

# Graduate Study at Cornell

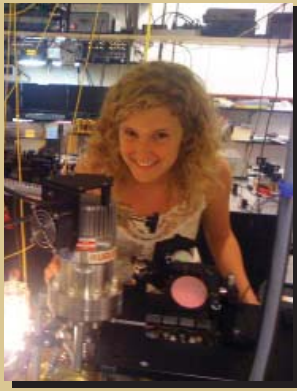
The graduate physics program at Cornell is multidisciplinary, broad and congenial, and has access to superb facilities.

**Multidisciplinary** Cornell University has always understood that the world does not appor- tion neatly into one discipline or another. That may be why Cornell, an Ivy League university where the pursuit of new knowledge is given free rein, has initiated many areas of multidis- ciplinary research. Yes, there are departments and faculties with familiar names at Cornell, but the walls between disciplines are so low that you can move easily in all directions.

**Broad** If multidisciplinary collaboration is one attribute of Cornell's graduate program in physics, the breadth of its curriculum and faculty is another. Of the nation's best-re- garded physics departments, Cornell is comfortably mid-sized. The faculty is comprised of more than 40 active professors, plus 20 emeritus professors (many of whom remain active in re- search), and half a dozen adjunct professors. Faculty members ad- vise approximately 65 post-docs and research associates and 180 graduate students—with, on av- erage, 30 new graduate students entering each year.

**Congenial** Given its stature, the physics department at Cornell surprises many people by its low-key congeniality. It is the sort of place where people talk to one another in the halls. Among graduate students, relationships are more cooperative than competitive. Gradu- ate students play intramural sports together, go to ballroom dancing classes and form musical ensembles. As one prospective student recently said to his Cornell hosts, "You can't be graduate students. You all seem far too happy."

**Superb Facilities** The strength of the Physics Department is complemented by major research facilities. Graduate students who want to learn to make use of these facilities will find willing mentors among faculty members, research associates, technicians and other staff members. By expressing an interest, a graduate student can learn to take apart and rebuild a particle accelerator, produce highest-quality images on a tunneling electron mi- croscope, or fabricate a silicon chip that will be a substrate for growing nerve cells.



**Lauren Aycock**

Uses ultra cold atoms to study quantum phase transitions and explore many-body physics.  
Professor Mukund Vengalattore



**Heng Li**

Nonlinear optics and fiber laser, ERL Project.  
Professor Frank Wise, Applied and Engineering Physics



Information about applying to Cornell's graduate program in physics is available at:  
[www.physics.cornell.edu/graduate/how-to-apply/](http://www.physics.cornell.edu/graduate/how-to-apply/)

# Major Research Facilities

**Cornell Electron Storage Ring (CESR)** The CESR accelerator circulates beams of electrons and positrons with energies from 1.8 to 5.3 GeV. Commissioned as a colliding beam machine in 1979, CESR was the source of e+e- collisions for the CLEO particle physics experiment until CLEO data-taking was completed in 2008. The focus is now on accelerator physics experiments, and on providing beams for x-ray science. For the accelerator experiments, CESR has been reconfigured for the study of the properties of tightly collimated (“low emittance”) beams. Such beams will be required by the International Linear Collider, a future high energy e+e- collider -- but to date, no accelerator facility has achieved beams of the necessary quality. The CESR Test Accelerator Project is developing techniques for achieving ultra-low emittance and exploring the physics of beams in the ultra-low emittance regime. CESR is the only facility in the western hemisphere that routinely produces, accelerates and stores beams of both electrons and positrons and is therefore uniquely suited to the study of damping ring physics.

## **Cornell High Energy Synchrotron Source (CHESS)**

CHESS provides high-intensity x-rays to both a national user community and researchers at Cornell for use in determining the structure and dynamics of materials in a wide range of scientific fields. X-ray diffraction is used to understand the growth modes of metal thin films used for making electronic devices, the defects in protein crystals, the motion of charge-density waves in quasi-1-dimensional metals and the dynamics by which

polymer materials self-assemble into controlled structures. New regimes of study are being opened with the development of high-speed area detectors for measuring time-dependent phenomena with x-rays, as well as entirely new sources of more brilliant x-rays.

## **Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)**

CLASSE provides facilities for experimental particle physics and accelerator physics. These facilities include clean rooms and cryogenic tools for the fabrication and characterization of superconducting RF cavities and other large instruments. There are also facilities for computing and for software development for large, widely distributed data sets, such as those anticipated at the energy-frontier LHC particle accelerator.

**Cornell Center for Materials Research (CCMR)** The Center for Materials Research supports interdisciplinary projects that include such themes as: controlling electrons at in-



## FACILITIES

Cornell Electron Storage Ring (CESR)

Cornell High Energy Synchrotron Source (CHESS)

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

Cornell Center for Materials Research (CCMR)

Cornell Center for Nanoscale Systems in Information Technologies (CNS)

Nanobiotechnology Center (NBTC)

Cornell NanoScale Science & Technology Facility (CNF)

Cornell Center for Advanced Computing

Kavli Institute at Cornell for Nanoscale Science (KIC)

terfaces, photonic building blocks from multiscale materials, growth of complex materials and atomic membranes as molecular interfaces. Its Materials Laboratory is equipped with thin film deposition equipment (e-beam, laser ablation, etc.), STM/AFM microscopes and optical/infrared spectrometers. The center also supports an Ion Beam Analytical Facility, UHV STEM Laboratory, X-Ray Diffraction, Polymer Characterization and Research Computing Facilities.



**Cornell Center for Nanoscale Systems in Information Technologies (CNS)** The CNS supports interdisciplinary research in the areas of silicon and carbon nanoelectronics, nanomagnetism, nanophotonics, nanocharacterization and nanoprocessing. The Center supports a shared facility for high-frequency electrical and optical measurements.

**Nanobiotechnology Center (NBTC)** NBTC is a highly interdisciplinary NSF-funded center featuring close collaboration between life scientists, physical scientists and engineers, exploring the emerging areas of scientific and technological opportunities that integrate nano/microfabrication and biosystems to the benefit of both.

