

THE STATE UNIVERSITY OF NEW JERSEY  
**RUTGERS**

Department of Physics and Astronomy  
Rutgers, The State University of New Jersey  
136 Frelinghuysen Road  
Piscataway, NJ 08854-8019  
[www.physics.rutgers.edu](http://www.physics.rutgers.edu)



## The University

Rutgers, The State University of New Jersey, has a unique history as a private college, land-grant college, and public university. Founded in 1766 as a private religious school, it is the eighth oldest university in the United States. Following a gradual transformation from private to state school, including consolidation with other state and private colleges, it was declared the state university in 1945. Rutgers is now the premier public research university of New Jersey. In addition to the graduate program in physics and astronomy, several graduate programs are among the top programs in the country.

The university has campuses in the Camden, Newark, and New Brunswick areas. The New Brunswick/Piscataway campus, home to the largest number of graduate programs, is located in central New Jersey, with easy access to New York City and Philadelphia. New Brunswick has become well known for its revitalized downtown area with a lively theater scene and a large variety of fine restaurants.

Rutgers, The State University of New Jersey, is dedicated by law and by purpose to serving all people on an equal and nondiscriminatory basis.

Photography by Dennis Connors and Nick Romanenko. Research imagery courtesy of: Eva Y. Andrei (p. 8), Premi Chandra/Lev Ioffe (p. 9), Sang-Wook Cheong (p. 8), Ivan Ermanoski/Theodore Madey (p. 15), Michael Gershenson/Vitaly Podzorov (p. 8), Jefferson Lab (p. 13), Amitabh Lath (p. 12), NASA/JPL-Caltech/Steward Observatory (p. 3), NRAO/AUI (p. 5), Rutgers' CDF Collaboration (p. 12), Ricardo Sanchez/Jeremy Sellwood (p. 5), David Vanderbilt (p. 9), and Theodore Williams (p. 4).

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Department of  
**Physics &  
Astronomy  
at Rutgers**

Rutgers, The State University of New Jersey

# Innovative Teaching, Forefront Research

## The Department of Physics and Astronomy at Rutgers,

The State University of New Jersey, is the premier physics department of the New Jersey university system.

With approximately 70 faculty members in the graduate program located on Rutgers' New Brunswick/Piscataway campus, it is one of the largest physics departments in the nation.

Faculty research—supported with external funding amounting to nearly \$10 million—

covers a wide variety of topics in astronomy, experimental physics, and theoretical physics.

Over the past two decades, the department has increased the number of faculty by 50 percent with concentrated growth in the areas of high energy theory,

astronomy, and surface science. The department's small student-faculty ratio allows graduate students easy access to research advisers and offers unique opportunities for research to undergraduates. Current research in astronomy and physics at Rutgers is highlighted in the following pages. Detailed descriptions of faculty research, as well as further information about the department, are available at

[www.physics.rutgers.edu](http://www.physics.rutgers.edu).

*Research in the nanophysics laboratory uses a novel method of nuclear resonance profiling to determine the composition and structure of ultrathin films, atomic layer by atomic layer.*

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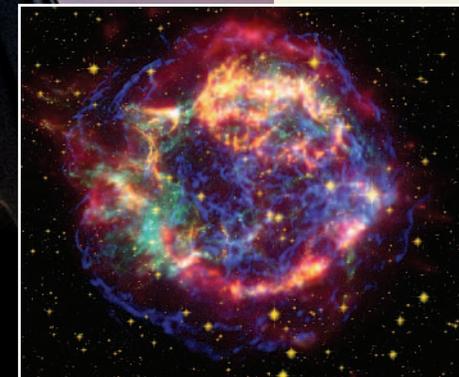
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# Astronomy



Rutgers astronomers pursue some of the most exciting questions in physics today through active observational and theoretical programs. Projects include searches for the nature and distribution of dark matter; attempts to determine the expansion rate and density of the universe; the origin, evolution, and nature of large galaxy clusters; the formation and evolution of galaxies; and the formation of the elements in supernovae.

Objects of study range from “nearby” globular star clusters in our own galaxy to the most remote galaxies and quasars. Observers and theorists in the astronomy group interact closely, and many recent student theses result from both theoretical and observational projects.



