA), and others. Thanks to these collaborations our students enjoy the opportunity to participate in the most important physics experiments currently under way around the world.

The Faculty of Physics takes an active part in the European Union's ERASMUS program, which allows our students to fulfill part of their study requirements at Europe's most renowned universities.

Students in the Faculty of Physics enjoy access to specialized libraries with large collections in the areas of physics and related sciences, as well as to computing labs with more than a hundred workstations with Internet access. They also have the use of well-equipped teaching labs for instruction ranging from basic measurement techniques to advanced methods in experimental physics in current use at research laboratories.

Students in the Faculty of Physics enjoy the possibility of expanding their qualifications via internships at high-tech firms, research institutions, industrial laboratories, hospitals, banks, media firms, and other places beneficial to their career advancement.

Studies at bachelor's, master's and PhD level in our Faculty are free of tuition charges.

Educational offering

First degree, undergraduate studies (three years, bachelor's degree)

• Physics

Students of this program receive training in the basics of general physics, plus an introduction to modern theoretical and experimental physics. They also become familiar with elements of higher mathematics and computer science.

Graduates of this program are well prepared to undertake second degree studies, whether at the Faculty of Physics itself or elsewhere. They obtain a breadth of knowledge in physics and mathematics, with the ability to apply rigorous quantitative methods to the description of physical phenomena, as well as to problems in other areas. They are skilled in computer programming, accessing sources of information and using a variety of operating systems. This program of study provides excellent preparation for work in research, as students become proficient in operating measurement devices: mechanical, optical, electrical and electronic. They are also prepared to access specialized literature and prepare and deliver presentations, in English as well as Polish. Graduates of the Physics program are taught the habit of constant self-instruction and creative thinking, an important asset in a highly variable job market.

• Astronomy

Students of this program become familiar with the basics of general astronomy, observational astrophysics, mathematics, information technology and physics. Graduates of the Astronomy program are well prepared to undertake second degree studies, whether at the Faculty of Physics itself or elsewhere. They obtain a breadth of knowledge in astronomy, physics and mathematics, with the ability to apply rigorous quantitative methods to the description of astronomical and physical phenomena, as well as to problems in other areas of science. They are skilled in computer programming, accessing sources of information and using a variety of operating systems. Graduates of the Astronomy program are taught the habit of constant self-instruction and creative thinking, an important asset in today's job market.

Within both majors, apart from traditional study programs, the option of **individualized studies** is available. This is addressed to individuals with an outstanding level of preparation in mathematics and physics, as certified by a diploma of Laureate or Finalist in the Mathematics, Physics or Astronomy Olympiad, or excellent marks in secondary school final examinations in physics and mathematics. This elite path of highly advanced studies provides the added pleasure of study in an ambitious group. Those who seek a future career in teaching can choose the program of **teaching in Physics**.

• Applications of physics to biology and medicine

The interface between physics and the biological sciences and medicine is one of the fastest growing areas of current scientific research, as well as an arena for the application of the most recent technologies. The unusual progress and growth of genetics, genetic engineering and some branches of physics and computer science observed in recent years has not only impacted on the development of biology and medicine, but in addition contributed to the growth of new fields, such as bioinformatics, molecular design, or neuroinformatics, and led to a revival of some well established fields, such as molecular biophysics and medical physics. The above mentioned areas require specialists trained in several different fields. In response to this demand, the University of Warsaw Faculty of Physics opened a new study program in the academic year 2009/2010: Applications of physics to biology and medicine, with a curriculum incorporating the basics of physics, biology, chemistry and mathematics – in correspondence with the interdisciplinary character of knowledge from the interface between physics, the biological and the medical sciences. Students of this program have the choice of one among five specializations:

- •• **Molecular biophysics**
  http://biofizyka.fuw.edu.pl
- •• **Molecular design and bioinformatics**
  http://bioinformatyka.fuw.edu.pl
- •• **Medical physics**
  http://fizykamedyczna.fuw.edu.pl
- •• **Neuroinformatics**
  http://neuroinformatyka.pl The world's first undergraduate study program in this field!
- •• **Ocular optics**
  http://optometria.fuw.edu.pl

• Engineering of nanostructures
http://nano.fuw.edu.pl

Nanotechnology is one of the great challenges of our times. A huge growth in nano-science and technologies on the borderlines of physics, chemistry and information science is taking place throughout the world. In response to these world-wide currents, the Faculties of Physics and

Chemistry at the University of Warsaw established in the academic year 2009/2010 a macro-program of Nanostructure Engineering, a qualitatively new course of study corresponding to the inter-disciplinary nature of the requirements for the design and fabrication of new structures for nanotechnology, research into their properties and functional applications.