**Cornell NanoScale Science & Technology Facility (CNF)** CNF is a national center for fabrication of micro- and nanostructures for applications throughout all of science and engineering. Here, physicists and other scientists, engineers and expert technicians make devices of metals, semiconductors and insulators of dimensions measured in nanometers. Fabrication techniques include the most advanced methods of thin film processing, electron beam and optical lithography, etching, film deposition and characterization.

**Cornell University Center for Advanced Computing (CAC)** The CAC helps faculty and graduate student researchers accelerate scientific discoveries with high-performance computing, application and data storage solutions. CAC enables simulations of complex materials, relativistic quantum field theories, black holes and galaxy formation, high-energy particle accelerators and the analysis of data from the Large Hadron Collider at CERN.

**The Kavli Institute at Cornell for Nanoscale Science (KIC)** KIC is devoted to the development and utilization of next-generation tools for exploring the nanoscale world. This Institute supports high-risk, high-payoff projects to image and dynamically control nanoscale systems and push the frontiers of nanoscale science. Current emphasis focuses on electron and optical microscopy, physical and electronic measurement and manipulation, and optoelectronic nanosensing.

# Multidisciplinary Research

The Physics Department actively collaborates with other departments on campus. Many physics faculty are members of the graduate fields associated with these departments:



**Kasturi Saha**

Light-matter interactions with hot atomic vapors (Rb) inside confined geometries and on-chip frequency comb generation for spectroscopy.

Professor Alex Gaeta, Applied and Engineering Physics

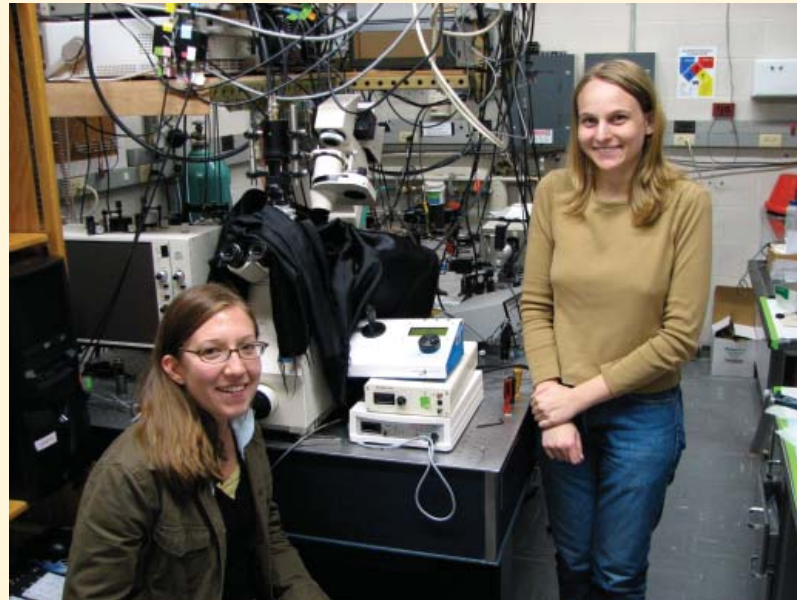


**Matt Farrar**

Nonlinear optics to develop tools for studying neurological diseases, such as spinal cord injury.

Professor Chris Schaffer, Biomedical Engineering

**Applied and Engineering Physics** There is close collaboration between the School of Applied and Engineering Physics (A&EP) in the College of Engineering and the Physics Department in research areas such as biophysics and biotechnology, magnetic physics and devices, nano-mechanical systems, x-ray physics, charge-density waves, thin film growth and processing and nanoscale device fabrication. The fourteen A&EP faculty members also extend the range of physical phenomena investigated at Cornell. Research efforts in optics and photonics (ultra-fast, non-linear and quantum), semiconductor quantum dots and high-resolution electron microscopy are centered within A&EP.



**Applied Mathematics** Graduate students interested in chaos, complexity and non-linear systems will find allies at Cornell's Center for Applied Mathematics. The center has nearly 100 affiliated faculty members from six colleges at Cornell.

**Astronomy and Space Sciences** The Astrophysics Theory Group at Cornell straddles the graduate fields of physics and of astronomy and space sciences. Several members of the physics faculty have joint appointments in the Department of Astronomy, representing the closest possible link between the disciplines. The Astrophysics Theory Group typically also includes a few members from other allied fields.

**Chemistry and Chemical Biology** The work made possible by Cornell's MacCHESS facility—studying macromolecules with the x-rays generated by a synchrotron—draws together physicists and chemists. In the effort to identify, isolate and synthesize proteins and viruses by growing high-quality protein crystals and then using synchrotron x-ray

## AREAS

- Applied and Engineering Physics
- Applied Mathematics
- Astronomy and Space Sciences
- Chemistry and Chemical Biology
- Materials Science and Engineering
- Molecular Biology and Genetics

diffraction to fully determine atomic structure, physicists play a crucial role in making protein crystallography measurements. There are also close collaborations between physicists and chemists in fabricating single-molecule electrical devices and in the modeling of gene dynamics—specifically, the activity of genes, proteins and mRNA in the cell as it switches between proliferative (reproducing), differentiated (specialized) and apoptotic (suicidal) states.

**Materials Science and Engineering** In recent years, many materials scientists have turned their attention to nanotechnologies, including the making of nanocomposites and biomedics, along with electronic polymers. A multidisciplinary group has been active at Cornell for many years, studying the dynamic evolution of materials, including thin film growth, patterned surfaces, electrochemical interfaces, polymers, liquid crystals, biomaterials and systems with novel electronic properties.