*Instructional facilities at the Serin Physics Laboratory include a 20-inch optical telescope (left), in the Robert A. Schommer Astronomical Observatory, as well as a radio telescope.*

*False-color picture of the supernova remnant Cassiopeia Amade (inset), comprised of images taken from three of NASA's Great Observatories: infrared light from the Spitzer Space Telescope, visible light from the Hubble Space Telescope, and X-ray data from the Chandra X-ray Observatory. Rutgers astronomers are users of each.*

# Astronomy



**The Southern African Large Telescope (SALT)** is one of the principal research facilities for the astronomy group. Rutgers astronomers have a 10 percent share of observing time on the 11-meter telescope—the largest optical telescope in the world—which began operations in mid-2005. As founding members of the consortium that built the telescope, the astronomy group contributed to its design and instrumentation. For Rutgers astronomers, SALT offers the opportunity to make cutting-edge observations of the cosmos through access to this world-class instrument.

**Rutgers has a 10 percent share of observing time at SALT, the largest optical telescope in the world.**

**Rutgers is also a partner in the Atacama Cosmology Telescope**, a six-meter microwave telescope located high in the Chilean Andes, which becomes operational in 2006. Its measurements of cosmic background radiation—the faint glow from the Big Bang—will tell us more about the origin and evolution of the universe.

Additionally, our astronomers are major users of NASA's Great Observatories, especially the Hubble Space Telescope, the Chandra X-ray Observatory, and the Spitzer Space Telescope, as well as many other ground-based optical and radio facilities.

**Astronomy has made tremendous advances in the past decade**, as many new ground- and space-based telescopes began operations. These telescopes enable astronomers to see not only much fainter objects with visible light, but also to explore the universe over a wide range of the electromagnetic spectrum—from radio wavelengths to gamma rays. Rutgers astronomers make observations at most wavelengths and have

contributed instruments to several projects around the world. The imaging Fabry-Perot spectrophotometer—which resides at the Cerro Tololo Inter-American Observatory in Chile—was designed and built at Rutgers, and the university's astronomers provided a similar instrument for the primary focus imaging spectrometer on SALT. Development of instrumentation continues to be an important activity, especially for observation in the ultraviolet region.

**Rutgers astronomers are major users of NASA's Great Observatories, especially the Hubble Space Telescope, the Chandra X-ray Observatory, and the Spitzer Space Telescope.**

**Rutgers has an extensive network of high-performance workstations** for the analysis of astronomical observations and for theoretical numerical computations. Data from a wide variety of sources can be processed, enhanced, and viewed using most major astronomy software packages. Theoretical research is often heavily computational, and N-body simulations at Rutgers make major contributions to understanding the dynamics of galaxies and stellar systems. ✨

*Rutgers astronomers use the SALT telescope (left), as well as the Green Bank Radio Telescope in West Virginia (second from left). A major area of research is the study of galactic dynamics and the search for dark matter through studies of barred galaxies (right and second from right).*

# Condensed Matter Physics



Condensed matter physics at Rutgers has a long and distinguished history. The first Ph.D. ever awarded by the department, in 1935, was in condensed matter physics. In 1951, Rutgers professor Bernard Serin—after whom the physics and astronomy building is named—discovered the isotope effect, a key discovery in the path to understanding superconductivity.

Traditional physics assumes that if you can understand matter on both the smallest and largest scales, then the properties of the world in between will become clear. We have discovered this isn't the case. Even