- **Nuclear energy and chemistry**
  – starting from 2011/2012
  http://atom.chem.uw.edu.pl

Second degree, graduate studies (two-year Master's program)

- **Physics**

The aim of the Master's Degree in Physics program is to provide a deeper knowledge of physics and a specialization in a chosen subfield of physics, developing the relevant concepts and theoretical and experimental methods. Following the initial semester, students choose one from the following specializations:

•• **Theoretical physics** – with the option to specialize in one of the following areas:
••• Quantum optics and atomic physics
••• Physics of condensed matter
••• Theory of elementary particles and interactions
••• Theory of nuclear structure
••• Relativity and gravitational theory
••• Theoretical particle physics and cosmology (taught in English)
••• Mathematical physics
•• **Geophysics** – with the options:
••• Atmospheric physics
••• Earth and planetary physics
••• Environmental physics
•• **Biophysics**
•• **Biomedical physics**
•• **Physics of condensed matter and semiconductor devices** – with the options:
••• Physics of condensed matter and semiconductor nanostructures
••• Physics of semiconductor devices
••• X-ray methods in condensed matter physics
••• Synchrotron and neutron methods in condensed matter physics
•• **Photonics**
•• **Optics**
•• **Physics of nuclei and elementary particles** – with the optios:
••• Physics of atomic nuclei
••• Structure of atomic nuclei
••• Physics of elementary particles and fundamental interactions
•• **Teaching and popularization of physics** – with the options:
••• Teacher training
••• Teaching and popularization of physics
•• **Physical methods in economics (econophysics)**
•• **Mathematical and computer modeling of physical processes**

Highly talented individuals are also offered the opportunity to follow an individual course of study at this stage.

- **Astronomy**

The aim of second degree studies in Astronomy is to provide an in-depth training in the observational and theoretical methods of astronomy and to familiarize the student with the contemporary state of knowledge in this field. Students obtain the knowledge required to describe and understand the physical mechanisms underlying astronomical phenomena and the structure and evolution of astronomical objects. Another purpose of these studies is to instruct in the methods of mathematical modeling and the statistical verification of these models – more broadly speaking, to develop the competence of future graduates in mathematical and natural science.

Second degree studies majoring in **Applications of physics to biology and medicine** and **Nanostructure engineering** are scheduled to begin in 2012.

PhD studies

The Faculty of Physics operates a four-year PhD study program. Studies leading to a PhD degree are individual studies – that is, they follow a framework curriculum and are conducted under the guidance of a tutor. All specializations present in the Faculty are available to PhD students. This program provides in-depth training towards

involvement in research, aims at developing an inquisitive approach to the surrounding world, demonstrated by the urge for a profound understanding of the processes taking place; teaches the skills required to seek out information relevant to the solution of problems posed, the skill to define, present lucidly and solve efficiently a variety of problems(not necessarily directly related to physics or astronomy) – both on a conceptual and theoretical level, and on a practical one; and provides a wide set of skills in computing methods – computational, information processing, and control of measurement devices.

Postgraduate studies

• **Postgraduate Studies in Physics and Astronomy**
This is a three-semester study program. Its aim is to provide students with a basic knowledge in physics and astronomy, and training in carrying out simple experiments. This program is targeted at science teachers wishing to obtain accreditation to teach physics, and at those who already hold such accreditation but wish to expand their qualifications.