**Molecular Biology and Genetics** Physicists bring some of their most powerful tools to the study of life at the molecular level—X-ray crystallography, optical and laser spectroscopy, nuclear magnetic resonance (NMR) spectroscopy and advanced computational science. One team of biophysicists at Cornell—the Structure-Based Drug Design Group—is applying advanced techniques for determining three-dimensional molecular structure to the development of new methods for creating novel drugs. Other examples of collaborative activities are in the area of development of new methods of x-ray based protein structure solution for structural genomics and statistical methods for analyzing genetic information.

# Accelerator Physics



**James Shanks**

Beam dynamics and control.  
Professor David Rubin



**Sam Posen**

New materials for superconducting  
accelerator cavities  
Professor Matthias Liepe

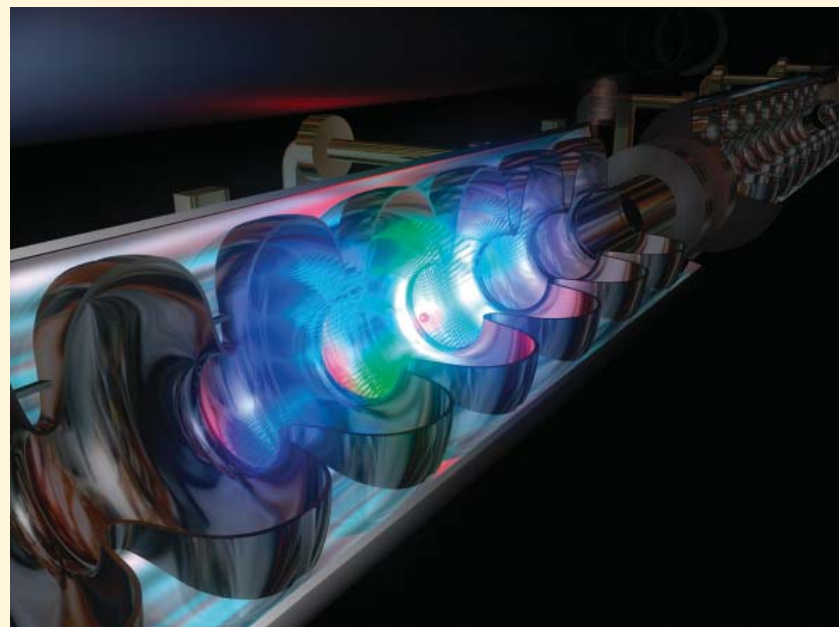
## FACULTY

Ivan Bazarov  
Gerald Dugan  
Donald Hartill  
Georg Hoffstaetter  
Matthias Liepe  
David Rubin

**Cornell accelerator physicists** pursue a broad range of topics in accelerator science and technology, from the operation of the on-campus Cornell Electron Storage Ring, also known as CESR, to the construction of an innovative new x-ray lightsource and the design and construction of future high energy colliders.

In operation for over 25 years, CESR has been a world class collider for particle physics and is now used as a test accelerator for components of the planned 30km long International Linear Collider. The site of numerous innovations in accelerator technology, its presence on-campus provides a unique opportunity for students to “drive” an accelerator, test their ideas and learn about nonlinear beam dynamics.

CESR is just one step in the long line of Cornell particle accelerators that have made Cornell a historically rich, technologically advanced, and internationally acclaimed laboratory for accelerator physics. The accelerator group is now developing an entirely new type of superconducting linear accelerator. This machine, known as an ERL (for Energy Recovery Linear accelerator), features x-ray beam brightness orders of magnitude higher than what is obtained with synchrotron sources and can produce femtosecond x-ray pulses with unprecedented average intensities. Cornell physicists expect to build the full 1.3 km ERL at Cornell at the end of this decade. A prototype that is being commissioned, tests critical components and offers opportunities for pioneering research in the physics and technology of beams.



Cornell's accelerator group is deeply involved in the design of the International Linear Collider (ILC), a TeV-scale electron-positron linear collider, proposed for construction and operation in the next decade. Cornell is contributing to the ILC damping rings, tracking sim-

ulations, construction of superconducting RF cavities and accelerator operation. In fact, Cornell has been operating CESR as an ILC damping ring test facility since early 2008.

As part of the program to advance the state-of-the-art in accelerator technology, the Superconducting Radio-Frequency lab has produced world-record setting superconducting accelerating cavities which are operating in accelerators around the world and are crucial to the success of proposed accelerators like the Energy Recovery Linac and the International Linear Collider. The Cornell accelerator physics group is and will continue to be an international leader in the development and application of advanced superconducting acceleration techniques and processes.

Cornell University is known world-wide for training accelerator physicists with one of the largest graduate programs in accelerator physics in the U.S. Graduate students are actively and crucially involved in each and every one of the existing and proposed accelerator projects being pursued at Cornell. Additionally, CESR provides students with an unrivaled opportunity to control and work directly with an operational high-energy accelerator. Students benefit from the talent and

experience of six accelerator physics faculty members and more than twenty research associates. Graduates of the program hold a variety of positions in science, business and government. In addition, Cornell graduates hold leadership positions at Cornell, as well as most of the other leading accelerator laboratories in the nation and abroad, including Argonne, Fermilab, DESY, SLAC, LBL, BNL and SNS. For more information about graduate studies in accelerator physics, visit [www.lepp.cornell.edu/Research/AP/Recruitment.html](http://www.lepp.cornell.edu/Research/AP/Recruitment.html).



# Experimental Elementary-Particle Physics



**Walter Hopkins**

CDF Experiment at the Tevatron.  
Professor Julia Thom



**Benjamin Kreis**

Searching for supersymmetric particles that decay into  $b$  quarks  
Professor Anders Ryd

## FACULTY

James Alexander  
Lawrence Gibbons  
Yuri Orlov  
J. Ritchie Patterson  
Anders Ryd  
Julia Thom  
Peter Wittich

**Cornell's particle physicists** are involved with the Large Hadron Collider (LHC) at CERN, the International Linear Collider and the Cornell Electron Storage Ring (CESR). The LHC, with first collisions in 2008, is the first collider to explore the TeV energy scale, where the Standard Model of particle physics breaks and new phenomena are expected to appear.