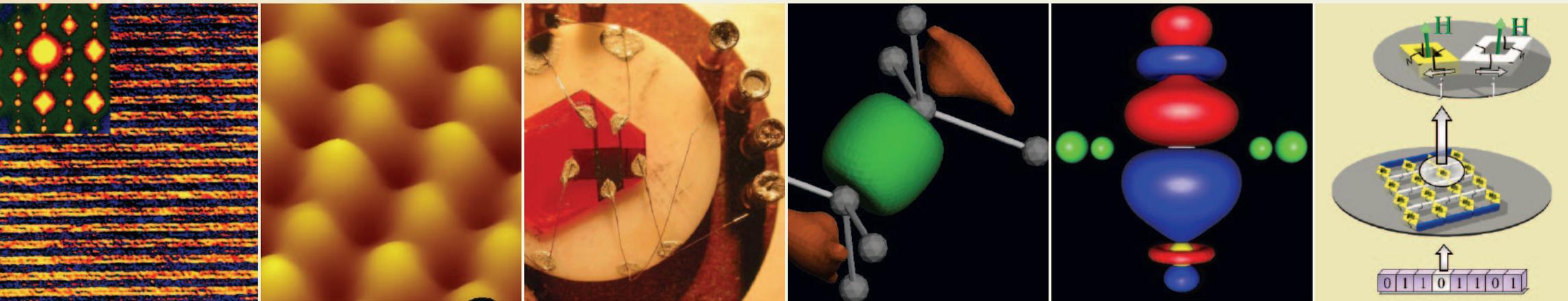
though the microscopic principles of the world around us are largely understood, we don't understand the collective, emergent physics that develops when we put matter back together again.

The quest to understand, explore, and apply discov-

eries across this new frontier is the stuff of condensed matter physics.

*The recently completed cleanroom serves a number of experimental groups and features the magnetron sputtering system shown here (left). Graduate student Jian Wei at work in the cleanroom (inset).*

# Condensed Matter Physics



The Rutgers condensed matter physics group is concerned with uncovering the new principles that govern the collective physics of matter—from the quantum scale, via chemistry, to the edges of biological physics. With a broad spectrum of interests, the group has made major discoveries in both theoretical and experimental aspects of condensed matter physics.

The quest to understand, explore, and apply discoveries across this new frontier is the stuff of condensed matter physics.

Theoretical efforts are based in the Center for Materials Theory. Research covers such diverse topics as: high-temperature superconductivity, quantum phase transitions, heavy electron physics, the glasses, ferroelectrics, metal-insulator transitions, quantum dots, quantum computation, and mesoscopics.

Our group is committed to the development of new mathematical techniques, both analytic and numeric, and has provided a pioneering lead in areas such as the exact solution of the Kondo model, the development of dynamical mean field theory, the first principles calculation of electronic structure, and the slave boson. New physical concepts—such as the marginal Fermi liquid and the scaling theory of localization—grew as part of a collaboration between Rutgers and surrounding New Jersey labs.

With interests ranging from ultra-cold superfluid helium-3; and the synthesis and discovery of new classes of oxide, semi-conducting, magnetic, and superconducting matter; to the design and fabrication of qu-bits for quantum computers, Rutgers' experimental condensed matter group is involved in some of the field's most highly cited discoveries of electronic phase separation in oxide materials.