• **Postgraduate Inter-faculty Studies in the Teaching of Natural Science**
These studies are operated by the Faculties of Physics, Chemistry, Geology, and Geography and Regional Studies of the University of Warsaw. This is a three-semester study program designed for teachers, with the aim of expanding their knowledge of the subject and preparing them to teach natural science as a second subject. Students receive training in inter-disciplinary thinking, equipping them to convey to their own students knowledge in natural science; they are also taught a range of computing and multimedia techniques.

Students at the Faculty of Physics have the opportunity to develop their scientific interests within the activities of a number of student societies, such as:

- The Circle of Physics Students
- Geophysics Scientific Circle
- Astronomy Scientific Circle
- Scientific Circle of Artificial Intelligence
- SPIN Association for the Spreading of Scientific Ideas
- Nucleotide
- Scientific Circle of Biological Chemistry.

There is also the opportunity to pursue less scientific interests, offered by the Faculty's choir and tourism club.

A student council and PhD students' council provide a forum for students with an interest in organizing.

We also offer a program of studies directed towards future high-school graduates. The Faculty of Physics invites them to prepare courses before their final examinations in physics and mathematics, operated on several different levels of study.

Popularization Activities

In addition to its research and teaching activities, the Faculty of Physics is also heavily involved in popularization. Our **Open Activities in Physics** (www.fuw.edu.pl/wo), prepared and presented by the best lecturers and demonstrators of our Faculty, have for years enjoyed great success.

• Saturday lectures for school students are aimed at a wide audience, with the purpose of making physical problems accessible by presenting a variety of experiments and demonstrations. Subjects of these lectures range from the foundations of physics to the most recent achievements. Such lectures are an excellent supplement to the teaching received in school.

• Wednesday activities, or "simple and spectacular experiments in physics", are aimed at students with an interest in physics and their teachers. During these activities interesting physical experiments that can be performed without major expense are demonstrated. The activity consists of two parts: the first being a lecture-workshop amply illustrated by demonstrations, while in the second, experiments prepared by the students themselves and their teachers are presented.

• Lectures for schools present modern problems in physics in the form of multimedia presentations, incorporating simple experiments; they are offered at schools in the greater Warsaw area.

• Physics laboratory for school students is an activity that allows students of middle and high schools a direct glimpse at the physicist's workplace, by offering participation in laboratory work. Both individuals and organized groups may apply. Students have the opportunity to conduct their own experiments, designed with the assistance of a teacher.

• Summer School of Physics is the Faculty's contribution to the "Summer in the City" vacation activities. Its attractive curriculum is aimed at students from the last year of middle school through high school – those with an interest in becoming acquainted with recent scientific achievements in physics and astronomy. The Summer School of Physics is organized in collaboration with the Polish Physical Society and the Municipality of Warsaw.

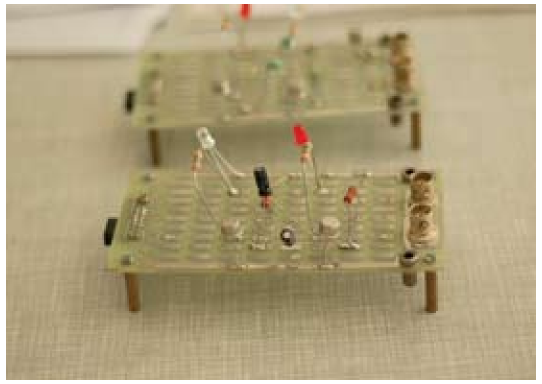
We also offer activities addressed to the youngest students: Monday's **Entertaining Physics** is an activity for students of the initial years of elementary school. Its purpose is to get the participants interested in the physical phenomena that occur in nature; to this end, simple experiments are designed to be performed by the students on their own. This activity allows students to find answers to many puzzling questions concerning the world around them.