Cornell is a member of CMS, one of two detector collaborations for elementary particle physics at the LHC. (CMS stands for the Compact Muon Solenoid detector – but it's compact only if you think a six-story detector is small.) Research topics include mechanisms for electroweak symmetry breaking, including the Higgs mechanism and alternatives, scenarios for physics beyond the Standard Model such as supersymmetry, extra dimensions and new strong interactions, top quark physics, and dark matter. Cornellians are designing on-line software for the pixel detector, developing strategies for identifying electrons in the electromagnetic calorimeter, writing analysis software capable of handling petabytes of data distributed world-wide, and ensuring that the trigger will successfully pluck new physics out of the huge background of conventional processes. In the next few years, they will also start developing hardware upgrades of the pixels and the trigger.



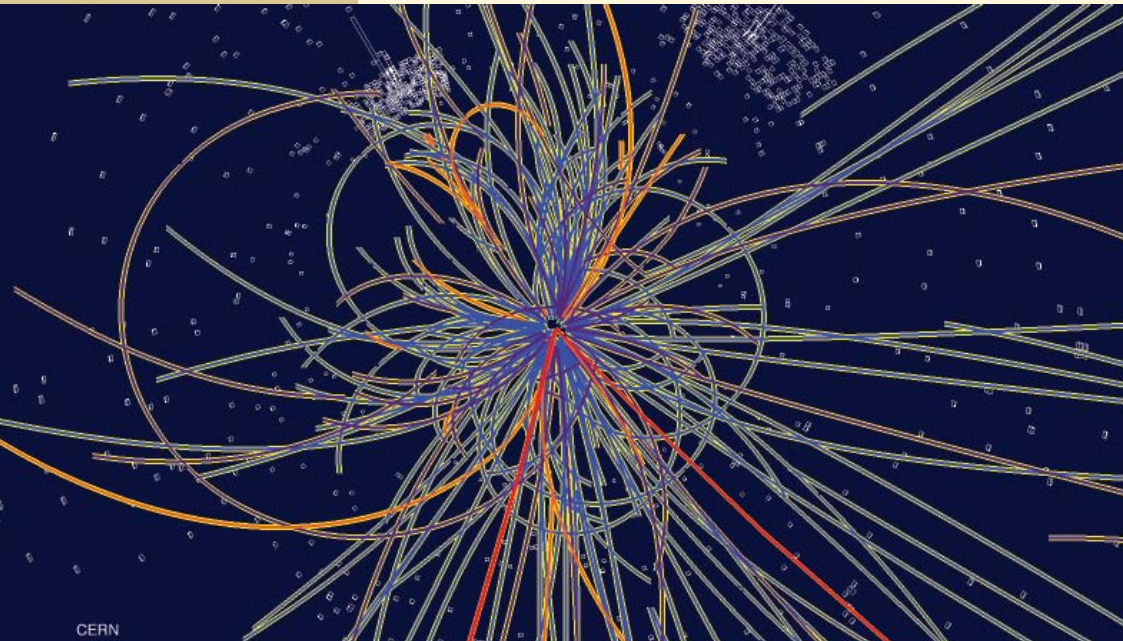
Cornell experimentalists are also laying the groundwork for the future International Linear Collider or ILC. Taking advantage of the precision available to electron colliders, the ILC will zero in on the phenomena discovered at the LHC, ruling out some possible explanations, and bolstering others. If dark matter candidates are there, it will determine their

properties, and it will shed light on the unification of forces. Cornell physicists are developing detectors for the ILC, and are studying its physics reach.

The Cornell high-energy group also participates in the CLEO collaboration, a 120-person operation based at the CESR storage ring. While data collection concluded in April 2008, CLEO physicists continue to analyze a copious and pristine sample of charm quarks in order to answer important questions about weak and strong interactions .

There is a close coupling between the interests of the particle experimentalists and Cornell's particle theory group for many aspects of the experimental program. This

can lead to lively interactions, discussion and collaboration at all levels: faculty, post-docs and graduate students.



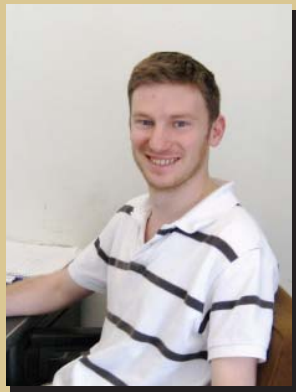
# Theoretical Elementary-Particle Physics



**Gang Xu**

The application of string theory to cosmology.

Professor Liam McAllister



**Dean Robinson**

Composite models and neutrino phenomenology.