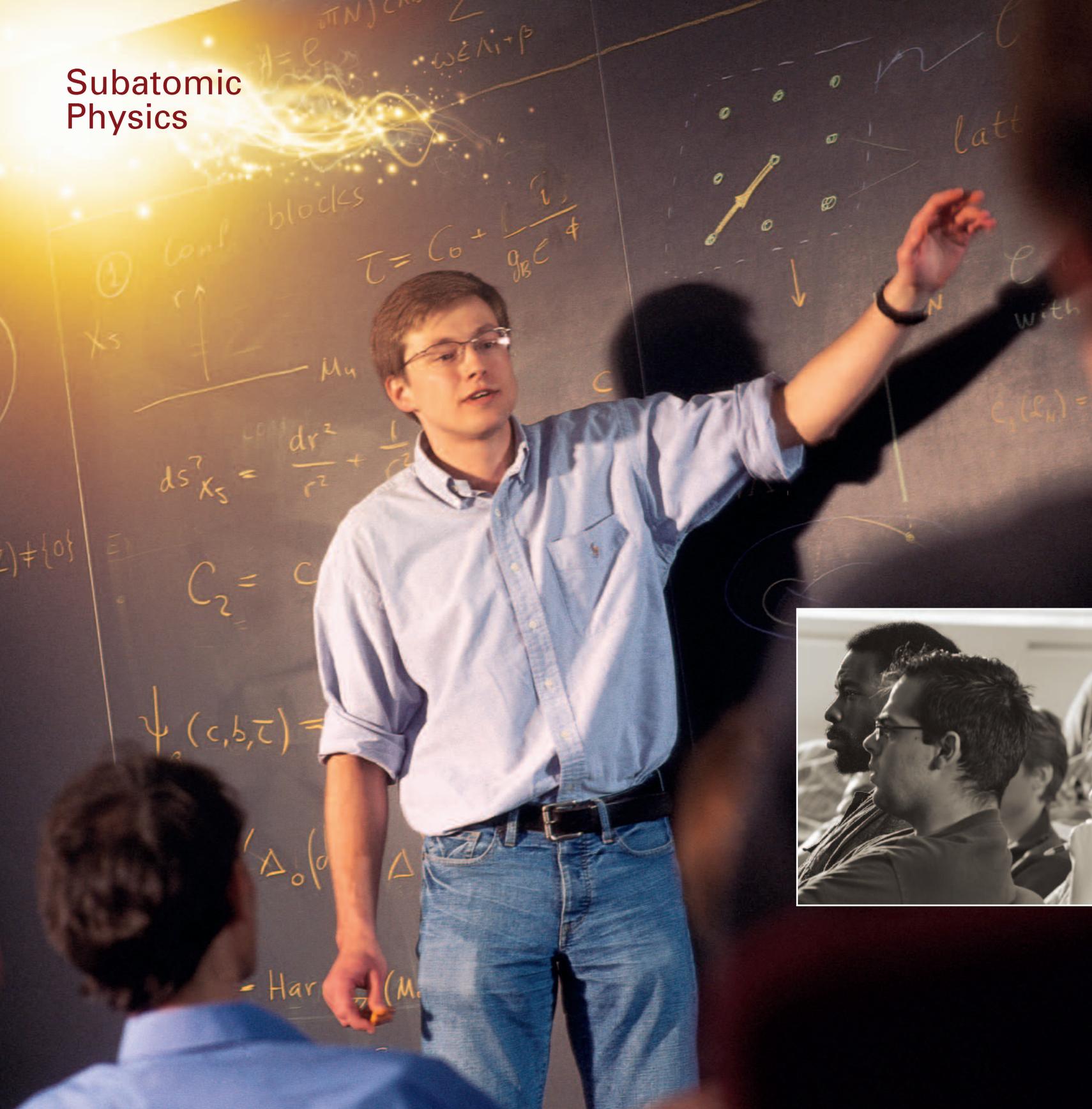
The group is actively involved in the implementation of these discoveries in real-world applications, and also has a strong role in the development of new classes of organic and inorganic semiconductors.

The condensed matter group is also closely allied with the Laboratory for Surface Modification and the BioMaPS Institute for Quantitative Biology, with faculty and students often collaboratively involved in both.

The group has made major discoveries in both theoretical and experimental aspects of condensed matter physics.

*Condensed matter experimentalists explore a wide variety of research, including studies of vortices in superconductors and multiferroic materials: nanoscale self-organization of charges in strongly correlated electronic systems shown in an electron diffraction pattern and a real space image (far left); image of carbon atoms using a state-of-the-art pinning force microscope (second from left); and the first single crystal organic field effect transistor, which was fabricated at Rutgers (third from left). Condensed matter theorists are finding new ways to visualize the electron states in crystals: an electron "Wannier function" nestles among the bonds deep in a silicon crystal (third from right); the nature of electrons in ferroelectric materials is being explored as shown for BaTiO<sub>3</sub> (second from right). Research into problems related to quantum computation by solid state devices also is being performed: a design of a fault-tolerant quantum bit (far right).*

# Subatomic Physics



The subatomic physics program encompasses a wide variety of topics in experimental and theoretical high energy and nuclear physics. Rutgers is one of the world's top centers for research in superstring theory, an ambitious attempt to unify the quantum mechanical standard model with Einstein's classical theory of gravity.

Our high energy experimentalists study the nature of matter at the shortest distance scales at the Collider Detector at Fermilab (CDF) and will soon begin experiments at the Large Hadron Collider (LHC) at CERN (the European Organization for Nuclear Research). Nuclear physics has expanded to encompass topics formerly considered the domain of particle physics including

exotic mesons, multi-GeV reaction studies, and the quark-gluon plasma. Because of the advent of more advanced detectors and accelerators, nuclear structure studies now explore regions of nuclei and nuclear excitation, angular momenta, and stability that were not previously accessible.