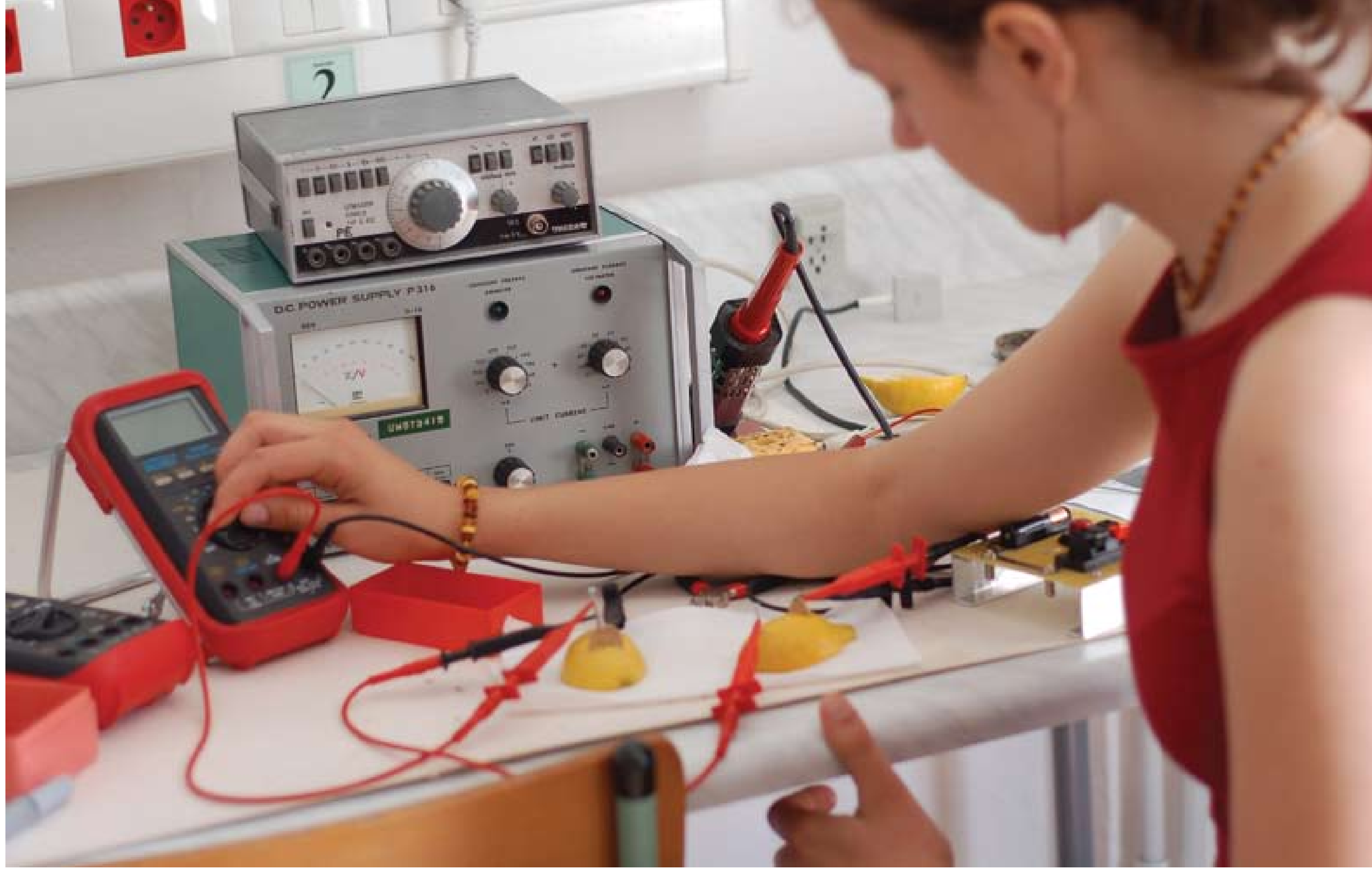
Our outreach program does not overlook teachers of physics. With them in mind we organize a periodic Nationwide Seminar of Physics Teaching (in collaboration with the Mazovian Regional Government Center for Teacher Perfection and the Warsaw Chapter of the Polish Physical Society).