Professor Yuval Grossman

## FACULTY

Csaba Csaki

Paul Ginsparg

Yuval Grossman

André LeClair

G. Peter Lepage

Liam McAllister

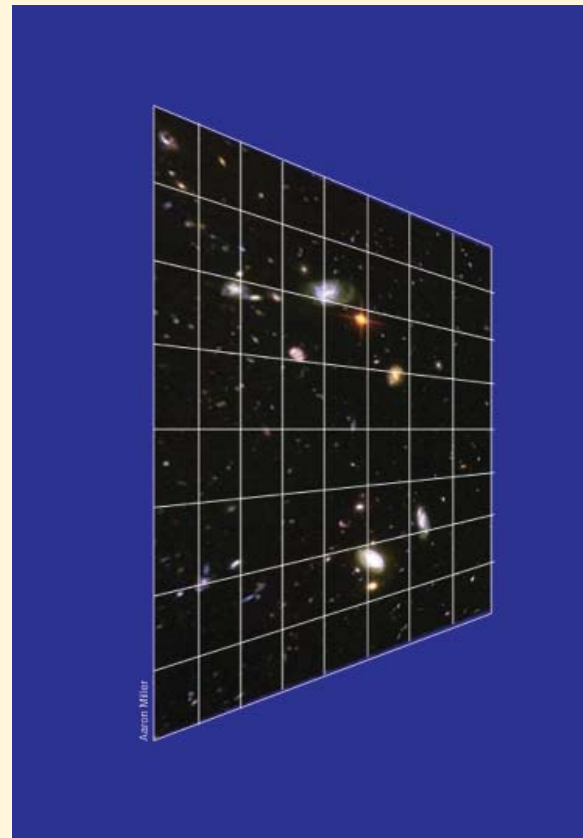
Maxim Perelstein

Henry Tye

**The Standard Model** of strong, electromagnetic and weak interactions is the crowning achievement of twentieth century physics. However, despite its many spectacular successes, the Standard Model is inconsistent at high energies and should be superseded by a new, more fundamental theory at the teraelectron-volt (TeV) energy scale. Many theoretical ideas about the nature of the physics at the TeV scale have been proposed. Examples include: supersymmetry, extra dimensions of space and new strong interactions. Members of the Cornell theory group are active in investigating these ideas. While so far this work has been purely theoretical, the experimental investigation of the TeV scale began in late 2009, when the Large Hadron Collider (LHC) at the CERN laboratory in Switzerland began operations. Theoretical interpretation of the LHC data is expected to be a major focus of research in the next few years. In this work, Cornell theorists will benefit from traditionally close connections with the LEPP experimental group, which is participating in the CMS experiment at the LHC.

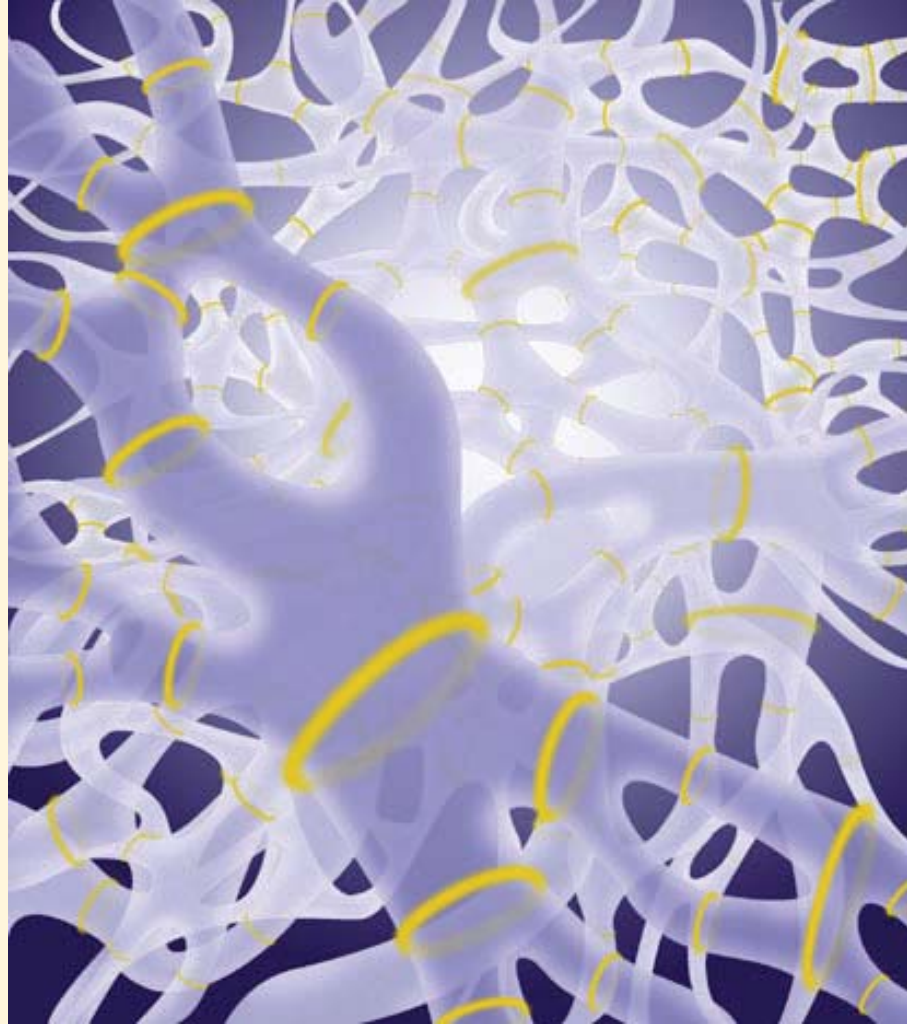
Two major experimental efforts presently underway are the study of the weak decays of B mesons and the mixings of neutrinos. The aim of this “flavor physics” is to explore the phenomenon of CP violation, to test the Standard Model and to search for new physics. Cornell theorists develop theoretical tools that make it possible to interpret the data from such experiments, and use the experimental results to build and test models of the baryon asymmetry of the Universe.

Another research area actively pursued at Cornell is superstring theory, the only known theory to incorporate gravity and quantum mechanics in a unified self-consistent framework. At the moment, research is mainly focused on the “brane world”. In the brane world picture, the standard model particles are confined to a 3+1 dimensional subspace (the “brane”) of a higher-dimensional space-time, while gravity can propagate in all dimensions. The main focus of research at Cornell is currently on using such models to find viable mechanisms of



inflation via the interaction of branes, and to find experimentally testable implications of these scenarios for cosmology.