*Rutgers' new High Energy Theory Center is one of the world's top centers for research in superstring theory. Doctoral student Dmitriy Belov (left) leads one of the regular string theory seminars with fellow students (inset) and faculty in attendance.*

# Subatomic Physics



## High Energy Theory

The Standard Model of elementary particles, formulated in the 1970s, is spectacularly successful at explaining all available high energy physics data. Since that time, theoretical particle physics has been fascinated with speculations about what lies beyond its frontiers.

Many of the dramatic advances in string theory over the past 20 years were initiated at Rutgers, and the field continues to see vigorous development. Our recent work centers particularly on the interplay between mathematics, string theory, and quantum field theory. This emerging area of “physical mathematics” led to important advances in algebraic geometry, the theory of infinite dimensional algebras, automorphic forms, and topology.

Rutgers physicists are in the forefront with their work in mathematical quantum field theory, particle phenomenology, and lattice gauge theory. In mathematical quantum field theory, the focus is on exactly solvable interacting quantum field theories in one spatial dimension, with many applications to condensed matter physics.

Particle phenomenology is closely connected with the work being done by both the high energy experiment and astronomy groups. The work focuses on theoretical predictions for new data obtained from both the Fermilab Tevatron in Batavia, Illinois, and CERN’s LHC in Geneva, Switzerland, as well as reconciling particle physics with the basic mysteries of cosmology: dark matter, dark energy, and structure formation.

The lattice gauge theory work concentrates on developing numerical techniques for solving quantum chromodynamics (QCD), the fundamental theory of strong interactions, as well as other strongly interacting systems.

## High Energy Experiment

The high energy experiment group has been a major participant in CDF at the Tevatron, currently the world’s most powerful particle accelerator. Protons and antiprotons are accelerated to high energies and collided, producing many particles, including massive particles not present in ordinary matter. The studies of those collisions led to the discovery of the top quark by the CDF collaboration in 1998.

And with LHC slated to begin operations in 2007, current particle physics promises to be completely revolutionized. LHC will collide protons at a center of mass energy of 14 TeV—seven times higher and at a luminosity more than 10 times greater than is possible at the Tevatron. One of the primary goals of LHC is the search for the Higgs boson, the last missing ingredient of the Standard Model. The interactions of the Higgs particle are believed to be the source of all mass. The Rutgers group is a member of the Compact Muon Spectrometer (CMS) collaboration, one of the two large experiments at LHC, which will be searching for the Higgs and physics beyond the Standard Model.

The astro-particle group is involved in an experiment in central Utah called HiRes, which studies the highest energy cosmic rays: particles of order  $10^{17}$ – $10^{20}$  eV that strike the earth’s atmosphere. These initiate giant showers of particles in the atmosphere, and light emitted by nitrogen atoms excited by the showers is detected by HiRes. The goal of HiRes is to determine the dynamical origin of these remarkable events and whether they can be identified with a particular source by measuring their energy spectrum and direction.

## Nuclear Theory

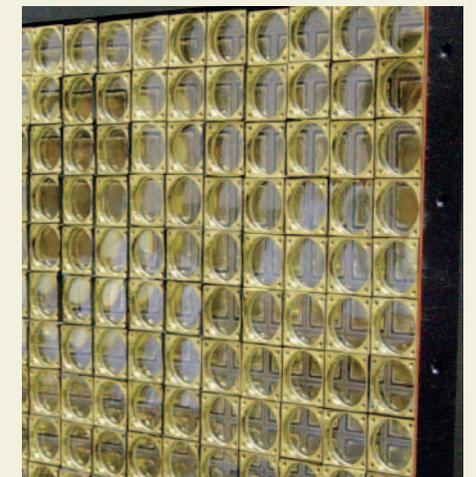
Nuclear theorists are exploring a variety of topics that range from sophisticated shell-model calculations related to double beta decay, which is a key to understanding the nature of the neutrino, to calculations of new forms of matter, such as the quark-gluon plasma. They also are exploring topics such as the transition from a hadron-meson-based description of the strong interaction to a quark-gluon-based description.