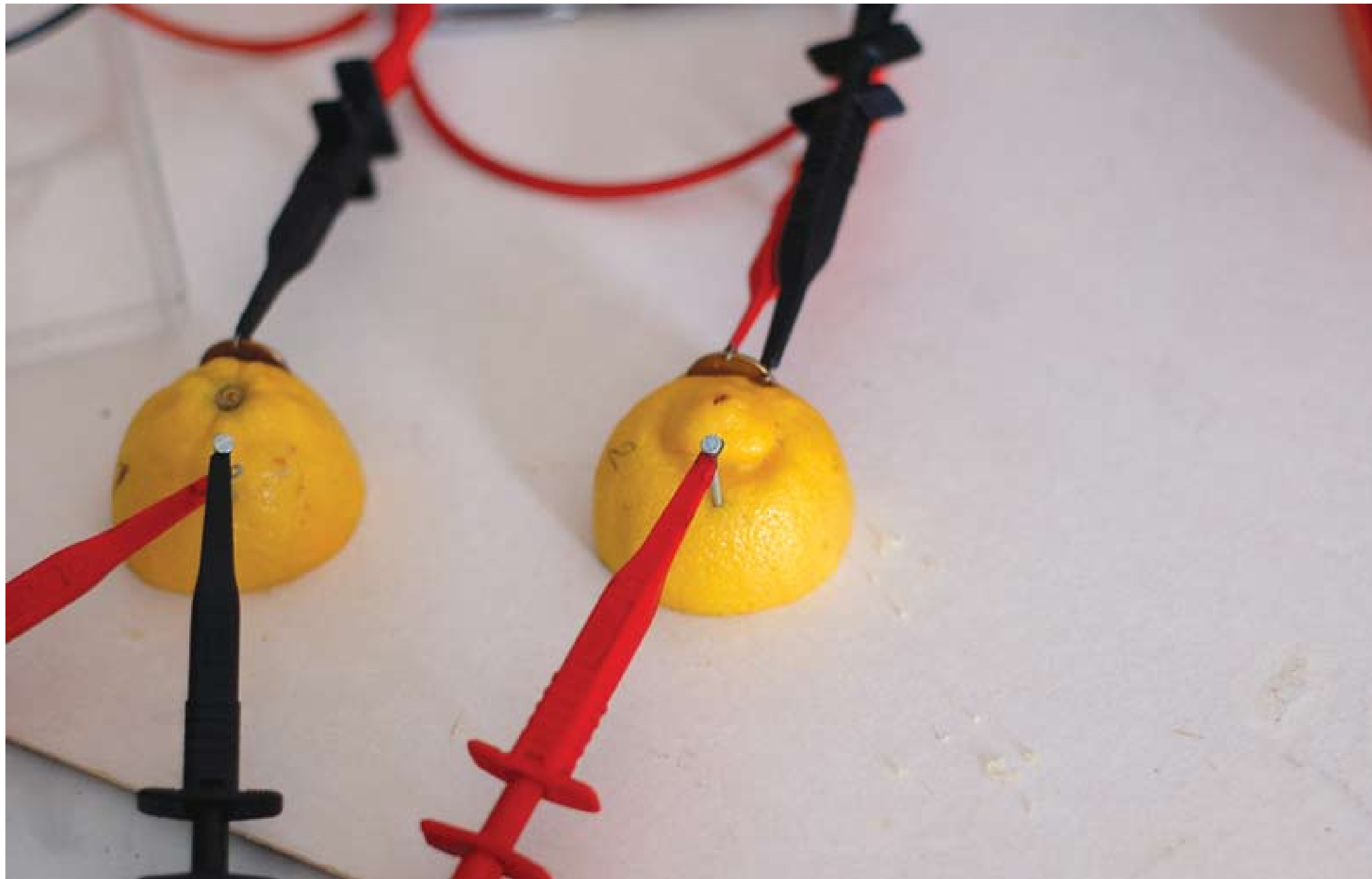
A section of the Faculty's website is addressed to aficionados of physics. There is also a forum, **"Ask a Physicist"**, available to anyone interested in obtaining answers to questions in natural science. Replies are given by competent experts, and the most interesting questions are published on the webpage.

The University of Warsaw Faculty of Physics takes a very active part in the organization of the yearly Festival of Science (www.festiwalnauki.edu.pl). There are also interesting lectures, offered within the framework of the Open University (www.ou.uw.edu.pl).

Our Faculty also lends its support to local community activities, such as "Hożarty", the "spring festivity of Hoża street".







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