Particle theory students at Cornell have the opportunity to explore a wide range of research areas, ranging from experiment-driven theory to highly mathematical analyses of supersymmetric field theories or quantum theories of gravity. There is also work at the interface between condensed matter physics and particle physics, where mathematical and numerical techniques from relativistic quantum field theory are adapted for use on condensed matter systems, and ideas from condensed matter physics



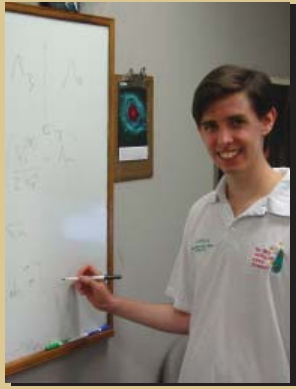
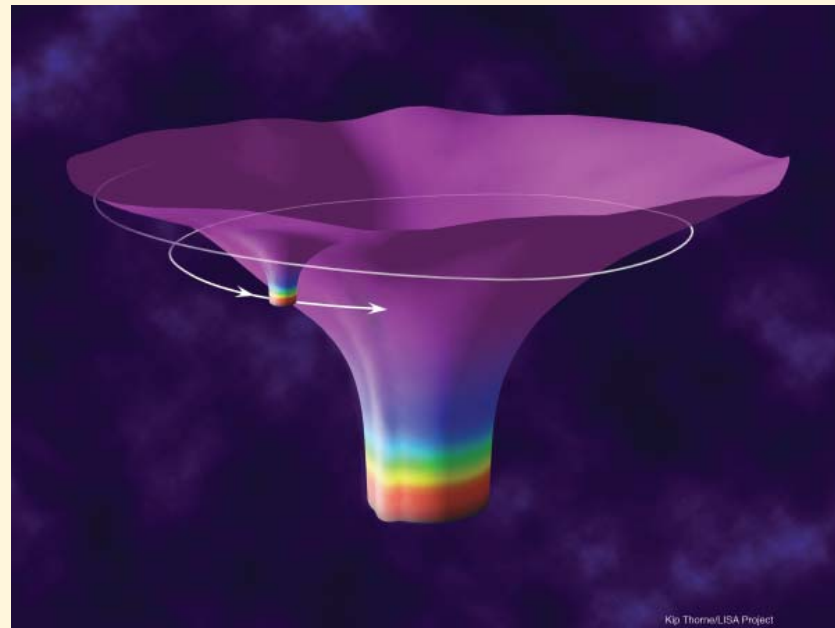
are applied to quantum field theories. Work can be analytical, or it can be computational, as in numerical simulations of quantum chromodynamics and other quantum field theories—a research area invented at Cornell. The particle theory program is very flexible: it is easy for theory students to work in more than one area, and it is not unusual for a student to co-author papers with more than one professor during their graduate career. In addition, there is close collaboration with Cornell's theoretical astrophysics group, focused on problems of common interest to particle physics and astrophysics/cosmology.

# Astrophysics and General Relativity

**Cornell has long been a leader in theoretical astrophysics**—the modeling of phenomena in our solar system, galaxy, distant galaxies and the early universe. In 1967, the late Professor Hans Bethe was awarded the Nobel Prize for his explanation of how stars shine by converting hydrogen to helium. Today, Cornell astrophysicists explore a wide variety of phenomena, including neutron stars, black holes, gravitational waves, dark matter, dark energy, the cosmic microwave background and inflation in the early universe.

The study of astrophysical phenomena can involve several areas of theoretical physics, including atomic physics, nuclear physics, condensed-matter and plasma physics, superfluidity, general relativity, and quantum-field theory. It is easy for theoretical astrophysics students to work in more than one research area, or with more than one professor.

Cornell's theoretical astrophysics group has faculty members in the physics department, as well as the astronomy department, and has close ties to the observational side of the astronomy department. That department administers the world's largest radio telescope, the Arecibo Observatory in Puerto Rico, which underwent a major upgrade in 1997. Cornell astronomers share the use of the Palomar telescope in California with astronomers from Caltech, and are developing plans to construct a 25-meter sub-mm telescope in northern Chile.



**Jolyon Bloomfield**

Low energy gravitational structure of five-dimensional models of the universe incorporating membrane localization of matter fields.  
**Professor Eanna Flanagan**



**Curran Muhlberger**

Black Hole Simulations.  
**Professor Saul Teukolsky**

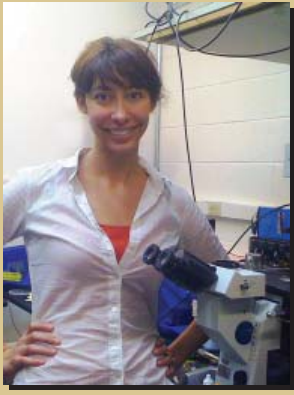
## FACULTY

Éanna Flanagan  
Saul Teukolsky  
Ira Wasserman

## ASTRONOMY FACULTY

Rachel Bean  
David Chernoff  
Dong Lai  
Richard Lovelace

# Experimental Condensed-Matter Physics



**Melina Blees**

Exploring the electrical properties of the junction between graphene and carbon nanotubes.

Professor Paul McEuen



**Ted Gudmundsen**

Magnetic random access memory and high-frequency nanomagnetics.

Professor Daniel Ralph

## FACULTY

Eberhard Bodenschatz

Itai Cohen

J. C. Séamus Davis

Carl Franck

Sol Gruner

Paul McEuen

Jeevak Parpia

Daniel Ralph

Robert Richardson

Kyle Shen

Albert Sievers

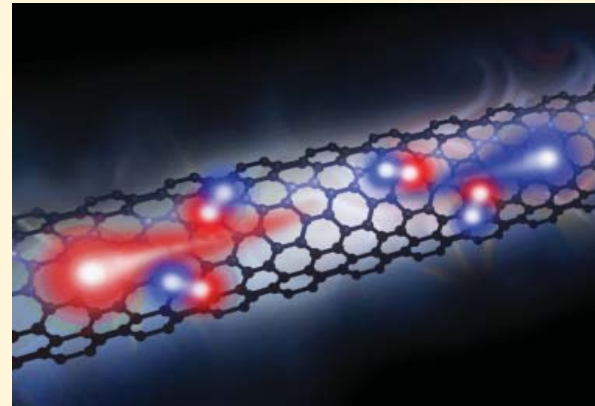
Robert Thorne

Mukund Vengalattore

Michelle Wang

**Condensed-matter physics** concerns atoms in close proximity to one another and interacting strongly, as in the liquid and solid states. Collective and cooperative phenomena that result from these interactions can produce a variety of unusual physical properties as represented by the superfluid phases of  $^3\text{He}$  or high-temperature superconductivity. Research areas of particular strength at Cornell include nanostructure physics, correlated quantum materials, low-temperature physics, x-ray physics and soft condensed matter physics.