*A simulated interaction at the LHC (far left). Rutgers’ high energy and nuclear experimentalists have made significant contributions to the permanent equipment at Fermilab and JLab. Graduate student Dongwook Jang (second from left) works on the CDF silicon vertex detector (third from left). The electromagnetic calorimeter (at right) at JLab.*

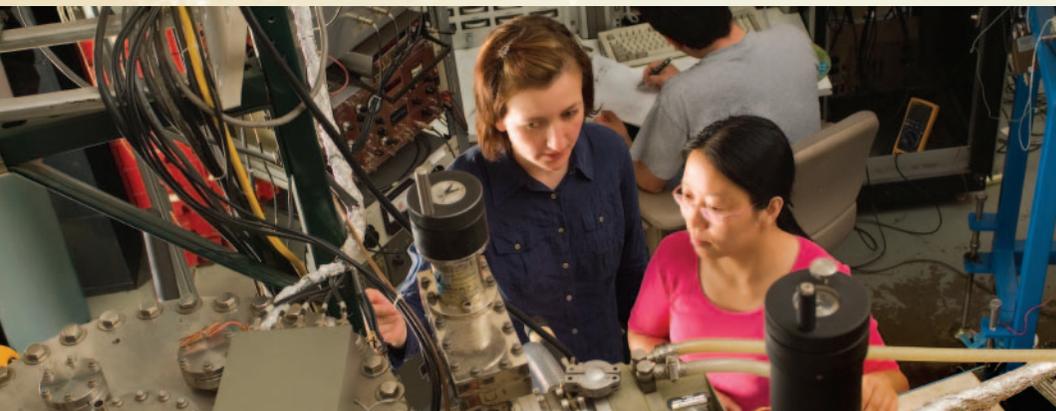
## Nuclear Experiment

The experimental nuclear structure group studies nuclei at the limits of stability. Nuclei with large neutron excess are produced in supernovae, through an as-yet poorly understood path by which all heavy elements are formed. Experiments at existing rare isotope accelerators are providing the first insights into the structure of these isotopes. The group specializes in transfer reactions, gamma-ray spectroscopy, and measurements of magnetic moments of excited nuclei.

The experimentalists working in the broad area of intermediate energy nuclear physics concentrate on understanding the basic structure of the nucleon and how the nuclear environment changes that structure. Much of this work is based on the use of spin as a sensitive probe of the nucleon. Recent highlights include measuring the proton electric structure, which showed the intrinsic deformation of the proton; illuminating the quark structure of nuclei in deuteron photo-disintegration; and finding indications of modifications of the nucleon structure in nuclei. Most recent research has been at Jefferson Lab (JLab) in Newport News, Virginia, but the group is playing a major role in MINERvA, a neutrino scattering experiment at Fermilab, planned to begin in 2008.



# Interdisciplinary Programs



## Much of physics today has significant overlap with other fields.

A number of professors in other departments are members of the graduate program in physics and astronomy, allowing them to supervise physics Ph.D. students. In addition to members of the two formal interdisciplinary programs—the Laboratory for Surface Modification and the BioMaPS Institute—the graduate program includes faculty from the departments of mathematics and education.

## Laboratory for Surface Modification

Surface science encompasses research in the overlapping disciplines of physics, chemistry, materials science, and engineering. Research in all these areas is necessary to understand the phenomena occurring at the atomic level at surfaces and interfaces, with considerable interest in fundamental concepts and phenomena at surfaces.

The mission of the Laboratory for Surface Modification (LSM) is to provide a focus for research in basic and applied studies of high technology surfaces and interfaces. Surface modification encompasses a broad spectrum of phenomena occurring at the atomic level on the surface of solids. The chemistry and physics of surfaces and interfaces are among the most challenging and exciting areas of condensed matter science. Advances in the technology of surface modification have a fundamental impact on multibillion-dollar industries in diverse fields like telecommunications, petroleum, superconductivity, computer science, minerals, and chemicals. Surface modification provides the scientific underpinnings of exciting new areas of nanoscience and nanotechnology.