Nanostructure physics was pioneered at Cornell, and we remain the leader in this field because of a unique and continually updated collection of advanced tools at the Cornell NanoScale Science & Technology Facility (CNF). Physicists at Cornell developed many “top-down” lithography techniques, now capable of building structures on scales less than 10 nm, as well as “bottom-up” guided-assembly techniques for incorporating nanometer-scale objects into functional devices. Current work involves understanding the effects of quantum mechanics on electron transport in carbon nanotubes, graphene and individual organic molecules. Nanometer-scale magnetic devices are an area of emphasis, with applications for using spin-polarized currents to control ultra-dense magnetic memories. The dynamics of high-quality mechanical oscillators made of silicon, silicon nitride, carbon nanotubes and graphene are approaching quantum-mechanical limits and can act as extremely sensitive force sensors in a wide variety of experiments.



The department is heavily invested in continuing to invent new tools to further understanding, including entirely new forms of scanning-probe microscopy for use in characterizing phenomena on the nanometer scale.

In correlated quantum materials, quantum many-body interactions between electrons or atoms play a key role in determining physical properties. These interactions can give rise to fascinating electronic or magnetic states such as high-temperature superconductivity or colossal magnetoresistance. In dilute gases of ultracold atoms, interactions can also allow the creation of entirely new forms of quantum matter. One of the major research thrusts at Cornell is in studying exotic superconducting materials, such as the cuprates, pnictide, ruthenates, or heavy fermion families. “Tunable” quantum materials are being explored, in which electronic interactions can be manipulated through external knobs such as epitaxial strain, interfacial engineering, or carrier concentration. To carry out this research, state-of-the-art techniques such as Spectroscopic-Imaging Scanning Tunneling Microscopy (SI-STM), Angle-Resolved Photoemission Spectros-

copy (ARPES) and x-ray spectroscopies are developed to image the electronic wavefunctions in both real space and momentum space. In atomic physics, the focus is on quantum fluids made from atoms with spin, which can simultaneously exhibit properties of both superfluids and ferromagnets, and the use of atomic gases to develop an ultrasensitive microscope for imaging magnetic fields on micrometer length scales.

Since the discovery of superfluid  $^3\text{He}$  at Cornell (for which Richardson, Lee, and Osheroff won the Nobel Prize), superfluid helium systems have become model systems for testing a wide variety of interesting theories. Current research in low-temperature physics focuses on potential supersolids, studies of superflow along grain boundaries in solid helium, the effects of disorder and confinement on superfluids and their quantum phase transitions, and the development of new cooling technologies for space-based applications.

High intensity x-rays produced by the Cornell High Energy Synchrotron Source (CHESS) are used in the Physics Department (and by a national user community) to study the growth modes of metallic thin films used in electronic devices, motion of charge-density waves in quasi-one-dimensional metals and the dynamics by which polymer materials self-assemble into controlled structures. New regimes of study are being opened with the development of high-speed x-ray detectors for probing time-dependent phenomena. Cornell is also pursuing a major expansion in our facilities, with planning underway for the design and construction of an Energy Recovery Linac x-ray source that should enable powerful new techniques in x-ray microscopy, coherent diffraction and time-resolved studies.

Soft condensed matter physics deals with liquids, polymers, liquid crystals and other 'squishy' materials that are central to biology and many industrial processes, and which could provide new applications based on their capacity to self-assemble into complex structures. Colloidal materials made of micron-sized polymer spheres in solution are being studied by confocal microscopy to see directly their correlations within both the liquid and solid states and to study the mechanisms of crystal growth at the level of single particles in real time. The process of understanding protein structure and function is limited by the bottleneck of making crystals of purified proteins for X-ray diffraction — we are studying the fundamental growth modes of protein crystals and their intrinsic defect structures with the goal of enabling better understanding of biological function. The physics of insect flight is also being investigated using high-speed photography together with large-scale simulations of the interactions between air flow and wing.

# Biological Physics



**Igor Segota**

Detection limits of single cells to weak chemical signals and the transition to multicellular life in dilute suspensions.

Professor Carl Franck



**Maxim Sheinin**

Torsion-induced DNA phase transitions.