LSM members hold faculty appointments in several Rutgers departments and graduate programs including physics and astronomy, chemistry and chemical biology, materials science and engineering, and electrical and computer engineering.

In support of the laboratory mission, strong industrial collaborations have been established with local high technology industries. Laboratory members are active participants in

the New Jersey Center for Biomaterials and the New Jersey Associated Institutions for Materials Sciences, a joint venture involving Rutgers, the David Sarnoff Research Center, New Jersey Institute of Technology, Princeton University, Stevens Institute of Technology, and the University of Medicine and Dentistry of New Jersey.

## BioMaPS Institute

The BioMaPS Institute for Quantitative Biology formally began operation in 2002 with a mission to promote research and education at the interface between the biological, mathematical, and physical sciences; to stimulate interactions among experimentalists and theoreticians working on problems in quantitative biology; and to train a new generation of scientists using the latest computational and modeling tools.

Research at the BioMaPS Institute combines molecular-level details and biophysical modeling with statistical and bioinformatics tools to provide a multiscale view of complex biological systems. A current collaborative research focus at the institute is transcriptional regulation of gene expression, which uses the concepts and techniques of molecular and structural biology, bioinformatics and computational biology, statistical physics, and mathematical modeling.

The institute's major educational activity is an interdisciplinary Ph.D.-granting program designed to serve the needs of the increasing number of graduate students drawn to the biological sciences from the physical, mathematical, and computational sciences. Through courses and faculty, the program provides the necessary infrastructure for molecular biosciences students to specialize in quantitative biology.

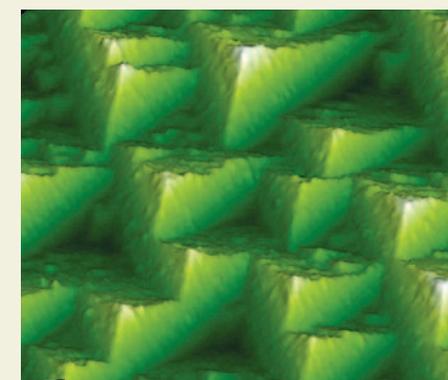
*Postdoctoral fellow Dr. Lyudmila Goncharova and graduate student Hua Yao planning experiments at the unique ion scattering facility in the nanophysics laboratory (far left), where research centers on the properties of ultrathin films, especially for applications in microelectronics.*

## Physics and Astronomy Education Research

Studying how students learn, and searching for ways to help them learn better, is the goal of the Physics and Astronomy Education Research (PAER) group. Recognizing the special difficulties that learning physics entails requires a physicist's great depth of subject knowledge. Rutgers' PAER group, made up of physicists and representatives from graduate programs in education and math, is looking into effective cognitive approaches to learning, with emphasis on investigation, evaluation, representation, and linguistics. The group also has been long involved in developing innovative teaching environments and expanding technological innovation in physics teaching. This includes Keller-type self-paced courses, minilabs, a hands-on physics learning center, and the use of student response systems.

The group founded the extended physics programs for engineering and science majors. These courses have had nearly two decades of success in helping underrepresented groups succeed in science and engineering programs. Methods to enhance the degree completion rates of women and underrepresented minorities continue to be developed. ☺

*Researchers at the Laboratory for Surface Modification are studying how a nanoscale textured surface of iridium (below) can be used to extract hydrogen from ammonia, which could provide hydrogen for tomorrow's fuel-cell-powered clean energy vehicles.*



# Programs of Study



## Undergraduate Program

Whether the goal is a Ph.D. or a solid background in preparation for a career, the undergraduate program of study in physics provides a quality education. The program has a national reputation as a leader in innovative instruction, and was recently named a successful model program by the National Task Force on Undergraduate Physics.