Professor Michelle Wang

## FACULTY

Eberhard Bodenschatz

Itai Cohen

Veit Elser

Carl Franck

Sol Gruner

Christopher Henley

Chris Myers

James Sethna

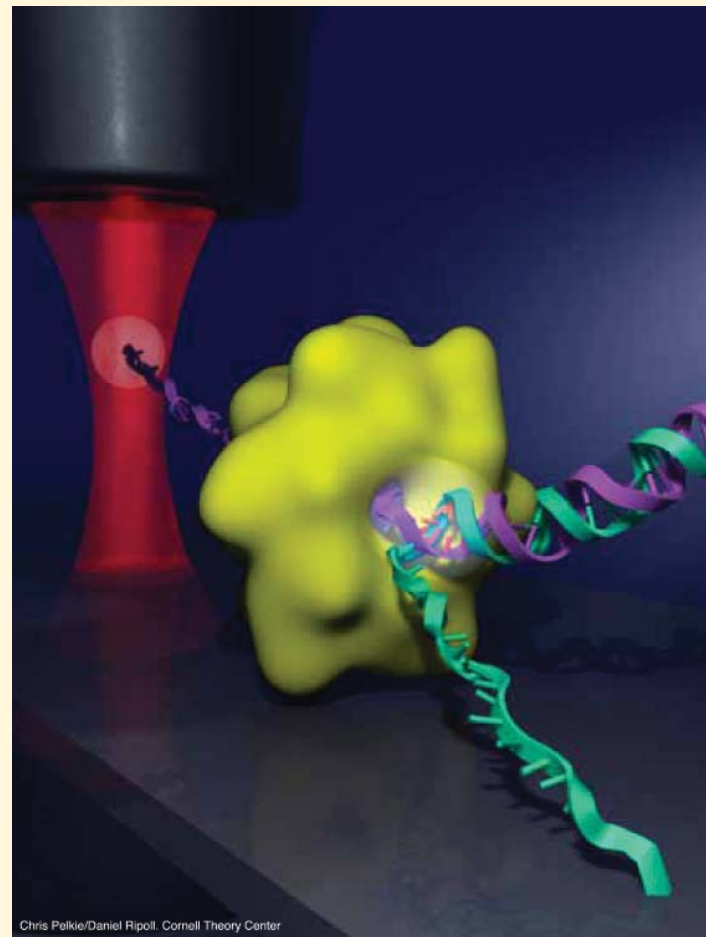
Eric Siggia

Robert Thorne

Michelle Wang

**Biological physics** uses the tools and techniques of physics to understand the inner workings of the machinery found in living organisms on length scales ranging from the molecular to the macroscopic. Cornell supports a growing range of activities in biological physics, including investigations into fluctuations in biological systems, imaging of molecular motion, the physical mechanisms of molecular motors, properties of biological macromolecules, interactions in living cells, biomembrane structure and function, mechanical properties of chromosomes and biological macromolecules, molecular diffusion and receptor-ligand interactions on membranes, ion channel dynamics, the link between micron scale structure and macroscopic tissue response and aero-elasticity in insect flight.

Physicists bring a quantitative approach to the study of biology, and an orientation toward seeking understanding at a fundamental level that is readily generalized to other systems. A defining characteristic of biological physics is the development of new instruments and techniques to better probe and manipulate biological materials. An example is optical traps, like the one shown in the figure, that stretch, twist and unzip individual DNA molecules. When coupled with high precision detection, these probe how DNA is packed and transcribed. Another example, is the use of nano-fabricated cells and synchrotron x-ray techniques to monitor protein folding. A third example, is the application of techniques of solid state crystal growth to better understand the process of protein crystallization. A fourth example, is the combined use of confocal microscopy and custom built shear cells to study tissue response under compression and shear.



Chris Pelkie/Daniel Ripoll, Cornell Theory Center

# Theoretical Condensed-Matter Physics

**Cornell set in place** several keystones of contemporary condensed-matter physics. The renormalization-group approach to critical phenomena, the theoretical description of exotic ordered phases (inspired by the discovery of superfluid  $^3\text{He}$ ), and the defining textbook of our field (Ashcroft & Mermin), were all developed at Cornell. These keystones now serve as foundations for new and exciting areas of research at Cornell.

The renormalization group approach is now being applied to and developed for many new systems. Among classical systems, the onset of chaos in low-dimensional systems and spatially extended dynamical systems as well as hysteresis loops in magnets and crumpled paper are such examples. The renormalization group approach is serving as a key tool for studying quantum phase transitions in strongly interacting systems such as high  $T_c$  superconductors as well.

The theoretical study of exotic phases is taken to new horizons at Cornell. Ordering induced by disorder is being investigated through models of frustrated magnets that include effects of thermal fluctuations, quantum fluctuations and vacancies. Quasicrystals—exotic phases with pentagonal or icosahedral order coexisting with long-range, but non-periodic translational order—are subjects of active research. Novel approaches and techniques such as large  $N$  methods are being applied to new “spin-liquid” materials. Topological phases such as fractional quantum Hall states and topological insulators are studied in close connection with rapid experimental developments.

Strange and beautiful emergent properties of quantum matter are studied through concepts of order parameters, symmetry breaking and topological defects that originated from the theory of superfluid  $^3\text{He}$ . Cornell has played a central role in the theory of defects



**Yan-Jiun Chen**

Scaling relations in critical phenomena, developing software for automatically fitting experimental data and extracting more accurate theoretical results.  
**Professor James Sethna**



**Kendra Weaver**

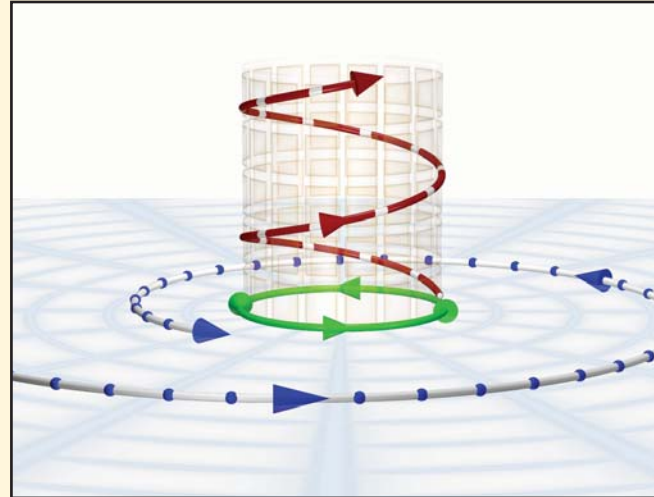
Computational condensed matter physics with applications to energy technology.  
**Professor Tomás Arias**

## FACULTY

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in liquid crystals; it is now actively developing the theory of “electronic” liquid crystals and their connection to high  $T_c$  superconductivity. Ultra cold atomic gases are new forms of such quantum matter. Under active study at Cornell are both classic phenomena including topological defects and fundamental new issues such as thermalization mechanisms. Effects of quantum mechanics and interactions amplified by spatial confinement in mesoscopic and nano-scale systems are studied through close collaboration with Cornell experimental groups.



Computational condensed-matter physics is a growing area within the theory group. The development of elegant software design and algorithms are all emphasized. Examples include wavelets in electronic structure, design patterns in multiscale modeling environments and iterative constraint-based methods for image reconstruction. Graduate students can use such elegant computational methods to study everything from magnetic grain boundaries through simulating fracture and crackling noise, to extracting the three-dimensional structures of proteins.