Majors in astrophysics and physics are available. The **astrophysics major**, leading to the B.S. degree, provides thorough preparation for graduate study in astronomy and is suitable for students who aspire to careers in astronomy research and/or education. Three options are available within the physics major:

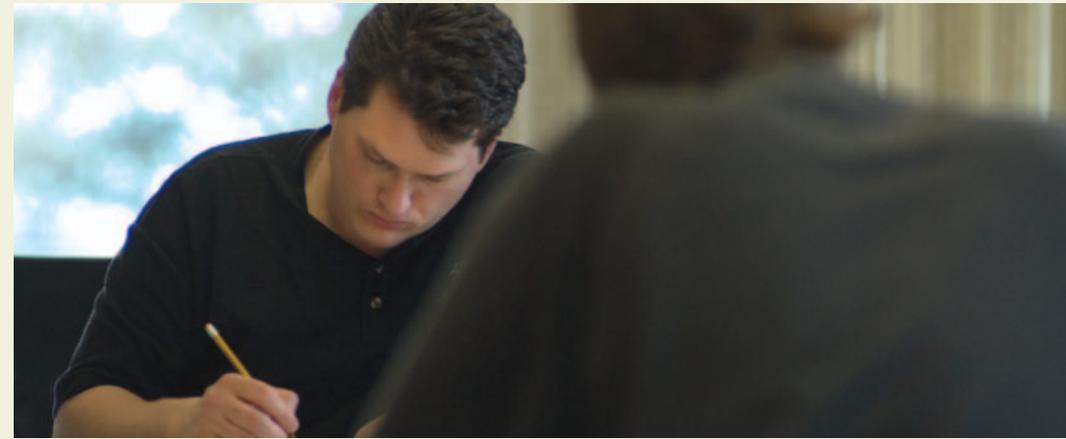
- **The professional option**, leading to the B.S. degree, provides suitable preparation for graduate study and is intended for students who wish to become physicists at universities or in industrial or government research laboratories.
- **The applied option**, leading to the B.S. degree, is intended for students who plan to pursue a technical career in industry without graduate study.

- **The general option**, leading to the B.A. degree, provides a broad scientific education to students who have an interest in physics but do not expect to become physicists or to do graduate work in the subject. This option is particularly suitable for interdisciplinary studies or double major programs.

The department offers a challenging three-semester introductory sequence called Honors Physics, open only to honors students and others who have advanced placement credit. Advanced physics majors with excellent academic records are invited to participate in the departmental honors program and work on research projects under the supervision of a faculty member.

Seven merit-based scholarships, each nearly full tuition, are offered annually to physics majors in their junior or senior years. These scholarships are in addition to the university's general program of financial aid.

For detailed information on the undergraduate program, visit [www.physics.rutgers.edu/ugrad](http://www.physics.rutgers.edu/ugrad). For information on admissions to Rutgers, visit [www.admissions.rutgers.edu](http://www.admissions.rutgers.edu).



## Graduate Program

The Rutgers graduate program in physics and astronomy is one of the leading programs in the nation; graduate students come from around the world in pursuit of research opportunities. The student-faculty ratio is less than two, allowing students to easily find a research adviser. Essentially all doctoral students are supported by teaching assistantships, research assistantships, or fellowships, which include a stipend and full tuition remission.

Although most students are enrolled in the doctoral program leading to the doctor of philosophy (Ph.D.) degree, the department also has programs leading to the master of science (M.S.) and master of science for teachers (M.S.T.) degrees.

The doctoral program is designed to give students a broad understanding of classical and modern physics, with intensive training in one of the frontier areas of modern research. A thesis of original research is required to give the students experience in advancing themselves to the leading edge of an important area of physics. Students are encouraged to study several subdisciplines of physics in order to

prepare for application of fundamental knowledge beyond their field of thesis work. An astronomy option allows students who intend to carry out their thesis work in that subject to replace several upper-division course requirements with astrophysics courses.

Graduates of the doctoral program have been successful in diverse careers at universities, in government research laboratories, and in industry. The master's programs provide attractive alternatives for students who wish to pursue a shorter advanced education program. The M.S.T. degree program is primarily a subject matter oriented program for teachers.

Detailed information on the graduate program, including admissions information, can be found at [www.physics.rutgers.edu/grad](http://www.physics.rutgers.edu/grad).

*Labs for undergraduates are equipped with a wide range of modern equipment. Physics majors Liz Tozour and Joe Walsh perform experiments with the instructional cyclotron (left). Physics major James Flakker studies at the Serin Physics Building's specialized library (above) where electronic access to all major journals is available through the Rutgers library system.*